

Innovative Approaches to Wound Healing with Phytoconstituents from Indian and Chinese Medicinal Plants

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ABSTRACT

Wound healing remains a major challenge in healthcare, with current treatments often limited by high cost, side effects, or lack of efficacy. Traditional medicine systems in India and China have long used medicinal plants to promote wound repair, drawing on centuries of empirical knowledge. This review explores recent advances in wound healing using phytoconstituents from Indian and Chinese medicinal plants. Key bioactive compounds such as flavonoids, alkaloids, terpenoids, and polysaccharides are highlighted for their antioxidant, anti-inflammatory, antimicrobial, and tissue-regenerating effects. Mechanistic insights reveal that these phytoconstituents modulate cellular pathways involved in inflammation, collagen synthesis, and tissue remodeling. Recent experimental and clinical studies confirm the efficacy and safety of plant-based therapies, with modern delivery systems like nanoparticles and hydrogels enhancing their stability and bioavailability. Challenges remain in standardization, quality control, and regulatory approval, but integration of traditional wisdom with modern science offers new opportunities for effective, affordable, and safe wound care solutions. Continued research and collaboration are needed to fully realize the therapeutic potential of these ancient remedies in contemporary medicine.

Keywords: Medicinal plants, Nanotechnology, Phytoconstituents, Traditional medicine, Wound healing.

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INTRODUCTION

When skin or tissues are damaged, wound healing helps repair them. Adequate care prevents infections, relieves pain, and promotes better healing. Improper healing can lead to higher medical costs, more pain, and future problems. While many therapies exist, some old methods have drawbacks, and others can be costly or cause undesirable side effects (Berk and Parker, 2009).

Due to these challenges, many are turning to natural remedies and medicinal plants for wound care. Plants' antibacterial, anti-inflammatory, antioxidant, and tissue-regenerating properties make them valuable in medical applications. These natural items support fast and safe wound healing (Ayisi *et al.*, 2025).

India and China have practiced herbal medicine for centuries. Traditional Chinese Medicine (TCM), Ayurveda, and Siddha use medicinal herbs for skin care and wound healing. Poultices, ointments, decoctions, and pastes are made from these plants. Modern science has supported many of these traditional remedies, showing which parts of the herbs aid healing (Singh *et al.*, 2024).

This article reviews recent research on medicinal plants from India and China for wound healing. Combining ancient wisdom with modern technology can lead to safer, more affordable treatment options. The globe map in Figure 1 highlights the herbs used for healing in India and China, showcasing their expertise in herbal medicine (Pereira and Bartolo, 2016).

TRADITIONAL PERSPECTIVES ON WOUND HEALING IN INDIAN AND CHINESE MEDICINE

The medical systems in India and China are ancient and cover almost all areas of healing. One aspect of these tools is steps for providing first aid. Skincare in ancient times mainly involved using herbs to treat wounds and diseases (Thirthalli *et al.*, 2016).



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Ayurveda and Siddha in India

Ayurveda, meaning the "Science of Life," is an Indian medical tradition focused on balancing the three main energy flows (doshas) in the body. In Ayurveda, wound care involves restoring balance within the body and healing the injury. Natural herbs like Neem (*Azadirachta indica*) are known for their strong antibacterial properties (Dutt *et al.*, 2023). *Curcuma longa*, or turmeric, contains curcumin, which helps fight inflammation and prevent damage from free radicals. Aloe Vera (*Aloe barbadensis*) is used to calm the skin and keep it hydrated, aiding the healing process (Kocaadam and Şanlıer, 2017).

The South Indian Siddha system shares many Ayurvedic concepts but emphasizes the use of minerals and herbs together. Its treatments include plant-based remedies, such as oils and pastes for the skin or decoctions, to aid in wound healing and prevent infections (Mukherjee and Wahile, 2006).

Traditional Chinese Medicine (TCM)

In TCM, the focus is on balancing Qi (energy) and blood flow within the body, a practice that dates back centuries. Many TCM treatments for wounds aim to increase blood circulation and promote tissue regeneration. Huang Qi (*Astragalus membranaceus*) supports immune functions and tissue repair. Dang Gui (*Angelica sinensis*), a type of ginseng, strengthens the blood. Sheng Di Huang (*Rehmannia glutinosa*) has a cooling effect and reduces inflammation (Zhang *et al.*, 2024).

Common Preparations and Methods

In traditional Chinese medicine, like in Indian medicine, poultices, oils, pastes, and decoctions are used for wound care. These can be applied to wounds or taken orally as needed. The combination of complementary herbs enhances antibacterial effects, reduces inflammation, and promotes tissue repair (Jaiswal *et al.*, 2016).

Table 1 summarizes key medicinal plants, their traditional preparations, and uses in wound healing from both traditions, highlighting how Indian and Chinese herbal medicine have developed complementary approaches (Dorai, 2012).

Table 2 captures the historical development and milestones in wound healing practices in Indian and Chinese medicine. It illustrates the origins of these systems, ancient texts, key medicinal plants, and the transition towards modern scientific validation and advanced wound care technologies, showing how ancient wisdom continues to influence contemporary research and product development.

PHYTOCONSTITUENTS RESPONSIBLE FOR WOUND HEALING

Phytoconstituents are bioactive chemicals found in medicinal plants used in Indian and Chinese herbal medicine. These chemicals help reduce inflammation, lower the likelihood of infections, and support tissue renewal during healing. Recent research has shown which phytochemicals significantly aid recovery (Ehrman *et al.*, 2007).

Major Bioactive Compounds

Flavonoids, studied for their antioxidant levels, help eliminate harmful free radicals and reduce inflammation. Quercetin and kaempferol, found in turmeric and *Astragalus membranaceus*, are examples of antioxidants that improve healing speed and hygiene (Zulkefli *et al.*, 2023).

Alkaloids, such as berberine, are effective against wound pathogens and found in neem and *Cypris chinensis*. They promote cell development and tissue restoration, aiding in wound closure and infection prevention (Pattnaik *et al.*, 2023).

Terpenoids, including curcumin from turmeric and ginsenosides from ginseng, fight inflammation and support collagen production, which is essential for tissue regeneration and remodelling (Mohammadi-Cheraghabadi and Hazrati, 2023).

Table 3 summarizes the main phytochemical groups in Indian and Chinese medicinal plants, their therapeutic properties, and complementary roles in wound repair.

Figure 2 presents the chemical structures of these phytoconstituents, aiding in the design of better formulations and synthetic analogs for wound healing.

MECHANISMS OF ACTION IN WOUND HEALING

The active molecules originating from plants, known as phytoconstituents, are crucial in wound healing. For better and quicker recovery, these chemicals encourage tissue regeneration, lessen inflammation, forestall infection, and activate critical cellular pathways (Vitale *et al.*, 2022).

Tissue Repair and Regeneration

Phytoconstituents aid in wound healing by promoting cell movement to the wound site, increasing cell proliferation, and encouraging differentiation into specific tissues. These activities help heal injured tissue and form new layers (Sankar and Muthukaliannan, 2024). Phytochemicals also support the growth of new blood vessels, ensuring the wound receives adequate nutrition, oxygen, and immune cells. Chemical mediators promote tissue formation and help build the extracellular matrix, speeding up the healing process (Adhikary *et al.*, 2024).

Anti-inflammatory, Antimicrobial, Antioxidant, and Collagen Synthesis Effects

One of the keyways phytoconstituents contribute to wound healing is through their anti-inflammatory, antimicrobial, antioxidant, and collagen synthesis effects:

Anti-inflammatory: Inflammation will always occur when harm happens, but too much can slow down healing and lead to complications. Chemicals in herbal extracts have an effect on immune cells and help reduce the quantity of inflammatory cytokines. Quicker healing is possible because of the redness, swelling and pain lessen (Vane and Botting, 1987).

Antimicrobial: Antibacterial properties found in many phytoconstituents help to protect the wound and avoid an infection. Such chemicals can kill many kinds of germs, fungus and viruses. They protect the wound from infection and make it easier for the body to fix the problem by stopping microbes from growing (Bittner Fialová *et al.*, 2021).

Antioxidant: An imbalance between antioxidants and free radicals causes oxidative stress which can weaken the work of cells and make healing slower. Antioxidants in phytoconstituents protect cells from free radicals that may harm them. Therefore, the wound is not disturbed, and cells recover faster with reduced damage (Aruoma, 1998).

Collagen Synthesis: The structure and strength of fresh connective tissue are provided by collagen, so it is very important in this type of tissue. They help the body build collagen at the wound site which speeds up healing and protects tissue. This step helps restore the structure of the wound which, in turn, lets healing occur fast and leaves behind few scars (Parry and Craig, 1984).

Molecular Pathways Influenced by Phytoconstituents

At the molecular level, phytoconstituents influence various molecular pathways that drive the processes of wound healing:

Growth Factor Signaling: Growth factors are promoted in tissue repair due to the action of phytoconstituents. VEGF encourages angiogenesis which leads to the formation of new blood vessels at the wound to bring more oxygen and nutrients. When damaged tissues occur, substances such as collagen are made by fibroblasts

and Platelet-Derived Growth Factor (PDGF) (Honnegowda *et al.*, 2015).

Gene Expression Regulation: Plant phytoconstituents may change gene activity to help during the healing of wounds. Upscaling genes in charge of regenerating tissues and producing collagen is just one capability. They can also lower the activity of genes that trigger long-lasting inflammation to avoid overinflammation problems (Vitale *et al.*, 2022).

Cell Signaling Pathways: Phytoconstituents also interact with important cell signaling pathways involved in wound healing. These include:

NF- κ B (Nuclear Factor kappa B): Managing inflammation and immune responses occur through this pathway. Excessive inflammation gets decreased and the risk of chronic inflammatory disorders affecting healing decreases, because phytoconstituents control NF- κ B activity (Tripathi and Aggarwal, 2006).

MAPK (Mitogen-Activated Protein Kinase): Several pathways called Mitogen-Activated Protein Kinases (MAPKs) oversee cell growth, development and handling stress. Preventing scarring from becoming worse and boosting cell survival and renewal are effects brought about by phytoconstituents in MAPK signaling. (Cowan and Storey, 2003).

PI3K/Akt Pathway: Role of the MAPK pathway in survival, cell growth and metabolism has been investigated. Many plant compounds are able to boost the action of PI3K/Akt which helps cells respond to injury and support wound healing (Jellusova and Rickert, 2016).

Phytoconstituents play a role in initiating the inflammatory phase and ensuring the beginning of tissue remodelling as part of wound healing (Figure 3). Overseeing different routes in the body ensures the healing process runs smoothly and reduces chances of problems (Criollo-Mendoza *et al.*, 2023).

RECENT SCIENTIFIC ADVANCES AND EXPERIMENTAL EVIDENCE

Recent studies have shown that plant extracts aid in wound healing by promoting tissue repair and growth (Valentino *et al.*, 2021). Scientific evidence supports the effectiveness of these traditional medicines, particularly from India and China, with

Table 1: Medicinal plants, preparations, and traditional uses for wound healing in Indian and Chinese medicine (Shedoeva *et al.*, 2019).

Tradition	Key Medicinal Plants	Common Preparations	Traditional Uses in Wound Healing
Indian Ayurveda	Neem, Turmeric, Aloe Vera, Ashwagandha	Pastes, Oils, Decoctions	Antimicrobial, anti-inflammatory, antioxidant, promotes tissue repair.
Siddha Medicine	Karisalai (Coleus amboinicus), Nellikai (Phyllanthus emblica)	Ointments, Oils	Accelerates healing, reduces infection, pain relief.
Traditional Chinese	Huang Qi (Astragalus), Dang Gui, Sheng Di Huang, Bai Zhu (Atractylodes)	Decoctions, Poultices	Promote blood circulation, reduce inflammation, detoxify.

Table 2: Timeline of key milestones in wound healing traditions of India and China (Fu et al., 2001).

Year (BCE/CE)	Milestone	Tradition	Description
~1500 BCE	Origins of Ayurveda	Indian Ayurveda	Foundation of Ayurveda, focusing on balance and holistic health, including wound management.
~1000 BCE	Development of Siddha Medicine	Siddha Medicine	Traditional South Indian system with unique plant formulations for healing and surgery.
600 BCE	Compilation of Sushruta Samhita (ancient surgical text)	Indian Ayurveda	Detailed surgical techniques and herbal wound care methods documented.
~200 BCE	Compilation of Huangdi Neijing (Yellow Emperor's Inner Canon)	Traditional Chinese	Core text of Traditional Chinese Medicine, outlining concepts of Qi and blood flow in healing.
1 st Century CE	Use of key medicinal plants like Neem, Turmeric, Huang Qi, Dang Gui	Both Traditions	Extensive use of medicinal plants in decoctions, poultices, oils, and pastes for wound healing.
20 th Century	Modern scientific research begins validating traditional wound healing plants	Both Traditions	<i>In vitro</i> , <i>in vivo</i> , and clinical studies confirm antimicrobial, anti-inflammatory, and regenerative properties of herbs.
21 st Century	Integration of phytoconstituents into advanced wound care products and delivery systems	Both Traditions	Development of nanoparticles, hydrogels, and standardized herbal formulations based on traditional knowledge.

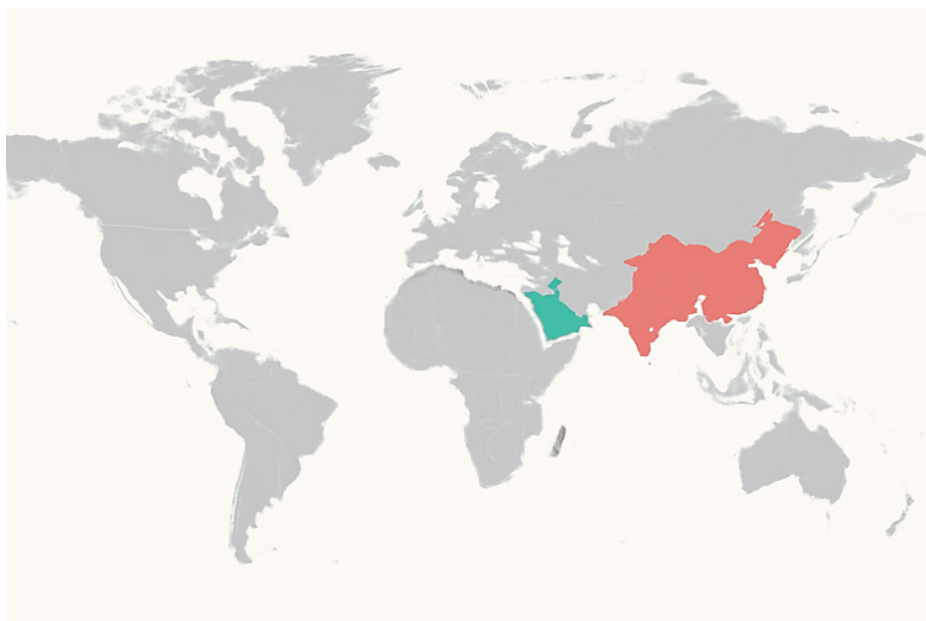


Figure 1: Global map highlighting India and China, two countries with rich traditions of medicinal plants. This figure is self-created by the authors using Adobe Illustrator and no external copyrighted material was used.

research focusing on their dosage, efficacy, and safety for medical use (Singh et al., 2014).

Summary of Important *in vitro* and *in vivo* Studies

Recent research shows that plant extracts promote cell migration, division, differentiation, and wound healing (Table 4). Plants like Aloe Vera, Turmeric (*Curcuma longa*), and *Centella asiatica* enhance cell growth and collagen production, essential for healing (Thangapazham et al., 2016).

Animal studies confirm that plant extracts can reduce infection and inflammation in wounds. Extracts from *Hypericum perforatum* and *Calendula officinalis* improve wound healing by supporting skin layer growth and blood vessel formation, which is crucial for healing (Melnyk et al., 2022).

Clinical Trials Involving Indian and Chinese Plant Extracts

Plant extracts from India and China have been the focus of clinical studies on wound healing. Research in India has shown that

turmeric (*Curcuma longa*) reduces inflammation and eliminates bacteria, enhancing healing and reducing infection risk in burns and chronic wounds (Fuloria *et al.*, 2022).

Ginseng and Gotu Kola, extensively studied in Chinese medicine, promote rapid collagen and tissue production during wound healing and boost the immune system. Gotu Kola also helps close wounds and reduce scarring after surgery (Sabaragamuwa *et al.*, 2018).

These clinical trials provide strong evidence supporting the practical benefits of plant extracts in wound healing, validating their use in both modern and traditional medicine.

Safety, Efficacy, and Dosage Findings

While plant extracts have shown effectiveness in wound healing, more research is needed to determine their safety and proper dosages. Clinical trials have found plant medicines to cause few toxic effects, but improper use or excessive amounts can lead to skin irritation or allergic reactions. For instance, turmeric is safe for most users, but prolonged use can cause skin sensitivity (Gurib-Fakim, 2006).

Topical plant remedies are used in various dosages, typically in gels, lotions, or creams with concentrations ranging from 1% to 5%. However, further research is needed to identify the best application methods and long-term safety for wound care (Ribeiro *et al.*, 2015).

Large-scale clinical trials are essential to better understand how to use plant extracts for wound healing, their long-term safety, and their full range of benefits (Freedman *et al.*, 2023).

MODERN FORMULATIONS AND DELIVERY TECHNOLOGIES

Recent advances in drug delivery have improved methods for applying plant chemicals in wound healing. New delivery systems using hydrogels and nanoparticles make traditional remedies more effective, secure, and easier to use (Pachua, 2015).

Advances in Drug Delivery Methods

Nanoparticles are a major advancement in modern medicine, designed to transport chemicals efficiently. Ranging from 1 to 100 nm, they penetrate the skin and deliver plant substances to hard-to-treat areas. Their large surface area and controlled release enhance therapeutic effects (Khan *et al.*, 2022; Isopencu *et al.*, 2023).

Hydrogels, made from polymers that hold water and remain moist, significantly improve wound healing. They are useful for applying plant extracts as they dissolve slowly, delivering active ingredients over time. Hydrogels aid chronic wounds by transferring substances and moisturizing, which promotes tissue growth (Gounden and Singh, 2024).

Enhancing Stability, Bioavailability, and Targeted Action

The effectiveness of plant extracts depends on their stability and absorption. Modern technologies, like nanoparticles and liposomes, protect active ingredients from heat, light, and air, maintaining their potency throughout the delivery process (Bilia *et al.*, 2019).

Bioavailability refers to how well the body absorbs and uses substances. Traditional plant extracts have low absorption, but

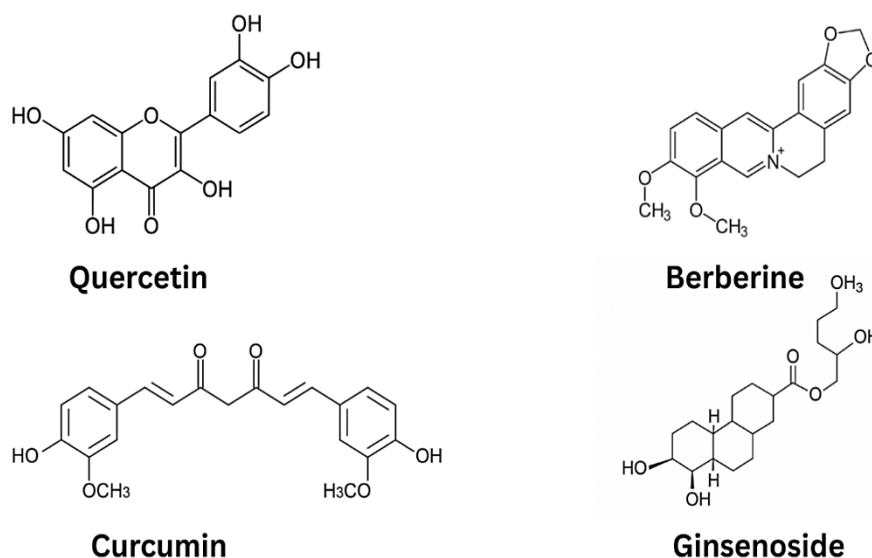


Figure 2: Chemical structures of key wound healing phytoconstituents (Yadav *et al.*, 2024).

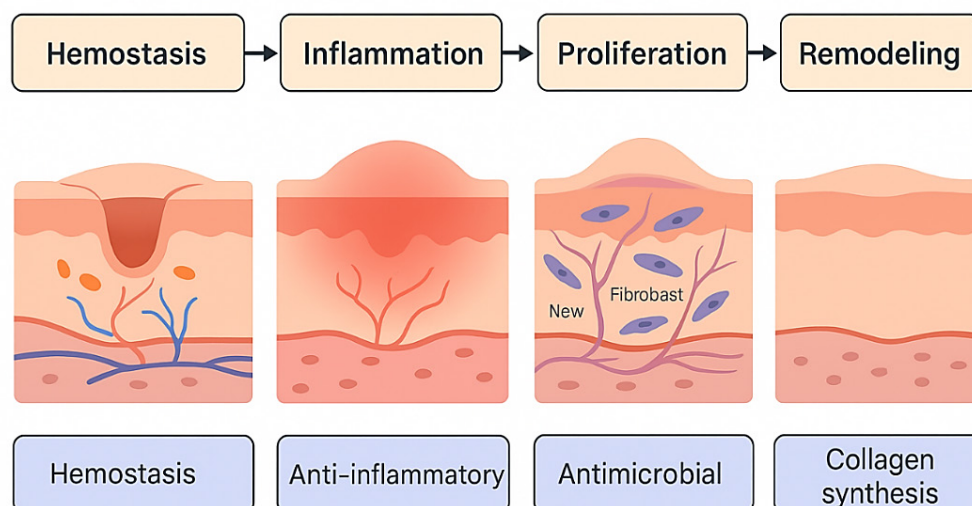


Figure 3: Diagram of wound healing stages. This conceptual diagram is original and prepared by the authors based on standard wound healing stages.

liposomes and nanoparticles improve solubility and skin delivery, increasing bioavailability while reducing the risk of side effects (Stielow *et al.*, 2023).

Recent advances in tailored medication delivery ensure active ingredients reach the targeted areas effectively. Traditional topical methods often fail to deliver ingredients to wounds, but new tools enable precise delivery, minimizing side effects and optimizing wound healing (Palombo, 2011; Manzari *et al.*, 2021).

Examples of Commercial Products Inspired by Traditional Knowledge

New commercial products improve upon traditional plant-based knowledge by using modern delivery technology, enhancing the healing effects of plants like *Centella asiatica*, *Aloe vera*, and Turmeric (Tachie *et al.*, 2023).

Aloe vera gels, long known for easing inflammation and speeding injury healing, now use nanoparticle technology for faster and longer-lasting results (Sahu *et al.*, 2024). Turmeric, known for its anti-inflammatory and antibacterial properties, benefits from nanoencapsulation, allowing quicker absorption and better wound healing with less scarring (Wojtyłko *et al.*, 2023).

Centella asiatica, known for boosting collagen and healing wounds, is included in many modern hydrogel formulations, promoting faster healing, less scarring, and enhanced tissue growth (Bansal *et al.*, 2024).

Modern science has made these plant-based products safer, easier to use, and more effective, bridging traditional and modern medical treatments (Akhtar *et al.*, 2024).

INTEGRATION OF INDIAN AND CHINESE MEDICINAL PLANTS IN CONTEMPORARY MEDICINE

Modern medicine is increasingly using medicinal herbs from India and China, with plant-based medicines gaining more recognition (Najmi *et al.*, 2022). However, strict regulations and challenges in global acceptance hinder their widespread use. Medicines combining traditional plant knowledge with modern science are becoming increasingly popular (Hossain *et al.*, 2022).

Challenges in Standardization and Quality Control

The lack of standardization is a major barrier to developing plant-based medicines from India and China. Factors like plant location, harvesting methods, seasonal changes, and processing affect the potency and quality of extracts (Yadav *et al.*, 2024). Evaluating the safety and effectiveness of herbal medications is challenging due to the absence of standard rules, unlike pharmaceutical drugs which follow strict regulations (Govindaraghavan and Sucher, 2015).

To ensure safety and effectiveness, plant-based medicines must adhere to quality standards and controlled preparation methods. Phytochemical profiling is necessary to measure active ingredients, and supplements should follow GMP rules to ensure safety, effectiveness, and freedom from pesticides and adulterants (Nafiu *et al.*, 2017).

Regulatory Frameworks and Global Acceptance

Many countries do not widely use medicinal plants due to varying regulations. Unlike India and China, where traditional medicines are well-regulated, plant-based treatments in Western nations are often viewed as dietary supplements, not tested as rigorously for safety and effectiveness (Hamilton, 2004).

Stricter regulations are needed to ensure the safety, effectiveness, and quality of plant-based medicines before they can be marketed (Müller *et al.*, 2006). Thanks to the WHO's efforts, global principles for traditional medicine have been established, blending ancient knowledge with modern science and increasing acceptance worldwide (Kasilo and Nikiema, 2014).

Collaborative Research and Fusion Therapies

To bridge the gap between traditional and modern medicine, joint studies are needed to integrate traditional plant-based knowledge with modern scientific methods, enhancing treatment efficiency (Waldram, 2002).

Fusion therapies combine traditional medical practices with modern technology, using plants from India and China. Traditional Chinese Medicine and Ayurveda, for example, address health conditions with plant therapies (Goyal and Chauhan, 2024). Health professionals now blend traditional practices with modern medications to treat pain, boost immunity, and manage chronic diseases (Abbasi *et al.*, 2023).

Research institutes from Western, Chinese, and Indian traditions have developed therapies that combine Western drugs with herbal remedies, isolating active substances to minimize side effects and improve recovery (Uzuner *et al.*, 2012).

FUTURE TRENDS AND RESEARCH OPPORTUNITIES

Innovations in biotechnology, nanomedicine, and medication development are creating new opportunities for using medicinal plants in modern medicine. These advancements offer new

treatments for various diseases while helping protect plant species from extinction (Prajapati *et al.*, 2024).

Emerging Technologies: Biotechnology and Nanomedicine

Biotechnology has transformed the use of medicinal plants, enabling genetic modification and enhanced production of bioactive compounds like alkaloids, flavonoids, and terpenoids through metabolic engineering (Fowler, 2006). Genetic engineering now allows the production of these compounds in greater quantities, reducing reliance on wild plants (Silva *et al.*, 1998).

Synthetic biology, which combines natural plant products with lab-made drugs, holds promise for creating safer and more effective medicines (Figure 4) (Berestetskiy *et al.*, 2023).

Nanomedicine, aided by nanotechnology, allows plant-based chemicals to be accurately targeted to specific body parts, overcoming barriers like the blood-brain barrier (Karnwal *et al.*, 2024). Nanocapsules improve the absorption and controlled release of plant extracts, offering long-lasting effects and fewer side effects (Armendáriz-Barragán *et al.*, 2016).

Nanoencapsulation also enhances the stability of plant compounds vulnerable to light, heat, and oxygen, making nanoformulations an essential part of future drug delivery systems (Mondéjar-López *et al.*, 2024).

Table 3: Key phytochemicals from Indian and Chinese plants and their wound healing roles. (Shah and Amini-Nik, 2017).

Phytochemical Group	Examples	Source Plants (Indian and Chinese)	Wound Healing Properties
Flavonoids	Quercetin, Kaempferol	Turmeric (<i>Curcuma longa</i>), Huang Qi (<i>Astragalus membranaceus</i>)	Antioxidant, anti-inflammatory, promote angiogenesis and tissue repair.
Alkaloids	Berberine	Neem (<i>Azadirachta indica</i>), <i>Coptis chinensis</i>	Antimicrobial, promotes cell regeneration, reduces inflammation.
Terpenoids	Curcumin, Ginsenosides	Turmeric (<i>Curcuma longa</i>), Ginseng (<i>Panax ginseng</i>)	Anti-inflammatory, collagen synthesis, tissue remodeling.
Tannins	Catechins, Ellagic acid	Indian gooseberry (<i>Phyllanthus emblica</i>), Chinese gall (<i>Rhus chinensis</i>)	Astringent properties that help contract tissues, antimicrobial, antioxidant.
Saponins	Ginsenosides, Diosgenin	Ginseng (<i>Panax ginseng</i>), Fenugreek (<i>Trigonella foenum-graecum</i>)	Promote collagen formation, anti-inflammatory, enhance wound contraction.
Phenolic acids	Gallic acid, Caffeic acid	Turmeric (<i>Curcuma longa</i>), Green tea (<i>Camellia sinensis</i>)	Antioxidant, antimicrobial, stimulate fibroblast proliferation.
Polysaccharides	Aloe polysaccharides	Aloe Vera (<i>Aloe barbadensis</i>)	Promote moisture retention, enhance cell proliferation and migration, stimulate immune response.

Table 4: Summary of Studies on Plant Extracts for Wound Healing (Maver et al., 2015).

Sl. No.	Study Type	Plant Extracts Used	Model (<i>In vitro</i> / <i>In vivo</i> /Clinical)	Key Findings
1	<i>In vitro</i>	Turmeric extract	Cell cultures	Enhanced fibroblast proliferation.
2	<i>In vivo</i>	Huang Qi extract	Rat wound model	Accelerated wound closure.
3	Clinical trial	Neem ointment	Human subjects	Reduced infection and faster healing.
4	<i>In vitro</i>	Aloe vera extract	Cell cultures	Stimulated cell migration and proliferation.
5	<i>In vivo</i>	Calendula extract	Rat wound model	Reduced wound size and inflammation.
6	Clinical trial	Gotu Kola cream	Human subjects	Improved tissue regeneration.
7	<i>In vitro</i>	Turmeric extract	Cell cultures	Promoted collagen synthesis
8	<i>In vivo</i>	<i>Centella asiatica</i> extract	Rat wound model	Enhanced cell differentiation and migration.
9	Clinical trial	Honey	Human subjects	Accelerated wound healing.
10	<i>In vitro</i>	Aloe vera gel	Cell cultures	Enhanced anti-inflammatory response.
11	<i>In vivo</i>	Ginseng extract	Mouse model	Promoted wound contraction.
12	Clinical trial	Tea Tree oil	Human subjects	Reduced infection and inflammation.
13	<i>In vitro</i>	<i>Centella asiatica</i> extract	Cell cultures	Boosted fibroblast activity.
14	<i>In vivo</i>	Turmeric extract	Rat wound model	Promoted wound closure and regeneration.
15	Clinical trial	Calendula extract	Human subjects	Reduced scarring.
16	<i>In vitro</i>	Ginseng extract	Cell cultures	Increased angiogenesis.
17	<i>In vivo</i>	Aloe vera gel	Rat wound model	Accelerated epithelialization.
18	Clinical trial	Neem extract	Human subjects	Boosted collagen formation.
19	<i>In vitro</i>	Garlic extract	Cell cultures	Reduced wound infection.
20	<i>In vivo</i>	Turmeric extract	Rat wound model	Enhanced skin regeneration.
21	Clinical trial	Calendula ointment	Human subjects	Reduced pain and inflammation.
22	<i>In vitro</i>	Ginseng extract	Cell cultures	Improved wound healing.
23	<i>In vivo</i>	<i>Centella asiatica</i> gel	Rat wound model	Enhanced wound contraction.
24	Clinical trial	Aloe vera extract	Human subjects	Reduced infection and faster tissue repair.
25	<i>In vitro</i>	Ginseng extract	Cell cultures	Promoted tissue regeneration.

Potential for New Drug Development and Combination Therapies

Research into medicinal plants holds great promise for discovering new drugs. Natural sources like the opium poppy and Pacific yew tree have provided important bioactive compounds for treatments. Advances in high-throughput screening, genomics, and metabolomics allow researchers to quickly test large numbers of plant extracts for potential biological effects (Sinha et al., 2023).

Polyphenols in green tea and grapes are being studied for their ability to combat oxidative stress and inflammation, linked to chronic diseases like heart disease, cancer, and brain disorders. Compounds in turmeric (curcumin) and garlic are also being researched for their potential to stop cancer cell growth (Mao et al., 2017).

A new approach combines traditional drugs with plant-based chemicals to improve treatment outcomes. Integrative medicine, blending herbal remedies like ginseng or echinacea with antibiotics, enhances effectiveness and reduces side effects. This approach is proving valuable in managing pain, boosting immunity, and treating chronic diseases (Gao et al., 2020).

Genetic research enables personalized treatments that combine plant-based products with other medications, guided by pharmacogenomics to increase effectiveness and reduce risks (Wei et al., 2012).

Conservation and Sustainable Sourcing of Medicinal Plants

Concerns over medicinal plant biodiversity are growing due to overharvesting driven by rising demand. To address this, there

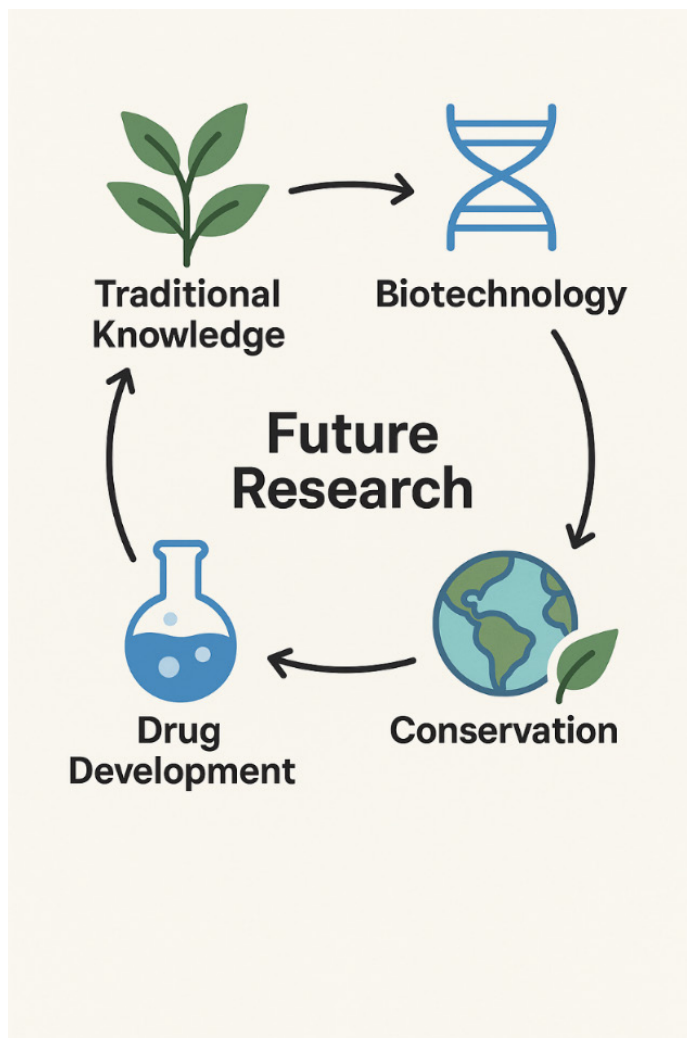


Figure 4: Conceptual diagram showing future research pathways combining traditional knowledge with biotechnology (Rist and Dahdouh-Guebas, 2006).

is a movement to preserve these plants through sustainable sourcing and protection efforts, as natural habitats face threats from climate change and deforestation (Corlett, 2020).

Sustainability can be achieved by establishing guidelines for cultivating medicinal plants like ginseng, turmeric, and echinacea. Agroforestry, which integrates trees and shrubs with crops, helps maintain soil quality, water levels, and biodiversity while growing medicinal plants (Alamgir and Alamgir, 2017).

Plant tissue culture techniques also support sustainable cultivation, allowing for pest- and disease-free, genetically uniform plants for industrial production, reducing the need for wild harvesting (Smith and Drew, 1990).

Ethical sourcing is crucial to ensure that local communities in biodiversity-rich areas benefit from the harvest and sale of medicinal plants. Fair trade practices empower farmers and reduce poverty (Heywood, 2011).

CONCLUSION

Integrating traditional herbs from India and China with modern medicine promises improved global health. Advances in biotechnology and nanomedicine have made plant-based compounds more potent and accessible.

Biotechnology and nanomedicine enhance the extraction, delivery, and targeting of plant compounds, improving absorption and yield. These technologies support sustainable sourcing to meet global demand. Combination therapies with plant-based remedies and conventional drugs show positive results, particularly for chronic and immune-related illnesses.

Merging traditional knowledge with modern science ensures remedies are effective and safe. This integration offers a holistic approach, providing more comprehensive treatment options.

For full potential, medicinal plants require continued interdisciplinary research. Rigorous clinical trials are essential to verify safety and effectiveness, facilitating their integration into conventional healthcare. Collaboration between modern scientists and traditional practitioners will lead to better, personalized treatments.

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ABBREVIATIONS

TCM: Traditional Chinese Medicine; **GMP:** Good Manufacturing Practices; **VEGF:** Vascular Endothelial Growth Factor; **PDGF:** Platelet-Derived Growth Factor; **ORCID:** Open Researcher and Contributor ID; **BCE/CE:** Before Common Era/Common Era; **NF- κ B:** Nuclear Factor Kappa B; **MAPK:** Mitogen-Activated Protein Kinase; **PI3K/Akt:** Phosphoinositide 3-Kinase/Protein Kinase B.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

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CREDIT AUTHOR STATEMENT

Conceptualization, Methodology, Software. Rohit Verma, Alok Kumar Mahor: Data curation, Writing- Original draft preparation. Rohit Verma, Prem Prakash Singh Visualization, Investigation, Supervision, Prem Prakash Singh, Software, Validation. Rohit Verma, Prem Prakash Singh: Writing, Reviewing, and Editing: Rohit Verma.

DECLARATION REGARDING THE USE OF GENERATIVE AI AND AI-ASSISTED TECHNOLOGIES IN WRITING

The authors employed OpenAI ChatGPT 4.1, AI tool to enhance clarity and language during the preparation of this work. After utilizing these tools, the authors thoroughly reviewed and edited the content as necessary, assuming complete responsibility for the published material.

SUMMARY

Wound healing is a major healthcare challenge, and traditional methods are often expensive, inefficient, or cause side effects. This review focuses on Indian and Chinese medicinal plants used for wound repair, such as neem, turmeric, aloe vera, Huang Qi (Astragalus), and Dang Gui (Angelica). These plants contain bioactive compounds-flavonoids, alkaloids, terpenoids, and polysaccharides-that have antioxidant, anti-inflammatory, antimicrobial, and tissue-regenerating effects.

Flavonoids like quercetin reduce inflammation and promote tissue healing. Alkaloids, including berberine, stimulate cell regeneration, while terpenoids in ginseng and turmeric aid collagen production, essential for tissue healing. These compounds enhance cell migration, decrease inflammation, prevent infections, and support collagen formation.

Recent scientific research supports the effectiveness of plant-based therapies in wound healing, with plant extracts shown to improve cell migration, collagen formation, and infection reduction. Modern drug delivery systems like nanoparticles and hydrogels further enhance these therapies by improving bioavailability, stability, and targeted delivery.

However, challenges remain, including the lack of standardization, quality control, and regulatory approval. Variations in plant extracts due to geographic and harvesting conditions make consistency difficult, and inconsistent regulations across countries hinder widespread use.

Standardization and continued research, including the integration of biotechnology and nanomedicine, hold great potential for developing effective, affordable, and accessible plant-based wound care therapies. Further research and clinical trials are crucial to confirm the safety and efficacy of these treatments, making them a valuable supplement to modern medicine.

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