International Journal of Biology Research
www.biologyjournal.in
ISSN: 2455-6548
Received: 26-05-2025, Accepted: 25-06-2025, Published: 10-07-2025
Volume 10, Issue 3, 2025, Page No. 1-2

Phytochemical insights into medicinal plants with wound healing potential, mechanisms and therapeutic implications.

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Abstract
Wound healing is a complex, multi-phase physiological process involving cellular regeneration, tissue repair, and extracellular matrix remodeling. Traditional medicinal plants offer a diverse reservoir of phytoconstituents that exhibit wound-healing properties, including antioxidant, anti-inflammatory, and antimicrobial actions. This review highlights key medicinal plants and their bioactive compounds known to enhance wound healing. It explores their mechanisms of action—such as promoting collagen synthesis, stimulating angiogenesis, and reducing inflammation. The integration of ethnopharmacological knowledge with scientific validation positions medicinal plants as valuable tools in modern wound care strategies.

Keywords: Medicinal plants, wound healing, phytochemicals, traditional medicine, inflammation, collagen synthesis, skin regeneration

Introduction

Wound healing is a multifaceted physiological process that plays a vital role in restoring skin integrity and function after injury. This dynamic process involves a cascade of cellular and molecular events that are typically categorized into four overlapping stages: hemostasis, inflammation, proliferation, and remodeling (Rodrigues *et al*., 2019) [9]. While modern medicine has advanced in the development of synthetic wound care agents, issues such as antibiotic resistance, delayed healing in diabetic or elderly patients, and high costs often limit their long-term use.

In contrast, traditional medicinal systems across the world have long embraced the use of herbal remedies in wound management. Indigenous communities in Asia, Africa, and South America have used herbal poultices, pastes, and extracts to promote healing and prevent infection. Plants used in Ayurveda, Traditional Chinese Medicine, and ethnomedicine are often rich in phytochemicals—such as flavonoids, saponins, tannins, terpenoids, and alkaloids—that target different phases of healing (Patil *et al*., 2014; Nasri *et al*., 2015) [6, 7].

Scientific investigations into these plant-derived compounds have revealed their capacity to modulate inflammation, stimulate angiogenesis, protect against microbial invasion, and enhance tissue regeneration (Gupta & Jain, 2012; Alves & Ferreira, 2013) [1, 4]. As a result, medicinal plants are increasingly being integrated into wound healing formulations in both pharmaceutical and cosmeceutical industries.

This review aims to synthesize current knowledge on medicinal plants with wound-healing potential, focusing on their phytochemical constituents, mechanisms of action, and prospects for clinical translation.

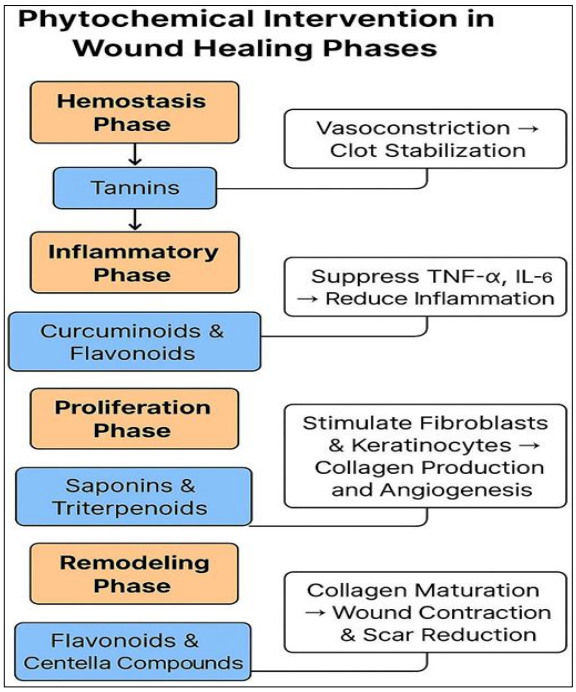
Methodology

This review was conducted using a systematic approach to identify, evaluate, and summarize scientific evidence on the wound healing properties of medicinal plants. Databases including PubMed, ScienceDirect, Google Scholar, and Scopus were used to collect peer-reviewed articles published between 2000 and 2024.

Keywords such as "medicinal plants," "wound healing," "phytochemicals," "skin regeneration," "herbal therapy," and "angiogenesis" were used in various combinations. Only studies published in English and focusing on experimental, *in vitro*, *in vivo*, or clinical investigations were included.

Review articles, ethnobotanical surveys, and pharmacological studies on plant-based wound healing agents were critically evaluated. Special emphasis was placed on articles detailing mechanisms of action, including those involving collagen synthesis, fibroblast proliferation, anti-inflammatory, antioxidant, and antimicrobial effects (Yahya *et al*., 2017; Badole *et al*., 2015) [2, 12]. The data were extracted and grouped according to plant species, phytochemical classes, and their biological effects in wound management.

The review followed PRISMA guidelines to ensure transparency and reproducibility (Moher *et al*., 2009) [5].



Phases of Wound Healing

1. **Hemostasis:** Initiates clot formation to stop bleeding
2. Inflammation: Recruitment of immune cells to prevent infection
3. **Proliferation:** Fibroblast proliferation, angiogenesis, and epithelialization
4. **Remodeling:** Collagen reorganization and scar maturation

Phytochemicals influence each of these phases, either accelerating repair or minimizing damage

Results

Key Medicinal Plants and Their Phytochemicals

Plant Name	Phytochemicals	Wound-Healing Activity
Aloe vera	Acemannan, tannins	Enhances fibroblast growth, anti-inflammatory
Curcuma longa	Curcumin	Reduces inflammation, supports granulation
Centella asiatica	Asiaticoside	Stimulates collagen, promotes angiogenesis
Calendula officinalis	Flavonoids, triterpenoids	Promotes epithelialization
Azadirachta indica	Nimbidin, quercetin	Antimicrobial, immunomodulatory
Ocimum sanctum	Eugenol, ursolic acid	Improves circulation, reduces infection
Lawsonia inermis	Lawsone, tannins	Astringent, helps contraction of wounds

Mechanisms of Action

Antioxidant Activity

Flavonoids and phenolic acids neutralize free radicals, reducing oxidative stress at the wound site.

Anti-inflammatory Effect

Phytochemicals like curcumin and ursolic acid suppress pro-inflammatory cytokines (e.g., TNF-α, IL-1β), shortening the inflammatory phase.

Collagen Synthesis and Fibroblast Proliferation

Triterpenoids from Centella asiatica enhance collagen production, essential for tensile strength and dermal repair.

Angiogenesis Promotion

Compounds like asiaticoside stimulate vascular endothelial growth factor (VEGF), leading to new blood vessel formation.

Antimicrobial Action

Essential oils and alkaloids inhibit bacterial colonization at the wound site, preventing infection and delayed healing.

Literature Support

Centella asiatica extract accelerated wound closure and increased tensile strength in rat models (Shukla *et al*., 1999) [10].

Curcuma longa exhibited significant anti-inflammatory and antioxidant effects by modulating NF-κB signaling (Chainani-Wu, 2003) [3].

Aloe vera gel promoted fibroblast proliferation and re-epithelialization (Surjushe *et al*., 2008) [11].

Calendula officinalis extract enhanced granulation tissue formation and improved healing rate (Preethi *et al*., 2009) [8].

Challenges and Future Prospects

Despite promising results, major challenges remain:

Standardization of plant extracts

Lack of clinical trials and regulatory approvals

Stability and shelf-life of herbal formulations

Future research should focus on nanoparticle-based delivery systems, combination therapies, and pharmacokinetic profiling of herbal actives.

Conclusion

Medicinal plants possess potent wound-healing properties, owing to their rich phytochemical content. Their multifaceted actions—ranging from antimicrobial to angiogenic effects—make them promising alternatives or adjuncts to modern therapies. A synergistic approach that combines traditional knowledge with contemporary science will pave the way for safe, effective, and affordable wound care solutions

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