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Natural Polymer-Based Polyherbal Hydrogels

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Abstract: ***Hydrogels made with two or more plant extracts, known as polyherbal hydrogels, have drawn interest for their potential use in antimicrobial and wound-healing applications, etc. Hydrogels containing various herbal extracts and natural polymers (such as chitosan, xanthan gum, guar gum, alginate, and pectin) are compiled in this review. A xanthan gum hydrogel containing extracts of Calendula officinalis and Hibiscus rosa-sinensis that markedly increased fibroblast/keratinocyte proliferation in vitro and mouse wound closure. In general, these polyherbal gels demonstrated good biocompatibility (MTT assays showed no cytotoxicity and even increased cell proliferation), and in certain instances, they displayed sustained drug-release profiles that frequently fit Higuchi kinetics.***

Polyherbal hydrogels made from natural polymers exhibit strong antimicrobial, antioxidant, and wound-healing activities due to the synergistic action of multiple plant extracts. They enhance

Herbal medicines are widely used in topical formulations due to their safety, biocompatibility, and multiple pharmacological activities. Polyherbal hydrogel can provide analgesic, anti-inflammatory, antiseptic, antioxidant, and antimicrobial effects with minimal side effects. Around 1-4% of people in the world suffer from arthritis. Rheumatoid arthritis is an autoimmune disease. Commonly treatment includes steroidal, non-steroidal anti-inflammatory, disease-modifying, antirheumatic and immunosuppressive medications. Ayurvedic and Siddha medicine have been recognised as alternative treatments for arthritis.

Medicinal plants like turmeric, ginger, cinnamon, aloe vera, and tulsi contain bioactive phytoconstituents that promote tissue repair. Conventional synthetic wound-healing agents often present limitations such as side effects. Hydrogels, owing to their high water content, biocompatibility, and soothing properties, are ideal for wound management.

The hydrogel is formulated with guar gum (gelling agent) and glycerine (humectant) to enhance consistency and hydration and enriched with curcumin, ginger, cinnamon, aloe vera, tulsi, and other extracts for their therapeutic benefits.

The hydrogel exhibited desirable physicochemical characteristics, including smooth texture, optimal viscosity, good spreadability and stability, making it suitable for topical use. Tests for colour, appearance, pH, texture, viscosity, and skin irritation were performed.

This review presents an overview of natural-polymer-based polyherbal hydrogels, including the basics of hydrogels, characteristics of natural polymers, rationale for polyherbal formulations, formulation strategies, parameters of evaluation, biological activities, applications, advantages, limitations, and future scope. Major natural polymers, including chitosan, sodium alginate, Gelatine, hyaluronic acid, guar gum, pectin, xanthan gum, and cellulose derivatives, are discussed along with their crosslinking mechanisms and physicochemical properties.

Keywords: Polyherbal hydrogels, Natural polymers, Wound healing, antimicrobial activity, Chitosan-based hydrogels, Herbal extract formulations

I. INTRODUCTION

Hydrogels are three-dimensional, hydrophilic polymeric networks that can imbibe large quantities of water without losing their structural integrity. They have been widely explored in pharmaceutical sciences, biomedical engineering, cosmetics, wound dressings, and tissue engineering. Natural polymers, which include chitosan, alginate, gelatin, hyaluronic acid, pectin, guar gum, and cellulose derivatives, have become increasingly preferred over synthetic polymers due to biodegradability, biocompatibility, non-immunogenicity, and ease of modification.

Traditional medicinal plants have long been used for treating wounds, burns, infections, inflammatory conditions, and skin diseases. Polyherbal formulation generally contains more than one herbal extract and is known for synergistic therapeutic action. These herbal extracts, upon incorporation into hydrogels, provide improved stability, controlled release, enhanced therapeutic efficacy, and ease of topical application.

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Natural-polymer-based polyherbal hydrogels are advanced drug delivery systems because of the combined benefits of natural polymers and phytochemicals. These hydrogels have shown promising results in wound healing, antimicrobial therapy, antioxidant delivery, anti-inflammatory treatment, and cosmetic formulations.

Running parallel to these developments, the use of polyherbal formulations, consisting of the combination of two or more herbal extracts, has been a major component of traditional medicine systems. It is the principle of synergy on which polyherbal therapy is based: bioactive compounds from different plants complement or potentiate each other's therapeutic effects. These phytoconstituents, when incorporated into hydrogels, present better stability, controlled release, enhanced permeation, and site-specific action. This has resulted in natural-polymer-based polyherbal hydrogels emerging as a promising hybrid drug-delivery modality that integrates the biological functionality of herbs with the structural and hydrophilic advantages of natural polymers.

Polyherbal hydrogels have been especially explored for wound-healing, antimicrobial, anti-inflammatory, antioxidant, and tissue-regeneration applications. Wound healing is a complex, multistage process that includes the inflammation, proliferation, and remodelling stages. Herbal extracts rich in flavonoids, terpenoids, alkaloids, tannins, and phenolic acids help modulate these phases by the enhancement of collagen synthesis, faster epithelialisation, reduction of oxidative stress, and suppression of pro-inflammatory cytokines. For example, extracts from Aloe vera, Azadirachta indica, Calendula officinalis, Centella asiatica, Curcuma longa, and Hibiscus rosa-sinensis are widely used for their antimicrobial, antioxidant, and fibroblast-stimulating activity.

Natural polymers further enhance the therapeutic outcomes. Chitosan exhibits intrinsic antimicrobial and haemostatic properties, while alginate forms gel-like layers on wounds and absorbs exudates. Hyaluronic acid supports cellular migration and hydration of tissues, whereas xanthan and guar gum are useful in developing stable and bioadhesive gel matrices. The use of these polymers in combination with various herbal extracts has resulted in the development of hydrogels that ensure moisture balance, bioadhesion, sustained drug release, reduced risk of infection, and speedy wound closure.

Recent studies attest to the higher bioactivity of polyherbal hydrogels over their single-extract or non-polymeric herbal counterparts. For instance, chitosan hydrogels loaded with aloe vera, neem, or Alternanthera brasiliana displayed enhanced antibacterial zones and rapid contraction of wounds, while xanthan gum hydrogels containing calendula and hibiscus extracts demonstrated enhanced in vitro fibroblast proliferation. These formulations also demonstrate excellent biocompatibility, as confirmed by MTT assays, and often follow predictable release kinetics such as Higuchi diffusion.

Polyherbal systems are in the context of the growing interest in natural, safe, and effective therapeutic agents. Their value for pharmaceutical, biomedical and cosmetic applications relies on their capability to combine herbal synergy with functional polymer networks. This review aims to compile current research on formulation strategies, polymer types, herbal extracts, evaluation parameters, bioactivities, and therapeutic potential concerning natural-polymer-based polyherbal hydrogels.

The versatility of polyherbal hydrogels is not confined to wound healing. They are increasingly investigated for application in:

- antimicrobial gels for curing bacterial and fungal infections,
- anti-inflammatory topical therapies for dermatitis, eczema, and psoriasis.
- burn wound care, hydration, and pain management
- including cosmetic applications like anti-aging, anti-acne, and skin-brightening gel
- transdermal delivery systems for controlled herbal drug delivery,
- Oral and vaginal mucoadhesive applications where prolonged retention is desired.

In sum, natural polymer-based polyherbal hydrogels are one of the fastest-growing areas of pharmaceutical technology; they combine the biological advantages of herbal medicine with the structural and functional benefits of hydrogel systems. Their potential to deliver multiple phytochemicals in sustained, safe, and targeted fashions positions them as attractive candidates for next-generation platforms in wound care and topical delivery. Polyherbal hydrogels of this nature will have a significant impact on future innovations in pharmaceuticals, dermatology, and biomedical applications, commensurate with the continued growth in interest in herbal therapeutics and degradable materials.

II. HYDROGELS: AN OVERVIEW

A. Definition

Hydrogels are cross-linked polymeric structures capable of absorbing substantial water without dissolving. Their network formation can occur through physical (ionic, hydrogen bonding, van der Waals) or chemical (covalent) crosslinking.

B. Properties

- High water absorption
- Soft and flexible structure
- Mimic natural tissues
- Non-toxic and biocompatible
- Ability to incorporate hydrophilic/hydrophobic bioactives.
- Provide controlled drug release

C. Types of hydrogels

Based on origin: natural, synthetic, semi-synthetic
Based on crosslinking: physical, chemical
Based on response: pH-sensitive, temperature-sensitive, enzyme-sensitive
Based on composition: homopolymer, copolymer, semi-IPN/IPN hydrogels

Hydrogels are three-dimensional, hydrophilic polymeric networks that can imbibe large quantities of water without losing their structural integrity. They have been widely explored in pharmaceutical sciences, biomedical engineering, cosmetics, wound dressings, and tissue engineering. Natural polymers, which include chitosan, alginate, gelatine, hyaluronic acid, pectin, guar gum, and cellulose derivatives, have become increasingly preferred over synthetic polymers due to biodegradability, biocompatibility, non-immunogenicity, and ease of modification.

Natural polymers used for polyherbal hydrogels include:

1) Chitosan

Derived from chitin; biodegradable, mucoadhesive, haemostatic, and antimicrobial. Forms gels via ionic crosslinking.

2) Sodium Alginate

An anionic polysaccharide; forms hydrogels with divalent ions like Ca^{2+}.

3) Gelatine

Protein-based polymer; thermoreversible gelation, excellent film-forming properties.

4) Hyaluronic Acid

A component of the extracellular matrix, highly hydrophilic, it enhances wound healing and tissue regeneration.

5) Pectin

Plant-derived polysaccharide; good gelling ability and compatibility with herbal extracts.

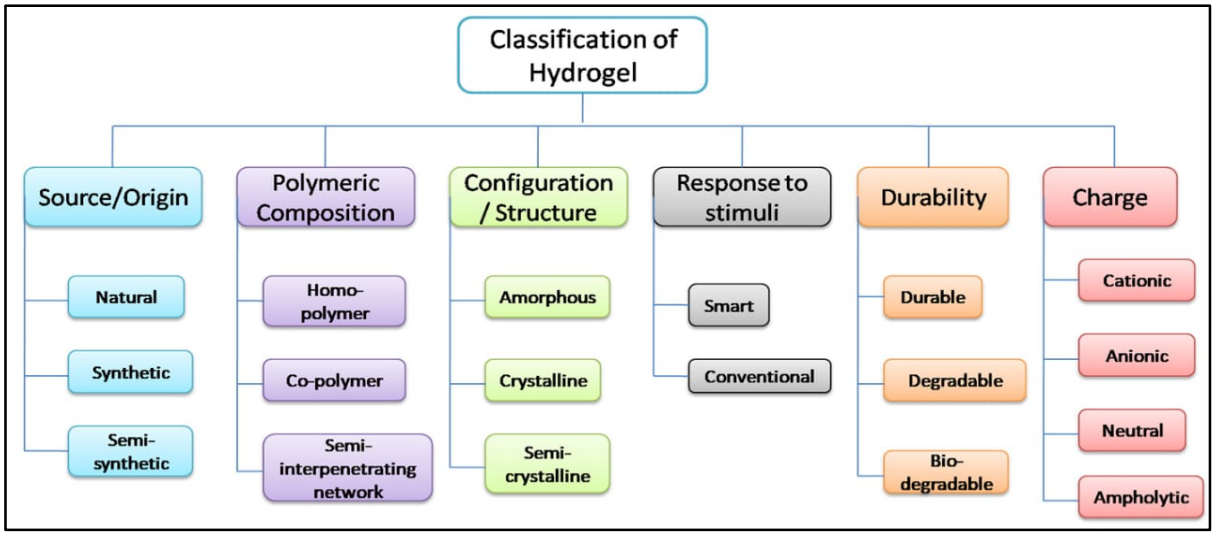
6) Guar Gum / Xanthan Gum

High-viscosity

Natural gums are widely used in herbal gels.

7) Cellulose Derivatives (HPMC, CMC, EC)

Stable, biodegradable, easy to hydrate, and widely used for topical gels.



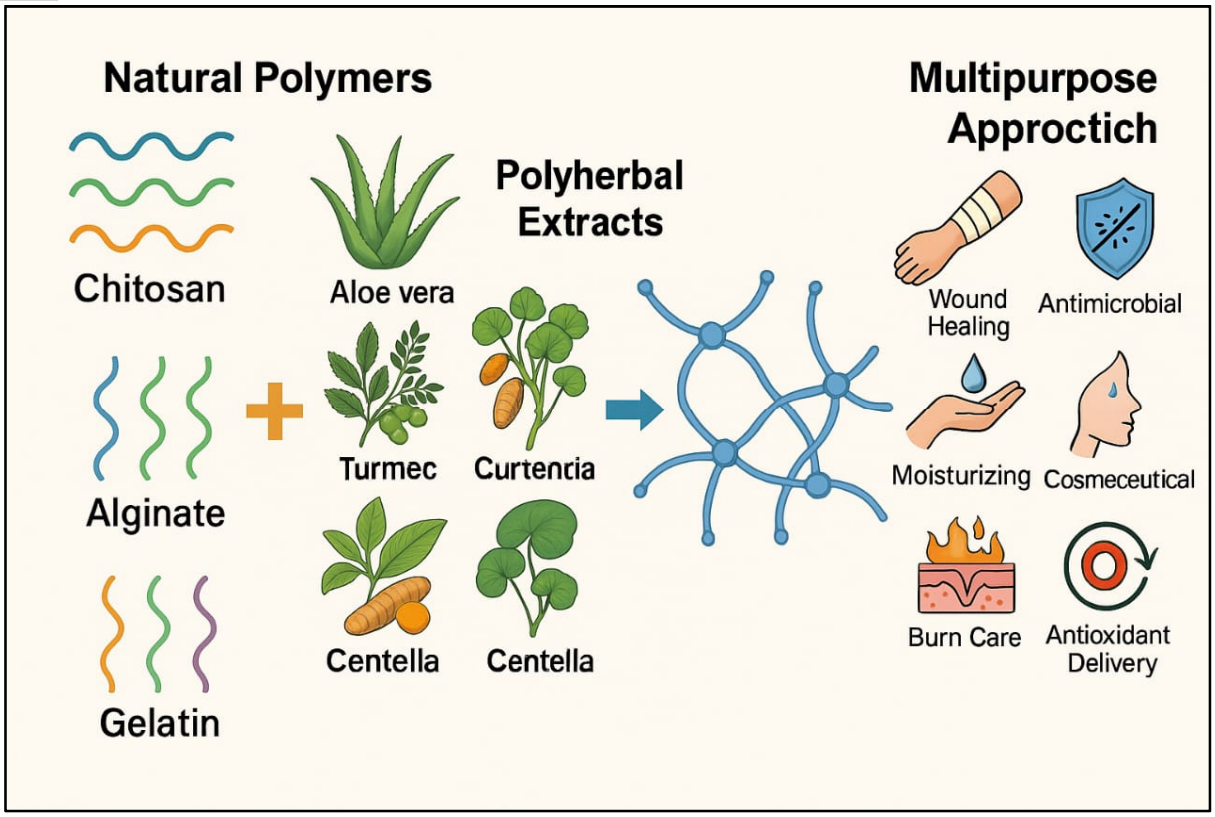
III. METHODS OF FORMULATIONS

We looked up terms like "polyherbal hydrogel", "chitosan hydrogel plant extracts", "natural polymer herbal hydrogel", and combinations of polymers (chitosan, xanthan, alginate, etc.) with several herbs. We included research in which two or more different plant extracts (or oils) were co-formulated with a natural polymer hydrogel matrix. Biomedical applications (wound healing, antimicrobial, antioxidant, and anti-inflammatory) were the focus. We know that synergistic phytochemicals (flavonoids + tannins + phenolics + terpenoids) produce stronger healing, faster epithelialisation, and better antimicrobial activity. To create summary tables, we took important formulation information (polymer system, crosslinking plant species, additives (like nanoparticles), and efficacy viability) from every study.

Polymer system	Crosslinking method	Polyherbal extracts used	Additives (nanoparticles/enhancers)	Efficiency of the matrix (overall performance)
chitosan	TTP ionic cross-linking	Aloe vera + neem	ZnO nanoparticles	High antimicrobial activity, strong gel strength, and good swelling
Sodium alginate	$CaCl_2$ ionic gelation	Centella asiatica + turmeric	Silver nanoparticles (AgNPs)	Excellent antibacterial efficiency, rapid wound closure
Chitosan PVA blend	Freeze-thaw crosslinking	Calendula + Plantago	none	Good mechanical strength, moderate antimicrobial activity
Gelatine chitosan	Gnepine chemical crosslinking	Aloe vera + calendula	Curcumin nanoparticles	High antioxidant and anti-inflammatory efficiency
Xanthan gum	Physical gelation	Hibiscus and calendula	none	Smooth topical application, moderate antibacterial activity
Pectin alginate	Ca^{2+} crosslinking	Aloe vera + pomegranate peel	Gold nanoparticles (AuNPs)	Strong antioxidant matrix, excellent tissue regeneration
Carboxymethyl cellulose	Citric acid crosslinking	Aloe, turmeric, and calendula	Chitosan nanoparticles	Very high biocompatibility and controlled release profile
Guar xanthan blend	Thermal gelation	Aloe vera + neem	None	Good viscosity + stable topical gel matrix
Gel and gum	Mg^{2+}/Ca^{2+} linking	Neem + turmeric	Curcumin-chitosan NPs	Very efficient antimicrobial and anti-inflammatory matrix
Starch-based	Citric acid mild crosslinking	Turmeric + Licorice	None	Low-cost matrix, good antioxidant, and soothing effects

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IV. FORMULATION OF NATURAL-POLYMER-BASED POLYHERBAL HYDROGELS

1) Selection of natural polymer

Criteria include:
Compatibility with herbal extracts
Gel strength
Non-irritancy
Ease of hydration
Biodegradability

2) Extraction of herbal materials

Common extraction methods:

- Maceration
- Soxhlet extraction
- Ultrasound-assisted extraction
- Cold percolation
- Hydroalcoholic extraction

3) Incorporation of extracts into polymeric base

Steps:

- Preparation of polymer dispersion.
- Hydration with controlled stirring.
- Incorporation of herbal extracts.
- Adjustment of pH.
- Addition of crosslinking agent (if required).
- Optimisation of viscosity and spreadability.

4) Typical formulation components

Component Role:

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Natural polymer Gel matrix formation
Herbal extracts Active agents
Glycerine/Propylene glycol Humectant
Preservatives Microbial control
Plasticiser texture improvement
Crosslinkers Enhance mechanical strength

V. EVALUATION OF POLYHERBAL HYDROGEL

1) Physicochemical evaluation

- Colour, odour, appearance
- pH measurement
- Viscosity (Brookfield viscometer)
- Spreadability test
- Homogeneity
- Gel strength

2) Phytochemical evaluation

- Qualitative screening of alkaloids, flavonoids, tannins, saponins
- Total flavonoid/phenolic content assays

3) Mechanical and structural evaluation

- Rheology
- Texture analysis
- SEM (surface morphology)
- FTIR (drug–polymer interaction)

4) In-vitro evaluation

- Swelling index
- Antimicrobial activity (agar diffusion, MIC)
- Antioxidant activity (DPPH assay)

5) In-vivo evaluation

- Wound healing models (excision, incision)
- Histopathological evaluation

6) Stability studies

- Accelerated stability (40°C/75% RH) collagen formation, cell proliferation, and overall tissue repair while offering sustained release of herbal actives. All these results highlight their potential as effective and biocompatible wound-care materials, warranting further optimisation and clinical validation.
- Physical change monitoring

VI. APPLICATIONS OF NATURAL-POLYMER-BASED POLYHERBAL HYDROGELS

A. Wound Healing and Tissue Regeneration

Wound management is the primary and most established application of natural-polymer hydrogels. The hydrophilic polymer network maintains a moist wound environment, which accelerates epithelialisation. Herbal extracts such as Aloe vera, Centella asiatica, Curcuma longa, Azadirachta indica, and Calendula officinalis promote collagen synthesis, angiogenesis, fibroblast proliferation, and faster wound contraction. Chitosan-based hydrogels possess intrinsic antimicrobial and haemostatic activity, reducing bleeding and preventing infection. Alginate-based hydrogels form a gel-like layer upon contact with wound exudate, providing cooling, soothing, and protective effects.

When several herbal extracts are mixed with natural polymers, clinical and preclinical research shows much faster healing, less scar formation, and better tissue remodelling. These results make polyherbal hydrogels especially effective for acute wounds, chronic ulcers, post-surgical wounds, and diabetic foot ulcers.

B. Antimicrobial and Antiseptic Applications

Polyherbal hydrogels exhibit a broad spectrum of antimicrobial activity due to phytochemicals like flavonoids, terpenoids, tannins, and alkaloids.

Herbs such as:

- Neem (Azadirachta indica)
- Tulsi (Ocimum sanctum)
- Turmeric (Curcuma longa – curcuminoids)
- Garlic (Allium sativum)
- Calendula officinalis

It possesses potent antibacterial, antifungal, and antiviral effects.

Natural polymers such as chitosan further enhance antimicrobial activity by disrupting microbial cell membranes. These dual action polyherbal hydrogels are useful for:

- Infected wounds
- Fungal skin infections
- Acne lesions
- Burn wound infections
- Post-operative wound care

Their ability to maintain localised antimicrobial action with minimal systemic absorption makes them safe for prolonged use.

C. Anti-Inflammatory and Antioxidant Therapy

Polyherbal hydrogels effectively reduce skin inflammation, itching, swelling, and redness due to the presence of anti-inflammatory herbs like

- Turmeric
- Aloe vera
- Green tea extract

These gels inhibit pro-inflammatory cytokines, scavenge free radicals, and block oxidative stress pathways.

Applications include:

- Dermatitis
- Eczema
- Psoriasis (adjunct relief therapy)
- Sunburn
- Insect bite inflammation
- Minor allergic skin reactions

Their cooling, soothing, and hydrating effects enhance patient comfort

D. Polyherbal Hydrogels in Rheumatoid Arthritis (RA)

Polyherbal hydrogels prepared using natural polymers, such as chitosan, alginate, carrageenan, xanthan gum, guar gum, and gelatin, and synergistic combinations of medicinal plant extracts, have emerged as promising topical or transdermal therapies for RA. RA is a chronic autoimmune inflammatory disorder characterised by synovial inflammation, joint stiffness, cartilage degradation, pain, and progressive disability. Conventional management of RA includes the use of NSAIDs, corticosteroids, and DMARDs, which generally result in long-term adverse effects. Polyherbal hydrogels thus represent a localised, biocompatible, sustained-release, and side-effect-reduced modality for the management of symptoms related to RA.

1) Localized Drug Delivery

They deliver anti-inflammatory and antioxidant herbal compounds directly to affected joints, minimising systemic side effects.

2) Multi-targeted Action:

Herbal combinations modulate:

- TNF-α
- IL-6, IL-1β

- COX-2, LOX
- NF-κB

all major inflammatory mediators of RA.

3) Antioxidant activity

Curcumin, gingerols, and Boswellia acids neutralise ROS, preventing cartilage degradation and slowing RA progression.

4) Improved joint mobility

Hydrogels soften skin, increase perfusion, and continuously deliver actives that reduce stiffness.

E. Burn Wound Management

Natural polymers like alginate and gelatin are widely used in burn-care dressings.

When combined with herbal extracts (aloe vera, turmeric, honey, and neem), hydrogels:

- Reduce wound temperature
- Alleviate pain
- Restore moisture
- Prevent microbial contamination
- Support natural healing

These hydrogels form a protective, semi-occlusive layer that prevents dehydration and minimises tissue trauma during dressing changes.

They are recommended for:

- Superficial burns (first-degree)
- Partial-thickness burns (second-degree)
- Thermal injuries caused by heat, chemicals, or radiation

F. Cosmetic and Dermatological Applications

The cosmetic industry increasingly uses polyherbal hydrogels due to their hydrating, cooling, anti-ageing, and skin-repairing properties.

Applications include:

- Anti-acne gels → Neem + Tea tree + Aloe vera
- Skin-whitening/brightening gels → Liquorice, mulberry, turmeric, niacin-boosted herb complexes
- Anti-aging hydrogels → Hyaluronic acid + antioxidant herbs
- Face masks / under-eye gels → Soothing and formulations
- Hydrating gels → Aloe vera–based transparent hydrogels
- After-sun care → Cooling polyherbal gels with cucumber, mint, and aloe

Natural polymers such as hyaluronic acid provide intense hydration and skin-plumping effects, while herbal antioxidants protect skin from UV-induced damage.

G. Transdermal and Controlled Release Drug Delivery

Hydrogels can act as vehicles for both hydrophilic and hydrophobic phytochemicals.

Key advantages:

- Sustained release over several hours
- Increased skin retention
- Enhanced absorption through hydrated stratum corneum
- Reduced irritation and side effects
- Polyherbal hydrogels are studied for transdermal delivery of:
- Anti-inflammatory agents
- Herbal analgesics
- Antioxidants (e.g., quercetin, curcumin)

Their ability to provide modulated drug release makes them suitable for chronic skin conditions.

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H. Use in Chronic Wound and Ulcer Therapy

Chronic wounds such as diabetic ulcers, venous leg ulcers, and pressure sores require long-term therapy.
Polyherbal hydrogels provide:

- Antimicrobial action
- Antioxidant protection
- Improved tissue oxygenation
- Balanced moisture level
- Painless dressing removal

Alginate-based and chitosan-based polyherbal hydrogels show promising results in improving wound closure rates in chronic wound models.

I. Ophthalmic and Mucosal Applications (Emerging)

Although still under research, natural polymer hydrogels are explored for:

- oral mucosal ulcers
- periodontal pockets
- vaginal/local infections
- ophthalmic gels for dry eye

Polymers like hyaluronic acid and chitosan have excellent mucoadhesive properties that prolong residence time on mucosal surfaces.

J. Veterinary and Agricultural Applications

Herbal hydrogels are used for:

- Wound healing in animals
- Treating hoof infections
- topical treatment for livestock injuries
- delivering botanical pesticides in agriculture

These applications show the versatility of polyherbal hydrogel technology beyond human medicine.

Summary of Key Application Areas

Application Area	Key benefits
Wound Healing	Moisture balance, collagen synthesis
Antimicrobial	Broad-spectrum protection
Burn Care	Cooling pain relief, infection control
Cosmetic Use	Hydration, anti-aging, anti-acne
Anti-Inflammatory	Reduced redness and swelling
Transdermal Delivery	Sustained release
Mucosal Therapy	Mucoadhesion, prolonged retention

VII. ADVANTAGES OF POLYHERBAL HYDROGELS

A. Synergistic Therapeutic Activity

Using more than one herbal extract enhances the overall pharmacological effect by targeting multiple biological pathways simultaneously. This synergy improves wound healing, antimicrobial efficacy, antioxidant protection, and anti-inflammatory action compared to single-herb formulations.

B. Biocompatibility and Safety

Natural polymers such as chitosan, alginate, gelatin, hyaluronic acid, pectin, xanthan gum, and cellulose derivatives are inherently biocompatible, non-toxic, and biodegradable. They closely mimic biological tissues and reduce the risk of irritation, making them ideal for sensitive or damaged skin.

C. Sustained and Controlled Release

Hydrogels form a hydrated three-dimensional network that enables gradual and prolonged release of herbal actives. This improves therapeutic effectiveness, maintains steady drug levels at the application site, and reduces dosing frequency.

D. Moisture Retention and Optimal Wound Environment

Hydrogels retain large amounts of water and maintain a moist wound environment, which accelerates epithelialization, promotes granulation tissue formation, and supports overall wound healing. This feature is particularly important for chronic wounds, burns, and ulcers.

E. Enhanced Skin Penetration

Hydrated polymer matrices improve the diffusion of phytoconstituents through the stratum corneum, leading to better percutaneous absorption and improved bioavailability of herbal compounds.

F. Cooling and Soothing Effect

Hydrogels provide an immediate cooling sensation upon application, which offers relief in conditions such as burns, inflammation, dermatitis, and irritated skin. This enhances patient comfort and compliance.

G. Non-Greasy and Aesthetically Acceptable

Unlike ointments and creams, hydrogels are lightweight, transparent, non-greasy, and smooth, making them cosmetically appealing. This increases acceptance among patients, especially for facial or daily-use applications.

H. Localized Delivery and Reduced Systemic Side Effects

Topical application keeps the phytochemicals confined to the site of action, minimising systemic absorption and reducing the risk of systemic toxicity or drug interactions.

I. Versatility of Formulation

Natural polymers can be easily modified or combined to achieve desired properties such as viscosity, spreadability, bioadhesion, mechanical strength, and release rate. This versatility allows hydrogels to be customised for various therapeutic needs.

J. Environmentally Sustainable

The use of plant-derived polymers and herbal actives makes polyherbal hydrogels biodegradable, renewable, and eco-friendly, supporting green pharmaceutical development.

K. Ability to Incorporate Hydrophilic and Hydrophobic Extracts

Hydrogels can incorporate a wide range of phytoconstituents, including flavonoids, alkaloids, tannins, terpenoids, and polyphenols, through polymer blending, solubilizers, or nano formulation techniques.

L. Reduced Need for Synthetic Preservatives

Many herbs (e.g., neem, tulsi, and turmeric) exhibit natural antimicrobial effects, reducing or eliminating the need for synthetic preservatives and making the formulation safer.

VIII. LIMITATIONS / DISADVANTAGES OF POLYHERBAL HYDROGELS

Polyherbal hydrogels, though highly promising as topical and wound-healing formulations, also present several limitations that need to be acknowledged for research and practical application. One of the primary limitations arises from the inherent variability of herbal extracts. The phytochemical composition of medicinal plants is influenced by numerous factors such as geographical origin, climate, soil composition, harvesting season, and extraction method. Because of this, achieving batch-to-batch consistency becomes challenging, making standardisation difficult and potentially affecting the therapeutic efficacy of the hydrogel.

Another major limitation is stability concerns. Herbal extracts often contain thermolabile, photosensitive, and easily oxidisable phytochemicals that may degrade over time, altering the colour, odour, viscosity, and overall therapeutic performance of the hydrogel. Natural polymers like chitosan, alginate, and gelatin also have limited long-term stability and may undergo microbial degradation or loss of viscosity, especially in aqueous environments.

Formulation challenges also arise due to complex interactions between multiple herbal extracts and polymers. These interactions can lead to phase separation, changes in pH, precipitation of active compounds, or inconsistency in gel texture. Ensuring uniform distribution of each extract throughout the gel matrix becomes increasingly difficult as the number of ingredients increases.

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Another limitation is inconsistent skin penetration. While hydrogels hydrate the skin and improve absorption of many phytochemicals, not all herbal actives penetrate effectively, especially those with larger molecular weights or a hydrophobic nature. Without penetration enhancers or nano-delivery systems, therapeutic outcomes may vary.

IX. FUTURE SCOPE

A. *Development of Smart and Stimuli-Responsive Polyherbal Hydrogel*

A major future direction involves engineering smart hydrogels that can respond to biological or environmental triggers such as pH, temperature, enzymes, glucose levels, or reactive oxygen species (ROS).

In chronic wounds, for example, local pH and ROS levels fluctuate significantly. A smart polyherbal hydrogel could release antimicrobial or anti-inflammatory phytoconstituents only when required.

Temperature-sensitive natural polymers (e.g., gelatin, methylcellulose) can be modified to form in-situ gelling systems, improving patient comfort and ease of application.

Enzyme-responsive hydrogels could release herbal actives specifically in infected or inflamed tissues where enzyme activity is elevated.

Such “intelligent” systems would significantly improve therapeutic precision and reduce excessive drug release.

B. *Integration of Nanotechnology (Nano-Herbal Hydrogels)*

The future of polyherbal hydrogel systems is closely tied to nanotechnology. Many herbal actives suffer from low solubility, instability, or limited penetration through the skin barrier. Incorporating nanoparticles, nanoemulsions, liposomes, niosomes, or phytosomes into hydrogels can dramatically enhance drug delivery by:

improving solubility and stability of phytochemicals

enhancing skin permeation

providing sustained and targeted release

reducing degradation of sensitive compounds like curcuminoids or flavonoids

For example, loading silver nanoparticles synthesized from plant extracts into chitosan hydrogels is a growing area for boosting antimicrobial effects. Similarly, nano-encapsulated antioxidants can improve wound healing by maintaining prolonged oxidative protection.

C. *Integration of Nanotechnology (Nano-Herbal Hydrogels)*

One of the biggest challenges limiting clinical use is the lack of standardization in herbal extracts. Future research must focus on:

establishing quality-control markers

developing HPLC/HPTLC fingerprints

quantifying key bioactive compounds

creating extract specifications for consistent batch-to-batch production

Standardization of both herbal extracts and natural polymers is essential for regulatory approval and commercial manufacturing.

D. *Advanced Characterization Techniques and Mechanistic Studies*

Future studies should employ advanced analytical and biological tools to better understand hydrogel behavior and therapeutic mechanisms, such as:

rheology mapping for controlled-release design

FTIR, DSC, and XRD for understanding polymer–extract interactions

confocal microscopy for cell–hydrogel interaction visualization

omics technologies (proteomics/transcriptomics) to elucidate wound-healing pathways

This mechanistic information will bridge the gap between empirical herbal use and evidence-based biomaterial science.

E. *Expansion into New Therapeutic and Biomedical Areas*

Although most studies focus on wound healing, polyherbal hydrogels have potential in many other therapeutic fields:

Burn management (moisturization + antimicrobial + anti-inflammatory synergy)

Dermatology (acne, eczema, psoriasis, pigmentation disorders)

Anti-aging and cosmetic skincare

Transdermal analgesic formulations

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Oral mucosal ulcers and periodontal pockets
Vaginal and rectal drug delivery
Veterinary wound care
The diverse pharmacology of polyherbal extracts makes them suitable for wide clinical use, provided safety and efficacy are validated

F. In-Vivo, Toxicity, and Clinical Studies

For real-world use, extensive in-vivo and clinical validation is essential. Future work must:
conduct systematic animal studies on chronic, diabetic, and infected wound models
evaluate long-term toxicity, irritation, and sensitization
compare polyherbal hydrogels with market products
establish human clinical trials for wound and skin applications
These steps will build credibility and support regulatory approval.

G. Biodegradable and Eco-Friendly Packaging and Manufacturing

With increasing demand for sustainable healthcare solutions, the use of environmentally friendly polymers aligns perfectly with global green initiatives. Future work may explore:
fully biodegradable hydrogel dressings
edible or compostable packaging
low-energy, solvent-free manufacturing techniques
This supports environmental sustainability while enhancing consumer acceptance.

H. Commercialization and Industrial Scale-Up

To translate research into healthcare products, efforts should focus on:
scalable extraction techniques
GMP-compliant hydrogel manufacturing
long-term stability studies
cost-effective natural polymer sourcing
shelf-stable formulations without strong synthetic preservatives
There is strong potential for these hydrogels in pharmaceuticals, cosmeceuticals, herbal health products, and wound-care dressings.

X. CONCLUSION

According to the reviewed research, polyherbal hydrogels with natural polymer backbones can have a variety of advantageous effects. Chitosan, xanthan gum, and guar gum are examples of natural polymers that offer a moist, biocompatible matrix that promotes tissue regeneration and cell adhesion. Natural polymer–based polyherbal hydrogels represent an emerging, effective, and safe approach for topical drug delivery and wound management. Their ability to integrate the strengths of both natural polymers and medicinal plant extracts makes them ideal candidates for biomedical and pharmaceutical applications. Recent research supports their promising potential in antimicrobial therapy, wound healing, anti-inflammatory treatment, and skin care. According to the studies, multi-extract gels frequently perform better than single-herb or single-polymer systems. Swellable, absorbing wound exudate before gradually releasing water and active ingredients.

The synergy of natural polymers with polyherbal extracts leads to enhanced therapeutic effects, sustained drug release, improved patient compliance, and minimal side effects. Although challenges remain in standardization, stability, and large-scale production, the future of polyherbal hydrogels is bright, with significant opportunities for innovation, commercialization, and clinical application.

Polyherbal hydrogels derived from natural polymers have shown promise as therapeutic gels and wound dressings. Strong pathogen inhibition, improved collagen formation and cell proliferation in wounds, and good biocompatibility are some of the main benefits. All things considered, the mounting data points to the synergistic benefits of incorporating several plant extracts into natural polymer hydrogels for wound treatment. Future research should keep improving polymer–herb combinations, measuring release kinetics, and confirming effectiveness in models that are pertinent to clinical settings.

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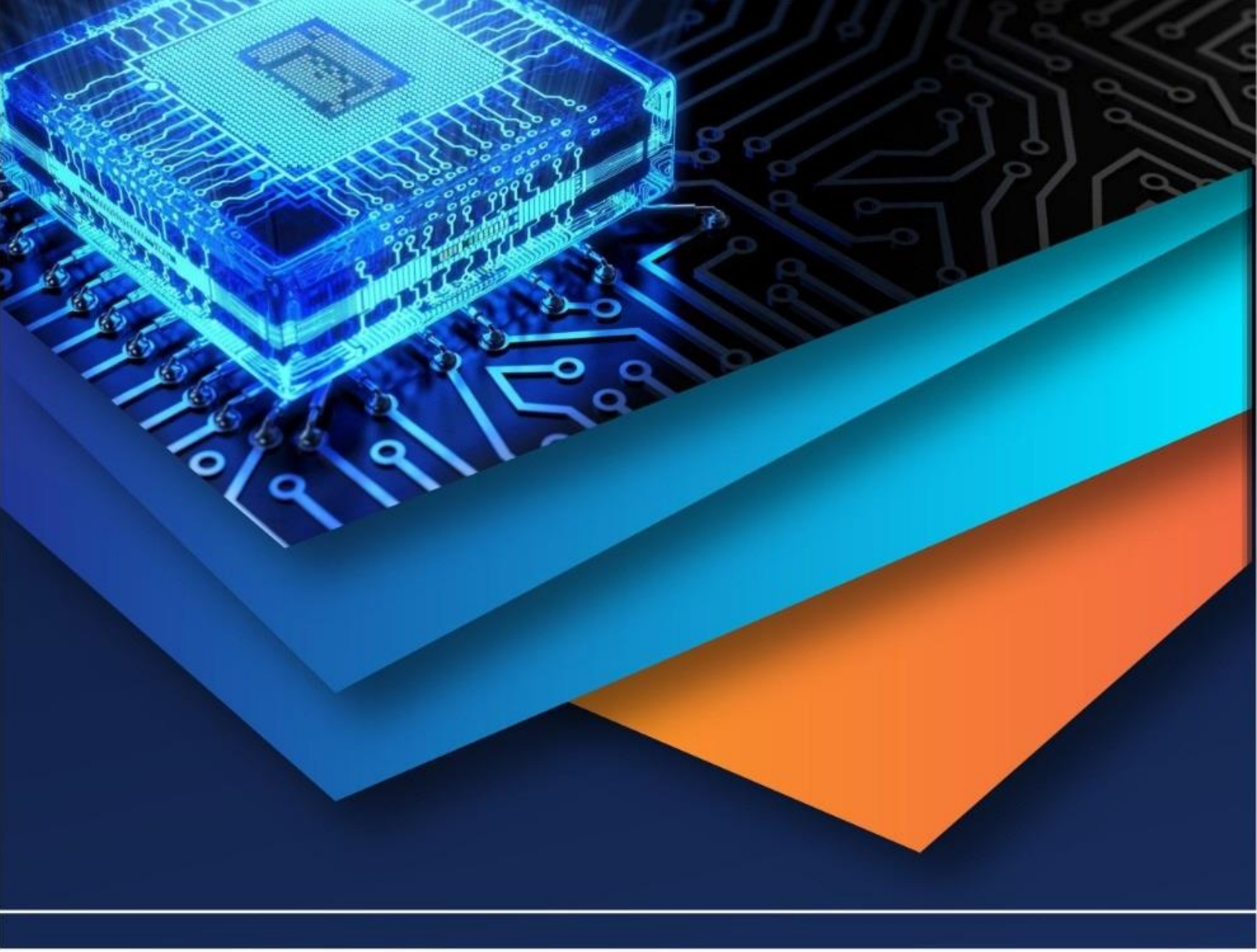
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