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Therapeutic potential of traditional Chinese medicine loaded nanocarriers in wound management: Current status and their future perspective

Jitendra Gupta [a,1,*], Devesh Kumar [a,1], Reena Gupta [a], Diksha Diwakar [b], Kumari Shanno [c], Arpan Kumar Tripathi [d], Akshay Kumar [e], Mohit Kumar [f,*]

[a] Institute of Pharmaceutical Research, GLA University, District-Mathura, U. P., 281 406, India
[b] Faculty of Pharmacy, IFTM University Delhi Road, NH-24 Moradabad, Lodhipur Rajput, Uttar Pradesh, 244102, India
[c] Bihar College of Pharmacy, New Baeily Road, Patna 80150, India
[d] Faculty of Pharmaceutical Sciences, Shri Shankaraacharya Technical Campus, Bhilai, Chhattisgarh, 490001, India
[e] Department of Pharmaceutical Sciences and Technology, Maharaja Ranjit Singh Punjab Technical University (MRSPTU), Bathinda 151001, Punjab, India
[f] Chitkara College of Pharmacy, Chitkara University, Rajpura, 140401, Punjab, India

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ABSTRACT

Introduction: Wound healing is the main physiological process that repairs tissue injury and maintains the body's protective barrier. Traditional Chinese medicine (TCM) has long been known for its herbal remedies promote wound healing. Nanocarriers, which include liposomes, nanoparticles, and hydrogel, enhance the stability, bioavailability, and targeted delivery of TCM's bioactive component. The integration of nanotechnology and TCM represents and an emerging frontier for advanced wound care.

Methods: Data was gathered from PubMed, ScienceDirect, and Google Scholar databases covering the period from 1965 to 2024 to ensure comprehensive inclusion of relevant literature. The search utilized keywords such as Traditional Chinese Medicine, Wound Healing, Herbal TCM, and Nanocarrier Systems. Studies that investigated the pharmacological effects of TCM in combination with nanocarriers were selected for analysis. Experimental wound healing models, in vitro assays, and in vivo animal studies were included to assess the efficacy of nanocarrier systems in enhancing the therapeutic potential of TCM as a nanotheranostic approach.

Results: The results showed that TCM compounds in nanocarriers like liposomes, nanoparticles, and hydrogel had a big impact on wound healing. Different TCMs, such as *Acorus calamus, Artemisia annua, Angelica dahurica,* etc., showed enhanced bioavailability and sustained release when incorporated into nanocarrier systems. In animal tests, they increased collagen production, lowered inflammation, and accelerated epithelialisation in preclinical models.

Conclusion: The integration of TCM with nanocarrier technology presents a promising approach to pursuing wound healing therapies. Nanocarriers increase the bioavailability and medical effect of TCM compounds, providing more effective and targeted treatment for wound care. The combination of ancient knowledge of TCM with modern nanotechnology can bring revolution in the future to heal wounds and provide innovative solutions for fast and more effective recovery.

1. Introduction

TCM is highly valued and honoured as one of the world's oldest and most recognised health and treatment systems. According to folklore and mythology, TCM, or Traditional Chinese Medicine, is believed to have originated around 5000 years BC. During China's Shang Dynasty (1766–1122 BCE), TCM was systematically structured and advanced by distinguished herbalists and healers within the imperial courts. The first documented source to mention the notion of Yin and Yang, which is the fundamental and unique principle of TCM, is the "Book of Changes", believed to have been written about 700 BCE [1,2]. Qi, also known as vital life energy or Chi, is the fundamental basis for the entire mind, body, and spirit doctrine and practice of TCM [3]. It has been known since ancient times that TCM were used to heal scars. Ancient Chinese

* Corresponding authors.
E-mail addresses: smartjitu79@gmail.com (J. Gupta), maddysharma3303@gmail.com (M. Kumar).
[1] Equal contribution.

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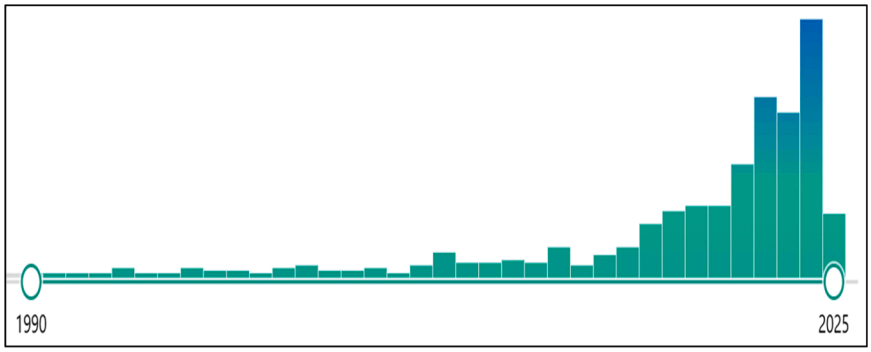

Fig. 1. Results from a PubMed search engine showcasing research publications published between 1990 and 2025.

medicine suggests that various plant-based TCMs that treat burns and wounds [4]. TCM for wound healing gives back thousands of years. Ancient Chinese medical literature advises treating wounds with various plant medications used in TCM. With time, significant advancements have been achieved in proving these herbal medication's ability to cure wounds and elucidate their possible processes.

The skin, the body's largest organ, functions as a protective barrier against external threats, controls temperature, and facilitates sensory perception [5]. Wounds, caused by physical, chemical, or thermal factors, disrupt this barrier and vary in depth and cause, ranging from minor abrasions to deep lacerations [6,7]. The wound healing process is important for restoring tissue integrity and consists of four stages hemostasis, inflammation, proliferation, and remodeling [8,9]. Hemostasis is the process that prevents excessive blood loss from promoting vasoconstriction and formation of blood clotting [10]. The inflammatory phase, which can last several days, recruits immune cells, including neutrophils and macrophages, to clear debris and pathogens [11]. The immune response is charactersize by redness, swelling and pain, which readies the wound for repair. Healing is crucial the maintaining the immune system work and recover well.

The bioavailability, stability and targeted delivery of therapeutic agents are significantly increased by these nanocarrier-encapsulated TCM, which notably promote wound healing [12]. TCM bioactive substances such as Protocatechuic aldehyde (PA), Asiaticoside (AS) [13], and Panax Notoginseng Saponins (PNS) have potent anti-inflammatory, oxidation resistance, and tissue regeneration capabilities [14]. However, their pharmaceutical efficacy is frequently restricted by low solubility, fast disintegration, and limited permeation through the skin [15]. Encapsulating drugs in nanocarriers, such as lipid nanoparticles, polymeric nanoparticles, or microneedles, enhances their solubility, extends their release, and facilitates deeper skin penetration, thereby ensuring prolonged therapeutic efficacy at the wound site [16]. Additionally, nanocarrier systems protect bioactive molecules from enzymatic degradation, which helps preserve their effectiveness [17]. Controlled release mechanisms may enhance the healing process by mitigating excessive inflammation, facilitating collagen production, and expediting re-epithelialization [18]. However, the integration of nanocarriers with TCM might reduce systemic toxicity and adverse effects by localising the medication to the targeted location [19]. This synergistic method conforms to the comprehensive principles of TCM while using current drug delivery technology, making it a potential strategy for the treatment of hypertrophic scars, chronic wounds, and diabetic ulcers [20].

2. Methods

In this review, we conducted a comprehensive literature search using several online databases, including PubMed, Google Scholar, Web of Science and Scopus covering studies from 1965 to 2024. The keywords used in our search included *"Traditional Chinese Medicine", "Wound Healing", "Herbal TCM", and "Nanocarrier Systems", etc.,* A total of 354 articles were thoroughly analysed, of which 207 were selected for detailed discussion based on their relevance, study quality, and contributions to the subject (Fig. 1). The selection criteria for articles included experimental studies, and reviews that examined the bioactive components, therapeutic effects, and nanocarrier applications of TCM in wound healing. The analysis emphasised the bioactivity of natural compounds, such as anti-inflammatory, and collagen-promoting properties, focusing on their nanocarrier-based delivery systems. This review emphasises how the combination of conventional herbal medicines and contemporary nanotechnology represents a strategy to improve the efficiency of wound healing while reducing toxicity.

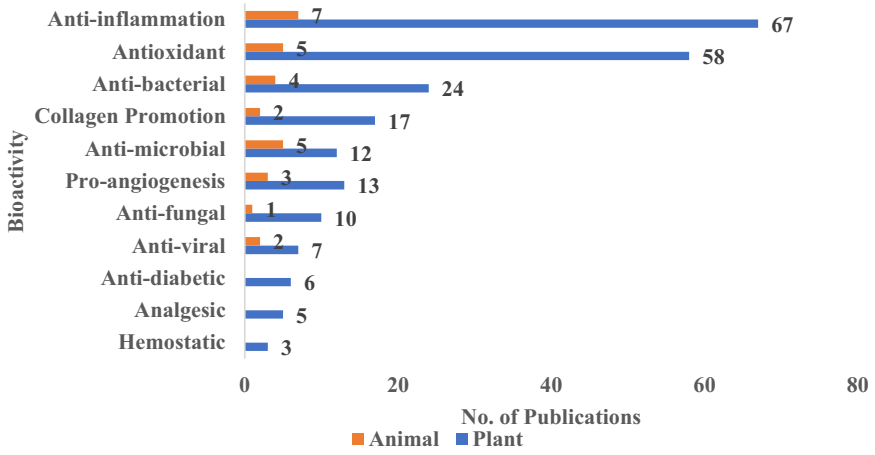

Fig. 2. A summary of literature on the bioactivities of natural substances used for wound healing.

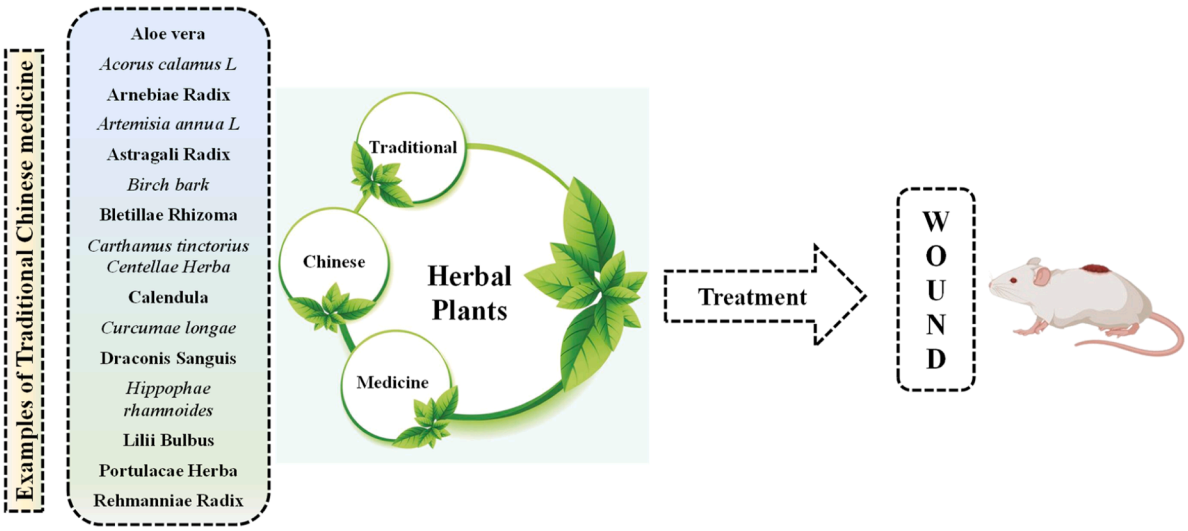

Fig. 3. TCM used in wound healing.

3. Classification of natural compounds for wound healing based on their medicinal uses

A comprehensive literature search was conducted to compile several research publications that specifically investigate the use of natural substances for wound healing. These studies were categorized based on their bioactivities, which include anti-inflammatory, antioxidant, antibacterial, and collagen-promoting effects. The overview highlighted the bioactivity of natural agents with emphasis on their nanocarrier-based therapeutic delivery systems, including anti-inflammatory, antioxidant, and collagen-stimulating characteristics. This review emphasises how the combination of conventional herbal medicines and contemporary nanotechnology represents a strategy to improve the efficiency of wound healing while reducing toxicity (Fig. 2) [21].

4. Physiology of wound healing

Hemostasis, inflammation, proliferation and remodeling are the four phases of wound healing. When the wound is closed, hemostasis and the ensuing inflammation begin [22]. Several factors, including growth factor (PDGF), platelet-derived transforming growth factor-beta (TGF-β), and other chemo-attractant factors generated by wounded parenchymal cells, induce blood to coagulate [23]. Additionally, platelets migrating to the wound site and blood vessel constriction play a role in the healing process. Following inflammation, the body enters a proliferative phase [24]. Cells like endothelial cells, fibrocytes, platelets, and mesenchymal cells proliferate to facilitate tissue regeneration and angiogenesis, building new blood arteries via the action of endothelial cells. The wounded cells get more blood as a result. Currently, angiogenesis, fibroplasia, and epithelization serve as the healing processes. The last phase of wound healing is called maturation and remodeling, and it is during this process that TIMPs (tissue inhibitors of metalloproteinases), ECM (extracellular matrix) and MMPs (matrix metalloproteinases) are produced. Myofibroblasts aid in the wound's constricting, and when these mechanisms work together, the wound heals and matures into a scar [25].

5. Herbal TCM: in management of wound healing

Herbal TCM has been utilized for millennia to address a variety of diseases, including wound healing. Many herbal TCM remedies contain bioactive components that promote the healing process through anti-inflammatory, antioxidant, and antibacterial properties, enhancing collagen production and angiogenesis (formation of new blood vessels) (Fig. 3 and Table 1) [26].

5.1. *Acorus calamus L*

Acorus calamus (*A. calamus)* L, a member of the Acoraceae family, is a medicinal plant with a vast distribution in China. Traditional folk medicine in China and Indonesia uses this substance to cure many conditions, such as inflammation, depression, hemorrhoids, and skin problems. The primary components found in this substance were phenylpropanoids, sesquiterpenoids, and monoterpenes [27]. In one study Ponrasu et al., developed the topical application of ethanolic extract of *A. calamus* on cutaneous wound healing in rats, resulting in enhancing of wound healing process [28]. In another study Pawar et al., researched on *Acorus calamus* methanol extract demonstrated potent antibacterial activity against methicillin-resistant *Staphylococcus aureus*, with synergistic effects when combined with antibiotics. The study correlated polyphenolics and flavonoids with bioactivity, highlighting *A. calamus* as a promising non-toxic candidate for skin disease treatment [29].

5.2. *Aloe vera*

Aloe vera (*A. vera*), belonging to the family Asphodelaceae, is a succulent plant species primarily sourced from *Aloe barbadensis miller*. It is native to arid regions, particularly in North Africa, the Arabian Peninsula, and certain parts of India. *A. vera* is a succulent plant well-known for its soothing and healing properties, particularly for skin-care [30,31]. Polysaccharides like acemannan and glucomannan, as well as enzymes, vitamins, minerals, and anthraquinones like aloin and emodin, are among the active ingredients that give aloe vera its wound-healing qualities [32]. A popular natural cure for burns, wounds, and other skin irritations, the gel within its leaves is rich in minerals, vitamins, and antioxidants. Beyond topical uses, *A. vera* is consumed in juice to support digestive health, has mild laxative properties and can help soothe the digestive tract. Its versatile benefits have made *A. vera* a staple in natural medicine and skin care [33]. Many studies have shown that *aloe vera* has less toxicity and effective healing effects by reducing inflammation and improving wound contraction, and epithelialization [34,35]. In one research on Hamid and Soliman highlighted that *aloe vera* enhances angiogenesis and accelerates healing in full-thickness skin burns by reducing inflammation, promoting mature granulation tissue, and improving collagen deposition. Histological analysis revealed decreased α-SMA expression and inflammatory infiltrate, indicating better wound remodelling [36]. In one research, Garima et al., used a burn model in rats to compare the effects of several *aloe vera*

Table 1
Examples of herbal TCM for the treatment and management of wound healing.

Plant Name	Family	Part used	Active Phytoconstituents	Wound type/ model	Special Comments/Outcomes	References
Aloe barbadensis	Liliaceae	Leaves	Mannose-6-phosphate	Excision wound model	Gel has a potential influence on the wound healing process.	[116]
			N/A	Full-thickness	Topically, *A. vera* enhanced the biochemical, morphological, and biomechanical properties of the healing cutaneous wounds in rats.	[117]
			Mannose-6-phosphate	Excision wound	*A. vera* aqueous extract to open wounds produces significant wound constriction and speeds healing.	[118]
Acorus calamus L	Acoraceae	Leaves	Phenylpropanoids, sesquiterpenoids	Rats with excision or incision wounds	The ointment of *A. calamus* leaf extract has significantly enhanced wound healing.	[119]
Angelica dahurica	Apiaceae	N/A	β-sitosterol (BZ12)	Full-thickness wounds	Pharmacology network analysis and *in-vivo* validation highlighted the possible effects and underlying processes of *A. dahurica's* therapeutic effect on diabetic wound healing.	[120]
		Dried root	Furanocoumarins	A full-thickness cutaneous wound model	*A. dahurica* promises significance as a therapeutic for vascular injury-related wounds.	[42]
		Roots and seeds	Imperatorin and Isoimperatorin,	Excision wound model	*A. dahurica* ethanolic extract (One-day application) treats diabetic patient's delayed wound healing and impaired blood vessel creation.	[121]
Angelicae sinensis radix	Apiaceae	Dried roots	SBD.4	Incisional wound	The SBD.4 isolate of *Angelica sinensis* enhanced wound therapy when incorporated in wound dressings.	[122]
Arnebiae Radix	Boraginaceae	Roots	Alkannins and shikonins	Full-thickness	On day 11, the wounds treated with the ointment based on Alkannins/Shikonins had a significantly higher epithelial thickness score ($P = 0.025$).	[123]
Astragali Radix (AR) and *Rehmanniae Radix* (RR)	Leguminosae and Scrophulariaceae	Raw herb	N/P	Diabetic foot ulcer rat model	RR and AR (2:1) ratio as NF3 to treat diabetic foot ulcers demonstrated that AR is the main herb in this herbal remedy.	[124]
Astragali radix	Fabaceae	Dried root	Formononetin	Full-thickness wound	The significant potential of formononetin for managing wound healing sparked interest in its further development and application.	[52]
Calendula officinalis	Asteraceae	Flower	Triterpenes	*In-vitro w*ound healing assay	The ethanolic extract increased the quantity of collagen in the human dermal fibroblast supernatant and reduced the activity of collagenase in vitro.	[73]
Dragon's blood	Arecaceae	Red resin	Dracorhodin perchlorate	Full-thickness wound	Accelerate and improve wound healing.	[125]
Glycyrrhiza uralensis	Fabaceae	Roots and rhizomes	Polysaccharide	Injury model	The combination of Glycyrrhiza soluble polysaccharide and microcapsules holds significant promise in expediting wound healing and promoting neovascularisation, a potential breakthrough in regenerative medicine.	[126]
Hippophae rhamnoides L	Elaeagnaceae	Leaves	Flavonoids, tannins, and triterpenes	Full-thickness wound	The aqueous sea buckthorn leaf extract may promote wound healing and raise the antioxidant levels of the granulation tissue.	[83]
Llilii Bulbus	Liliaceae	Bulb	Steroidal glycosides	*In-vitro w*ound healing Assay	The traditional use of lily bulbs to heal burns and wounds and raise the possibility of using steroidal glycosides derived from lily bulbs in regenerative medicine.	[127]
Lonicerae Japonicae (*L. japonica)*	Caprifoliaceae	Flowering aerial parts	Chlorogenic acid	Excision wound	Antibacterial and anti-inflammatory properties *L. japonica* concert to hasten wound healing.	[128]
Reynoutria japonica Hout	Polygonaceae	Rhizomes	Total Polyphenols and Tannins Content	*In-vitro w*ound Healing	*R. japonica* rhizome 25 % EtOH extract is a potential gingival wound healing agent deserving of both animal and human testing.	[129]
Rheum officinale Baill	Polygonaceae	Dried root and rhizome	Emodin	Excision wound	Emodin improved the healing of rats' excisional wounds via a complicated mechanism, including activating tissue regeneration and modulation of the Smads-mediated TGF-β1 signalling pathway.	[130]
Streptocaulon juventas (Lour.) *(SJ)*	Apocynaceae	Dried roots	Periplogenin Digitoxigenin	Full-thickness skin	Periplogenin and digitoxigenin improved the pathological status of injured skin tissue, increased the amount of hydroxyproline in wound tissue, and dramatically accelerated wound healing in rats.	[108]
		Dried roots	Hydroxyproline	Full-thickness wound	Ethanol extract of SJ markedly enhanced both *in-vivo* and *in-vitro* wound healing.	[109]
Zingiberis Rhizoma Recens	Zingiberaceae	Rhizomes	10-shogaol	*In-vitro*	The research strongly supports 10-shogaol potential in wound healing. It acts as an antioxidant that promotes the proliferation of human skin cells and is a migratory enhancer, paving the way for a cutting-edge treatment.	[131]

Where N/A = Not Available.

preparations with framycetin sulfate on wound healing. By day 21, the groups treated with Aloe pulp and Framycetin had the greatest amount of wound contracture and the quickest rate of re-epithelization, indicating that Aloe pulp is a safe and efficient substitute for local burns [37].

5.3. Angelicae rahuricae Radix

An effective TCM demonstrated to have wound-healing characteristics is called *A. dahuricae* [38]. The primary bioactive compounds include coumarins (imperatorin, isoimperatorin, and oxypeucedanin), polysaccharides, flavonoids, and essential oils [39]. These compounds exhibit the anti-inflammatory, antimicrobial, and antioxidant activities necessary to accelerate wound healing [40]. Coumarins, in particular, help to reduce inflammation and prevent infection, while polysaccharides promote tissue regeneration and improve collagen synthesis [41]. Additionally, the antioxidant effects of flavonoids protect skin cells from oxidative stress, further supporting the repair and recovery of damaged tissues. Guo et al., investigated *A. dahuricae* increased angiogenesis and enhanced wound healing in hereditary mice models of diabetes. These furanocoumarins were found to be the main active ingredients and relatively abundant. According to the author indicated *A. dahurica* shows potential as a treatment for wounds caused by vascular damage [42].

5.4. Angelicae sinensis Radix

Angelicae sinensis (*A. sinensis*) Radix, also known as Dong Quai or Chinese angelica root, is a traditional herb used in Chinese medicine. Both in Europe and America, it is also taken as a functional food. Its biological role includes promoting angiogenesis [43]. One study conducted by Hsiao et al., explored *A. sinensis* and its active component, ferulic acid, studied for their wound healing properties using proteomic and biochemical analysis. The study identified 51 differentially expressed proteins and showed effects on collagen secretion, migration, and reactive oxygen species regulation. These findings support the potential of *A. sinensis* in developing wound-healing formulations [44].

5.5. Arnebiae Radix

Dry roots of the Arnabia species of the Borginai family, such as Arnabia Eukaroma, Arnabia Gutta or *Lithospermam Erytrizone*, are also called Arnabia Redics. Xinjiang, is a province in China, *Arnabia eukaroma* (Royle ex Benth.). Arnebia Guttata Bunge and *Lithospermum erythorrhizon* Siebold and Zuccc are both members of the Boraginaceae family. East is originally from the Inner Mongolia in China, while the latter is a regular facility in Japan, Korea and China. Recent studies have revealed that Arnebiae RBSIX, Shikonin, has wound healing properties in the active ingredient [45]. Gao et al., investigated the molecular processes behind Radix Arnebiae Oil's (RAO) capacity to promote wound healing. This oil contains shikonin (24.57 mg/mL), imperatorin (3.15 mg/mL), and ferulic acid (0.13 mg/mL). In a Rotte's combustion model, RAO improved wound closure and tissue repair. It was shown by increased activity of supexide dysmutter, which reduced the level of malaondioladehyde and pro-inflammatory cytokines (IL-6, TNF-α, IL-1β). The author found that RAO increases the expression of TGF-Rand and activates the Pi3K/act signaling pathway, which suggests its ability as an effective medical remedy to promote incinerator healing [46]. A study by Pan et al., showed that plasma-activated radix arnebiae oil (PARAO) is created through a single-step, energy-efficient plasma process. This process produces reactive oxygen species that increase the antibacterial and wound healing properties of oil. Parao effectively MRSA and *P. aeruginosa* eliminates Euruginosa, reducing inflammation, reccling epithelialization, and untreated Radics improves the treatment of burning of 11.3 % to another degree compared to arnebiae oil [47].

5.6. Artemisia annua L

According to the Compendium of Material Medica, *Artemisia annua* L. (Asteraceae) can be used to treat wounds. Artemisia ketone (30.7 %), oxygenated monoterpenes, and camphor (15.8 %) were the main components of essential oil. Numerous studies have provided scientific proof of the antibacterial, anti-inflammatory, antifungal, and antioxidant qualities of *Artemisia annua* L. [48]. Mirbehbahani et al. created a wound dressing by combining *Artemisia annua* L. extract with gelatin and used electrospinning technology to build a nanofibrous structure. A study on wound dressings made from *Artemisia annua* L. demonstrated no adverse effects on cellular health, supported the growth and attachment of fibroblast cells, and shown potent antimicrobial activity against *S. aureus* [49]. Oh et al., researched on *Artemisia annua Linne* callus extracts revealed their potential as natural cosmetic and medical materials, with ethanol extracts promoting wound healing and suppressing COX-2 for anti-inflammation. These findings highlight the plant's eco-friendly applications in skincare and therapeutic products [50].

5.7. Astragali Radix

Astragali radix, derived from the dried root of *Astragalus mongholicus* Bunge, a member of the Fabaceae family, is a type of TCM. It is believed to have anti-inflammatory effects and aid wound healing [51]. Huh et al., investigated how formononetin affected the expression of growth factors that aid in wound healing as well as early growth response factor-1 (Egr-1). Formononetin has been shown to improve wound healing and endothelial cell repair. It boosted the synthesis of the transcription factor Egr-1 and controlled the p38 mitogen-activated protein kinase (p38 MAPK) and extracellular signal-regulated kinase 1 and 2 (ERK1/2) pathways [52].

5.8. Birch bark

Birch bark, derived from trees in the *Betula genus* has been utilized in traditional medicine for centuries [53]. Rich in betulin and betulinic acid, it possesses potent anti-inflammatory, antiviral, and antioxidant properties, making it beneficial for treating skin conditions, promoting wound healing, and supporting overall immune health [54]. In one study, Ebeling *et al.*, showed that *Birch bark*, traditionally used for wound healing, has been clinically proven to accelerate this process. Triterpene extract (TE) from *birch bark*, particularly betulin, enhances keratinocyte migration and transiently upregulates pro-inflammatory cytokines and cyclooxygenase-2, aiding wound healing. These findings highlight *birch bark's* potential as an effective remedy for improving wound healing [55]. Scheffler evaluated on *Artemisia annua Linne* callus extracts revealed their potential as natural cosmetic and medical materials, with ethanol extracts promoting wound healing and suppressing COX-2 for anti-inflammation. These findings highlight the plant's eco-friendly applications in skincare and therapeutic products [56]. Emrich et al., researched Austrian larch, birch, and beech bark extracts revealed strong antimicrobial activity, particularly against Gram-positive bacteria, and enhanced wound healing. The total phenolic content of the crude extracts is 4.1 % greater than that of sterile filtered extracts, and their antioxidant activity is 0.9 % lower. Notably, beech bark exhibited novel beneficial effects, highlighting its potential for dermatological applications, including acne treatment [57].

5.9. Bletillae Rhizoma

Bletilla Strait (Thunab.) Rchb of orchid species. F, known as Bletillae Rhizoma, has a long history of medical use in China, such as hemoptis, stomach ulcers, painful bleeding and conditions such as dehydrated skin. Phytochemical research has identified Blotillae Rhizoma Polycecarides (BRP) as the primary chemical components of this plant. The main connections found include polyme caride, phenantrain, bibenzil

and various flavonoids. By boosting angiogenesis, collagen production, and cell proliferation all essential for tissue repair Polymearides is one of these that contributes significantly to wound healing. Furthermore, Fennantrain and Bibenzil have antibacterial and anti-inflammatory qualities, which aid in lowering wound site infection and inflammation [58]. Flavonoids found in *Bletillae Rhizoma* provide antioxidant properties that protect cells from oxidative stress and enhance injury recovery [59]. Yan et al., developed a synergistic aerogel dressing that combines hemostatic and antibacterial properties using oxidized *bletilla rhizome* polysaccharide Schiff Base and polyvinyl alcohol. This was accomplished through a freeze-drying and cross-linking process. The oxidized *bletilla rhizome* polysaccharide schiff Base was synthesized via a Schiff base reaction with silver sulfadiazine, a process that was confirmed through FTIR and NMR analysis. The resulting aerogel exhibited strong antibacterial properties, effective hemostatic capabilities, and enhanced wound-healing effects. It promoted angiogenesis and epithelialization while also reducing inflammation in models of full-thickness skin defects [60]. He et al., developed a homogeneous polysaccharide (BSPS) from fresh tubers of Bletilla striata. BSPS significantly enhances cellular viability, differentiation, migration, and invasion in C2C12 cells. It also stimulates epidermal regeneration and wound healing in mice. These findings indicate that BSPS has promise as a new natural agent for wound healing [61].

5.10. *Carthamus tinctorius L*

Carthamus tinctorius L, a member of the Asteraceae family, is a traditional botanical remedy used to cure conditions such as blood stasis and unpleasant menstruation problems [62]. *Carthamas Tinchorius* L. *(Kusum)* has shown promising potential in healing wounds, roughly because of its bioactive compounds, especially in the oil and flowers. Medical activities in this drug are mainly attributed to flavonoids, alkaloids and organic acids [62]. Cai et al., demonstrated that safflower-expressed oleosin-rhFGF9 localizes to oil bodies and promotes hair growth and wound healing in mice by upregulating β-catenin expression. This novel plant-based system offers a promising source of rhFGF9 for potential clinical applications in alopecia and wound treatment [63].

5.11. *Centellae Herba*

Centellae Herba, often known as Gotu Kola (Centella Asiatica), is considered a high in traditional medicine because of its many medical and healing properties [64]. It is especially known for healing wounds and increasing skin health. As a result, it is often included in skin care products to improve skin elasticity, reduce scars and treat conditions such as eczema [65]. While generally safe, it should be used cautiously, especially in high doses or by individuals with specific health conditions. Saeidinia et al., assessed the effectiveness of Centiderm and silver sulfadiazine (SSD) in treating partial thickness burns. The author demonstrated that using Centiderm ointment resulted in rapid improvement of both objective and subjective indications over less than 3 days. Furthermore, the use of Centiderm ointment promoted re-epithelialization and full healing, while also preventing infection, in the participants, compared to SSD [66]. Liu et al., investigated the wound-healing effects of madecassoside from *Centella asiatica* on burn injuries, showing that oral administration (6–24 mg/kg) accelerated wound closure, reduced inflammation, and enhanced fibroblast proliferation. The healing effects were associated with antioxidative activity, collagen synthesis, and angiogenesis, supporting its traditional use in burn treatment [67]. Wu et al., studied on *Centella asiatica* identified asiaticoside and madecassoside as the primary active compounds for burn wound healing, rather than their metabolites asiatic acid and madecassic acid. Madecassoside was found to be more effective than asiaticoside in promoting collagen synthesis and accelerating wound healing [68].

5.12. *Calendula*

Calendula, often called as marigold, botanically *Calendula officinalis* (*C. officinalis)*, is a vibrant, golden-hued flower known for its medicinal and therapeutic properties [69]. Traditionally used in herbal medicine, calendula is prized for its anti-inflammatory, antimicrobial, and healing abilities. It's commonly found in creams, ointments, and teas to soothe skin irritations, promote wound healing, and reduce inflammation. Additionally, it is used in herbal teas and tinctures to support digestive health and alleviate menstrual discomfort. Its gentle effective nature makes it a popular remedy in natural skincare and holistic wellness practices [70]. In a study, Buzzy stated the clinical effectiveness of the *C. officinalis* extract, Plenusdermax, in treating venous leg ulcers (VLUs). The Author demonstrates that *C. officinalis* extract is a promising therapy for VLUs [71]. Givol et al., evaluated the use of Calendula officinalis flower extract for wound healing, showing positive effects on acute wound healing and inflammation resolution in animal studies and some clinical trials. However, results for chronic wounds, burns, and radiation dermatitis were mixed, highlighting the need for larger randomised controlled trials to confirm its efficacy [72]. Nicolaus et al., revealed that *Calendula officinalis* extracts have long been used for skin inflammation and wound healing. The study identifies the molecular mechanisms behind these effects, showing that n-hexanoic and ethanolic extracts activate NF-κB and enhance collagen formation, contributing to wound healing [73].

5.13. *Curcumae longae*

Turmeric, scientifically named *Curcuma longa,* is a perennial herb belonging to the *Zingiberaceae* family, including ginger [74]. Turmeric, native to South Asia, particularly India, is renowned for its vibrant yellow-orange rhizomes containing the bioactive compound curcumin. Curcumin is widely recognised for its potent antioxidant, anti-inflammatory, and antimicrobial properties, making turmeric a main component in traditional medicinal systems such as Ayurveda and TCM [75]. It is extensively used to treat various conditions, including digestive disorders, skin issues, and joint inflammation. Beyond its medicinal uses, turmeric is a popular culinary spice, imparting both colour and flavour to dishes, and is also used as a natural dye. As a consequence, new formulations were researched, and curcumin-based wound healing treatments, like Psoria-Gold® and CumarGOLD Gel® Curcumin Gel, were marketed in various countries.

5.14. *Sanguis Draconis (SD)*

The Chinese Pharmacopoeia lists *Calamus draco* Willd. (Arecaceae) is the source of the crimson resin known as Draconis sanguis [76]. In one study, Lu et al., investigated the effects of dracorhodin, a compound derived from Daemonorops draco, on human immortalized keratinocytes in wound healing. Their findings revealed that dracorhodin perchlorate promotes wound closure and enhances cell migration without accelerating cell proliferation. Additionally, it notably activates several crucial signaling pathways, such as β-catenin, AKT, ERK, and p38. In summary, dracorhodin perchlorate shows potential as a phytochemical for advancing skin wound healing [77]. Tang et al., researched a soluble polyvinylpyrrolidone-based microneedle patch (MN-SD@SMR) incorporating herbal extracts of SD and SMR for diabetic wound healing. The patch demonstrated improved blood flow, cell migration, and wound healing, showcasing significant potential for transdermal drug delivery and diabetic wound treatment [78].

5.15. *Glycyrrhizae Radix et Rhizoma*

Glycyrrhizae Radix et Rhizoma, often known as licorice, is the dried root and rhizome of a Glycyrrhiza species. This TCM is sourced from plants like *Glycyrrhiza glabra* and *Glycyrrhiza inflata, Glycyrrhiza*

uralensis. The main active constituents of *Glycyrrhizae Radix et Rhizoma* (Licorice root) in wound healing include glycyrrhizin [79], which has anti-inflammatory and skin-soothing effects, liquiritin, which promotes fibroblast proliferation and collagen synthesis, and flavonoids (e.g., isoliquiritigenin) that exhibit antioxidant and antimicrobial properties, accelerating tissue regeneration. TCM is extensively used for its diverse medicinal benefits, including antiviral, antioxidant, and anti-inflammatory properties. It plays a significant role in Chinese herbal medicine, particularly in treating conditions like hepatitis, cough, stomach ulcers, and wounds [80]. According to a research, licorice-derived isoliquiritin (ISL) accelerates wound healing in zebrafish by increasing angiogenesis, recruiting macrophages, and up-regulating genes linked to inflammation and tissue repair. This shows that ISL is a viable option for promoting wound healing [81].

5.16. Hippophae rhamnoides L

Hippophae rhamnoides L., a shrub belonging to the Elaeagnaceae family, is indigenous to different areas, such as Russia, China, Nepal and India. This plant has been widely utilized in traditional medicine to treat a range of conditions, like coughs, skin disease, and inflammation [82]. According to reports, the fruits, seeds and leaves of *Hippophae rhamnoides* L. all have wound healing properties [83–86]. Researchers found that lyophilized aqueous leaf extract of sea buckthorn (*Hippophae rhamnoides*) speeds wound healing, increases collagen production, and stimulates angiogenesis in rats with experimental burn wounds. The extract also increased antioxidant levels, reduced lipid peroxides, and showed no cytotoxicity, demonstrating significant potential for burn wound treatment [87].

5.17. Notoginseng Radix et Rhizoma

Notoginseng Radix et Rhizoma, a plant from the Araliaceae family and scientifically named *Panax notoginseng* (Burkill) F.H. Chen, has a long history of use in managing severe injuries and various forms of bleeding. This plant is the active ingredient in Yunnan Baiyao, a well-known medicinal product in China. It is used as the treatment of wound healing [88].

5.18. Lonicerae Japonicae Flos

Lonicera japonica Flos pertains to the dried flower bud or open bloom of *Lonicera japonica* Thunb, a member of the Caprifoliaceae family. It contains bioactive compounds such as polysaccharides (lilium polysaccharides) that enhance fibroblast proliferation and collagen synthesis, flavonoids (kaempferol, quercetin) [89] with strong antioxidant and anti-inflammatory effects and saponins that promote re-epithelialization and angiogenesis. It was also used to manage surface swellings and ulcers. Modern scientific research has identified that *Lonicera japonica* Flos has antiviral, antioxidant and anti-inflammatory properties. The active compounds in this plant include flavonoids, iridoid glycosides, organic acids, and saponins [90].

5.19. Lilii Bulbus

Lilii Bulbus is dried, fleshy, petal-like layers from the bulbs of *Lilium brownii* var. *viridulum, Lilium pumilum and Lilium lancifolium.* In TCM, this substance is considered excessive for its medical benefits, especially the ability to reduce inflammation and fight bacterial infections. Its anti -inflammatory and antibacterial properties make it beneficial to promote wound healing [91].

5.20. Portulacae Herba

The dried aboveground sections of the *Portulacae oleracea* L plant, a member of the Portulacaceae family, are referred to as Portulacae Herba. This plant is commonly found in tropical and subtropical regions worldwide. Portulacae Herba (*Portulaca oleracea*) contains flavonoids (kaempferol, quercetin), alkaloids (oleracein A–E), and polysaccharides, which exhibit antioxidant, anti-inflammatory, and antimicrobial properties that accelerate wound healing [92]. Omega −3 fatty acids (α-linolenic acid) and vitamins A, C and E support tissue regeneration and collagen synthesis. Milk and phenol compounds increase the moisture retention, reduce scarring and closes the wound rapidly [93]. According to Tang Materia Medica, portulacae herba has medical properties that make it suitable for the treatment of wounds. Recent medical studies have shown that portulacae herba has anti -inflammatory, antibacterial, antioxidants and antiulcerogenic properties [94].

5.21. Periploca Forrestii Schltr

Perplana Forrestii Schltr is a plant belonging to the Apocynaceae family and is traditionally used in Chinese folk medicine, especially to treat painful injuries. This plant is well known for its medicinal properties, especially in promoting wound healing. A study examined the effect of healing the wounds from perploca forestry (hlg), focusing on fibroblast proliferation, migration and collagen production in l929 cells. Using HPLC-Q-TOF-MS/MS, 38 compounds were identified, and cardiac glycosides were highlighted as the active constituents. The 65 % ethanol eluate fraction, rich in these glycosides, exhibited enhanced fibroblast proliferation, wound contraction, and collagen synthesis, establishing a chemical foundation for the development and quality evaluation of HLG-based therapeutic products [95]. Li et al. confirmed that the 65 % ethanol fraction of *Periploca forrestii* (EPFE65) promotes wound healing *in-vitro* and *in-vivo* by enhancing fibroblast proliferation, migration, and collagen production. EPFE65 accelerates wound closure and tissue regeneration via activation of Src-mediated Mek/Erk and phosphatidylinositol 3-kinase (PI3K)/protein kinase B signaling pathways, as demonstrated through inhibition assays and western blot analysis. Cardiac glycosides, particularly periplocin, were identified as the main active compounds contributing to the observed wound healing effects [96].

5.22. Rehmanniae Radix

Rehmanniae Radix refers to the dried root tuber of *Rehmannia glutinosa*, a plant extensively used in TCM. This herb is known for its nourishing and restorative properties, particularly in treating conditions related to blood, yin deficiency, and inflammatory diseases. According to the Compendium of Materia Medica, *Rehmanniae radix* is suggested as a treatment for acute mastitis. *Rehmanniae radix* is used extensively in TCM formulas to treat wounds. In wound healing, *Rehmanniae Radix* has been traditionally used to promote tissue regeneration and improve wound healing, particularly in diabetic foot ulcers. The herb's active compounds, including iridoid and phenylpropanoid glycosides, contribute to its anti-inflammatory and antioxidant effects, which help reduce inflammation, promote angiogenesis, and accelerate the overall healing process. Lau et al., showed that via improving tissue regeneration, angiogenesis (VEGF expression), and inflammation management, RR aqueous extract markedly accelerated wound healing in a diabetic foot ulcer rat model. Although it had no effect on glycemic control, the extract also reduced inflammation brought on by carrageenan. These results offer scientific backing for the conventional application of RR in the management of diabetic foot ulcers [97].

5.23. Rhei Radix et Rhizoma

Rhei Radix et *Rhizoma*, or Rhubarb Root and Rhizome, is a traditional herbal remedy in Chinese and Western medicine. It is derived from the roots and rhizomes of the Rheum plant species, recognized in the Chinese Pharmacopoeia distributed throughout China. This herbal medication is well known for its powerful pharmacological actions, including

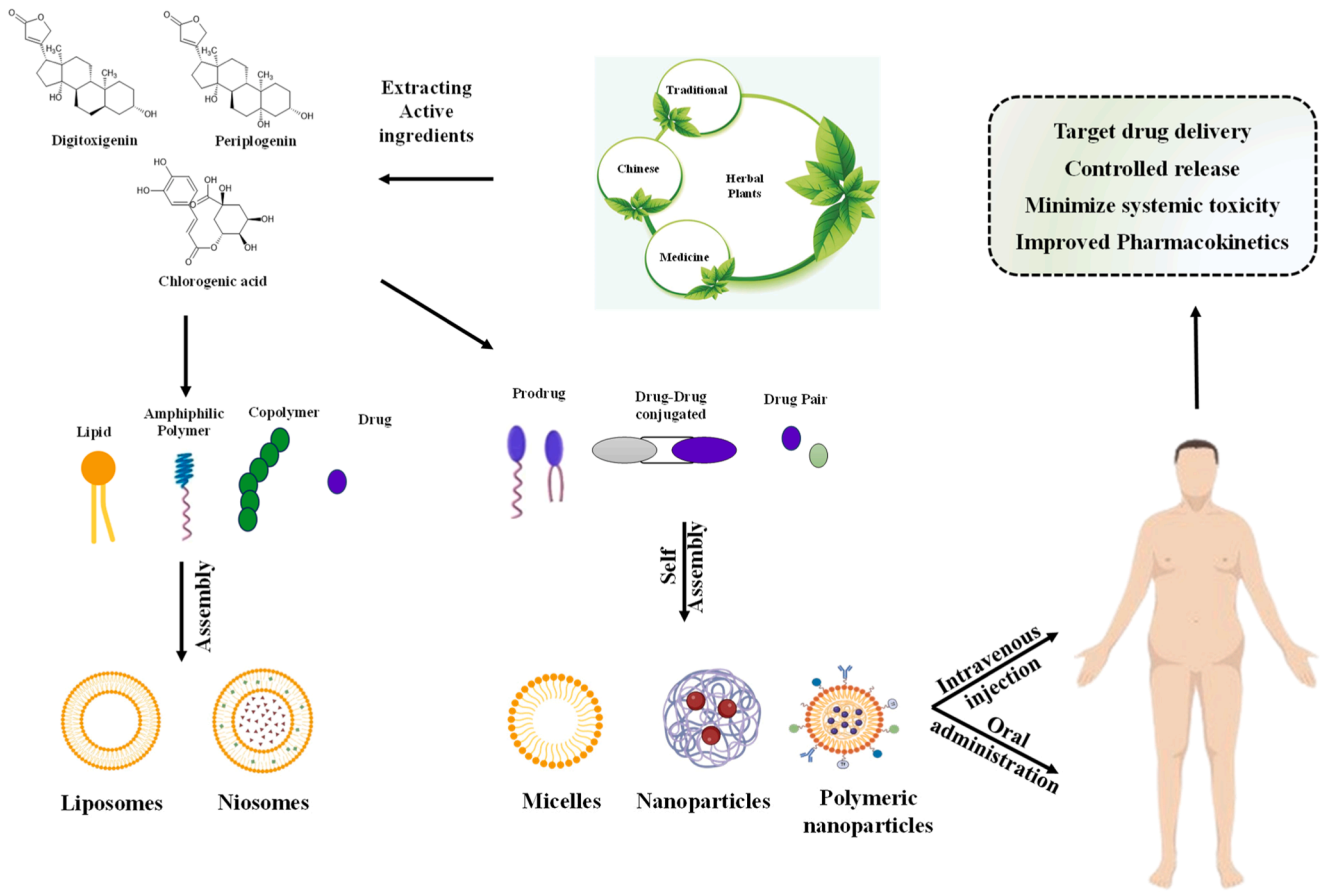

Fig. 4. Diagrammatical representation of TCM uses in nanodrugs.

hemostatic, antibacterial, and anti-inflammatory qualities [98]. *Rhei Radix* et *Rhizoma* (Rhubarb root and rhizome) contains anthraquinones (emodin, aloe-emodin, rhein), which exhibit antimicrobial and anti-inflammatory effects, aiding in wound healing [99]. Its tannins (gallic acid, catechins) promote hemostasis and collagen synthesis, accelerating tissue repair.

5.24. *Reynoutria japonica Houtt*

Reynoutria japonica Houtt, a plant from the Polygonaceae family, is a notable herbal remedy commonly found in different areas of Central and South China, as well as Southwest and East China [100]. *Reynoutria japonica* treats jaundice, scalds, inflammation, and favus. Several compounds were identified in *Reynoutria japonica* Houtt, such as flavonoids, coumarins, stilbenes, quinones and various polyphenols [101]. Among these, resveratrol is a main ingredient, commonly incorporated into skincare products to enhance skin health [102,103].

5.25. *Salviae miltiorrhizae Radix et Rhizoma*

Salviae miltiorrhizae Radix et Rhizoma, also called Danshen or Red Sage Root, is a traditional herbal remedy that is used extensively in Chinese medicine. It is made from the rhizome and root of the *Salvia miltiorrhiza* plant [104]. Traumatic injuries, cardiovascular diseases, and cerebrovascular conditions are just a few of the many ailments that this medication can help alleviate. In terms of wound healing, Salviae miltiorrhizae Radix et Rhizoma is highly valued for its ability to promote tissue regeneration and repair by enhancing blood circulation and reducing inflammation. These properties make it an important herb for treating wounds, especially those associated with poor circulation and chronic conditions [105].

5.26. *Streptocaulon juventas (Lour.) Merr*

Streptocaulon juventas (Lour.) Merr is a plant from the Apocynaceae family that is widely used as a traditional remedy by the Dai minority in China. It is well-known for its significant properties in reducing inflammation, fighting cancer, and promoting wound healing [106]. Nguyen et al., assessed the wound-healing properties of the ethanolic extract from the root of *Streptocaulon juventas* (Lour.) Merr. using a mouse excision wound model [107]. Yang et al., researched *Streptocaulon juventas* (Lour.) Merr. (SJ) as a wound-healing herbal medicine, cardiac glycosides periplogenin and digitoxigenin are identified as the main constituents. UPLC-QqQ-MS/MS analysis and rat models confirmed their role in enhancing wound healing by increasing hydroxyproline levels and improving skin tissue recovery [108]. Researched SJ's ability to heal wounds and its molecular pathways using in vitro tests, network pharmacology, and rat wound models. By stimulating collagen production and cell migration through the AKT-mTOR and ERK-p38 pathways, ESJ accelerated wound healing [109].

5.27. *Urtica dioica L*

Urtica dioica L, belonging to the Urticaceae family, is a widely utilized herbal remedy for addressing various health issues, like cardiovascular diseases, wound healing, diabetes and hypertension [110]. *Urtica dioica* L. (Stinging Nettle) aids wound healing through its rich phytoconstituents, including flavonoids (quercetin, kaempferol) with antioxidant and anti-inflammatory effects, phenolic acids (caffeic, ferulic acids) that enhance collagen synthesis, and terpenoids & sterols (β-sitosterol) that promote tissue regeneration [111]. Additionally, its polysaccharides and tannins accelerate re-epithelialization and provide antimicrobial protection. These bioactive compounds reduce

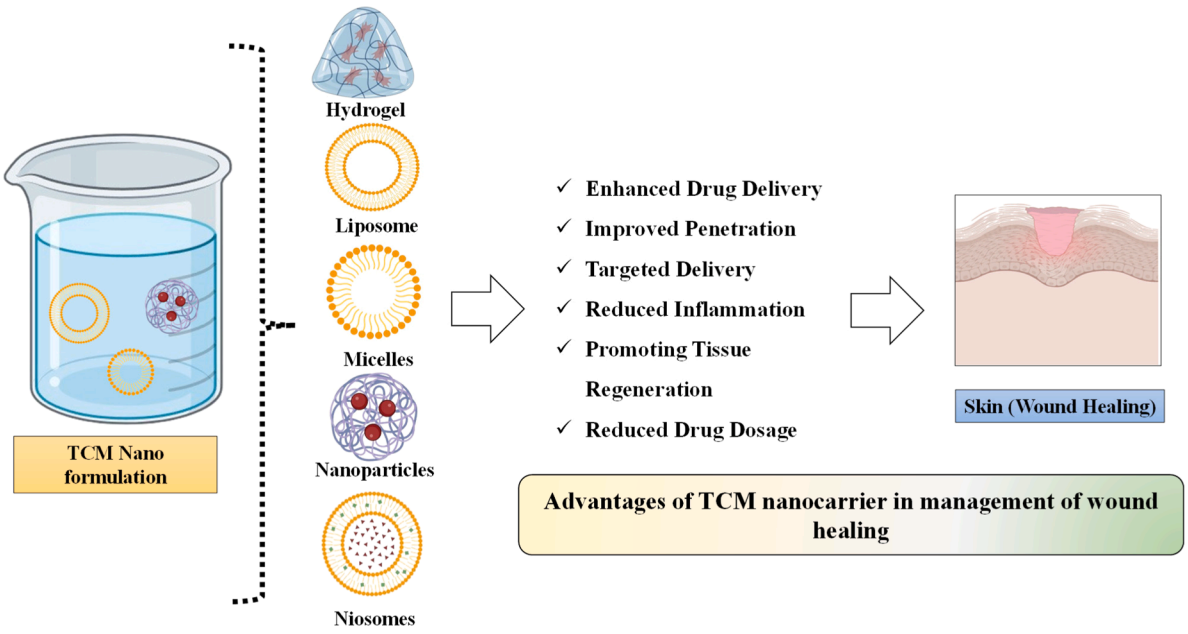

Fig. 5. Advantages of TCM nanocarriers in the treatment of wound healing.

inflammation, prevent infections, and boost fibroblast proliferation for faster wound repair. Razika et al., evaluated the pharmacological effects of crude saponins extracted from *Urtica dioica* L. leaves, focusing on their antioxidant and wound healing properties, resulting in saponins exhibiting significant antioxidant activity. Comparable to ascorbic acid and shows a remarkable wound healing effect, with a 100 % reduction in wound size after 15 days, outperforming the reference product Madécassol®. These findings suggest potential applications for these saponins in pharmaceuticals and cosmetics [112]. Kasouni et al., *Urtica dioica* L. extract accelerates wound healing by promoting cell proliferation, migration, and anti-inflammatory effects, leading to faster recovery in Wistar rats. Its potential as a novel wound healing agent is supported by in vitro and in vivo findings, demonstrating enhanced healing compared to untreated wounds [113].

5.28. *Zingiberis Rhizoma Recens*

Zingiberis Rhizoma Recens is the newly harvested rhizome of Zingiber officinale Roscoe, a Chinese plant that belongs to the Zingiberaceae family. According to the Compendium of Materia Medica, Zingiberis Rhizoma Recens has the ability to stimulate the development of new tissue. The warming and invigorating properties of fresh ginger rhizome are highly regarded in TCM. Fresh ginger is often used to dispel cold, promote circulation, and enhance the body's overall energy (Qi). Fresh ginger in TCM improves blood flow and reduces inflammation, which are crucial for wound-healing. The enhanced circulation can bring more nutrients and oxygen to the affected area, accelerating tissue repair. Additionally, its anti-inflammatory and antimicrobial properties help prevent infection and reduce swelling, promoting a cleaner and faster healing environment. Scientific research has unequivocally demonstrated the efficacy of *Zingiberis Rhizoma* Recens. The active components of this herb, including gingerols, essential oils, and diarylheptanoids, have been extensively studied. These studies have consistently shown that *Zingiberis Rhizoma* Recens possesses potent antioxidant, antibacterial, anticancer, and anti-inflammatory properties [114]. Ko and Leung conducted a study on acetic acid-induced gastric ulcers in rats, where both ginger extract and polaprezinc significantly reduced ulcer area and oxidative damage. Polaprezinc uniquely restored mucosal glutathione levels and enhanced the expression of growth factors, while ginger extract improved growth factor expression but had a lesser impact on tumor necrosis factor alpha. Both treatments demonstrated anti-oxidative properties, aiding in mucosal protection and ulcer healing [115]. Some examples of TCM for wound healing are shown in Table 1.

6. TCM-loaded nanocarriers used in wound healing

Nanocarriers have become a promising approach for delivering therapeutic chemicals derived from TCM [132]. TCMs have been used for a long time and include many physiologically active ingredients that provide potential therapeutic benefits for several diseases. Nevertheless, concerns over their capacity to be absorbed and their potential for harm have hindered their use in medical practice. Liposomes, organic nanoparticles and polymeric nanoparticles are examples of nanocarriers that may enclose TCM and prevent it from degrading in the biological environment [133,134]. Fig. 4 structural illustration of application in nanodrugs of TCMs. Advantages of conventional TCM with and without nanocarriers are shown in Fig. 5

6.1. *Liposomes*

Liposomes are spherical vesicles that may contain both hydrophilic and hydrophobic TCM components because of their lipid bilayer composition [135]. Liposomes enhance the absorption and bioavailability of herbal compounds while reducing toxicity [136,137]. Lipids are essential ingredients in nanocarrier formulations and are essential to the *in-vitro* and *in-vivo* performance of nanocarriers due to their structural similarity to vesicular cell membranes and lipid bilayers [138, 139]. The incorporation of TCM active substances can improve therapeutic efficacy, reduce toxicity, influence tissue distribution, and allow liposomes to target specific areas [140]. In one study Shu et al., developed a shikonin-liposome formulation with enhanced anti-MRSA and wound-healing effects, tested through *in-vitro* antibacterial and *in-vivo* wound healing assessments in rats. Results indicated that SH-liposome effectively damaged bacterial cell walls, controlled infection, reduced inflammation via the I-κBα/NFκB-p65 pathway, and promoted wound repair. This formulation demonstrates potential as an alternative therapy for treating drug-resistant infections in burn wounds [141]. Pathak et al., showed that curcumin can be successfully nano-encapsulated using self-assembling nanocarriers made of biodegradable lipids and multimers, effectively addressing these challenges [142].

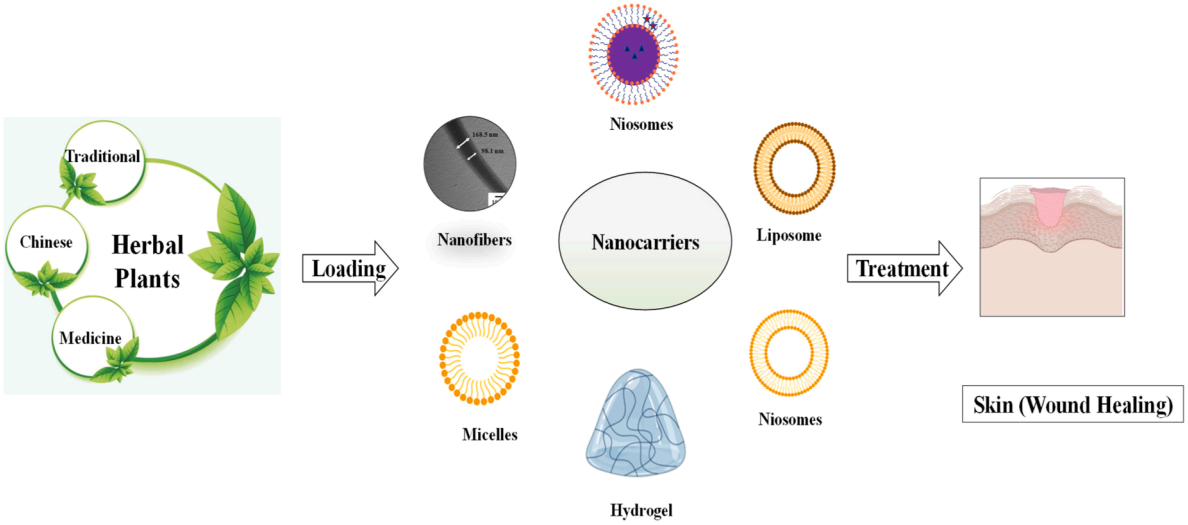

Fig. 6. Applications of TCM nanocarriers in wound healing management.

6.2. Nanoparticles

Nanoparticles are a versatile class of nanocarriers used for drug delivery, including in the context of TCM [143]. They are typically in the size range of 1 to 100 nanometers and can be made from a variety of materials, such as polymers, lipids, metals, or even proteins [144]. Their small size and customizable surface properties make them ideal for improving the delivery and therapeutic efficacy of bioactive compounds in TCM [19]. In one research Baharvandi et al., biosynthesised silver nanoparticles (AgNPs) using the fungus *Alternaria alternata*, achieving nanoparticle formation within 24 h. The synthesized Ag NPs, primarily spherical and sized between 27 and 79 nm, were characterized by SEM and FTIR, indicating biomolecule involvement. These biologically synthesized nanoparticles hold potential applications in agriculture due to their stability and non-toxic production process [145].

6.3. Nanostructured lipid carriers

Nanostructured Lipid Carriers (NLCs) are an advanced type of lipid-based nanopreparation designed to enhance drug delivery efficiency [146]. Unlike solid lipid nanoparticles (SLNs), which consist entirely of solid lipids, NLCs incorporate a blend of solid and liquid lipids. TCM, with its vast repertoire of bioactive compounds such as flavonoids, alkaloids, and polysaccharides, has been widely used for wound management due to its anti-inflammatory, antimicrobial, and tissue-regenerative properties. The integration of TCM into NLCs enhances penetration, prolongs therapeutic action, and improves wound healing efficiency. In one research Elkhateeb et al., developed Curcumin-loaded nanostructured lipid carriers (CURC—NLCs) demonstrated enhanced phenolic and flavonoid content, leading to significantly improved antioxidant activity. CURC—NLCs exhibited potent antimicrobial effects, doubling the efficacy against Gram-positive, Gram-negative bacteria, and fungi compared to curcumin. The in vivo studies showed accelerated wound healing, with 1.15- and 1.9-fold higher wound closure rates than curcumin and control, respectively [147].

6.4. Hydrogel

Hydrogels are 3D polymeric networks capable of absorbing water, making them suitable for the controlled and prolonged release of herbal compounds [148]. This combination of TCM with modern drug delivery systems like hydrogels enhances the efficacy, stability, and bioavailability of traditional herbs. Yuniarsih evaluated hydrogel formulations of *Sansevieria trifasciata* extract (HESt) for wound healing activity. The formulations were examined for physical properties, pH, stability, and rheological behavior and tested on mice. HESt at 20 % and 25 % showed significant wound closure, making it a promising herbal-based wound-healing agent in hydrogel form [149].

6.5. Micelles

Polymeric or surfactant-based micelles are used to solubilize poorly soluble TCM compounds [150]. They form core-shell structures where the hydrophobic core encapsulates the herbal compound, enhancing its solubility and bioavailability [151]. In one study, Zhou et al., developed a curcumin-loaded hyaluronic acid (Cur/HA) gel, which effectively promoted skin wound healing in rats. The gel provided continuous drug release, leading to 96 % wound healing after 14 days, along with enhanced collagen formation, re-epithelialization, and angiogenesis. Cur/HA gel shows promise as a wound dressing material for long-term protection and healing [152]. Recently, researchers led by Huile Gao created a polymer-based nanocarrier to transport TCM medications. A pH-sensitive supramolecular nanosystem containing triptolide and chlorin e6 was created, for instance, to co-deliver for chemo-photodynamic combination treatment [153].

Numerous studies have demonstrated that nanocarriers effectively reduce toxicity, increase the half-life of TCMs, and target specific cells and tissues. The ability of these nanocarriers to specifically target unhealthy cells or tissues can be improved by incorporating targeting moieties such as antibodies or peptides. This enhancement allows for higher concentrations of TCMs to reach the intended area, thereby improving the efficacy of the treatment. There are a number of advantages to using nanocarriers to transfer active ingredients from TCMs, such as increased therapeutic efficacy, less toxicity, and better bioavailability. As a result, they provide a strong basis for creating novel TCM-based treatments for a range of disease (Fig. 6 and Table 2).

The use of nanocarriers in TCM greatly improves the treatment of wounds [154]. Many active ingredients in TCM, while therapeutic, are often limited by their poor water solubility, rapid degradation, and inefficient absorption in the body [155]. By encapsulating substances in nanocarriers like hydrogels, liposomes, and nanoparticles nanotechnology gets around these problems. By protecting bioactive substances from premature deterioration, these carriers allow for tailored administration to the wound site and prolonged release [156,157].

Additionally, nanocarriers can penetrate deeper into the skin layers, enabling the TCM compounds to reach affected tissues more effectively [143]. This results in improved wound healing outcomes, including

Table 2
Nanocarrier systems in TCM: advancing ancient remedies with modern technology.

Herbal compound	Nano-formulation	Particle size	Experimental Model	Special Outcomes	References
Achillea millefolium (AM)	Nano-ethosomal	Smaller than 300 nm	*In-vitro* and *Ex-vivo* Permeation Studies	Topical gel infused with nanoethosomes containing AM extract is a promising method for delivering drugs via the skin.	[160]
Acorus calamus	Zinc oxide nanoparticle	N/A	*In-vivo study*	The formulations of zinc oxide nanoparticles may aid in the age of antibiotic resistance as topical medications in the future	[161]
Artemisia annua L.	Nanofibrous	242.00 ± 67.53 nm	*In-vitro* studies	The generated crosslinked-PCL/gelatin-*Artemisia annua* L. sample shows potential for use as a nanofibrous antibacterial wound dressing in future.	[49]
	Copper oxide nanoparticles (CuO NPs)	35 nm	*In-vivo* experiment	The green-produced CuO NPs displayed increased antioxidant and wound-healing activities and, consequently, may be regarded as viable contenders in the biomedical sector.	[162]
Aloe vera	Nano emulsion	458 ± 132 nm	*In-vivo* model	The combination of *A. vera* and insulin-loaded nanoemulsion has a synergistic impact on the wound-healing in diabetic rats. This suggests that it might be a promising and successful therapy for wounds in diabetic people.	[163]
Danggui Buxue	Liposomes	75.53 ± 0.60 nm	*In-vivo* model	*Danggui Buxue* extract-loaded liposomes in thermosensitive gel (DBLTG) significantly improved cutaneous wound healing in rats.	[164]
Yunnan Baiyao	Micro particles and nanofibers	640 ± 130 nm and 2.56 ± 0.78 μm	*In-vitro* antibacterial effects	The merging of Chinese herbs with Western medicine has led in many benefits, such an enhanced antibacterial impact, a prolonged release of active chemicals from YB, and a convenient use as a wound dressing.	[165]
Berberine	Nanoparticle hydrogel scaffold	150 ± 0.37 nm and 250 ± 0.52 nm	*In-vitro* antibacterial activity and *in-vivo* diabetic wound	The hydrogel dressing, which is sensitive to ROS and contains BR@Zn-BTB, offers a novel approach to enhance the healing of diabetic wounds.	[166]
Baicalein	Nano-composited	125 ± 2.9 nm	*In-vitro* cytotoxicity	Baicalein-encapsulated zeolite imidazole framework-8 nano-DDSs are efficient and appropriate drug delivery systems for post-caesarean section wound care that is triggered by certain stimuli.	[167]
Carpobrotus edulis (C. edulis)	Liposome	158.80 ± 2.88 nm - 178.80 ± 7.42 nm	*In-vivo* model	The liposomal formulations of *C. edulis* extract had positive effects on the healing process, namely on the tissues around the incision and the excision.	[168]
Clitoria ternatea	Niosomes	4.7 nm to 122.7 nm	*In-vitro* and *In- vivo*	The use of anthocyanin complex (AC) niosome gel topically demonstrated an anti-inflammatory effect and facilitated the healing of oral wounds in rats, maybe attributed to the enhanced permeability of the mucosal layer and the existence of AC delivery depots inside the niosome gel.	[169]
Curcumin	In situ injectable nano-composite hydrogel	(~50 nm)	*In-vitro* release study and *In -vivo* experiment	The nano-curcumin/CCS-OA hydrogel has significant promise for use in wound healing.	[170]
	Nano micelles	26.9 ± 1.4 nm	*In-vitro* release and *in-vivo* excision model	The potential applicability of the biodegradable Cure-M-H composite in wound healing is significant.	[171]
	Ethosomal	120 nm	*In-vivo* studies	The findings demonstrate that ethosomal curcumin effectively combats wound infection and enhances wound healing in burn injuries in rats.	[172]
Hypericum perforatum	Niosomal	490.45 ± 27.64 nm	*In-vitro* drug release and *in-vivo* wound healing effect	After a period of 21 days, there was evidence of full re-epithelization, the production of new matrix fibers, and a considerable decrease in wound size. These results were compared to the control group and the group treated with PanthenolVR 2 % cream.	[173]
Fraxinus angustifolia	Nanovesicles	~200 nm	*In-vitro* and *in-vivo* study	On the contrary, in vivo experiments demonstrated that the phytocomplexes in EG-PEVs exhibited the most potent antioxidant and anti-inflammatory properties, leading to enhanced wound healing.	[174]
Matricaria chamomilla L	Hydrogel	N/A	*In-vivo*	A new bilayer dressing that is both biodegradable and biocompatible has been successfully created. This dressing features a primary layer made of a Sodium alginate (SA)/gelatin hydrogel, complemented by a secondary layer of PAN fibers.	[175]
Bromelain (BRO)	Nanofibrous	176 ± 63 nm	*In-vitro* and *in-vivo* study	Gel-based PCL/CS nanofibrous dressings incorporated with BRO and Ag NPs present a promising approach for enhancing skin wound healing.	[176]
Egg yolk oil (EYO)	Nanofibrous	191 ± 61 nm	In vitro *cell* culture studies. and *in-vivo* study	Polycaprolactone (PCL) -polyethylene glycol (PEG) - Egg yolk oil (PCL-PEG-EYO) nanofibrous scaffolds showed significant promise in the treatment of full-thickness burn wounds in vivo studies	[177]

Where N/A = Not Available.

increased collagen production, reduced inflammation, and faster re-epithelialization, as seen in preclinical models. Additionally, the use of nano-preparations minimizes potential toxicity by delivering precise concentrations of therapeutic agents directly to the wound, which reduces systemic exposure [158].

For future drug development, the success of nano-preparations in wound healing provides stimulation. The approach of combining ancient herbal wisdom with modern nanotechnology can be applied to a broader range of diseases. Nanocarrier-based systems could be adapted to deliver other herbal compounds or even synthetic drugs with low bioavailability, opening new avenues for developing advanced therapeutic solutions. Moreover, the ability of nanocarriers to target specific cells or tissues could be leveraged for personalized medicine, where treatments are tailored to the unique physiological conditions of each patient [159].

Table 3
In-vivo studies on TCM herbal plants incorporated with various nano-carrier types, their outcomes, and clinical significance.

TCM Herbal Plant	Nano-Carrier Type	*In-vivo* Model	Clinical Significance	References
Ginger	Lipid-based nanoemulsions	Rats with full-thickness wounds	Revolutionise wound treatment and improve overall healthcare outcomes.	[183]
Curcumin	Chitosan nanoparticles	Diabetic rats	Improved collagen deposition and skin regeneration	[184]
Aloe Vera	Chitosan nanoparticles	Mice with full thickness wounds	Accelerated re-epithelialization and reduced scar formation	[185]
Ginseng	Solid lipid nanoparticles	Albino rats	SLNs could make suitable semi-finished materials for use in dosage forms for wound healing.	[186]

7. *In-vivo* studies of nano-carriers incorporated with herbal plants

In-vivo studies of nano-carriers incorporated with herbal plants for wound healing have garnered significant attention due to their potential to enhance therapeutic efficacy and accelerate tissue regeneration (Table 3) [178,179]. Various nano-carrier systems, including liposomes, polymeric nanoparticles, and solid lipid nanoparticles are commonly used in these investigations to encapsulate bioactive substances from herbal plants with wound-healing qualities, such as *aloe vera* and curcumin [180]. By improving the solubility and bioavailability of these compounds, nano-carriers facilitate sustained and targeted release at the wound site, leading to enhanced cellular uptake and prolonged therapeutic effects [181]. For instance, in animal models, formulations incorporating nano-carriers have shown improved rates of epithelialization, collagen deposition, and reduction in inflammation compared to conventional treatments [182]. Moreover, these formulations often exhibit antimicrobial properties, reducing the risk of infection and further promoting wound healing. Integration of herbal extracts with advanced nano-carrier systems presents a promising strategy for developing effective wound healing therapies.

8. Marketed formulation of TCM for the treatment of wound healing

TCM has been used for thousands of years to treat various diseases, including wound healing. Many herbal medicines are now available in marketed formulations designed for practical use. These formulations combine traditional remedies with modern delivery methods to enhance their therapeutic effects. In wound healing, TCM products are primarily focused on promoting tissue regeneration, reducing inflammation, and improving blood circulation. Below are some examples of marketed TCM formulations and their applications in Table 4.

After extensive literature and product database searches, we found a smaller number of officially marketed and globally recognized nanocarrier-based formulations of TCM specifically approved for wound healing as of now (April 2025). However, some experimental products and limited regional offerings claim to combine nanotechnology with herbal or TCM-inspired ingredients for topical application (Table 5).

9. Challenges and prospects

The challenges and prospects of nanocarriers in TCM for wound healing. The combination of TCM with nanotechnology holds significant promise, but there are challenges that need to be addressed to fully realize its potential [155]. These challenges include the complexity of bioactive compounds in TCM, which can make standardization and dosage control difficult, as well as the potential for toxicity if not properly formulated. Additionally, scalability and regulatory approvals for nanocarrier-based TCM products can be hurdles. Advancement in nanotechnology, especially more biocompatible and the development of effective nanocarrier, provides important opportunities to increase the medical effect of TCM. By improving bioavailability, stability, and targeted distribution of TCM compounds, these nanocarriers have the ability to revolutionize wound treatment, making them more effective and safe [154]. Furthermore, integrating modern technologies such as AI and machine learning in drug delivery design could lead to more personalised and optimised wound healing solutions.

Table 4
Overview of TCM: marketed formulations, therapeutic application.

Plant Name (TCM Name)	Marketed Formulations	Uses	References
Panax Notoginseng (Sanqi)	Yunnan Baiyao, Sanqi Powder, Sanqi Tablets	Promotes blood circulation, reduces swelling, stops bleeding, and aids wound healing.	[187]
Carthamus Tinctorius (Hong Hua)	Die Da Yao Jing, Hong Hua Oil, Hong Hua Tincture	Enhances blood circulation, alleviates pain, used for trauma, bruises, and wound healing.	[188]
Curcuma Longa (Jiang Huang)	Jin Huang San (Golden Yellow Powder)	Anti-inflammatory, antibacterial, treats wounds and reduces swelling.	[189]
Lithospermum Erythrorhizon (Zi Cao)	Ching Wan Hung, Zi Cao Ointment, Zi Cao Oil	Promotes skin regeneration, treats burns and wounds.	[190]
Coptis Chinensis (Huang Lian)	San Huang San, Huang Lian Paste, Huang Lian Powder	Strong antibacterial properties, treats infected wounds and ulcers.	[191]
Scutellaria Baicalensis (Huang Qin)	San Huang San, Huang Qin Cream, Huang Qin Powder	Anti-inflammatory, antibacterial, treats wounds, reduces swelling.	[192]
Phellodendron Amurense (Huang Bai)	San Huang San, Huang Bai Ointment	Anti-inflammatory, antibacterial effective for wounds and skin conditions.	[193]
Angelica Sinensis (Dang Gui)	Ba Bao Gao (Eight Treasure Ointment), Dang Gui Cream	Promotes blood circulation and tissue regeneration, used in wound healing ointments.	[194]
Rheum Palmatum (Da Huang)	Jin Huang San, Da Huang Paste, Da Huang Powder	Purgative and anti-inflammatory, treats wounds and sores.	[195]
Sesamum Indicum (Zhi Ma)	Ching Wan Hung, Zhi Ma Oil	Moisturizes, promotes healing of wounds and burns.	[196]
Angelica Dahurica (Bai Zhi)	Bai Zhi Ointment, Bai Zhi Powder	Promotes blood circulation, reduces pain in wound healing.	[197]
Borneol (Bing Pian)	Yunnan Baiyao, Bing Pian Ointment	Analgesic and antiseptic, promotes faster wound healing.	[198]
Myrrh (Mo Yao)	Hua Tuo Gao, Mo Yao Paste	Anti-inflammatory, promotes wound healing.	[196]
Siegesbeckia Orientalis (Xi Xian Cao)	Ji Gu Cao Extract, Xi Xian Cao Ointment	Treats chronic wounds, ulcers, skin conditions.	[199]

Table 5
Nanocarrier loaded marketed formulation for management of wound healing.

Product Name	Manufacturer	Description	References link
NANOSIL Plus Wound Healing Spray	Opus Pet Pvt. Ltd.	It contains silver nanoparticles and essential oils; forms a protective layer around the wound to kill bacteria and promote healing. Suitable for post-operative care and chronic wounds in animals.	https://animeal.in/products/nanosil-plus-spray-75ml?srsltid=AfmBOoqtlBqfQPoBf8su3-DXFIgbAc3To9-3FVlbs-ffbNnqzmOuQM8r
NanOlife Wound Care Gel	NanOlife	Formulated with 100 % silver nanoparticles; provides a protective layer to reduce microbial infection, promotes natural healing, and offers pain relief with cooling effects.	https://store.iafaforallergy.com/products/nanolife-wound-care-gel?variant=46063577989294
NanoSALV Catalytic Advanced Wound Care Treatment Matrix	NanoTess Inc.	Health Canada-approved medical device utilizing catalytic technology to optimize natural wound healing, reduce inflammation, and provide broad-spectrum antimicrobial effects.	https://nanotess.com/products/nanosalv-catalytic-advanced-wound-care-treatment-matrix-5g-unit?srsltid=AfmBOoqR8CBXo06kv6HQjStp97rTbs6VacS_a8ebem0XNV1GFU-lZqUm
CUMARGOLD Gel®	Dai Bac Company Limited	CUMARGOLD Gel® is a topical formulation designed for wound healing and skin regeneration. It contains Nano Curcumin, the active component derived from turmeric (Curcuma longa), which is known for its strong anti-inflammatory, antioxidant, and antimicrobial properties.	https://nhathuocmanhty.com/san-pham/cumargold-gel/
NanoCurc™	Haus Bioceuticals Inc	NanoCurc™ is a polymeric nanoparticle formulation of curcumin, designed to enhance the bioavailability and therapeutic efficacy of curcumin, the active compound derived from turmeric (Curcuma longa).	https://nanocur.com/

10. Conclusion

The integration of TCM with modern nanocarrier technology provides a promising approach to increase wound healing. TCM has a long history of success in the treatment of lesions, and performs important therapeutic effects with different herbal medicines. However, questions related to bioavailability, stability and targeted distribution have often limited the efficiency of these herbal drugs. Nanocarriers, such as liposomes, niosomes and hydrogel, have the ability to revolutionize wound care. By encapsulating TCM herbal compounds within nanocarriers, it is possible to improve their stability, control the release of active ingredients, and enhance their targeting capabilities. This combination of old knowledge and modern technology can change wound care, leading to more efficient, targeted and safe treatment. The successful application of the nanocarrier system in distributing TCM connections for wound healing emphasizes the importance of ongoing research and development in the field. This development has the ability to significantly improve both traditional medicine and modern therapeutic practice. Overall, the merger of TCM with nanocarrier technology represents an exciting area in the development of advanced wound healing treatments, and possibly offers more efficient and targeted treatment to patients worldwide.

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Declaration of competing interest

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