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Review Paper

Therapeutic Potential of Various Medicinal Plants in Wound Management: A Comprehensive Review

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ABSTRACT

Wound healing is a complex biological process which involves four distinct phases like hemostasis, inflammation, proliferation and tissue remodeling. The various phytoconstituents present in the medicinal plants made them a potential wound healing agent. This review summarizes the wound healing potential of medicinal plants based on various phytoconstituents like alkaloids, flavonoids, tannins, saponins, phenolics terpenoids and glycosides present in it, which exhibits antioxidant, antimicrobial, anti-inflammatory, angiogenic and collagen promoting effect.

INTRODUCTION

Globally, wounds particularly chronic wounds are a major source of expense for healthcare systems. According to estimates, at least 2% of people in the United States of America (USA) may suffer from a chronic wound of some kind. According to a study by Queen and Harding, the three nations that spent the most on wound care in 2022—the United States, China, and Japan were expected to have spent $148.65 billion, $42.78 billion, and $22.91 billion, respectively. Additionally, the worldwide wound care market is projected to rise at a compound annual growth rate of 6.1% from 2024 to 2032, reaching $20.33 billion[1].

Both the market for wound care products and the yearly expenditures made by individuals and governments to manage this health issue are growing[1]. The majority of the more than 5,000 commercially available wound care products are dressings[2].

Wound healing is a complicated and dynamic biological process with four overlapping phases: hemostasis, inflammation, proliferation, and tissue remodeling[2]. This sequence of actions is essential for the complete healing of wounded tissues. Impaired wound healing, particularly in the case of

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chronic wounds, is a serious issue in clinical practice.

Medicinal plants have long been recognized as valuable resources in traditional medicine systems across the world, owing to their ability to promote wound healing through a wide range of bioactive phytochemicals with minimal adverse effects. These phytochemicals, including flavonoids, alkaloids, tannins, saponins, and phenolic acids, possess potent antioxidant, anti-inflammatory, and antimicrobial activities that collectively enhance the various stages of the wound healing process. Growing scientific interest has led to extensive investigations into the therapeutic potential of underexplored medicinal plants, with the aim of discovering novel, safe, and effective wound healing agents that can complement or serve as alternatives to conventional wound care therapies.

CLASSIFICATION OF WOUND [3]

Wounds are categorized according to several factors, such as their anatomical site, the type and cause of injury, clinical presentation, depth of tissue damage, extent of tissue loss, and morphological characteristics. Depending on the mechanism responsible for their occurrence, wounds are generally classified as either open or closed. Based on the normal progression of tissue repair, they are also grouped into acute wounds, which heal within an expected timeframe, and chronic wounds, which exhibit delayed or impaired healing.

a) Open Wounds:

Open wounds are characterized by a break in the skin or underlying tissues, resulting in visible bleeding as blood escapes from the body. These injuries expose the affected tissues to the external environment and are commonly classified into several types, including incisions, lacerations, abrasions, puncture wounds, avulsions, and penetrating injuries such as gunshot wounds. The severity of an open wound depends on the extent of tissue damage and the risk of contamination or infection.

b) Closed Wounds:

Closed wounds occur when the skin remains intact, but the underlying tissues and blood vessels are damaged. In these injuries, blood leaks from the circulatory system and accumulates beneath the skin without an external opening. Common examples include contusions (bruises), hematomas, and crush injuries. Although the skin surface appears unbroken, significant internal tissue damage may be present.

c) Acute Wounds:

Acute wounds are injuries that progress through the normal stages of wound healing in a predictable and timely manner. They usually result from surgical procedures, accidental cuts, or other forms of trauma and undergo an orderly sequence of hemostasis, inflammation, proliferation, and remodeling. With appropriate care, acute wounds generally heal completely within the expected period, restoring both the structural and functional integrity of the affected tissue.

d) Chronic Wounds:

Chronic wounds are those that fail to heal within the expected timeframe due to disruption of the normal healing process. These wounds often remain in a prolonged inflammatory phase, delaying tissue regeneration and repair. Factors such as infection, poor blood circulation, diabetes, repeated trauma, or underlying systemic diseases can contribute to their persistence. As a result, chronic wounds may take months to heal, frequently recur, and require specialized management strategies.

THE STAGES OF WOUND HEALING: TARGETS FOR BIOLOGICAL SCREENING[4]

Wound healing is a complex and well-regulated biological process that restores the integrity of injured tissue through four overlapping phases: hemostasis, inflammation, proliferation, and remodeling. Immediately after injury, the skin barrier is disrupted, resulting in blood loss and an increased risk of microbial invasion. During the hemostatic phase, blood clot formation controls bleeding and provides a protective barrier, while proper wound cleansing and antiseptic treatment help prevent infection.

The inflammatory phase involves the recruitment of immune cells and the release of cytokines to eliminate pathogens and remove damaged tissue. This is followed by the proliferative phase, during which fibroblast proliferation, angiogenesis, collagen deposition, and re-epithelialization promote tissue regeneration. Finally, in the remodeling phase, collagen fibers are reorganized, and scar tissue matures, restoring the strength and function of the affected tissue. Therapeutic interventions that support these phases can enhance wound repair and improve healing outcomes.

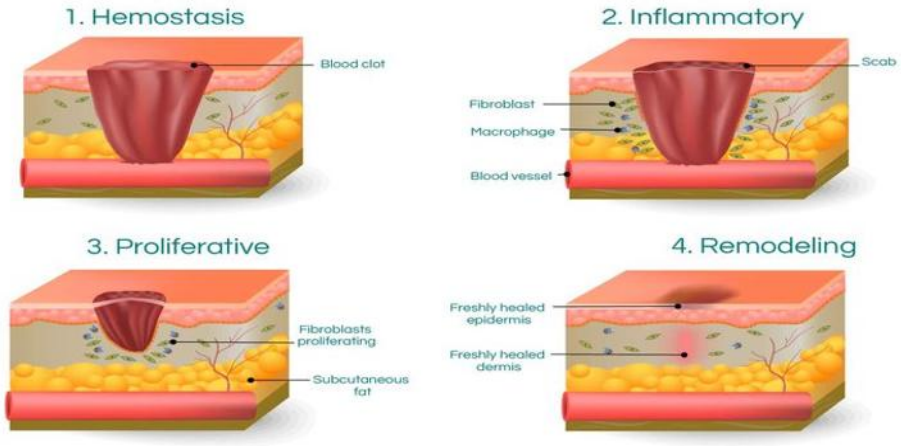

Fig 1: Four stages of wound healing

a) Homeostasis: blood clotting and wound closure

Hemostasis is the first phase of wound healing and occurs immediately after injury to prevent excessive blood loss. Local vasoconstriction reduces blood flow at the injury site, while platelet activation and aggregation lead to the formation of a temporary platelet plug. Simultaneously, the coagulation cascade is activated, resulting in the conversion of fibrinogen to fibrin by thrombin. Cross-linking of fibrin strands by factor XIII stabilizes the clot, which seals the wound, limits blood loss, and provides a protective barrier against microbial invasion.

Preventing wound infection is essential for normal healing, as microbial contamination can prolong inflammation and lead to complications such as cellulitis, osteomyelitis, sepsis, and necrotizing fasciitis. Therefore, maintaining an aseptic wound environment is a key aspect of wound management. The most common wound pathogens include Staphylococcus aureus, Staphylococcus epidermidis, Streptococcus pyogenes, Enterococcus faecalis, Pseudomonas aeruginosa, Escherichia coli, Klebsiella pneumoniae, and Proteus species, making them important targets for antimicrobial wound therapies.

b) Inflammation

The inflammatory phase is a critical stage of wound healing that enables the immune system to eliminate pathogens, remove damaged tissue, and initiate repair. Following injury, immune and resident cells, including macrophages, neutrophils, fibroblasts, and epithelial cells, release inflammatory mediators such as cytokines, chemokines, prostaglandins, and leukotrienes. Pro-inflammatory cytokines, including interleukin (IL)-1β, IL-2, IL-6, interferon-γ (IFN-γ), and tumor necrosis factor-α (TNF-α), coordinate the inflammatory response, while anti-inflammatory cytokines such as IL-10 help regulate inflammation and prevent excessive tissue damage. Chemokines, including macrophage inflammatory protein-2 (MIP-2) and monocyte chemoattractant protein-1 (MCP-1), recruit leukocytes to the wound site. Additionally, activation of the arachidonic acid pathway through cyclooxygenase (COX) and lipoxygenase (LOX) enzymes generates prostaglandins and leukotrienes, further modulating the inflammatory process. Together, these coordinated events prepare the wound for the subsequent stages of tissue repair and provide important therapeutic targets for enhancing wound healing.

c) Proliferative Phase

The proliferative phase is characterized by rapid tissue regeneration and restoration of the wound structure. During this stage, chemokines, cytokines, and growth factors stimulate fibroblast migration and proliferation through signaling pathways such as MAPK, YAP, and TGF-β. Fibroblasts synthesize collagen and other extracellular matrix (ECM) components, forming a scaffold for new tissue development. Some fibroblasts differentiate into myofibroblasts, which promote wound contraction and facilitate closure of the injured area. These coordinated processes are essential for effective tissue repair and regeneration.

d) Remodeling Phase

The remodeling phase is the final stage of wound healing, during which the newly formed tissue undergoes maturation and reorganization to improve its strength and functionality. This phase may continue for several months or even years. Type III collagen is gradually replaced by the stronger type I collagen, while the extracellular matrix is reorganized to enhance tissue integrity. Continued myofibroblast-mediated wound contraction and collagen remodeling result in the formation of mature scar tissue with increased tensile strength.

VARIOUS PLANTS USED FOR WOUND HEALING

1. *Marsilea minuta Linn.*

Marsilea minuta Linn., commonly known as water clover, is an aquatic fern of the family Marsileaceae with traditional uses in treating fever, skin disorders, and inflammation. Its pharmacological activities are attributed to various bioactive phytoconstituents present in the plant. Previous studies have demonstrated its antioxidant and anti-inflammatory properties, suggesting potential wound healing activity. However, its wound healing efficacy remains underexplored, particularly through in vivo studies[5].

The major compounds identified were benzoic acid-4-ethoxy-, ethyl ester (43.39%) and farnesol acetate (18.42%), a sesquiterpene derivative. These compounds were selected for molecular docking studies against TEM-72 and topoisomerase IV to investigate their potential antibacterial mechanisms. Other identified compounds included phenol, 2,4-bis(1,1-dimethylethyl) (8.37%), oxacycloheptadec-8-en-

2-one (5.68%), and trans-farnesol (5.11%). The presence of phenolic and other bioactive compounds may contribute to the antioxidant and antibacterial activities of the plant, as phenolic compounds are reported to possess antioxidant, antimicrobial, hepatoprotective, and antidiabetic properties[6].

2. *Cassia fistula*

Cassia fistula, commonly known as the golden shower tree, belongs to the family Leguminosae. It is traditionally used by various tribal communities for the treatment of rhinosinusitis and other ailments, including rheumatism, hemoptysis, itching, leukoderma, and gastrointestinal disorders. The plant contains several bioactive secondary metabolites, such as tannins, terpenes, flavonoids, and carbohydrates, which have been reported to exhibit antimicrobial properties[7].

The leaves of Cassia fistula have demonstrated anti-inflammatory and wound healing potential. They exhibit notable antiseptic properties, supporting their traditional use as broad-spectrum antibacterial agents for preventing infections. Additionally, the plant has been reported to possess anti-inflammatory and glycemic-regulating activities[8].

3. *Ficus religiosa*

Ficus religiosa, a prominent member of the family Moraceae, is commonly known as peepal. Various parts of the plant, including the bark, fruits, leaves, and stems, have been widely used in traditional medicine. Its therapeutic properties have been reported for several activities, including antibacterial, antioxidant, anti-inflammatory, wound healing, cardioprotective, antithrombotic, and antimutagenic effects. Additionally, the plant exhibits astringent, antiparasitic, antiulcer, antiviral, and antifungal activities, supporting its traditional use in managing various conditions, including tumors, dermatitis, and other skin disorders[9].

The wound healing activity of *Ficus religiosa Linn.* is attributed to its bioactive phytoconstituents, including flavonoids (quercetin, kaempferol, and myricetin), tannins, phenolic compounds, terpenoids, alkaloids, saponins, and phytosterols such as β-sitosterol and β-sitosteryl-D-glucoside, which promote wound repair through antioxidant, anti-inflammatory, antimicrobial, and tissue-regenerative effects[10].

4. *Mimosa pudica Linn*

Mimosa pudica Linn. Which belongs to the family Fabaceae is mainly known as a sensitive plant, humble plant sleeps sleeping, honteuse, dormidera, morivivi, touch-me-not, marie-honte, mayhont, grass, timawi and having many other sleep names.

The plant contains several bioactive constituents, including mimosine, mimosinamine, tyrosine, 3,4-dihydroxypyridine, D-glucuronic acid 4-O-(3,5-dihydroxybenzoic acid)-β-D-glucuronide, mimosine acid, tubulin, C-glycosylflavones, and phenolic ketones. These phytochemicals contribute to its diverse pharmacological properties, including antimicrobial, antidiabetic, antivirulent, antifertility, antioxidant, hepatoprotective, hypoglycemic, lipid-lowering, antidote, antidepressant, and wound healing activities[11].

Ethanolic extracts of the plant have been reported to significantly reduce blood glucose levels in streptozotocin-induced diabetic rats, demonstrating its potential antidiabetic activity. Additionally, topical application of chloroform and methanolic extracts of the root and shoot showed notable wound healing effects, as evidenced by increased hydroxyproline content, tensile strength, and dry weight of granulation tissue in incision wound models. Due to these therapeutic properties and the presence of

bioactive phenolic compounds, the plant was selected for evaluating its wound healing potential in diabetic animal models[11].

The precise mechanism by which *Mimosa pudica* (lajwanti) extract enhances wound repair and regeneration remains unclear; however, several pathways may contribute to its activity. The extract promotes collagen, hexosamine, and DNA synthesis, which are essential for tissue regeneration. Its wound healing effect may also be associated with the reduction of oxidative stress, as evidenced by increased glutathione (GSH) levels, enhanced catalase and superoxide dismutase (SOD) activities, and decreased lipid peroxidation. The extract may regulate inflammatory responses by modulating NF-κB activation and stimulating the production of growth factors and cytokines, including PDGF, TGF-β, and VEGF, which support cell proliferation and tissue repair. Increased antioxidant activity suggests possible activation of the Nrf2 pathway, which helps control excessive inflammation during wound healing. These effects may be attributed to the presence of bioactive constituents such as flavonoids (quercetin, luteolin, and rutin) and mimosine present in the extract[12].

5. *Murraya koenigii*

Murraya koenigii, commonly known as curry leaf, belongs to the family Rutaceae and is valued for its characteristic aroma and medicinal properties. The plant contains various bioactive compounds, including alkaloids, phenolic compounds, quercetin, saponins, polypeptides, and steroids, which contribute to its therapeutic potential. Different parts of the plant have been traditionally used in the management of several ailments and are reported to possess antispasmodic, antidiarrheal, gastroprotective, purgative, and blood-purifying activities[13].

The plant contains abundant carbazole alkaloids, flavonoids, and phenolic compounds, which are responsible for its wide range of pharmacological effects, including antioxidant, anti-inflammatory, antimicrobial, and wound healing activities. Traditionally, its leaves have been utilized for the treatment of wounds, skin infections, and inflammatory disorders[14].

The wound healing potential of *Murraya koenigii* fruits may be associated with their antioxidant activity, which helps reduce free radical generation at the wound site, thereby decreasing inflammation and promoting angiogenesis and collagen formation. Additionally, triterpenoids and tannins contribute to wound repair through their astringent and antimicrobial properties, facilitating wound contraction and enhancing the process of epithelialization[15].

6. *Musa paradisiaca*

Musa paradisiaca, commonly known as banana, belongs to the family Musaceae. Various parts of the plant contain diverse bioactive constituents, including quercetin, tannins, polyphenols, alkaloids, and carbohydrates. Extracts of *Musa paradisiaca* have demonstrated several pharmacological activities, including antidiarrheal, antioxidant, hypoglycemic, cardiovascular protective, wound healing, anti-allergic, antiseptic, antimalarial, and antivenom properties[16].

The decoction prepared from *Musa paradisiaca* leaves contain phytoconstituents like quercetin, catechin, gallic acid, chlorogenic acid, rutin, dopamine, β-carotene, ascorbic acid, tannins, and saponins[17] which is traditionally used for the treatment of wounds, scratches, and insect bites. In Nigeria, traditional practitioners have employed banana leaf extracts for managing infectious diseases, gastroenteritis, malaria, abdominal pain, and ulcers. The leaves are also

rich in dietary fiber, which may help reduce cholesterol levels, relieve constipation, and support colorectal health by improving intestinal function[16].

Treatment with methanolic and hexane extracts of *Musa paradisiaca* peel demonstrated enhanced wound healing, characterized by complete epithelialization, increased collagen fiber deposition, and fibroblast infiltration. Furthermore, the methanolic peel extract promoted greater proliferation of blood capillaries, indicating improved tissue regeneration and vascularization during the healing process[18].

7. *Centella asiatica*

Centella asiatica, commonly known as Gotu Kola, is a perennial herb belonging to the family Apiaceae (Umbelliferae). The aerial parts of this plant have been extensively used in traditional Asian medicine, particularly for dermatological conditions, due to their therapeutic properties[19].

The major bioactive constituents of *C. asiatica* are triterpenoids, including glycosides such as madecassoside and asiaticoside, and aglycones such as asiatic acid and madecassic acid[20]. These compounds are primarily responsible for its pharmacological effects, especially its wound healing and skin-regenerative activities[21]. Due to these properties, *C. asiatica* extracts and their triterpenoids are widely utilized in pharmaceutical and cosmeceutical applications for promoting tissue repair and improving skin health[22].

8. *Xanthosoma sagittifolium (L.) Schott*

Xanthosoma sagittifolium (L.) *Schott* is a pantropical plant species belonging to the family Araceae, originating from Central and South America and now widely distributed across Africa, Asia, and Oceania[23]. Beyond its agricultural and cultural importance, the plant has been traditionally used in ethnomedicine for managing various health conditions, including diabetes, gastrointestinal disorders, abscesses, and wounds. In several African and South American communities, crushed leaves or inflorescences are applied topically to wounds and skin injuries to promote hemostasis and enhance tissue repair, reflecting its long-standing role in traditional wound management practices[24].

The wound-healing activity of *Xanthosoma sagittifolium* is attributed to the presence of chlorogenic acid, caffeic acid, quercetin, kaempferol, catechin, rutin, tannins, saponins, alkaloids, and ascorbic acid, which possess antioxidant, anti-inflammatory, antimicrobial, and collagen-promoting properties that facilitate wound repair[25],[26].

9. *Boerhavia diffusa L.*

Boerhavia diffusa L., commonly known as Punarnava, is a perennial creeping herb belonging to the family Nyctaginaceae and is widely distributed throughout India. It is an important medicinal plant in the traditional Indian system of medicine and has been reported to possess diverse pharmacological activities, including immunomodulatory, anticancer, antidiabetic, antifibrinolytic, anti-inflammatory, diuretic, hepatoprotective, antimicrobial, antifungal, anticonvulsant, and antioxidant properties, many of which have been scientifically validated[27].

The wound-healing activity of *Boerhavia diffusa* is attributed to the presence of boeravinones (A–F), punarnavine, quercetin, kaempferol, eupalitin, ursolic acid, β-sitosterol, lignans, rotenoids, and flavonoids, which exhibit antioxidant, anti-inflammatory, antimicrobial, and collagen-promoting activities that accelerate wound healing[28].

10. *Andrographis paniculata*

Andrographis paniculata, commonly known as the "King of Bitters," is a medicinal plant belonging to the family Acanthaceae and is native to South and Southeast Asia. It has been traditionally used in AYUSH and Traditional Chinese Medicine systems and is recognized for its diverse pharmacological activities, including anti-inflammatory, antiviral, antibacterial, hepatoprotective, antipyretic, and anticancer effects[29]. These properties are mainly attributed to its bioactive secondary metabolites, particularly diterpenoid lactones such as andrographolide, 14-deoxy-11,12-didehydroandrographolide, and neoandrographolide, along with flavonoids and polyphenols. Among these constituents, andrographolide is considered the major active compound due to its potent antioxidant, anti-inflammatory, and immunomodulatory activities[30]. These phytochemicals may support wound healing by regulating inflammatory mediators, enhancing fibroblast proliferation, promoting collagen synthesis, and reducing oxidative stress, thereby facilitating tissue regeneration and repair[31].

A study reported that topical treatment with a 10% aqueous leaf extract of *Andrographis paniculata* significantly accelerated wound closure in rats. The treated animals showed reduced inflammation and scar formation, along with enhanced angiogenesis and increased collagen fiber deposition during wound repair. Andrographolide, a bicyclic diterpenoid isolated from *A. paniculata* leaves, has also been clinically evaluated and demonstrated beneficial effects in various autoimmune disorders[32].

11. *Amphimas pterocarpoides*

Amphimas pterocarpoides, a member of the family Leguminosae, is widely distributed across tropical regions of Africa and is traditionally known as "yaya" in Ghana[32]. Various parts of the plant, particularly the leaves and bark, are used in traditional medicine for managing conditions such as cough, pneumonia, venereal diseases, pox infections, swellings, pain, wounds, malaria, and gouty arthritis[33]. The reddish bark resin is traditionally used for treating dysentery, anemia, schistosomiasis, hematuria, dysmenorrhea, mumps, and as an antidote for certain poisons. Additionally, twigs and wood preparations are used traditionally for preventing miscarriage and managing impotence[32].

Isoflavonoids such as amphiisoflavone, methoxyisoformononetin derivatives, and isoformononetin from *Amphimas pterocarpoides* exhibit antimicrobial and antioxidant activities[32]. Its wound healing effects are mainly associated with isoflavonoids, including genistein, daidzein, formononetin, biochanin A, afrormosin, coumestrol, and prenylated derivatives, which promote tissue repair through antioxidant, anti-inflammatory, and regenerative actions[34].

12. *Elaeis guineensis Jacquin*

Elaeis guineensis Jacq., commonly known as African oil palm, is an evergreen, single-stemmed multipurpose plant belonging to the family Arecaceae. It has long been used in West African traditional medicine, where various parts of the plant are considered therapeutically valuable. The fruit oil is traditionally used as a hair treatment, for headaches, stomach disorders, and as a poison antidote for livestock. It is also utilized for non-medicinal purposes, including roofing, firewood, and fuel for goldsmithing. Studies have reported that mesocarp oil and palm kernel oil are used traditionally for treating dermatitis, regulating body temperature during childhood convulsions, and managing ailments such as wounds, rheumatism, bronchitis, gonorrhea, and menorrhagia[35].

Recent research by Olasunkamin and colleagues in 2018 demonstrated that the root extract of Elaeis

guineensis Jacq. exhibits antimicrobial activity against wound-associated pathogens, suggesting its potential role in wound healing. Medicinal plants with wound-healing properties are increasingly being explored because affordable and natural therapies can enhance healing, reduce mortality, lower healthcare costs, and minimize complications such as amputation and adverse effects associated with synthetic drugs[35].

A previous study by Che Zain et al. in 2020 reported that the extract of Elaeis guineensis Jacq. leaves (EGL) exhibited wound-healing potential due to the presence of bioactive phytoconstituents such as flavonoids, phenolic compounds, tannins, terpenoids, alkaloids, saponins, carotenoids, tocopherols, and tocotrienols by enhancing cell proliferation and migration in 3T3 fibroblast cells. The methanolic EGL extract demonstrated significant migratory activity in a scratch-wound assay, achieving approximately 85.83–93.34% wound closure, indicating its potential role in promoting tissue repair[36].

13. *Blumea balsamifera (L.) DC.,*

*Blumea balsamifera (*L.) DC., commonly known as Sambong, is a medicinal herb belonging to the family Asteraceae and is characterized by a high content of essential oils, which have been widely utilized in Traditional Chinese Medicine. Its leaves have traditionally been applied for the management of various disorders, including eczema, dermatitis, skin wounds, bruises, beriberi, lumbago, menorrhagia, and rheumatism. Recent studies have demonstrated that leaf extracts possess several pharmacological activities, including plasmin inhibition, antifungal effects, free radical scavenging, and anti-obesity properties. Historical records, including the ancient Chinese medical text Seeking Herbal Medicines in Lingnan, document the use of B. balsamifera extracts for treating snakebite injuries, skin wounds, and itching[37].

Blumea balsamifera (L.) DC. contains a variety of bioactive phytoconstituents, including flavonoids such as quercetin and luteolin derivatives, phenolic compounds, tannins, terpenoids, essential oil components (monoterpenes and sesquiterpenes), alkaloids, and saponins, which contribute to its diverse pharmacological activities[38]. The essential oil obtained from the leaves of *Blumea balsamifera* (L.) DC. (BB oil) contains L-borneol as its major bioactive component. However, the pharmacological potential of BB oil has not been extensively investigated. Recent research has therefore focused on evaluating its wound-healing activity and exploring the possible mechanisms underlying its therapeutic effects[37].

14. *Martynia annua L*

Martynia annua L., belonging to the family Martyniaceae, is a glandular, hairy annual herb commonly known as Bichchhu. It has been traditionally used for various medicinal purposes, including the treatment of epilepsy, sore throat, inflammation, and wounds. The leaf paste has been applied to wounds of domestic animals, while root extracts have demonstrated antifungal activity against Alternaria alternata and Aspergillus niger[39]. Phytochemical investigations of *M. annua* have revealed the presence of glycosides, tannins, carbohydrates, phenolic compounds, flavonoids, and anthocyanins. Specific bioactive compounds identified include cyanidin-3-galactoside in flowers, p-hydroxybenzoic acid, sinapic acid, and gentisic acid in leaves and fruits, chlorogenic acid in leaves, and fatty acids in seeds[40]. Additionally, ethanol extracts of *M. annua* leaves have shown anti-inflammatory and wound-healing activities in animal models, demonstrating their potential in promoting tissue repair[41].

15. ***Aloe vera (L.) Burm. f.***

Aloe vera (L.) *Burm. f.* belonging to the family Liliaceae, is one of the most extensively studied medicinal plants due to its therapeutic potential, particularly in skin disorders[42]. Traditionally known as the "plant of immortality," *A. vera* has been used in various cultures to treat burns, wounds, psoriasis, dermatitis, and infections[43]. Numerous in vitro, in vivo, and clinical studies have confirmed its wound-healing properties through different preparations, including gel, latex, juice, and extracts. The healing activity is attributed to the synergistic effects of bioactive constituents such as polysaccharides, acemannan, aloin A and B, and emodin, which promote wound repair through antioxidant, anti-inflammatory, antimicrobial, and tissue-regenerative mechanisms[44],[45]. Although the gel and leaf extracts are well studied, *A. vera* flowers, containing compounds such as apigenin glycoside derivatives with antioxidant and anti-inflammatory properties, remain comparatively less explored for cutaneous wound healing[43].

Aloe vera (L.) *Burm. f.* is a medicinal plant with diverse pharmacological properties, including anti-inflammatory, antibacterial, antioxidant, hypoglycemic, and wound-healing activities[46],[47]. Studies in animal models have demonstrated that *A. vera* gel accelerates wound repair by reducing inflammation, promoting fibroblast proliferation, collagen synthesis, wound contraction, re-epithelialization, angiogenesis, and enhancing growth factors such as TGF-β1 and VEGF[48]. Bioactive compounds such as β-sitosterol and aloesin have been reported to stimulate endothelial cell proliferation and migration, thereby supporting angiogenesis and tissue regeneration. The fresh leaves contain anthraquinone-rich yellow latex and a clear mucilaginous gel composed mainly of water, polysaccharides (including glucomannan and acemannan), proteins, vitamins, minerals, and other bioactive constituents responsible for its therapeutic effects[48].

The polysaccharides and glycoproteins present in the leaf pulp of *Aloe vera* (L.) *Burm. f.* contributes significantly to its wound-healing and anti-inflammatory activities. The healing effect is primarily attributed to glucomannan, which enhances fibroblast proliferation and activity, thereby promoting collagen synthesis and secretion[49]. Additionally, *A. vera* extracts exhibit antimicrobial properties due to bioactive compounds such as lupeol, salicylic acid, urea nitrogen, cinnamic acid, phenols, and sulfur, which show inhibitory effects against bacteria, fungi, and viruses. Enzymes present in *A. vera*, including amylase, lipase, and carbopeptidase, also contribute to its therapeutic effects by aiding digestion and reducing inflammation through bradykinin inactivation[49].

16. ***Copaifera L.***

Copaifera L. belongs to the family Fabaceae, tree native to Central and South America, and Africa. Various studies have investigated the pharmacological properties of *Copaifera* extracts, particularly hydroalcoholic leaf extracts and copaiba oleoresin, demonstrating their potential therapeutic applications[49].

The oleoresin of Copaifera L. contains abundant bioactive terpenoids, particularly sesquiterpenes and diterpenes such as β-caryophyllene, α-humulene, β-bisabolene, caryophyllene oxide, copalic acid, kaurenoic acid, and hardwickiic acid. These compounds contribute to wound healing through their anti-inflammatory, antimicrobial, antioxidant, and tissue-regenerative activities by promoting collagen deposition, re-epithelialization, and protection against microbial infection[50],[51].

The pharmacological effects of Copaifera L. oleoresin are mainly attributed to its high

sesquiterpene content, which constitutes more than 90% of its composition. However, its therapeutic activity is not related to a single compound but results from the synergistic interactions among multiple bioactive constituents. Studies have demonstrated that copaiba oil exhibits antibacterial, anti-inflammatory, and anti-psoriatic activities. Additionally, *Copaifera langsdorffii* oleoresin showed no cytotoxic effects on fibroblasts at 100 µg/mL and promoted wound healing in rabbit and rat models, indicating its potential as a wound-healing agent[51].

17. *Curcuma longa Linn.*

Curcuma longa L., commonly known as yellow turmeric, belongs to the family Zingiberaceae and is an important medicinal and economically valuable plant[52]. Its major bioactive compound, curcumin, possesses potent antioxidant, anti-inflammatory, and anticancer properties[53]. The rhizome of *C. longa* has traditionally been used for treating diarrhea, vomiting, fever, boils, sores, and various skin disorders due to its therapeutic effects[54].

Curcuma longa L. contains several bioactive constituents, including curcumin, demethoxycurcumin, bisdemethoxycurcumin (curcuminoids), and volatile oil components such as arturmerone, α-turmerone, β-turmerone, zingiberene, and atlantone. These compounds exhibit anti-inflammatory, antioxidant, antimicrobial, and collagen-promoting properties, contributing to wound healing by reducing oxidative stress, enhancing fibroblast proliferation, stimulating collagen synthesis, promoting angiogenesis, and accelerating re-epithelialization[55],[56].

The wound-healing activity of *Curcuma longa* L. extract is mainly attributed to the inhibition of inflammatory mediators, including cyclooxygenase-2 (COX-2) and lipoxygenase (LOX), which reduces inflammation and promotes tissue repair. Curcumin enhances re-epithelialization, cell proliferation, granulation tissue formation, and collagen synthesis during wound healing. This bioactive compound is considered safe and has been widely used in traditional Ayurvedic and Chinese medicine for managing inflammation and various disorders. Its therapeutic effects are mediated through regulation of multiple molecular pathways, including NF-κB, STAT3, transforming growth factor-β (TGF-β), pro-inflammatory cytokines, and oxidative stress-related pathways, supporting fibroblast activity and extracellular matrix formation in wound repair[57].

18. *Ocimum tenuiflorum L.*

Ocimum tenuiflorum L. commonly known as Tulasi, belongs to the family Lamiaceae and is widely distributed in tropical and subtropical regions of India. Various parts of the plant are traditionally used in Ayurveda and Siddha medicine for treating infections, skin disorders, liver-related conditions, and as a remedy for snake and scorpion bites[58]. Leaf extracts of *O. sanctum* exhibit anti-inflammatory, analgesic, and immunomodulatory activities[59]. Its flavonoids possess strong free radical scavenging and antioxidant properties, which contribute to wound healing by reducing oxidative stress and protecting tissues from free radical-mediated damage[60].

Ocimum tenuiflorum L. contains several bioactive phytoconstituents, including eugenol, ursolic acid, rosmarinic acid, oleanolic acid, apigenin, luteolin, carvacrol, linalool, β-caryophyllene, flavonoids, and tannins. These compounds contribute to its wound-healing potential through antioxidant, anti-inflammatory, and antimicrobial activities by reducing oxidative stress, controlling inflammation, preventing microbial infection, enhancing fibroblast proliferation and collagen synthesis, and promoting angiogenesis and re-epithelialization[61],[62].

Free radical scavenging activity is considered one of the key mechanisms through which *Ocimum tenuiflorum* L. protects cells from oxidative damage. Studies in animal models suggest that *O. sanctum* can modulate immune responses by influencing antibody production, hypersensitivity mediator release, and tissue responses. Additionally, *O. sanctum* has demonstrated antimicrobial activity against pathogenic microorganisms in vitro. Traditional herbal formulations containing *O. sanctum* have shown wound-healing effects comparable to standard treatments, such as nitrofurazone and propamidine creams, in infected wound models[63].

19. ***Calendula officinalis L.***

Calendula officinalis L., a member of the family Asteraceae, is a widely recognized medicinal plant with diverse therapeutic applications. Bioactive compounds present in its flowers exhibit antiviral, antifungal, antibacterial, antigenotoxic, and anti-inflammatory activities. Due to its skin-protective and regenerative properties, *C. officinalis* flower preparations are commonly applied to damaged and irritated skin. Additionally, marigold promotes collagen synthesis, thereby improving skin strength, maintaining hydration, and accelerating the healing of wounds and surgical scars[64].

The flowers of *Calendula officinalis* L. contain several bioactive constituents, including triterpenoids, saponins, flavonoids, carotenoids, fatty acids, polysaccharides, and essential oils. Although the levels of these compounds may vary depending on geographical origin, the therapeutic effects of topical *C. officinalis* preparations remain consistent. In vitro studies have demonstrated the cytotoxic and tumor-inhibitory potential of *C. officinalis* extracts against various cancer cell lines, including cervical, breast, leukemia, prostate, and fibrosarcoma models. Traditionally, *C. officinalis* has also been used internally for managing gastrointestinal conditions such as peptic and duodenal ulcers, gastritis, colitis, and mucosal inflammation[65],[66].

In Ayurvedic medicine, Calendula officinalis L. is recognized for its scar-reducing and emollient properties, which are associated with enhanced collagen metabolism and increased angiogenesis at wound sites. Studies have demonstrated that *C. officinalis* flower extract can improve scar reduction and skin-softening effects[67]. Experimental investigations using ethanolic, hexane, and dichloromethane fractions of *C. officinalis* have shown significant wound-healing and angiogenic activities, with ethanolic extract promoting new blood vessel formation and reducing wound size compared with control treatments[68].

Studies have demonstrated that *Calendula officinalis* L. extract enhances epithelialization in chronic venous ulcers and promotes wound repair in burn models. Treatment with ethanolic flower extract improved healing by increasing collagen hydroxyproline and hexosamine levels, while reducing tissue damage markers, acute-phase proteins, and lipid peroxidation through its antioxidant activity[69]. The ethanolic extract also enhances collagen synthesis and blood circulation at wound sites[70]. Due to its antimicrobial, antioxidant, antiseptic, and anti-inflammatory properties, *C. officinalis* gel and ointment preparations have shown improved wound healing and are suitable for topical application because of their stability, skin penetration, and ease of use[71].

Although the wound-healing mechanisms of Calendula officinalis L. are not completely understood, studies have shown that its extracts promote fibroblast migration and proliferation through a PI3K-dependent pathway. Flower extracts of *C. officinalis* enhance granulation tissue formation by regulating the expression of connective tissue growth factor (CTGF) and α-smooth muscle actin (α-SMA) in excisional

wound models. Additionally, *C. officinalis* has been reported to stimulate angiogenesis, as demonstrated in chicken chorioallantoic membrane assays and rat skin wound-healing models[71].

20. *Arctium lappa L.*

Arctium lappa L., commonly known as burdock, is a perennial herb belonging to the family Asteraceae and is widely cultivated for medicinal use. Traditionally, it has been used in North America, Europe, and Asia for treating sore throat and various skin disorders, including boils, rashes, and acne. Scientific studies have reported that *A. lappa* exhibits antioxidant, anti-inflammatory, antidiabetic, antimicrobial, antiviral, anticancer, and hepatoprotective activities. Additionally, its root extract has been shown to improve dermal extracellular matrix metabolism by regulating glycosaminoglycan turnover and reducing skin aging-related changes[72].

Arctium lappa L. contains several bioactive phytoconstituents, including lignans such as arctiin and arctigenin, chlorogenic acid, caffeic acid, quercetin, rutin, inulin, polyphenols, flavonoids, tannins, and sesquiterpene lactones. These compounds contribute to its antioxidant, anti-inflammatory, antimicrobial, and wound-healing properties by promoting fibroblast proliferation, enhancing collagen synthesis, modulating extracellular matrix remodeling, and facilitating re-epithelialization during tissue repair[73].

Arctium lappa L. has been reported to influence cell adhesion and gene expression in canine dermal fibroblasts by modulating the Wnt/β-catenin signaling pathway, which plays an important role in wound repair[74]. Additionally, a pilot clinical study involving a commercial ointment containing *A. lappa* demonstrated improved pain management and enhanced healing of first- and second-degree burns compared with control treatment[75].

21. *Astragalus propinquus and Rehmannia glutinosa*

Astragalus propinquus, commonly known as Mongolian milkvetch in English is a flowering plant in the family Fabaceae.

Rehmannia glutinosa is a flowering broomrape, belonging to the family Orobanchaceae.

Astragalus propinquus contains several bioactive phytoconstituents, including astragalosides I–IV (particularly astragaloside IV), calycosin, formononetin, ononin, isoflavonoids, astragalus polysaccharides, flavonoids, and saponins. These compounds exhibit antioxidant, anti-inflammatory, immunomodulatory, and pro-angiogenic activities, contributing to wound healing by promoting fibroblast proliferation, collagen synthesis, angiogenesis, and re-epithelialization[76].

Rehmannia glutinosa contains several bioactive phytoconstituents, including catalpol, rehmanniosides, acteoside (verbascoside), aucubin, iridoid glycosides, phenylethanoid glycosides, flavonoids, and polysaccharides. These compounds possess antioxidant, anti-inflammatory, immunomodulatory, and tissue-regenerative properties, contributing to wound healing by enhancing fibroblast proliferation, collagen deposition, angiogenesis, and reducing oxidative stress[77].

The roots of *Astragalus propinquus* and *Rehmannia glutinosa* are widely used in Traditional Chinese Medicine for the management of urinary retention, edema, and diabetes-related disorders[78]. A herbal formulation containing both roots has shown clinical efficacy in treating diabetic foot ulcers, with subsequent studies in diabetic rats confirming its wound-healing potential[79]. The combined extract promotes diabetic wound repair by enhancing

angiogenesis, reducing oxidative stress, activating the TGF-β1 signaling pathway, and stimulating extracellular matrix deposition in human skin fibroblasts[80].

22. *Ampelopsis japonica*

Ampelopsis japonica is a perennial climbing vine belonging to the family Vitaceae and is native to China, with distribution across East Asia and eastern North America[81]. The roots of A. japonica have been traditionally used to treat burns, ulcers, and other inflammatory conditions. Pharmacological studies have demonstrated that the plant possesses neuroprotective, antimicrobial, and anticancer activities, supporting its therapeutic potential[82],[83].

Ampelopsis japonica contains several bioactive phytoconstituents, including resveratrol, ε-viniferin, ampelopsin (dihydromyricetin), catechin, epicatechin, quercetin, kaempferol, gallic acid, and other polyphenols and flavonoids. These compounds exhibit antioxidant, anti-inflammatory, antimicrobial, and tissue-regenerative properties, contributing to wound healing by reducing oxidative stress and inflammation, promoting fibroblast proliferation, enhancing collagen synthesis, stimulating angiogenesis, and accelerating re-epithelialization[84].

Lee et al. demonstrated that ethanolic root extracts of *Ampelopsis japonica* significantly accelerated the healing of cutaneous scald wounds in rats. Treatment enhanced re-epithelialization, granulation tissue formation, angiogenesis, and collagen deposition compared with Vaseline and silver sulfadiazine. The wound-healing effect was associated with the regulation of inflammatory cytokines, characterized by early increases in TNF-α and TGF-β1 followed by elevated IL-10 during the later stages of healing, facilitating tissue repair and wound closure[85].

23. *Angelica sinensis*

Angelica sinensis, commonly known as dong quai or female ginseng, is a herb belonging to the family Apiaceae, indigenous to China.

Angelica sinensis is widely used for treating gynecological disorders, inflammation, headaches, mild anemia, fatigue, and hypertension[86]. It exhibits diverse pharmacological activities, including anti-inflammatory, antioxidant, anticancer, and immunomodulatory effects. Studies have shown that *A. sinensis* extracts promote wound healing by enhancing fibroblast proliferation, collagen secretion, cell migration, glycolysis, and cell viability[87]. Some reports also suggest that aqueous extracts stimulate angiogenesis through activation of JNK1/2, p38, and VEGF signaling pathways[88],[89], although the effects on blood vessel formation remain controversial, as the isolated compound *n*-butylidenephthalide has been reported to inhibit angiogenesis and induce apoptosis[90].

Angelica sinensis contains several bioactive phytoconstituents, including ferulic acid, Z-ligustilide, butylidenephthalide, senkyunolide A, polysaccharides, coniferyl ferulate, flavonoids, and volatile oils. These compounds possess antioxidant, anti-inflammatory, antimicrobial, pro-angiogenic, and tissue-regenerative properties, contributing to wound healing by promoting fibroblast proliferation, collagen synthesis, angiogenesis, and re-epithelialization while reducing oxidative stress and inflammation[91].

24. *Boswellia sacra*

Boswellia sacra, also known as Boswellia carteri and others, and commonly called the frankincense tree or the olibanum tree, is a tree in the genus Boswellia, in the Burseraceae family.

Boswellia sacra produces frankincense resin, which has been traditionally used in Africa, India, and the Middle East for managing trauma and inflammatory disorders such as rheumatoid arthritis[92],[93]. Bioactive compounds such as boswellic acid derivatives exhibit therapeutic effects, including modulation of inflammation and cellular responses. Frankincense is also a component of the traditional formulation ANBP, containing *Agrimonia eupatoria*, *Nelumbo nucifera*, *Boswellia sacra*, and *Typha angustifolia* pollen. ANBP promotes wound repair by activating TGF-β1/Smad signaling, regulating inflammation, enhancing organized granulation tissue formation, re-epithelialization, and extracellular matrix maturation[94]. Studies have further shown that ANBP reduces scar formation and accelerates wound closure in diabetic wound models by promoting neovascularization[95].

Boswellia sacra is rich in bioactive phytoconstituents, including pentacyclic triterpenoids (α- and β-boswellic acid, acetyl-β-boswellic acid, 11-keto-β-boswellic acid [KBA], and 3-O-acetyl-11-keto-β-boswellic acid [AKBA]), monoterpenes (α-pinene, limonene, myrcene, and p-cymene), sesquiterpenes, diterpenes, and essential oils. These phytoconstituents promote wound healing[96].

25. *Caesalpinia sappan L.*

Caesalpinia sappan L. is a species of flowering tree in the legume family, Fabaceae, that is native to tropical Asia. Common names in English include sappanwood and Indian redwood. It is used in Traditional Chinese Medicine to improve blood circulation and alleviate edema and pain[97]. Its bioactive homoisoflavonoids exhibit antiallergic, anti-inflammatory, and antiviral activities[98],[99]. Ethanolic extracts of *C. sappan* demonstrate broad-spectrum antibacterial effects against various wound-associated pathogens, including *Staphylococcus aureus*, MRSA, *Pseudomonas aeruginosa*, *Acinetobacter baumannii*, *Escherichia coli*, and *Klebsiella pneumoniae*[100]. Additionally, root extracts enhance dermal fibroblast proliferation, migration, and collagen synthesis, thereby promoting cutaneous wound healing[101].

Caesalpinia sappan L. contains several bioactive phytoconstituents, including homoisoflavonoids (brazilin and brazilein), flavonoids (sappanchalcone, protosappanin A and B), phenolic compounds, tannins, saponins, terpenoids, and gallic acid derivatives that promote wound healing[102],[103].

26. *Camellia sinensis*

Camellia sinensis is a species of evergreen shrub or small tree in the flowering plant family Theaceae. It is rich in bioactive phytoconstituents, including catechins [epigallocatechin-3-gallate (EGCG), epigallocatechin (EGC), epicatechin gallate (ECG), and epicatechin (EC)], flavonoids, quercetin, kaempferol, phenolic acids, tannins, caffeine, and L-theanine. These phytoconstituents promote wound healing through their antioxidant, anti-inflammatory, antimicrobial, collagen-stimulating, angiogenic, and re-epithelialization activities[104].

Camellia sinensis, the source of green tea, is widely consumed in Asia due to its health-promoting properties[105]. Its pharmacological effects, including antioxidant, anti-inflammatory, antimicrobial, anticancer, antiaging, antiobesity, cardioprotective, and neuroprotective activities, are mainly attributed to polyphenolic catechins, particularly epigallocatechin-3-gallate (EGCG)(105). EGCG promotes keratinocyte proliferation and differentiation, modulates TGF-β signaling, reduces matrix metalloproteinase expression, and regulates collagen synthesis, contributing to scar prevention[106]. Additionally, C. sinensis extracts enhance fibroblast proliferation, collagen production[107],

angiogenesis, and wound closure, demonstrating potential in improving normal and diabetic wound healing[108].

27. *Carthamus tinctorius*

Carthamus tinctorius also false saffron, is a highly branched, herbaceous, thistle-like annual plant in the family Asteraceae. It contains several bioactive phytoconstituents involved in wound healing, including quinochalcone glycosides such as hydroxysafflor yellow A (HSYA), safflor yellow A and B, and carthamin; flavonoids such as quercetin, luteolin, kaempferol, and acacetin; phenolic acids including chlorogenic acid and ferulic acid; polysaccharides, serotonin derivatives, and seed oil constituents such as linoleic acid, oleic acid, tocopherols, and phytosterols. These phytochemicals collectively contribute to wound healing through antioxidant, anti-inflammatory, antimicrobial, angiogenic, collagen-promoting, and re-epithelialization activities[109].

Carthamus tinctorius seeds are widely used as a source of edible oil and have a long history in Traditional Chinese Medicine for managing blood-related disorders. Studies have demonstrated that *C. tinctorius* exhibits diverse pharmacological activities, including antioxidant, anti-inflammatory, immunomodulatory, vasodilatory, anticoagulant, anticancer, and analgesic effects[110]. Hydroxysafflor yellow A (HSYA), a major water-soluble pigment component of safflower, possesses antioxidant, anti-inflammatory, pro-angiogenic, and anti-apoptotic properties. Topical application of low-dose HSYA has been shown to enhance diabetic wound healing by promoting angiogenesis, re-epithelialization, and granulation tissue formation, although higher concentrations may inhibit wound repair[111].

28. *Celosia argentea*

Celosia argentea L., commonly known as silver cockscomb, belongs to the family Amaranthaceae and is traditionally used for treating skin sores, ulcers, eruptions, and other dermatological disorders[112]. Leaf extracts of *C. argentea* exhibit antioxidant, hepatoprotective, antidiabetic, and antimicrobial activities[113]. Studies have shown that alcoholic extracts of *C. argentea* accelerate burn wound healing in rats by enhancing collagen and hexosamine levels in granulation tissue and promoting dermal fibroblast proliferation and migration[112].

Celosia argentea contains several phytoconstituents that are relevant to wound healing, including flavonoids (quercetin, kaempferol), phenolic compounds, saponins, alkaloids, tannins, terpenoids, glycosides, steroids, polysaccharides, and betalain pigments (betacyanins and betaxanthins). These bioactive compounds contribute to wound repair by exerting antioxidant, anti-inflammatory, antimicrobial, collagen-stimulating, angiogenic, and re-epithelialization effects, thereby accelerating tissue regeneration and wound closure[112].

29. *Cinnamomum cassia*

Cinnamomum cassia (L.), a member of the family Lauraceae, is widely used as a spice and traditional medicine. Its bark has been traditionally used to improve blood circulation and relieve pain. *C. cassia* is also included in several traditional formulations, such as Shexiang Baoxin Pill, used for cardiovascular disorders[114]. Cinnamaldehyde, the major bioactive compound of *C. cassia*, exhibits antimicrobial, anti-inflammatory, antidiabetic, antioxidant, and neuroprotective activities[115]. It promotes angiogenesis by activating PI3K/AKT and MAPK signaling pathways, increasing VEGF expression, and has been shown to enhance wound healing in experimental models[116].

Cinnamomum cassia contains several major phytoconstituents associated with wound healing, including cinnamaldehyde (the principal bioactive compound), eugenol, cinnamic acid, cinnamyl acetate, coumarin, procyanidins, catechins, epicatechin, quercetin, kaempferol, and other polyphenols. These compounds promote wound healing through antioxidant, anti-inflammatory, antimicrobial, collagen-stimulating, angiogenic, and re-epithelialization activities, thereby enhancing tissue repair and reducing the risk of wound infection[117].

30. *Commiphora myrrha*

Commiphora myrrha, called myrrh, Somali myrrh, herabol myrrh, common myrrh is a tree in the family Burseraceae. It contains several bioactive phytoconstituents that contribute to wound healing, including sesquiterpenes (furanoeudesma-1,3-diene, curzerene, lindestrene), terpenoids, furanosesquiterpenes, triterpenes, steroids, volatile oils, resins, guggulsterones, flavonoids, phenolic compounds, and tannins. These phytochemicals promote wound healing through antimicrobial, anti-inflammatory, antioxidant, analgesic, collagen-stimulating, and re-epithelialization activities, thereby accelerating tissue regeneration and reducing wound infection[118].

Commiphora myrrha produces myrrh resin, which possesses well-established antioxidant, anti-inflammatory, antibacterial, and analgesic properties[119]. Traditionally, myrrh has been used for managing gastrointestinal disorders, fractures, arthritis, parasitic infections, and for topical wound care to reduce swelling and pain[120]. Studies have shown that myrrh-based formulations, including combinations with other medicinal plants such as *Adiantum capillus-veneris*, *Aloe vera*, and *Lawsonia inermis*, enhance wound healing in diabetic animal models[121]. Additionally, myrrh may promote tissue repair by regulating wound-healing mediators, including TGF-β1 and VEGF, in dermal fibroblasts[122].

31. *Daphne genkwa*

Daphne genkwa a member of the family Thymelaeaceae and one of the fundamental herbs in Traditional Chinese Medicine, is widely distributed in regions of China along the Yellow and Yangtze Rivers. It has traditionally been used for its anticonvulsant, analgesic, diuretic, antitussive, expectorant, and sedative properties[123]. The major bioactive constituents of *D. genkwa*, including biflavonoids, coumarins, diterpenes, and triterpenes, contribute to its anti-inflammatory, antitumor, immunomodulatory, and antimelanogenic activities[123]. Flavonoid extracts from *D. genkwa* flowers enhance wound healing by activating the ERK/MEK signaling pathway, promoting fibroblast proliferation and increasing collagen-related gene expression, including COL1A1 and COL3A1[124].

It contains several bioactive phytoconstituents associated with wound-healing activity, including daphnane-type diterpenes (genkwadaphnin, yuanhuacine, yuanhuadine), flavonoids (apigenin, luteolin, quercetin derivatives), coumarins, lignans, phenolic compounds, triterpenoids, and steroids. These constituents exhibit anti-inflammatory, antioxidant, antimicrobial, and tissue-regenerative properties that may support wound healing by reducing oxidative stress, modulating inflammation, and promoting repair processes[125].

32. *Entada phaseoloides*

Entada phaseoloides commonly known as St. Thomas bean, is a climbing vine belonging to the family Fabaceae and is distributed across tropical forests of Africa, Australia, Asia, and the Western Pacific. The bark and seeds are rich in saponins

and tannins and have traditionally been used as analgesic, antimicrobial, hemostatic, anticancer, and topical agents for skin injuries[126],[127]. Studies have shown that tannin-enriched extracts of *E. phaseoloides* accelerate the healing of infected wounds in rats through antibacterial effects and by promoting cell proliferation and migration. However, further clinical studies are required to confirm its wound-healing efficacy in humans[128]. It contains several phytoconstituents that may contribute to wound healing, including saponins, flavonoids (quercetin and kaempferol derivatives), tannins, phenolic compounds, alkaloids, terpenoids, steroids, triterp enes, and fatty acids. These constituents exhibit antioxidant, anti-inflammatory, antimicrobial, and collagen-promoting activities, which support wound contraction, fibroblast proliferation, collagen deposition, and tissue regeneration[129].

33. *Hibiscus rosa-sinensis*

Hibiscus rosa-sinensis L., commonly known as shoeblackplant, is an evergreen shrub belonging to the family Malvaceae and native to tropical Southeast Asia[130]. Traditionally, its leaves and flowers have been used for promoting hair growth and preventing premature graying[131]. Studies have reported that *H. rosa-sinensis* exhibits antibacterial and wound-healing properties. Its extracts promote tissue repair by reducing inflammation, enhancing fibroblast proliferation and collagen deposition, and increasing the expression of wound-healing mediators such as VEGF and TGF-β1 in excisional wound models[132].

It contains several phytoconstituents associated with wound-healing activity, including flavonoids (quercetin, kaempferol, anthocyanins), phenolic compounds, tannins, saponins, alkaloids, terpenoids, steroids, mucilage, and vitamin C. These constituents contribute to wound healing through antioxidant, anti-inflammatory, antimicrobial, collagen synthesis, fibroblast proliferation, and re-epithelialization activities, promoting faster wound contraction and tissue regeneration[130].

34. *Ganoderma lucidum*

Ganoderma lucidum commonly known as lingzhi or the "mushroom of immortality," is a medicinal fungus belonging to the family Ganodermataceae and is traditionally used in Chinese, Korean, and Japanese medicine to enhance immunity. It exhibits diverse pharmacological activities, including immunomodulatory, anti-inflammatory, antioxidant, anti-infective, cardioprotective, and lipid-regulating effects[133],[134]. Polysaccharide extracts from the fruiting body of *G. lucidum* have demonstrated wound-healing potential in diabetic rat models by promoting fibroblast proliferation and migration[135], enhancing angiogenesis, and reducing oxidative stress[136]. These effects may also be associated with its ability to modulate immune responses and improve tissue repair mechanisms.

It contains several bioactive phytoconstituents (mycochemicals) associated with wound healing, including triterpenoids (ganoderic acids, ganodermanontriol), polysaccharides (β-glucans), proteins, peptides, sterols, nucleosides, phenolic compounds, and flavonoids. These constituents contribute to wound repair through immunomodulatory, antioxidant, anti-inflammatory, antimicrobial, angiogenic, and collagen-promoting activities, enhancing fibroblast proliferation, extracellular matrix formation, and tissue regeneration[137].

35. *Ligusticum striatum*

Ligusticum striatum belongs to the family Apiaceae (Umbelliferae). It contains several bioactive phytoconstituents associated with

wound healing, including phthalides (ligustilide, butylidenephthalide, senkyunolide A), phenolic acids (ferulic acid, caffeic acid), volatile oils, flavonoids, coumarins, terpenoids, and polysaccharides. These compounds contribute to wound repair through anti-inflammatory, antioxidant, antimicrobial, angiogenic, and blood circulation-enhancing effects, which may support granulation tissue formation, collagen deposition, and tissue regeneration[138].

It has a long history of use in traditional medicine for promoting cardiovascular and cerebrovascular health and is commonly used for managing ischemic conditions, menstrual disorders, and headaches. More than 170 chemical constituents have been identified from *L. striatum*, with phthalide lactones and alkaloids representing the major pharmacologically active groups[139]. Essential oils derived from *L. striatum* have demonstrated potential anti-scarring effects by reducing dermal scar formation in rabbit ear wound models[140].

36. *Lonicera japonica*

Lonicera japonica commonly known as honeysuckle, belongs to the family Caprifoliaceae and has been extensively used in traditional medicine in Japan, Korea, and China for treating infectious diseases[141]. Pharmacological studies have revealed that *L. japonica* exhibits antimicrobial, anti-inflammatory, antipyretic, antioxidant, anticancer, hepatoprotective, and lipid-regulating activities[142],[143]. Ethanol extracts from its flowering aerial parts have been reported to enhance cutaneous wound healing by promoting re-epithelialization, angiogenesis, granulation tissue formation, and wound contraction[144]. Although traditionally consumed as a health-promoting herb, excessive doses may cause adverse neurological effects[142].

It contains several phytoconstituents associated with wound healing, including chlorogenic acid, caffeic acid, flavonoids (luteolin, quercetin, rutin), iridoid glycosides (loganin, secologanin), triterpenoid saponins, phenolic compounds, essential oils, and anthocyanins. These constituents contribute to wound repair through antioxidant, anti-inflammatory, antimicrobial, and tissue-regenerative activities by reducing oxidative stress, inhibiting inflammatory mediators, preventing microbial infection, and promoting collagen formation and re-epithelialization[142].

37. *Paeonia suffruticosa*

Paeonia suffruticosa, commonly known as moutan peony, belongs to the family Paeoniaceae and has been cultivated for centuries. The root bark is the primary source of bioactive compounds used Pharmacological studies have demonstrated that *P. suffruticosa* possesses antioxidant, neuroprotective, antitumor, anti-inflammatory, and antidiabetic activities[145]. Traditionally, its dried root is applied to cracked skin to promote healing and relieve pain[146]. In vitro studies have shown that low concentrations of *P. suffruticosa* extracts enhance the viability and proliferation of human dermal fibroblasts and HaCaT keratinocytes, indicating its potential role in wound repair[147].

It contains several bioactive phytoconstituents associated with wound healing, including monoterpene glycosides (paeoniflorin, oxypaeoniflorin), phenolic compounds (paeonol, gallic acid), flavonoids, tannins, phenolic acids, terpenoids, and polysaccharides. These constituents contribute to wound healing through anti-inflammatory, antioxidant, antimicrobial, and collagen-promoting activities, supporting fibroblast proliferation, extracellular matrix formation, reduction of oxidative damage, and tissue regeneration[148].

38. *Panax ginseng*

Panax ginseng belonging to the family Araliaceae, is a widely used medicinal plant in China, Japan, Korea, and Eastern Siberia for improving cognitive function, memory, immunity, physical endurance, and reducing fatigue. It has traditionally been used for managing conditions such as depression, anxiety, and chronic fatigue syndrome. Pharmacological studies have demonstrated that *P. ginseng* exhibits vasodilatory, lipid-regulating, anti-inflammatory, antioxidant, anticancer, antibacterial, antiallergic, antiaging, and immunomodulatory activities. Its major bioactive constituents are ginsenosides (also known as panaxosides), a group of saponins considered responsible for many of its therapeutic effects[149].

It contains several bioactive phytoconstituents associated with wound healing, including ginsenosides (Rb1, Rg1, Rg3, Re, Rd), polysaccharides, flavonoids, phenolic compounds, peptides, polyacetylenes, and saponins. These constituents promote wound healing through anti-inflammatory, antioxidant, antimicrobial, angiogenic, immunomodulatory, and collagen-stimulating activities by enhancing fibroblast proliferation, keratinocyte migration, angiogenesis, and extracellular matrix formation[150].

Root extracts of *Panax ginseng* have demonstrated protective effects against UVB-induced skin damage and have been shown to accelerate healing in laser-induced burns and excisional wound models[151]. Studies indicate that *P. ginseng* extracts enhance keratinocyte migration, promote cell proliferation, and stimulate collagen synthesis in human dermal fibroblasts[152]. Additionally, ginsenoside Rb2, a bioactive compound isolated from *P. ginseng*, promotes epidermal formation by increasing the expression of key wound-healing mediators, including epidermal growth factor, fibronectin, keratin, and collagen-related factors[153].

CURRENT CHALLENGES AND FUTURE PROSPECTS

The integration of herbal therapeutics with polymer-based delivery systems offers promising opportunities for developing advanced wound care therapies[154],[72]. However, the development and commercialization of herbo-polymeric wound care products face several challenges, including formulation stability, improved bioavailability, regulatory requirements, and ethical concerns related to sustainability and traditional herbal knowledge[155],[156]. Advances in material science, biotechnology, regulatory frameworks, and collaborative approaches in integrative medicine provide new possibilities to overcome these limitations. These developments may support the creation of safe, effective, accessible, and ethically sustainable wound healing therapies[157],[158].

CONCLUSION

The medicinal plants reviewed in this article demonstrate significant wound-healing potential owing to their diverse phytoconstituents and multiple pharmacological activities. Bioactive compounds such as flavonoids, terpenoids, alkaloids, tannins, phenolic compounds, saponins, and glycosides contribute to wound repair by exerting antioxidant, anti-inflammatory, antimicrobial, angiogenic, and collagen-promoting effects. These phytoconstituents collectively enhance fibroblast proliferation, collagen synthesis, re-epithelialization, and tissue remodeling, thereby accelerating the wound-healing process. Although the findings from experimental studies are promising, further standardization and well-designed clinical studies are required to validate their therapeutic efficacy and ensure their successful translation into clinical wound management.

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