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## Review Article

# Botanical Innovations in Wound Healing: Exploring the Potential of Herbal Hydrogels

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### ABSTRACT

In recent decades, interest in natural and sustainable therapies in healthcare has grown. People increasingly seek alternatives to synthetic drugs, leading to a resurgence in exploring traditional herbal remedies. Using plants and extracts for medicinal purposes has a history dating back thousands of years, with various cultures documenting their use for treating wounds and promoting healing. The rise of antimicrobial resistance and complications with conventional wound care has driven the search for alternative methods. Herbal remedies with antimicrobial properties are being investigated as potential solutions for infections and improved wound healing. In an era of patient-centred care, individuals are drawn to natural and holistic health approaches. Herbal hydrogels, like those made with turmeric, aloe vera, and neem, align with this trend by offering potential benefits with fewer side effects. Further research and clinical studies are essential to establish their effectiveness and safety. This approach integrates traditional knowledge with modern science to improve patient outcomes and provide sustainable healthcare solutions.

### INTRODUCTION

Wound healing is a complex and dynamic physiological process that plays a crucial role in maintaining the integrity of the skin and underlying tissues. Wound healing complications and infections poses significant challenges to healthcare systems worldwide. The rise of antibiotic-resistant pathogens has underscored the urgency of finding innovative solutions that not

only facilitate wound healing but also effectively control infections. Conventional wound management approaches often involve the use of antimicrobial agents and wound dressings. Herbal remedies, rich in bioactive compounds, have been historically used for their therapeutic properties. Plants harbor a vast array of bioactive compounds with antimicrobial, anti-inflammatory, and tissue-regenerative potential. Integrating these natural

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compounds into wound care strategies presents hydrogel, offers a promising avenue for addressing both wound healing and infection control[1,2]. Through the development and evaluation of herbal hydrogels, can strive to contribute to the advancement of effective, sustainable, and holistic strategies for promoting wound healing while mitigating infection risks[3–5]. Herbal hydrogels are topical formulations that blend the benefit of herbal extracts, essential oils or other plant-derived components with the unique properties of hydrogel matrices. These hydrogels are gaining attention for their potential to facilitate wound healing by providing moist environment, delivering bioactive compounds and offering antimicrobial and anti-inflammatory effects[6,7].

#### TYPES OF WOUNDS:

Wounds can be categorized into various types based on their causes, severity, and characteristics[8–10]. Some common types of wounds are as follows:

- i. **Incision:** These wounds are clean, straight, and typically caused by a sharp object like a knife or a razor blade. Surgical incisions made during medical procedures also fall into this category.
- ii. **Laceration:** Lacerations are irregular, jagged wounds that result from blunt trauma or tearing of the skin. Common causes include accidents, falls, and animal bites.
- iii. **Abrasion:** An abrasion, often referred to as a scrape or road rash, occurs when the skin rubs against a rough surface. These wounds are superficial and may not bleed much but can be painful.
- iv. **Puncture:** Puncture wounds are deep, narrow injuries caused by pointed objects like nails, needles, or splinters. These wounds can be at risk of infection due to their depth and the potential for foreign material to be embedded.
- v. **Avulsion:** Avulsion wounds involve the tearing away of a portion of the skin and underlying tissue. These injuries can be significant and may require surgical intervention.
- vi. **Contusion:** Also known as a bruise, a contusion occurs when blood vessels beneath the skin rupture, leading to discoloration and swelling. While not an open wound, it is still a type of injury.
- vii. **Burn:** Burns are injuries to the skin and underlying tissues caused by exposure to heat, chemicals, electricity, or radiation. They are typically categorized into degrees (first-degree, second-degree, and third-degree) based on their severity.
- viii. **Pressure Ulcer (Bed Sore):** Pressure ulcers, commonly known as bed sores, develop when prolonged pressure on the skin restricts blood flow, leading to tissue damage. They often occur in individuals who are bedridden or use wheelchairs.
- ix. **Gunshot Wound:** Gunshot wounds are caused by firearms and can vary in severity depending on the type of firearm, bullet caliber, and the range at which the shot was fired.
- x. **Crush Injury:** These injuries result from excessive pressure or force applied to a body part, often due to accidents involving heavy machinery or falling objects. Crush injuries can cause significant tissue damage and may involve fractures.
- xi. **Bite Wound:** Bite wounds can result from human bites, animal bites (e.g., dog or cat bites), or insect stings. They may introduce bacteria into the wound and can be prone to infection.
- xii. **Ulcer:** Ulcers are chronic open sores that often develop on the skin or mucous membranes, such as in the mouth (oral ulcers) or on the legs (venous ulcers). They



are associated with underlying medical conditions and poor wound healing.

- xiii. **Chronic Wounds:** Chronic wounds are long-lasting wounds that do not progress through the normal stages of healing. Examples include diabetic ulcers and pressure ulcers.
- xiv. **Surgical Wounds:** These are wounds resulting from surgical procedures. They are typically incisions made intentionally and are expected to heal through the normal wound healing process.
- xv. **Infected Wounds:** Any of the above types of wounds can become infected if bacteria or other pathogens enter the wound. Signs of infection include redness, swelling, warmth, pain, and the presence of pus.

#### **WOUND HEALING PROCESS:**

The wound healing process is a complex series of events that occurs to repair damaged tissue and restore the skin's integrity[11,12]. It typically involves four overlapping phases: hemostasis, inflammation, proliferation, and remodeling[13,14]. Wound Healing occurs in several phases as mentioned below:

##### **A. Hemostasis:**

- i. **Immediate Response:** When a wound occurs, the body's immediate response is to stop bleeding. Platelets in the blood gather at the wound site and form a temporary plug to seal the damaged blood vessels (hemostasis).
- ii. **Vasoconstriction:** Blood vessels near the wound constrict to reduce blood flow, helping to minimize bleeding.
- iii. **Clot Formation:** The clotting cascade begins, leading to the formation of a stable blood clot (hemostatic plug) composed of fibrin and blood cells. This clot acts as a temporary barrier.

##### **B. Inflammation:**

- i. **Cellular Response:** Inflammation is a crucial phase for wound healing. White blood cells, primarily neutrophils and macrophages, migrate to the wound to remove debris, dead cells, and potential pathogens.
- ii. **Cytokine Release:** Various signaling molecules, called cytokines, are released to coordinate the inflammatory response. These molecules also stimulate the recruitment of fibroblasts and endothelial cells.
- iii. **Angiogenesis:** New blood vessels (angiogenesis) begin to form, supplying the wound with oxygen and nutrients needed for repair.
- iv. **Granulation Tissue:** Granulation tissue, which is rich in collagen and blood vessels, starts to develop at the wound site.

##### **C. Proliferation:**

- i. **Fibroblast Activity:** During this phase, fibroblasts play a key role. They produce collagen, a structural protein that strengthens the wound, and other extracellular matrix components.
- ii. **Re-epithelialization:** Epithelial cells migrate from the wound edges to cover the wound's surface, forming a new epidermal layer.
- iii. **Contraction:** Myofibroblasts contribute to wound contraction, reducing the wound's size.
- iv. **Continued Angiogenesis:** Blood vessels continue to grow into the wound, ensuring adequate blood supply to support tissue repair.

##### **D. Remodelling (Maturation):**

- i. **Tissue Remodelling:** This phase can last for several months or even years. The newly formed collagen fibers gradually reorganize and mature, making the wound stronger.



- ii. Scar Formation: The wound is filled with collagen, and the scar tissue becomes more organized. The scar may initially appear raised and red but tends to flatten and fade over time.
- iii. **Strength Restoration:** The wound gradually regains its strength, although it may never reach the full strength of the original tissue.
- iv. **Functional Recovery:** If the wound affected a functional area (e.g., a joint), functional recovery occurs during this phase as tissues adapt and regain their functionality.

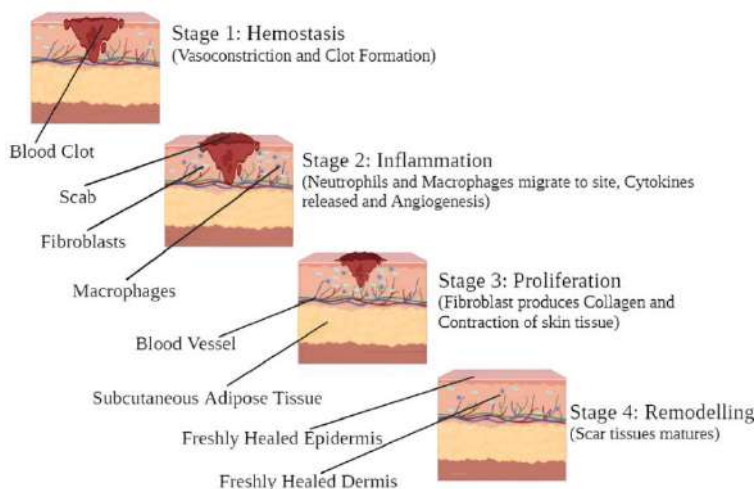


Figure 1: Stages of wound healing (Figure made in Biorender.com)

## EXPLORATION OF THE PLANTS

### 1. ALOEVERA (GHRITAKUMARI)



Figure 2: Herbarium of *Aloe barbadensis* (own picture)



Figure 3: Aloe Vera Plant in BST Herbal Garden

**a. Scientific name:** Aloe barbadensis

**b. Taxonomical classification:**

**Kingdom:** Plantae

**Phylum:** Angiosperms (Magnoliophyta)

**Class:** Monocots (Liliopsida)

**Order:** Asparagales

**Family:** Asphodelaceae (formerly Aloaceae)

**Genus:** Aloe

**Species:** Aloe vera

**c. Plant Description:**

Aloe vera is a short-stemmed plant with thick, fleshy green leaves that are filled with a gel-like substance. This gel is the part of the plant most used for its medicinal and cosmetic applications[15–17].

**d. Medicinal Properties:**

- i. **Skin Health:** Aloe vera gel is renowned for its soothing and moisturizing properties. It is often used to treat minor burns, sunburn, cuts, and skin irritations. It can help reduce pain, redness, and inflammation.
- ii. **Wound Healing:** Aloe vera promotes wound healing by stimulating collagen production and tissue repair. It can enhance the healing process of minor wounds and reduce scarring.
- iii. **Anti-Inflammatory:** Aloe vera has natural anti-inflammatory properties, making it useful for conditions like psoriasis, eczema, and insect bites.
- iv. **Digestive Health:** Some people use aloe vera juice or supplements to aid digestion and relieve gastrointestinal discomfort. It may have a mild laxative effect.
- v. **Antimicrobial:** Aloe vera contains compounds with antimicrobial properties that can help prevent infection in minor wounds and cuts.
- vi. **Anti-Aging:** Aloe vera is a common ingredient in skincare products due to its potential to reduce wrinkles and improve skin elasticity.

vii. **Cosmetic Applications:** Aloe vera is often found in a wide range of cosmetic and skincare products, including moisturizers, lotions, shampoos, and conditioners. It is used in these products for its hydrating and soothing effects on the skin and hair.

viii. **Oral Consumption:** Aloe vera can be consumed orally, but it's important to use preparations specifically designed for internal use. Some people take aloe vera supplements for various health benefits, although the efficacy of these supplements is still a subject of research.

**e. Phytoconstituents:**

Aloe vera contains a variety of chemical compounds and phytoconstituents that contribute to its medicinal and therapeutic properties.

- i. **Polysaccharides:** Aloe vera contains complex carbohydrates, primarily glucomannans, which have immune-boosting and anti-inflammatory effects. These polysaccharides are known for their ability to stimulate the immune system and promote wound healing.
- ii. **Aloin:** Aloin is a bitter-tasting compound found in the latex (the yellowish sap) of the Aloe vera leaf. It has laxative properties and is used in some traditional remedies for digestive issues. However, it can also cause digestive discomfort and should be used with caution.
- iii. **Anthraquinones:** These compounds have natural laxative effects and can be found in the latex of Aloe vera. Some common anthraquinones in Aloe vera include aloin and emodin.
- iv. **Phytosterols:** Aloe vera contains phytosterols, which are plant compounds with potential cholesterol-lowering properties. They may also have anti-inflammatory effects.



- v. **Enzymes:** Aloe vera contains several enzymes, such as amylase, lipase, and bradykinase, which have digestive and anti-inflammatory properties. Bradykinase, in particular, may help reduce inflammation and pain.
- vi. **Vitamins and Minerals:** Aloe vera contains various vitamins (e.g., vitamins A, C, and E) and minerals (e.g., calcium, magnesium, and zinc) that contribute to its overall nutritional value and support skin health.
- vii. **Amino Acids:** Aloe vera contains several essential and non-essential amino acids, which are the building blocks of proteins. These amino acids are involved in various physiological processes in the body.
- viii. **Salicylic Acid:** Aloe vera contains salicylic acid, a natural exfoliant and anti-inflammatory compound often used in skincare products to treat acne and skin conditions.
- ix. **Saponins:** Saponins are glycosides with natural cleansing and antimicrobial properties. They can help cleanse the skin and may aid in wound healing.
- x. **Flavonoids:** Aloe vera contains flavonoids, which are antioxidants that help protect cells from damage caused by free radicals. Flavonoids may contribute to the plant's anti-inflammatory effects.
- xi. **Lignin:** Lignin is a complex natural substance found in Aloe vera that enhances the penetration of other compounds into the skin. It aids in the delivery of beneficial substances to deeper skin layers.

## 2. TURMERIC (HALDI)



**Figure 4 : Herbarium of Curcuma longa (own picture)**



**Figure 5 : Turmeric Plant in BST Herbal Garden**

**a. Scientific name:** *Curcuma longa*

**b. Taxonomical classification:**

Kingdom: Plantae

**Phylum:** Angiosperms (Magnoliophyta)

**Class:** Monocots (Liliopsida)

**Order:** Zingiberales

**Family:** Zingiberaceae

**Genus:** *Curcuma*

**Species:** *Curcuma longa*

**c. Plant description:** Turmeric is a herbaceous plant known for its lance-shaped leaves and vibrant trumpet-shaped flowers, but its prized component is the bright orange rhizome, used for its culinary and medicinal properties, particularly as the spice turmeric. It's native to South Asia, thriving in tropical and subtropical regions [18–20].

**d. Medicinal properties:**

- i. **Anti-Inflammatory:** Curcumin is a potent anti-inflammatory agent. It inhibits the activity of various inflammatory molecules in the body, which helps reduce inflammation and ease symptoms associated with inflammatory conditions such as arthritis and inflammatory bowel disease.
- ii. **Antioxidant:** Curcumin is a powerful antioxidant that neutralizes harmful free radicals and prevents oxidative damage to cells and tissues. This antioxidant property may contribute to its anti-aging effects and potential in preventing chronic diseases.
- iii. **Pain Relief:** Turmeric is often used as a natural pain reliever. Its anti-inflammatory properties make it effective for alleviating pain and discomfort associated with conditions like osteoarthritis and rheumatoid arthritis.
- iv. **Digestive Health:** Turmeric has traditionally been used to aid digestion. It stimulates bile production, which can help with the breakdown of fats and support overall digestive function. Some people use turmeric to relieve indigestion and bloating.
- v. **Antibacterial and Antiviral:** Curcumin exhibits antibacterial and antiviral properties, which may help combat infections. It has been studied for its potential role in fighting various bacteria and viruses.
- vi. **Wound Healing:** Turmeric can be applied topically to wounds and cuts due to its antimicrobial and anti-inflammatory properties. It may accelerate the wound healing process and reduce the risk of infection.
- vii. **Skin Health:** Turmeric is used in skincare products for its potential to reduce acne and improve skin complexion. It can help control excess oil production and has anti-inflammatory properties that may benefit various skin conditions.
- viii. **Heart Health:** Some research suggests that curcumin may have a positive impact on heart health. It may improve the function of the endothelium (the lining of blood vessels), which can contribute to better cardiovascular health.
- ix. **Neuroprotective:** Curcumin has been studied for its potential neuroprotective properties. It may help protect against neurodegenerative diseases like Alzheimer's and Parkinson's disease by reducing inflammation and oxidative stress in the brain.
- x. **Cancer Prevention:** While more research is needed, some studies have indicated that curcumin may have anticancer properties. It may inhibit the growth of cancer cells and suppress the development of tumors.
- xi. **Immune System Support:** Curcumin may enhance the immune system's response to infections and diseases, potentially boosting overall immunity.
- xii. **Anti-Allergic:** Some research suggests that turmeric and curcumin may have anti-allergic properties, helping to alleviate allergy symptoms.



**e. Phytoconstituents:**

- i. **Alkaloids:** Alkaloids are nitrogen-containing compounds with diverse biological activities. Examples include caffeine (in coffee and tea), morphine (from poppy plants), and nicotine (in tobacco). Alkaloids can have stimulating, sedative, or toxic effects.
- ii. **Flavonoids:** Flavonoids are antioxidants found in fruits, vegetables, and herbs. They have anti-inflammatory and immune-boosting properties and are associated with various health benefits. Examples include quercetin, kaempferol, and catechins.
- iii. **Terpenoids:** Terpenoids are hydrocarbons that give plants their characteristic scents and flavors. They are found in essential oils and resins and have antimicrobial, anti-inflammatory, and antioxidant properties. Examples include limonene, menthol, and curcumin.
- iv. **Phenolic Compounds:** Phenolic compounds are antioxidants with a wide range of health benefits. They include phenolic acids (e.g., gallic acid), lignans, and stilbenes. These compounds can protect cells from oxidative stress and reduce the risk of chronic diseases.
- v. **Glycosides:** Glycosides are compounds formed by the combination of a sugar molecule and another compound (aglycone). They have various functions, such as cardiac glycosides that affect heart function and anthraquinone glycosides that have laxative properties.
- vi. **Tannins:** Tannins are astringent compounds found in plants like tea, wine, and fruits. They can bind to proteins and other compounds, which can have both beneficial and detrimental effects. Tannins are known for their antioxidant properties.
- vii. **Saponins:** Saponins are glycosides with a foamy structure that can produce a lathering

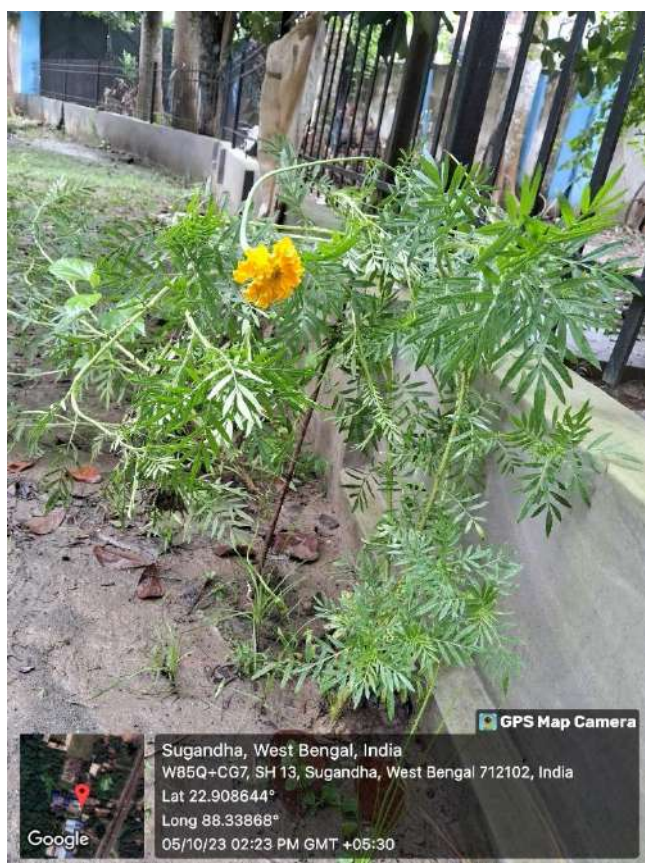
- effect. They have antibacterial and anti-inflammatory properties and are often found in legumes and some medicinal herbs.
- viii. **Lignans:** Lignans are phytoestrogens found in flaxseeds, sesame seeds, and whole grains. They may have hormone-balancing properties and contribute to heart health.
- ix. **Carotenoids:** Carotenoids are responsible for the red, orange, and yellow pigments in fruits and vegetables. They are precursors to vitamin A and have antioxidant properties. Examples include beta-carotene and lutein.
- x. **Glucosinolates:** Glucosinolates are sulfur-containing compounds found in cruciferous vegetables like broccoli and cabbage. They have anticancer properties and can be converted into bioactive compounds called isothiocyanates.

**3. MARIGOLD**



**Figure 6 : Herbarium of Tagetes erecta (own picture)**





**Figure 7** Marigold Plant in BST Herbal Garden

a. **Scientific name:** *Tagetes erecta*

b. **Taxonomical classification:**

**Kingdom:** Plantae

**Phylum:** Angiosperms

**Class:** Asterids

**Order:** Asterales

**Family:** Asteraceae

**Genus:** *Tagetes*

**Species:** *Tagetes erecta*

c. **Plant description:** *Tagetes erecta*, commonly known as Marigold, is an annual flowering plant known for its vibrant, double-layered flowers in shades of yellow, orange, and red. It grows up to 1-3 feet tall, has pinnately dissected green leaves, and blooms from late spring to fall. They prefer full sun, well-draining soil, and moderate watering. Propagated from seeds, they are generally resistant to pests and diseases[7,21,22].

d. **Medicinal properties:**

i. **Anti-Inflammatory:** Marigold contains compounds with anti-inflammatory properties,

such as flavonoids and triterpenoids. It has been used topically to reduce inflammation and soothe skin conditions like rashes, eczema, and minor burns[10,16].

- ii. **Wound Healing:** Marigold is known for its ability to promote wound healing. The plant's extracts can help stimulate tissue repair, reduce inflammation, and prevent infection. Calendula, a type of marigold, is often used in topical ointments and creams for wound care.
- iii. **Antimicrobial:** Marigold extracts have demonstrated antimicrobial activity against certain bacteria and fungi. This property can be useful in preventing infections in wounds and skin conditions.
- iv. **Skin Care:** Marigold extracts are commonly used in cosmetics and skincare products due to their soothing and moisturizing properties. They can help with conditions like dry skin, chapped lips, and dermatitis.
- v. **Anti-Aging:** Some skincare products use marigold extracts for their potential anti-aging effects, as they may help improve skin elasticity and reduce the appearance of wrinkles.
- vi. **Digestive Health:** Marigold has been used traditionally as a remedy for digestive issues. It may help alleviate symptoms of indigestion and gastritis, although more research is needed to confirm these effects.
- vii. **Eye Health:** Marigold extracts, particularly those containing lutein and zeaxanthin, are believed to support eye health. These compounds may help protect the eyes from oxidative damage and reduce the risk of age-related macular degeneration.
- viii. **Menstrual Pain:** Marigold has been used in traditional medicine to alleviate menstrual cramps and discomfort. Some herbal preparations contain marigold for this purpose.
- ix. **Anti-Cancer Potential:** Preliminary research suggests that certain compounds in marigold

may have anti-cancer properties, although further studies are needed to fully understand this potential.

- x. **Anti-Spasmotic:** Marigold has been used to relax smooth muscles, which can be beneficial for conditions involving muscle spasms, such as menstrual cramps or gastrointestinal issues[23].

#### e. Phytoconstituents:

- i. **Carotenoids:** Marigolds are rich in carotenoid pigments, including lutein and zeaxanthin, which are known for their antioxidant properties. These compounds are particularly beneficial for eye health and may help protect against age-related macular degeneration.
- ii. **Flavonoids:** Marigolds contain various flavonoids, such as quercetin and patuletin. Flavonoids are known for their antioxidant and anti-inflammatory properties and can contribute to the plant's medicinal benefits[24,25].
- iii. **Triterpenoids:** Triterpenoids are compounds found in marigold that have anti-inflammatory and wound-healing properties. Calendula, a type of marigold, is particularly rich in triterpenoids and is often used in skincare products.
- iv. **Sterols:** Marigold also contains sterols, which are compounds with potential anti-inflammatory and cholesterol-lowering effects.
- v. **Essential Oils:** Marigold flowers may contain essential oils that contribute to their fragrance. These oils can vary in composition and may have aromatherapeutic properties.
- vi. **Polysaccharides:** Marigolds contain polysaccharides, which are complex carbohydrates. These compounds may have immune-boosting and anti-inflammatory properties.
- vii. **Alkaloids:** Some marigold varieties contain alkaloids, although in relatively low

concentrations. Alkaloids can have diverse effects on the body, depending on their type and concentration.

- viii. **Saponins:** Saponins are natural compounds found in marigold that can have foaming and emulsifying properties. They are sometimes used in cosmetics and skincare products.
- ix. **Phenolic Compounds:** Phenolic compounds, including phenolic acids and flavonoids, contribute to the antioxidant and anti-inflammatory properties of marigold[26].
- x. **Coumarins:** Coumarins are aromatic compounds that can have anticoagulant and anti-inflammatory effects. They are found in some marigold varieties.

#### HYDROGELS:

Hydrogel is a unique type of material with a high-water content that resembles the consistency and properties of natural tissue[27–29]. It is widely used in various medical, pharmaceutical, and consumer applications due to its remarkable characteristics[30,31].

##### A. Composition:

Hydrogels are primarily composed of water (usually over 90% by weight) and a three-dimensional network of hydrophilic polymer chains[32–34]. The polymer used in hydrogels can vary, but common choices include polyacrylates, polyvinyl alcohol, polyethylene glycol, and natural polymers like agarose and alginate[35–37].

##### B. Properties:

- i. **High Water Content:** Hydrogels are known for their exceptional water-holding capacity, which makes them excellent for retaining moisture.
- ii. **Biocompatibility:** Many hydrogel formulations are biocompatible and are used in medical applications, such as wound dressings and contact lenses.



- iii. **Flexibility:** Hydrogels are soft, pliable, and can be designed to mimic the mechanical properties of human tissues.
- iv. **Porosity:** The porous structure of hydrogels allows for the diffusion of nutrients and oxygen, making them suitable for tissue engineering[38].
- v. **Swelling Capacity:** Hydrogels can swell and absorb water, leading to an increase in volume. This property is exploited in various applications, including drug delivery[39].

### C. Applications:

- i. **Medical:** Hydrogels are widely used in wound dressings, tissue engineering, and drug delivery systems. They can provide a moist environment for wound healing and release drugs in a controlled manner.
- ii. **Contact Lenses:** Soft contact lenses are often made from hydrogel materials due to their biocompatibility and ability to retain moisture.
- iii. **Diapers and Hygiene Products:** Hydrogels are used in the absorbent core of diapers and other hygiene products to efficiently absorb and retain liquids.
- iv. **Cosmetics:** Hydrogels are used in cosmetics, particularly in skincare products like face masks and moisturizers, to provide hydration and cooling effects.
- v. **Agriculture:** Hydrogel-based soil conditioners can improve soil water retention and nutrient delivery to plants.
- vi. **Food Industry:** Hydrogels can be used to encapsulate flavors, colors, and nutrients in food products.

### D. Types of Hydrogels:

- i. **Natural Hydrogels:** Derived from natural polymers such as alginate, chitosan, and agarose. They are often used in biomedical applications.
- ii. **Synthetic Hydrogels:** Made from synthetic polymers like polyacrylamide and polyvinyl

alcohol. They offer precise control over properties.

- iii. **Hybrid Hydrogels:** Combine natural and synthetic components to leverage the benefits of both types.

### MECHANISM OF HERBAL HYDROGELS AGAINST BACTERIA IN WOUNDS

Wounds can become infected with various bacteria, depending on the environment, cleanliness and type of injury[40,41]. The presence of such bacteria can lead to complications and delayed wound healing[42,43]. Common bacteria that can be found in wounds include-

- i. Staphylococcus aureus
- ii. Staphylococcus pyogenes
- iii. Pseudomonas aeruginosa
- iv. Escherichia coli
- v. Clostridium perfringens
- vi. Enterococcus species
- vii. Proteus species

Herbal hydrogel may have several mechanisms through which can act against bacteria in wounds.

- a. **Antimicrobial properties:** Herbal extracts of aloe vera, turmeric, marigold contain natural antimicrobial compounds that can inhibit the growth of bacteria.
- b. **Anti-inflammatory effects:** The mentioned herbal ingredients with anti-inflammatory properties can help to reduce the body's inflammatory response to the infection, which may create a less favourable environment for bacteria to thrive.
- c. **Promotion of tissue regeneration:** The herbal hydrogels might contain components that stimulate tissue repair and regeneration. A faster healing process can limit the window of opportunity for bacteria to multiply and cause further infection.
- d. **Moisture regulation:** Hydrogels maintain a moist wound environment, which can enhance the body's natural healing processes



and discourage bacterial growth, as some bacteria thrive in dry conditions[44].

- e. **Biofilm disruption:** Herbal compounds may interfere with bacterial biofilms, which are protective matrices that bacteria create in wounds. Disrupting biofilms can make bacteria more susceptible to antimicrobial treatments[45].

## DISCUSSION

One of the prominent themes emerging from the literature is the efficacy of herbal hydrogels in promoting wound healing. Multiple studies have substantiated the ability of these hydrogels, enriched with botanical extracts, to expedite the wound healing process through diverse mechanisms. Additionally, the antimicrobial activity found in certain plant compounds, such as polyphenols and flavonoids, plays a pivotal role in preventing infections, a common hurdle in wound healing. Furthermore, herbal hydrogels demonstrate an impressive capacity for enhancing tissue regeneration. These findings underscore the potential of herbal hydrogels as a valuable addition to wound care protocols, particularly in cases of chronic wounds and burn injuries, where conventional treatments often encounter limitations. The clinical applications of herbal hydrogels in wound healing are expanding rapidly. A multitude of studies and clinical trials have rigorously evaluated the effectiveness of these innovative formulations in various wound types, yielding highly promising results. In the management of chronic wounds, such as diabetic foot ulcers and pressure ulcers, herbal hydrogels have demonstrated the capacity to expedite healing rates while concurrently reducing complications. In cases of burn injuries, where infection control and tissue regeneration are critical, these hydrogels exhibit tremendous potential in enhancing patient outcomes. However, despite these promising results, the widespread adoption of herbal hydrogels in clinical practice does face certain

challenges and considerations that merit careful attention. A primary challenge revolves around the standardization of formulations. Given the variation in potency and composition of herbal extracts, establishing standardized protocols for herbal hydrogel production is imperative to ensure consistency and predictability of outcomes. Additionally, concerns regarding safety and potential side effects must be addressed. While botanical extracts are generally considered safe, it is essential for clinicians to exercise vigilance in monitoring patients for adverse reactions and allergies when employing herbal hydrogels. While existing studies exhibit promise, larger-scale trials are essential to solidify the long-term efficacy and safety profile of herbal hydrogels across a broader patient spectrum. The future directions of this field are abundant with opportunities for research and development. Collaboration among researchers, herbalists, and pharmaceutical companies is critical to establishing standardized formulations with consistent therapeutic benefits. This entails defining appropriate extraction methods, identifying active compounds, and ensuring batch-to-batch consistency.

## CONCLUSION

Botanical innovations in wound healing, particularly using herbal hydrogels containing aloe vera, turmeric, and marigold, offer a compelling avenue for advancing wound care. These natural ingredients bring a range of benefits, from their anti-inflammatory and antimicrobial properties to their ability to promote tissue regeneration and provide a moist wound environment. While the potential of herbal hydrogels in wound healing is promising, further research and clinical trials are needed to fully understand their efficacy, safety, and specific applications for different types of wounds. Collaboration between traditional herbal medicine and modern medical science can lead to the development of more effective and holistic wound care solutions. As with any medical



treatment, it's crucial to seek guidance from healthcare professionals when considering herbal remedies for wound healing, especially for serious or chronic wounds. The integration of botanical innovations with established wound care practices holds the potential to improve patient outcomes and enhance the quality of wound management. As we continue to explore and refine these botanical innovations, it is essential to conduct rigorous scientific studies and clinical trials to establish their safety, effectiveness, and best practices for integration into wound care protocols. Collaboration between herbalists, healthcare professionals, and researchers is key to harnessing the full potential of herbal hydrogels for wound healing. Ultimately, the future of wound care may involve a synergistic approach that combines traditional herbal wisdom with modern medical knowledge, providing patients with more comprehensive and personalized treatment options. Always consult with healthcare providers and experts in wound care when considering these innovative botanical solutions to ensure the best possible outcomes for patients.

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