

Medicinal Plants in Wound Healing: Evidence Review

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ABSTRACT

Wound healing is a complex biological process involving hemostasis, inflammation, proliferation, and remodeling. Medicinal plants, used since antiquity, remain a primary therapeutic option in many cultures due to their accessibility, affordability, and diverse pharmacological activities. Evidence shows that bioactive compounds such as flavonoids, tannins, alkaloids, saponins, and terpenes accelerate wound closure, reduce infection, and promote tissue regeneration through antioxidant, anti-inflammatory, antimicrobial, and angiogenic mechanisms. Common plants such as Aloe vera, Calendula officinalis, honey, tea tree oil, and lavender have demonstrated significant wound-healing potential in experimental and clinical settings. Despite promising outcomes, challenges remain regarding safety, standardization, dosage, and drug interactions. This review highlights the historical background, mechanisms of action, phytochemical contributions, and clinical evidence supporting medicinal plants in wound management. It also underscores the need for further research, ethical considerations, and innovative formulations to integrate traditional knowledge with modern pharmacological approaches for safe and effective wound care.

Keywords: Medicinal plants; Wound healing; Phytochemicals; Antimicrobial; and Tissue regeneration.

INTRODUCTION

Many preparations are made from medicinal plants to accelerate wound healing; these preparations reduce inflammation, bleeding, and pain while simultaneously stimulating the repair of damaged tissue [1-5]. Medicinal plants have long been recognized as a source of compounds that promote wound healing. The therapeutic use of plants and natural products persists globally, particularly in developing countries [6-9]. In Mexico, approximately 300 plant species have been reported for wound treatment, although scientific evidence supporting their effectiveness is limited. This review addresses aspects of wound healing, including the roles of plants, their extracts, and natural products administered orally or topically to accelerate the process. It also considers studies conducted both in vivo and in vitro [10-15]. The use of medicinal plants in healing processes dates to prehistoric times. Traditional applications involve the use of poultices for hemostasis, prevention of infection, and promotion of cicatrization. Several medicinal plants were also ingested to exert systemic effects [16-19]. Ethnopharmacological research combines traditions and practices with chemical and pharmacological analyses, offering models for sustainable exploration of herbal pharmacology in wound healing [20-24]. In developing countries, traditional medicine, primarily based on plants, serves as the principal healthcare system for around 80% of the population. Contemporary medicine continues to recognize the importance of medicinal plants as sources of active molecules for treatment. Each year, nearly 100 million patients worldwide develop scars following surgery, burns, or injuries, a situation that constitutes a major therapeutic challenge [25-27]. Healing involves coordinated sequences of biological, molecular, and cellular events, including immune responses, inflammation, new tissue formation, and re-epithelialization. Medicinal plants offer novel compounds with significant therapeutic effects on wound healing. Ethnobotanical studies have identified 62 families and 109 genera employed in wound management worldwide. The most commonly used plant parts are leaves, fruits, seeds, and roots. Phytochemical screening indicates 36% of these genera contain alkaloids, steroids, flavonoids, saponins, tannins, and terpenes [28-32].

Wound Healing Process

Wounds are injuries that disrupt normal skin function. The healing process initiates immediately after the injury and involves cells, tissues, and mediators cooperating to restore damage [33-36]. The process consists of four

continuous, integrated, and overlapping phases: hemostasis, inflammation, proliferation, and tissue remodeling. Hemostasis begins at injury to prevent further blood loss; platelets adhere and form a clot, releasing proteins and growth factors (EGF, FGF, and TGF). During inflammation, hemostasis, platelet activation, chemotaxis, and leukocyte recruitment prevent infection. The proliferative phase supports tissue growth and repair through granulation, re-epithelialization, and angiogenesis. Lastly, tissue remodeling enhances wound closure, wound strength, and structural integrity [37-42].

Phases of Wound Healing

Wound healing begins immediately after tissue injury and involves four phases: hemostasis, acute inflammation, proliferation, and remodeling [43-47]. The success of healing depends on whether it occurs by first intention, where wound edges are directly apposed, or second intention, where edges remain apart. Incision denotes surgical cutting, whereas excision refers to tissue removal. When damage occurs, the skin launches multiple responses such as vasoconstriction, platelet degranulation, platelet aggregation, and fibrin clot formation to limit bleeding and prevent further harm. Platelet-derived factors then stimulate new cellular activities, signaling the progression toward the next phase of repair [48-49].

Factors Affecting Wound Healing

Factors affecting the wound healing process that must be considered include wound closure rate, epithelialization, tensile strength, histopathology, and granuloma weight [50-54]. The dressing material and the preparation of formulations incorporating medicinal plants into release and distribution systems to convey anti-inflammatory, antioxidant, and wound-healing activity require further investigation. Acquiring standard quantities of pure compounds and extracts is necessary to achieve the standardization of such formulations. Medicinal plant extracts have been documented to arrest bleeding from fresh wounds, inhibit microbial growth, and promote healing [55-58]. These effects may be linked to the free-radical scavenging activity of compounds that enhance collagen strength, increase circulation, or prevent cell damage. Reactive oxygen species inhibit healing at high levels because they damage DNA, proteins, and lipids; therefore, antioxidant-rich plant extracts might be efficacious therapeutic sources for wound treatment. Various ingredients contribute to wound healing through antioxidant, antimicrobial, and cellular mechanisms [59-63]. Flavonoids reduce lipid peroxidation and associated cell damage by scavenging free radicals and exert antimicrobial action that prevents wound infections, which can substantially delay healing. Tannins act as free-radical scavengers and reduce cell damage. Triterpenoids and steroids promote the wound-healing process by initiating wound contraction. Alkaloids and saponins promote wound contraction and epithelialization, which help to prevent wound infections and further damage to underlying tissues. Zinc acts as a cofactor for matrix metalloproteinases that control keratinocyte migration; it also regulates intramembranous and endochondral ossification during wound healing [64-68].

Role of Medicinal Plants in Wound Healing

Wound healing is a sequential process involving coagulation, inflammation, formation of new tissue, and eventual remodeling [4]. Traditionally, several medicinal plants have been used globally to promote wound healing [69-72]. Medicinal plants contain a variety of phytochemicals with known pharmacological activities. The active principles contribute to the major phases involved in tissue repair: inflammation, cell proliferation, and remodeling.

Mechanisms of Action

Plants ensure an efficacious wound-care strategy when their action influences all the healing stages [1]. The therapeutic potential of some herbal extracts and phytochemicals has been demonstrated on different wound types. The relevance of systematic recovery, identification, and investigation of known or unknown medicinal plants and phytochemicals arises; one must act consciously to combine increased efficacy with minimal toxicity [5]. Medicinal plants influence the process at various levels, so relevant bioactivities and phytochemical groups must inform the selection of candidates for study [1].

Types of Medicinal Plants Used

Medicinal plants have been studied to identify the pharmacologically active secondary metabolites involved in healing, such as alkaloids, flavonoids, saponins, tannins, and terpenes. An extensive literature search identified 78 plants frequently mentioned as useful for wound treatment, and from these, the 36 with the highest reported activity were selected [73-77]. Fifty-eight genera in 27 botanical families were recorded from 200 years of data reviewed in 106 scientific articles. Five species recommended for their therapeutic activity were selected from 65 plants cited statistically more than four times: Aloe vera, Capparis spinosa, Phyllanthus emblica, Plantago major, and Ziziphus mauritiana [1]. Various ethanomedical models associate phytochemical content with biological activity and mechanisms of action to identify pharmaceutical targets within the wound-healing process. This evidence supports the therapeutic use of medicinal plants for the effective treatment of wounds and the alternative management of scars. Medicinal plants constitute the principal source of drugs for most people in developing countries, either as self-medication or through traditional healers [1]. The World Health Organization estimates

that 80% of the population living in developing countries currently depends on traditional medicine for primary health care, mainly because of economic reasons or cultural beliefs. Aromatic and spicy plants have been widely used in food and pharmaceutical industries, and the practice of collecting herbs for medicine, health care, cosmetics, and rituals represents an important economic factor for local inhabitants [3]. Studies on these plants provide valuable information for new research strategies directed toward human health consumption. Historically, medicinal plants have been used to favor wound healing [5]. A wound is the rupture of anatomic and cellular continuity caused by physical, chemical, microbiological, or immunological injuries. In the healing process, proteins, lipids, saccharides, and nucleic acids combine with cellular components to provide a structure for cell anchoring and the delivery of biochemical factors. It is well accepted that, in the 21st century, acute-care wound management remains an unsolved problem. Due to this challenge, natural pharmacy continues to play an important role in the health care of wounds. A wound is defined as a breach in the continuity of the skin, mucous membrane, or both caused by physical, chemical, biological, or immunological damage. The need to treat wounds is therefore as old as mankind itself; wounds remain a major challenge to clinicians, especially since the complexity of the repair process and the extent of the wound must be considered not only to speed the repair process but also to restore tissue integrity and function [4].

Common Medicinal Plants for Wound Healing

Various medicinal plants possess wound healing properties and have been extensively studied as pharmacological agents promoting Tissue Regeneration [1]. Aloe Vera has been used as a healing agent due to its antimicrobial, anti-inflammatory, and antioxidant activities. Calendula, a well-known plant widely used to treat wounds, contains triterpenes that accelerate the repair of damaged tissues [6]. Numerous medicinal plants have historically served as sources of novel bioactive molecules. Given that many plant-derived products have undergone limited testing, it remains problematic to discern genuine therapeutic effects from those elicited by placebos. Active compounds such as tannins, flavonoids, and alkaloids have demonstrated favorable influences on the tissue repair process [1].

Aloe Vera

The use of Aloe Vera as an agent for wound healing was reported in ancient times, and both its leaves and gel have been applied to biomedical purposes in recent years. Aloe Vera has shown activity against gastroesophageal reflux disease with evident gastric protection and accelerated healing. It has been used in acute radiation proctitis and irritable bowel syndrome, while an Aloe Vera cream has improved wound healing, diminished pain, and fostered futuristic tissue regeneration of chronic anal fissures [5]. Studies involving Aloe Vera have shown that this plant promoted cell proliferation, enhanced differentiation of epidermal keratinocytes, and increased mechanisms related to wound healing, such as the expression of TGFβ1 and bFGF. Wound healing activity induced by Aloe Vera has been demonstrated in several types of cells, including fibroblasts, gingival, oral, and corneal cells, resulting in accelerated wound closure. Aloin and aloein, natural compounds extracted from Aloe Vera, also support this plant as an agent for skin protection and wound repair since they alleviate oxidative stress and regulate key signalling pathways involved in the healing process [5, 7]. These results demonstrate the importance of Aloe Vera as a medicinal plant with wound healing, anti-inflammatory, and tissue regeneration properties [6]. The increasing interest in the use of Aloe Vera-based hydrogels for biomedical applications is due to their therapeutic effects and various properties. They represent reliable platforms for the administration of different therapeutic agents in wound dressings and for promoting wound healing [7]. Therapeutic agent release from the hydrogels occurs by diffusion, swelling, or degradation of the polymeric network. The effects obtained when using Aloe Vera-based hydrogels as wound dressings include reduction of inflammation, antimicrobial activity, and tissue regeneration. The range of antimicrobial, anti-inflammatory, or angiogenesis agents that may be incorporated in Aloe Vera hydrogels widens their potential for use in wound healing applications.

Calendula Officinalis

Calendula officinalis, a herbaceous plant of the Asteraceae family, has been extensively investigated for its wound healing, anti-inflammatory, antimicrobial, and angiogenic activities [8]. In vitro and animal studies confirm its capacity to accelerate wound closure. Extracts exhibit antimicrobial effects against various fungi and bacteria [9]. The plant enhances microcirculation and vascularization in damaged areas, promoting tissue repair. Its secondary metabolites contribute anti-infective and healing properties, underpinning its use in medicinal and cosmetic formulations. A randomized controlled clinical trial assessed the influence of calendula ointment on cesarean wound healing [9]. Prior findings demonstrated that calendula extract reduces plaque index and bleeding in gingivitis. The anti-inflammatory mechanisms of *Calendula officinalis* flower extract involve modulation of acute phase proteins, antioxidant defenses, and granuloma formation during thermal burns. Calendula oils have proven effective in epithelial reconstruction of surgical wounds following cesarean sections. These results support the therapeutic potential of *Calendula officinalis* during the inflammatory phase and throughout the entire healing process [8, 9].

Honey

The wound-healing properties of honey have been known for several millennia, and medical applications date back to ancient times [10]. A systematic review highlights studies showing that the healing effect of honey could be classified by its antibacterial, antiviral, anti-inflammatory, and antioxidant properties [11]. Sufficient evidence exists recommending the use of honey in the management of acute wounds and for mild to moderate superficial and partial thickness burns. However, additional evidence supporting the use of honey in other areas of clinical practice is needed.

Tea Tree Oil

Tea tree oil (TTO) is an essential oil derived from *Melaleuca alternifolia*, a tree native to Australia of the family Myrtaceae. Its high content of terpinen-4-ol, γ -terpinene, and α -terpinene has given the oil a valuable place in traditional medicine as an anti-inflammatory and antimicrobial agent [1]. Recent decades have witnessed a resurgence in interest in the application of natural plant phytochemicals for wound healing, alongside previous industrial and commercial uses [12]. The traditional medicines, largely derived from native plant species, are closely held secrets among early Aboriginal inhabitants that have been explored experimentally only in the last few decades. A recent global resurgence in the application of natural plant secondary metabolites for wound management has therefore attracted renewed interest. Laboratory and clinical studies with many botanical products have established that the process of wound healing entails a cascade of cellular, molecular, physiological, and immunological events that are multifactorial and highly complex. Efficacy is dependent on the formulation, and the Phytochemicals involved often remain nebulous [12].

Lavender

Lavandula angustifolia (lavender) is a shrub native to the northwest Mediterranean Basin. *Lavandula stoechas* and *Lavandula angustifolia* are presently the most common species in industry [9]. Lavender's secondary metabolites include tannins, flavonoids, coumarins, sterols, triterpenes, saponins, and cardiac glycosides. Lavender extracts exert pain-reducing and anti-inflammatory effects [1].

Phytochemicals in Medicinal Plants

Certain chemical compounds present in medicinal plants exert several beneficial effects, including accelerated wound healing, anti-inflammatory effects, antimicrobial activity, and wound contraction [1]. The phytochemical constituents of these plants include alkaloids, saponins, flavonoids, tannins, and phenolic compounds, which contribute to their therapeutic activity. Flavonoids constitute a major and widely spread group of hydroxylated phenolic compounds known for their strong free radical-scavenging capacity and may promote wound-healing activity by controlling the initial phases of the wound-healing process [1]. They also enhance collagen synthesis, promoting fibroblast proliferation, which is an essential step in the synthesis of extracellular matrix fibers during wound healing. Tannins have the ability to scavenge reactive oxygen species and other free radicals; they form complexes with proteins, thereby making free proteins unavailable for bacterial growth, and exhibit antimicrobial activity through interactions with bacterial cell membranes.

Flavonoids

Wound healing consists of several interconnected phases involving various parameters such as chemotactic factors, inflammatory cells, extracellular matrix components, and parenchymal cells. The process can be subdivided into inflammatory (24 h), proliferation (up to 8 days), and maturation (up to 1 year) phases. Medicinal plants are widely employed in wound care due to their desirable therapeutic properties, primarily attributed to their phytochemical components [1]. Flavonoids are polyphenolic compounds containing 15 carbon atoms distributed in two benzene rings connected by a heterocyclic pyranic ring (C6-C3-C6). They exhibit antiproliferative effects and regulate free radical production, thereby limiting inflammation. Flavonoids enhance antioxidant enzyme levels and display lipophilic activity against Gram-positive bacteria [1, 2]. Their polyhydroxy structure underpins anti-inflammatory, antimicrobial, and antifibrotic actions, making them suitable for treating various skin lesions with minimal side effects. Representative flavonoids, including quercetin, epigallocatechin gallate, and naringenin, accelerate healing by reducing inflammatory mediators such as prostaglandins, leukotrienes, and cytokines, while elevating anti-inflammatory mediators like interleukin-10. Prenylated flavonoids, located in roots, bark, seeds, and buds, possess additional antimicrobial, antifungal, anticancer, and anti-inflammatory properties [1].

Tannins

Many plant genera contain tannins, a class of water-soluble polyphenols characterized by multiple phenol units [1]. Tannins protect plants from predation by herbivores, and their antioxidant properties also protect plants against oxidative stress. In wound healing, tannins precipitate microbial proteins from wounds, accounting for their astringent and antimicrobial properties [3]. Tannins also facilitate wound contraction and inhibit microbial growth, which is why tannin-rich plants such as *Manilkara salzmannii*, *Olea europaea*, and *Bixa orellana* are often employed in wound treatment [2]. Dried bark of Itaja, an unknown species, and fresh leaves of *Mangifera indica*

serve as remedies for wounds and cuts, respectively, due to their tannin content. Various wound-healing products incorporate tannins.

Alkaloids

Alkaloids comprise a vast and diverse group of naturally occurring substances containing nitrogen atoms in heterocyclic rings [7]. They constitute the largest category of plant secondary metabolites and are nearly ubiquitous in the plant kingdom. Classified by chemical structure or biogenetic pathways, alkaloids are found in numerous families, including Papaveraceae, Ranunculaceae, Lauraceae, Amaryllidaceae, Berberidaceae, Convolvulaceae, Rubiaceae, Solanaceae, and Euphorbiaceae [1]. They have demonstrated a wide range of pharmacological effects, such as antihypertensive, antitumor, anticancer, antimicrobial, antimalarial, antihyperglycemic, analgesic, anti-inflammatory, antiasthmatic, anticholinergic, cardiotoxic, and antioxidant activities. Given the complex process of wound healing, the combination of these activities qualifies alkaloids as promising candidates for further investigation in this context [8]. While few alkaloids have been fully characterized regarding their role in dermal regeneration, there is ample evidence of their beneficial effects in other healing domains. Several alkaloids have demonstrated potent anti-inflammatory properties, with their activity sometimes surpassing that of non-steroidal anti-inflammatory drugs. Inflammation, being a critical initial phase of wound healing, such properties offer clear advantages. Additionally, certain alkaloids effectively inhibit microbial growth by targeting bacterial cell walls and membranes, thereby preventing or limiting infections that could impede healing. Flavonoids and tannins complement alkaloids as these polyphenolic compounds contribute antioxidant, anti-inflammatory, and antimicrobial functions, further supporting the complex requirements of the wound healing process [9].

Saponins

Saponins are bioactive phytochemicals found in many medicinal plants commonly used for wound healing. These compounds enhance the process of repair, regeneration, and strengthening of new tissues at the site of skin lesions [1]. Saponins have been isolated from various plants, including *Acacia angustissima*, *Amaranthus spinosus*, *Asparagus racemosus*, *Baphia nitida*, *Ficus exasperata*, *Glycine max*, *Luffa cylindrica*, *Panax quinquefolium*, and *Polyalthia longifolia*. Traditionally, plant extracts used for the treatment of skin wounds often contain saponins, carbohydrates, compounds, and glycosides. The presence of saponins contributes to the observed efficacy of medicinal plants in promoting burn wound healing and broader tissue recovery throughout the healing process [10].

Traditional vs. Modern Approaches

Tracing the origins of the modern use of medicinal plants for the production of pharmaceutical-grade drugs proves a challenging task. Because many cultures have traditions of anthropomorphising nature, plants featuring prominently in the latter centuries' folkloric pharmacopeias still occupy a prominent position in modern botanical and etymological studies, so the curiosity of understanding these is frequently arrested by the desire to understand the foundations of the transition from magical practice to empirical therapy [1]. Early views of the relationship between plant constituents and healing benefit followed a simple one-to-one paradigm and engaged the alkaloids; recent approaches favour multicomponent, prosynergistic perspectives revealing complex mixtures of interacting, interconnected chemicals as the source of therapeutic efficacy [13]. Whilst their biological efficacy frequently remains sketchy, they nevertheless still feature frequently among herbal remedies, often because the aphrodisiac role of various alkaloidal species is repeated uncritically in many modern sources. Most of our views of the uses of such species by the ancient peoples, as reported by the writings of the classic period, are now known to be untenable, as the understanding of the composition and physiological actions of the extracts improves and the identification of the species is clarified [14]. Ethnobotanical studies are generally undertaken under the young science of ethnopharmacology and based on the detailed analysis of the traditional knowledge of the societies involved. Such programmes are important sources of information for modern ethnopharmaceutical approaches, endeavouring to isolate those therapeutic agents that support the generalized medicinal uses of various species but also, in the context of ethnobotanical surveys, reveal one of the principal challenges confronting modern bioprospecting; the great diversity of assumptions, social valuation, and expectations that surround healing within all traditional societies often inhibit those historians from incorporating the field into their studies [15]. Where the concern lies more with the medicinal objective of the practice, the term ethnopharmacology encompasses a wide range of social values concerning the uses of medicine and related issues of phytochemistry, biology, and therapeutic practices. The extension of the medical metaphor and the ambivalence concerning the underlying ethnoscience can provide one explanation of the importance of the distinction. Medicinal ethnobotanical practices exemplify this ambiguity between different forms of ethnoscience and the problems caused by failure to appreciate these distinctions, enabling traditional practices to be dismissed as unscientific parallel practices and devaluing the pragmatism embodied in the societal texts. Equally, the translation of the social science conceptualisation of the

field limits the relevance of the wide field of medical anthropology, medical geography, medical biology, and ethnomedicine to botanical studies [16].

Clinical Evidence and Case Studies

Randomized clinical trials hold promise for establishing the efficacy of medicinal plants in wound healing [1]. A large Cochrane review compared honey to conventional dressings and saline but concluded that the current evidence did not support the widespread clinical use of honey in wound healing [2]. In contrast, an earlier, smaller Cochrane review from 2010 found that honey dressings improved healing in burns. An important controlled trial of 407 patients with mild or moderate atopic dermatitis demonstrated that a 5% ointment derived from birch bark was significantly more effective than placebo in reducing eczema area and severity after 28 days [5].

Systematic Reviews

Systematic reviews have significantly advanced the exploration of medicinal plants as therapeutic wound-healing agents [1]. A number of plant species have been assessed for efficacy against various wound types. Aloe vera is applied to chronic wounds, acute wounds, burns, and frostbite. Calendula officinalis is formulated in creams for burn wounds and surgical scars. Recent reviews of experimental and randomized clinical trial-eligible studies by [1] provide comprehensive evaluations of such applications.

Randomized Controlled Trials

A probiotic formulation combined with clinical antimicrobial therapy has been compared with antimicrobials alone for chronic venous leg ulcers in a randomized controlled trial. Application of the probiotic agent resulted in reduced bacterial bioburden, a higher ratio of pro-angiogenic to anti-angiogenic cytokines, fewer treatment days, and improved healing outcomes [1].

Safety and Efficacy of Medicinal Plants

Medicinal plants have been identified as a rich source of bioactive compounds of therapeutic value for a range of diseases. They improve skin regeneration and promote wound healing [1]. Numerous medicinal plants exhibit promising wound-healing potential due to their analgesic, anti-inflammatory, antimicrobial, antioxidant, and collagen-synthesis properties. The frequent use of herbal plants for self-medication and the ease of buying them can lead to adverse effects and toxicity. Unfavorable drug interactions and/or lack of efficacy can also occur [4]. Some plants commonly employed in traditional remedies have been shown in clinical trials to be ineffective or harmful in treating various health conditions. Hence, safe use must be prioritized over efficacy. Coagulation disorders, tissue damage, or the onset of infection could ensue if plant-based remedies are indiscriminately applied to treat injuries [3].

Adverse Effects

Wounds pose a major clinical, social, and economic burden to the healthcare systems across the globe, and there is an increasing demand for therapeutic agents to accelerate the process of healing. Conventional synthetic medicines have adverse effects and are generally expensive. Therefore, the population, particularly in the developing countries and rural areas, depends on complementary and alternative medicines that are predominantly derived from medicinal plants. The wound healing property of medicinal plants is attributable to the phytochemical constituents present in those plants that are able to hasten the process of wound healing [1, 14]. This review focuses on exotic and native medicinal plants that exhibit wound-healing potential with supporting evidence [1]. The modern knowledge of the mode of action of the bioactive principles from traditional medicines provides an alternative for the improvement or acceleration of wound healing with minimum toxicity and side effects. Consideration must also be given to toxicity to human cells, wound types, chronicity, application timing, optimal dosage, and wound-healing kinetics. Studies have established that adequate dosages of plants accelerate the rate of wound contraction, epithelialization, tensile strength, histopathology, and granuloma weight [14]. In the absence of additional evidence, these medicinal plants are most suitably applied as complementary therapies because the safety of many of these medicinal plants remains unclear. Additionally, the fact that they may interfere with the pharmacokinetics and pharmacodynamics of many of the conventional drugs prescribed needs to be noted.

Drug Interactions

The use of plant-based medicines is widely accepted in many countries because medicinal plants are relatively free from side effects, are readily available, and are cheap [1]. However, some plants are known to cause wound infection, skin irritation, allergy, and wound reopening. The concomitant use of herbal remedies with other drugs has revealed many dangerous and fatal interactions. The profiles of fluctuation in the use of medicinal plants and their relative toxicities are well known, especially for those considered important for agriculture and industry. The most frequently reported medicinal plants that may cause drug interactions when taken together with other drugs are aloe, pawpaw, Siberian ginseng, lizipa, ginkgo, clove, garlic, St John's wort, ginger, and grapefruit juice [1, 15]. Aloe, for example, may exacerbate hypoglycemia in diabetic patients and has a diuretic property that may increase the excretion of other drugs before their action; grated pawpaw may cause respiratory depression. Medicinal plants are used for the treatment of a number of wounds, often without knowledge of the compounds

responsible for the healing activity. *Ageratina pichinchensis* (Asteraceae) is used in Mexican traditional medicine for the treatment of fungal infection and chronic wounds [15]. The wound healing properties of a standardized flavonoid fraction of *A. pichinchensis* have been studied in two animal models in vivo: an excision and a burn model, where its mechanisms of action have been elucidated. The extract and fractions obtained from the plant also showed activity in terms of cellular proliferation in the same study. Mesenchymal stem cells isolated from human amniotic membrane (AM) and amniotic fluid (AF) are used to evaluate the effects of *A. pichinchensis* and the isolated compounds on the proliferation and migration of cells, proposing a mechanism of action involved in the wound healing process. Several studies concerning the therapeutic potential of *A. pichinchensis* to elucidate its wound-healing mechanism and its related compounds have been performed [15].

Regulatory Aspects

In the United States, the legal framework classifies natural products into medicinal products, dietary supplements, cosmetics, and foods. Regulation applies primarily to medicinal products intended for diagnosis, mitigation, treatment, or prevention of disease [1]. Medicinal plants and their active ingredients are often considered safer alternatives to conventional drugs, attracting significant attention. Medicinal products made from medicinal plants are regulated under Council Directive 2004/24/EC, which permits a simplified registration procedure for traditional herbal medicinal products that have been in use for at least 30 years [1].

Future Directions in Research

The changing trends in the use of herbal extracts or their active constituents, holiday or domestically, point to the potential for obtaining innovative wound-healing formulations in the future [1]. The mostly anecdotal clinical reports on the safety and efficacy of natural compounds in wound healing represent ample opportunities for conducting randomized controlled trials. It will be of value to investigate whether the mentioned anti-inflammatory, antioxidant, and antimicrobial properties of plant extracts and pure compounds are responsible for stimulation of the various stages of wound healing [8]. The preparation of formulations that include medicinal plants as part of their release and distribution systems requires further research. Agents involved in modulation of the immune system, systemic antibiotic therapy for infected wounds, and further stimulation of the cellular components of healing are areas for continued work. Future studies should focus on toxicity to human cells, kinetics and speed of healing, wound types, chronicity, timing of application, and dose of therapeutic agent [14]. The wide array of bioactive compounds present in medicinal plants should be explored for their potential to improve or accelerate the healing process with minimal toxicity [5].

Innovative Formulations

Formulations containing medicinal plants are gaining importance in wound treatment due to their potential to enhance healing [1]. Medicinal plants have been used since ancient times, and their value depends on the preparation of formulations that optimize pharmacological efficacy and the release of phytoconstituents at the injury site. Innovative formulations based on natural products open new perspectives for wound management and regenerative medicine. A deep understanding of the wound healing process and the mechanisms of action of medicinal plants underlies the design of novel delivery systems [9]. To improve healing efficiency, continued research is necessary to develop new topical drugs based on phytoconstituents with antioxidant, antibacterial, and anti-inflammatory activities.

Integrative Approaches

The success of current wound-healing management clearly depends on treatment efficacy and safety. Complex events occur during the healing process; therefore, different medicinal plants or combinations of them could improve the final outcome [1, 12]. A comprehensive overview of recent advances in this field indicates that isolated phytoconstituents, plant extracts, or polyherbal formulations may offer superior options to synthetic products, natural or semi-synthetic pharmaceuticals. Under these conditions, wound healing proceeds by first controlling haemostasis and inflammation; later, regeneration occurs when the rate of proliferation of epithelial cells and formation of new vessels overcomes the rate of degradation. 6conditions are not always fulfilled when an insufficiency of any of these elements appears [13]. A practical strategy involves selecting and combining medicinal plants and pharmaceutical drugs to obtain innovative formulations crafted to exert anti-inflammatory action; stimulate the collagen, fibronectin, and hyaluronic acid synthesis required to promote the adhesion and migration of keratinocytes; and enhance the proliferation of a wide variety of cells that produce fibroblasts and endothelial cells [1].

Ethical Considerations

The use of medicinal plants for wound healing raises important ethical considerations related to consent, bioprospecting, and equitable access. Medicinal plants are an indispensable part of the cultural heritage of many ethnic groups, yet these same communities have often been excluded from the benefits of scientific research into their knowledge [1]. Since many Western pharmaceutical companies have profited from products linked to traditional knowledge collected from across the globe, however, it is important that efforts are made to guarantee

access and benefit-sharing for the original holders of this knowledge [16, 17]. Obtaining consent from participants in any scientific study and collecting data on the local regulations governing research in a particular geographical area are key considerations. This includes respecting agreements on the use of medicinal plants to avoid exploitation or the possibility of subsequent disputes. Organizations such as the World Health Organization and the International Society of Ethnobiology provide information and guidelines to safeguard traditional knowledge and avoid practices that violate indigenous rights. Since medicinal-plant research and healing practices have become urgent and popular fields of such study during the last few decades, increased focus must be placed on ensuring observance of ethical norms. The large number of issues involved makes it impossible to provide a truly comprehensive discussion of this subject, and supplementary sources should be consulted by anyone wishing to undertake further research [16]. Obtaining consent from participants in a scientific study and collecting data on the local regulations governing research in a particular geographical area are key considerations. This includes respecting agreements on the use of medicinal plants to avoid exploitation or the possibility of subsequent disputes. Organizations such as the World Health Organization and the International Society of Ethnobiology provide information and guidelines to safeguard traditional knowledge and avoid practices that violate indigenous rights [13]. Since medicinal-plant research and healing practices have become urgent and popular fields of study during the last few decades, increased focus must be placed on ensuring observance of ethical norms. The large number of issues involved makes it impossible to provide a truly comprehensive discussion of this subject, and supplementary sources should be consulted by anyone wishing to undertake further research [17].

Cultural Perspectives on Wound Healing

The use of medicinal plants in wound healing reflects the cultural perspectives of different regions. Traditional knowledge regarding medicinal plants has been handed down from generation to generation [17]. In various geographical regions, the same or different plant species are employed for similar or different medicinal purposes, depending upon the cultural and historical background of the community. Dependency on traditional medicines is due to easy accessibility, a high cost, and sometimes the no availability of modern medicines and treatment methods [1]. The use of alternative and complementary medicine is increasing day by day, being mostly preferred in developing countries because of the limited availability of modern medicine. It is generally acceptable that people belonging to different cultural backgrounds use different plants for similar purposes or different medicinal plants to treat similar diseases [18-20].

CONCLUSION

Medicinal plants represent a valuable source of bioactive compounds that can accelerate wound healing by modulating inflammation, enhancing collagen synthesis, and preventing infection. Their long history of use, combined with growing scientific validation, supports their role as complementary or alternative therapies in modern wound management. However, variability in plant preparations, lack of standardization, and potential adverse effects present significant limitations to their widespread adoption. Future research should focus on randomized clinical trials, toxicity studies, and innovative formulations that optimize phytochemical delivery at wound sites. Moreover, ethical considerations, including respect for traditional knowledge and equitable benefit-sharing, must guide bioprospecting and commercialization. By integrating ethnopharmacology with evidence-based medicine, medicinal plants may contribute to safer, more affordable, and culturally inclusive wound-healing therapies.

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