

MEDICINAL HERBS WITH PROMISING WOUND HEALING PROPERTIES: A COMPREHENSIVE REVIEW

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ABSTRACT

The skin is utilized by the body as the first phrase of defense mechanism in order to shield its inner organs from heat, chemical, and mechanical injuries. It is a well-developed immune system network that defends the body against injurious diseases. The wounds are cured with the help of various medicinal plants or their products. The utilization of plants and their extracts can be extremely helpful for wound control and healing. Aside from to being easily accessible and economical, phytomedicines for healing wounds are safe because they hardly cause hypersensitive reactions. Humans are able to use a number of medications from plants, and medicinal plants are a gift from nature that can heal wounds with even fewer risks. All the plants that have been used in the past and scientifically utilized to offer wound treatment are emphasized in the review. In addition, some of herbal wound dressing patent technologies have also been summarized.

KEYWORDS: Wound Healing, Skin, Patents, Herbal Medicine, wound dressing, Active Constituent.

INTRODUCTION

The skin is the body's largest organ by surface area, serving as a critical barrier that protects internal tissues from extreme temperatures, UV radiation, physical injury, and microbial invasion. Wounds represent a form of physical injury^[1] that can cause pain, distress, infection, inflammation, or even compromise organ function if not treated appropriately. Wound healing is a complex, multi-stage biological process involving clot formation, bleeding control, extracellular matrix protein synthesis (including collagen), parenchymal and connective tissue cell proliferation, and tissue remodeling.^[2] This process relies on intricate interactions between cells and the matrix, occurring concurrently through stages like inflammation, granulation tissue formation, angiogenesis, wound contraction, remodeling, and re-epithelialization.^[3,4] Although several therapeutic

approaches exist, their effectiveness in enhancing wound healing remains limited, underscoring the need for more potent therapies. Many therapeutic plants have demonstrated significant potential in promoting wound repair. Plant-derived therapies are often more effective because they enhance healing processes naturally.^[5] In fact, over 60% of wound-healing preparations are plant-based, about 30% are mineral-based, and the remainder are derived from animal products. In first aid, herbal formulations are frequently used as antiseptics, coagulants, or wound cleansers. Medicinal plants contribute to wound healing by modulating repair processes, reducing microbial load, promoting collagen deposition, and increasing fibrocyte activity.^[6] Global interest in medicinal plants has surged, with researchers investigating approximately 14,000 plant species in the past five years for their therapeutic potential.^[2]

Phytochemicals have shown considerable promise in preventing microbial infections and healing wounds. Many bioactive plant compounds possess combined wound-repair, antimicrobial, and antioxidant properties: they promote blood clotting, combat infection, and accelerate wound closure.^[7,8] Polyphenol-rich herbs, in particular, have demonstrated strong wound-healing effects. Phenolic compounds, due to their antioxidant, antibacterial, and astringent properties, play a key role in tissue repair. Flavonoids, a type of polyphenol, support healing by scavenging free radicals, inhibiting lipid peroxidation which otherwise damages cells and improving collagen fibril integrity.^[9] In underdeveloped regions, traditional herbal medicine remains a vital resource for wound treatment. Research into plant-based remedies for wound healing has intensified recently because they tend to be inexpensive, readily available, and associated with fewer side effects.^[10,11] Plants are rich in diverse bioactive phytochemicals such as alkaloids, carotenoids, flavonoids, tannins, terpenoids, and saponins many of which belong to the phenolic family and contribute to their therapeutic efficacy.

PROCESS OF WOUND HEALING

When an injury occurs, either from surgery or trauma, the body reacts right away, and the injured tissue or wound goes through four stages before undergoing a complete repair.

Hemostasis Phase: The body's natural response to prevent bleeding upon injury to the skin is to constrict the wall of the artery. Therefore, two concurrent platelet-dependent, interrelated processes allow both primary and secondary hemostasis to occur. Primary hemostasis involves both platelet deposition and platelet plug formation due to the exposure of collagen within the sub-endothelial matrix.^[12] Secondary hemostasis is the activation of the coagulation cascade, which converts soluble fibrinogen into the insoluble strands of the fibrin

mesh. The platelet plug and fibrin mesh collaborate to form a thrombus, which stops bleeding, releases growth factors, and provides a temporary scaffold for cell infiltration necessary for wound healing.^[13]

Defensive or Inflammatory Phase: The inflammatory process begins shortly after the injury and typically lasts 24 to 48 hours, but it can occasionally extend up to two weeks. Immediately, the inflammatory phase initiates hemostatic pathways to stop the bleeding from the wound site. As a result, clinically identifiable cardinal symptoms such as inflammation, skin redness, color, tumor, pain, and function start to appear.^[14,15]

Proliferative Phase: The acute wound moves on to tissue healing once hemostasis has been established, chronic damage has stopped, and an immune system has been successfully established. The proliferative phase lasts for almost two weeks and starts on the third day after injury. Fibroblast migration and the deposition of freshly created extracellular matrix, which takes the place of the temporary network of fibrin and fibronectin, are its defining characteristics. This wound-healing process appears to involve a macroscopic increase in granulation tissue development.^[15,16]

Maturation Stage or Remodeling Phase: Granulation tissue slowly degrades during this last phase of wound healing. The skeletal muscle's nerves, myofibers, dermal vasculature, and epidermis all undergo remodelling to produce functional tissue. Glycosaminoglycan and proteoglycans, which are essential for hydration and structure, are also declining in frequency. Collagen metalloproteinase secreted by macrophages and fibroblasts break down Type I collagen to produce a cell-poor scar and replace Type III collagen of granulation tissue. Following that, the collagen of type I is reorganized into parallel fibrils. It will take months to complete this final step.^[16]

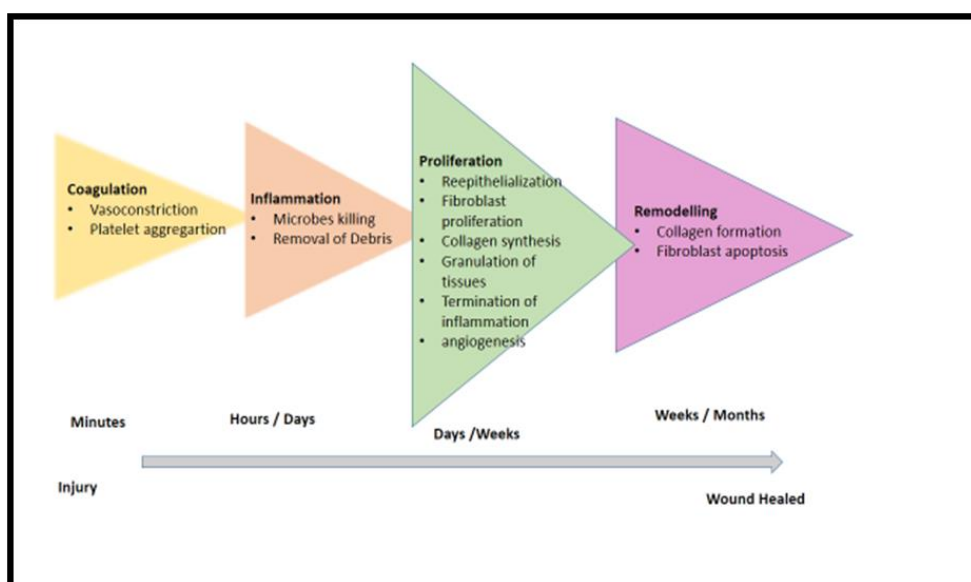


Fig. 1: Stages of wound healing.

WOUND HEALING MANAGEMENT USING HERBAL PLANTS

Several treatments were used sequentially and locally to enhance the healing of a wound. Collagenase ointment, antibiotics, antibacterial agents, desloughing agents such as hydrogen peroxide, and other components such as extracts, minerals, vitamins, and plant products are some of the therapeutic agents implemented in wound healing. Through the enhancement of blood coagulation, alleviation of inflammation, medicinal plants facilitate healing of a wound and accelerate wound healing. Plant-derived chemical compounds and herbs may be employed to assist treatment and preserve wound healing. Through various processes, including the control of the rate of healing of a wound, reducing the count of microbes, facilitating the deposition of collagen, and enhancing fibroblasts and fibrocytes, medicinal plants possess healing properties for wound. Egyptians, indigenous people of African, Asian descent, the ancient Romans, and the Native Americans used herbal remedies as a first-line treatment for blisters ulcers, inflammatory illnesses, and surgical scars for over 5,500 years.^[17] Below is an example list of some therapeutic plants and ways they might help to heal wounds.

Medicinal plants frequently employed for wound repair are as follows:

Aloe Vera

Aloe vera is also referred to as kumari and is amongst the most common herbal drugs used in India. *Aloe vera* has more than 120 bioactive compounds which are extensively studied for their wound healing property. Burns, ulcers, and surgical wounds are still being treated with *Aloe vera* as a first-line drug.^[18] Several naturally occurring bioactive molecules including pyrocatechol, saponins, acemannan, anthraquinones, glycosides, oleic acid, phytol, and monomeric and polymeric water-soluble polysaccharides are present in *Aloe vera*.^[19] Aqueous and alcoholic extracts of leaves of *Aloe vera* were less active against microbes compared to acetone extracts. Gram-positive bacteria are more sensitive to *Aloe vera* compared to Gram-negative bacteria. The *aloe vera* pulp has been reported to have several applications, including to hasten the wound healing process, to exert astringent, anti-inflammatory, antibacterial, and antiseptic activities.^[20] Histological examination demonstrated that *Aloe vera* gel enhances wound contraction, promotes neo-vascularization, and causes epithelialization in the later stages of healing. Healing activity is largely attributed to glucomannan, a polysaccharide that influences collagen synthesis and fibroblast function, making healing smoother.^[21,22] Acemannan, anthraquinone derivatives, and saponins were also found to possess antibacterial activities. One of the chief mucopolysaccharides of *Aloe vera*, acemannan, is a mesoglycan, which stimulates macrophage and T-cell activity and causes pro-inflammatory mRNAs, including nitrous oxide, IL-1 α , IL-1 β , IL-6, TNF- α , PGE2, and others, to be synthesized. In support of phagocytosis, mesoglycan moieties bind and sequester

endogenous mitogen inhibitors as well as reactive oxygen species. All this notwithstanding, in a rat model of wound, topically applied acemannan has been found to reduce wound closure time through stimulation of the AKT/mTOR and cyclin D1 signaling pathways.^[23] *Aloe vera* glycosides have also been found to enhance tremendously de novo granulation tissue formation by a mechanism yet to be known.

Allium Sativum

The herb *Allium sativum*, popularly known as garlic, is found in the Amaryllidaceae family. Garlic is a widely used primary spice in many forms of cuisine worldwide owing to its distinct flavor and odor.^[24] Besides food preparation, garlic has been in use as a medicine for decades. Allicin, the organic chemical responsible for garlic's strong smell and flavor, is the most bioactive sulfurous compound.^[25] In excisional wound healing by full-thickness, an allium ointment was found to cure wounds twice as well as the vehicle with fewer aesthetically displeasing scars. Thiosulfate-enriched *A. sativum* extract, in a different study, up-regulated mRNA expression in the epidermis, three days after wounding, and lowered transepidermal water loss on day eight. *A. sativum* extract was found to inhibit the formation of nuclear factor-kB (NF-kB), nitric oxide (NO), MMP-2, IL-6, and angiotensin-converting enzyme, and thus is a therapeutic agent for keloids. Farahpour *et al.* established that the topically administered *A. sativum* accelerated the healing process by enhancing intracytoplasmic carbohydrate ratio and accelerated the wound healing due to its initial effect on mast-cell distribution, enhanced collagen synthesis, and up-regulated angiogenesis. By altering sulfhydryl groups of microbial proteins, particularly in *Pseudomonas aeruginosa* and *Staphylococcus aureus*, which are known to develop bacterial infection in burns, allicin illustrates its antibacterial activity.^[26] In addition, allicin is significant in the activation of fibroblasts, accelerates alignment of the skin border, and stimulates promoting tensile strength of the newly formed tissue and promoting organized collagen synthesis will promote wounds for faster healing.^[27]

Black Catechu

Also known as *Acacia catechu*, it belongs to leguminosae family and is also called other names such as khadir, kattha, khair, and catechu. Flavonoids, catechutannic acid, and catechin in black catechu fruit, gum, and leaves are wound healing agents because of its anti-inflammatory and antifungal activities.^[28] For example, Prasad SK *et al.* conducted research well justified the wound healing activity of *Acacia catechu* bark extract in diabetic mice. The inclusion of (–) epicatechin and phytochemicals may be the cause for the wound healing activity found. Additionally, maximum effective outcome was experienced when treatment was given in combined i.e. topical and oral. The experiment would further be extended to the preparation of herbal

formulation with *Acacia catechu* bark extract which would be a beneficial help to assist diabetic patients.

Burdock (*Lappa Arctium*)

The most common herbaceous crops are *Arctium lappa*, or burdock. *A. lappa* is used in North America, Europe, and Asia for its application against sore throats and dermatological diseases such as rashes, boils, and acne.^[29,30] Phytoconstituents of *A. lappa*, such as tannins, arctin, and arctigenin, have exhibited hepatoprotective, antiviral, anticancer, antibacterial, and anti-inflammatory activities in experimental studies.^[31] It has also been noted that *A. lappa* regulates cell adhesion and gene expression in canine dermal fibroblasts, which in turn modulates the Wnt/ β -catenin signaling pathway, an important wound healing regulator.^[32] *A. lappa* commercial topically applied ointment burns and Wounds TM (B&W), was more efficient than the control treatment in the healing of pain and second- and first-degree burns in human patients in a pilot study. In *in vivo* studies, it has been noted that *A. lappa* root extract enhances skin extracellular matrix metabolism significantly and the number of wrinkles in human cutaneous tissue.^[33]

Commiphora Myrrha

Commiphora myrrha, or "True Myrrh" or "Molmol Myrrh," a plant resin that is derived from the bark of Burseraceae trees. The resin has been used to cure numerous diseases, including pain, arthritis, obesity, hyperlipidemia, and resistance to parasitic and bacterial infection.^[34] Myrrh was locally used for the healing of wounds, edema reduction, and pain relief.^[35] Myrrh is seen to be being mixed with other drugs quite often. *Aloe vera*, *Lawsonia inermis*, *Adiantum capillus-veneris*, and myrrh all enhanced significantly wound healing in diabetic mice, reports a study by Galehdari *et al.*^[36] When used for a short time, myrrh dramatically alleviates pain and prevents relapse of mouth ulcers in patients.^[37] Myrrh regulates the expression of TGF- β 1 and VEGF in mouse dermal fibroblasts *in vitro*. It possesses therapeutic activities in various ways, including an antibacterial, anti-inflammatory, and antiulcer activity. Additionally, investigations have established that it possesses immunopotentiating and antioxidant activities. *Commiphora* suppresses the production of nitric oxide, TNF- α , and interferon- γ *in vitro*, which is indicative of its anti-inflammatory activity, these activities promote wound healing.^[38]

Centella Asiatica

For decades, *Centella asiatica*, commonly referred to as Asiatic pennywort, has been employed to support the healing of wounds.^[39] In Sprague-Dawley rat studies, fractions of the aerial parts of *C. asiatica* have been shown to enhance the size, depth, and longevity of healing in chronic ulcers. In rat models of acute radiation dermatitis, fractions from *C. asiatica* promoted quicker healing of wounds than a control group that had not been treated.^[40] Studies suggest that *C. asiatica* aerial part

extracts can increase chronic ulcer size, depth, and complete closure. The bioactive compounds obtained from *C. asiatica* such as asiatic acid, asiaticoside, madecassoside, and madecassic acid contribute to collagen synthesis and tissue repair in punch-type wounds.^[41]

Calendula Officinalis

Calendula officinalis, or pot marigold, is a herb used extensively in the treatment of diverse skin diseases including dermatitis, burns, and wounds. In both human and murine fibroblast cultures, it has been found that extracts of *C. officinalis* facilitate fibroblast migration and proliferation in a PI3K-dependent manner.^[42] Also, *in vivo* studies of excisional wounds of BALB/c mice show that *C. officinalis* flower extracts induce granulation tissue formation through the modulation of connective tissue growth factor (CTGF) and α -smooth muscle actin (α -SMA) expression.^[43,44] For instance, *C. officinalis* has been shown to augment angiogenesis *in vivo* with a cutaneous wound model in rat and the chicken chorioallantoic membrane (CAM) assay. Multiple skin conditions, such as dermatitis, burns, and wounds, are managed using *C. officinalis*.^[45]

Pharmacological activities of phytoconstituents like rutin, terpenoids, carotenes, and chlorogenic acid involve anti-inflammatory, antioxidant, antibacterial, antiviral, antifungal, and anticancer activities.^[46] However, the exact mechanisms behind its action on wound healing are yet to be understood. Human and murine fibroblast cell studies suggest that *C. Officinalis* extracts block the migration and proliferation of fibroblasts by a PI3K enzymes-dependent pathway.

Crocus Sativus

A spice obtained from the dried stigmas of *Crocus sativus* L. belonging to the family Iridaceae is commonly known as saffron. Saffron is used in therapeutic treatments by traditional Chinese, Ayurvedic, Persian, and Unani systems of medicine. A Greek doctor by the name of Pedanius Dioscorides in the first century A.D. wrote a book called *Materia Medica*, which discussed the medicinal properties of saffron and how it was used in curing.^[47] Saffron extract or its bioactive compounds, including apocarotenoids, mono-terpenoids, flavonoids, phenolic acids, and phytosterols, have been demonstrated in recent pharmacological research to possess a variety of medicinal properties.^[48,49] The main carotenoids of saffron extracts (SE) are crocin, crocetin, picrocrocin, and safranal. Crocin, crocetin, and safranal suppressed lipid peroxidation and nitric oxide and increased glutathione, antioxidant enzymes (i.e., superoxide dismutase, catalase, and glutathione peroxidase), and thiol content, as reported in recent studies. An *in vivo* study was carried out in rat burn injury model to compare the effect of saffron extract with silver sulfadiazine (SSD), the most widely used topical treatment for burn injury. At day 7, $p < 0.001$, there was a higher wound closure, i.e., narrowing and re-

epithelialization of the wound, in 20% saffron pomade-treated animals compared to SSD-treated and controls ($83.04 \pm 1.36\%$ vs $57.57 \pm 2.8\%$ vs $35.53 \pm 3.5\%$, respectively).^[50] According to the scratch test, the healing activity of saffron against fibroblast proliferation and migration in the remodeling stage, anti-scarring, and regenerative activities (Zeka *et al.*) crafted a new hydrogel with antioxidants of saffron flowers. Fibroblast cells from newborn mice (as a skin model) were found to exhibit increased proliferation upon application of kaempferol or 10 μM crocin-loaded hydrogels.^[51] Chemicals that are extracted from saffron petal and flower bio wastes can be used for the wound healing, additional studies however need to be conducted in order to achieve the wound healing mechanisms and pathways.^[52]

Glabra *Glycyrrhiza* Linn.

Glycyrrhiza glabra is said to yield liquorice, a sweet, fragrant flavor from its root. Antifungal, antibacterial, antifungal, and antioxidant properties of the plant are probably being utilized for thousands of years in traditional medicine. This plant is used primarily as a natural remedy in cosmetic commercial products.^[53] Liquorice flavonoids are thought to contain anti-inflammatory and antioxidants compounds, Liquorice extracts suppress TNF α and other inflammatory cytokines like IL-1 and IL-6. Its antibiotic, antifungal, antibacterial, and antioxidant properties have been utilized in traditional medicine for millennia. They also suppress healing of colitis mucosal ulcers and oral and gastric ulcers. *G. glabra* has been utilized to manufacture ointment that has shown remarkable progress in various phases of the wound healing process, as shown by a 2019 review article by Zangeneh *et al.*^[54] Wound-healing activity of *G. glabra* on full-thickness dermal wounds has been described by very few articles, although others have demonstrated its antiulcer activity in gastric, oral, and colitis mucosal ulcers and corneal neovascularization.^[55] Triterpenes and flavonoids, two anti-inflammatory and antioxidant constituents of *G. glabra* decreased pus and free radicals in the wound area, enhancing wound healing.^[56,57] Hanafy *et al* recently studied the efficacy of *G. glabra* extract on full-thickness wound healing in a Guinea pig model. Topical application with a cream base of 5–10% w/w *G. glabra* extract increased wound healing in the present study. Its flavonoids are more likely to be the reason for the statistically significant variations in re-epithelialization in treated wounds.^[58]

Neem

Neem, or *Azadirachta indica*, is a member of the Meliaceae family, which also includes mahogany. Extracts from neem leaves and seed oil have antibacterial properties and aid in the recovery of infected wounds. Clinical investigations have shown that *neem* extract reduces inflammation, which promotes wound healing. The components of *neem* leaf extracts and seed oil—margosic acid, fatty acid glycerides, butyric acid, and

trace amounts of valeric acid—give them antibacterial properties. They prevent subsequent infection and bacterial activity in wounds and lesions. Studies have shown that *neem* extract reduces inflammation, which promotes healing.^[60] Its active constituents, i.e., nimbin, nimbidin, and nimbidol, exhibit antibacterial and anti-inflammatory activity that helps in wound healing, induces the development of new blood vessels, and promotes DNA synthesis.^[59] Wound-healing activity of *neem* leaves has been an old traditional medicine for centuries. In one study, the study of the use of *neem* oil in the treatment of chronic, non-healing wounds was done, and the finding showed that after 8 weeks of treatment, there was 50% healing of the wound in almost 44% of the patients. In another study, aqueous extract of *neem* leaves was used to screen the wound-healing activities, and a significant reduction in the longest diameter wounds has been reported. The wound-healing activities of the aqueous *neem* leaf extracts are said to act biochemically *via* inflammatory response and neovascularization.

Panax *Notoginseng*

Panax notoginseng, not to be confused with *panax ginseng* and other *ginsengs*, is employed to manage pain, bruising, oedema, and bleeding. Terpenes and saponins in the leaves of *panax notoginseng* possess significant pharmacological properties, including immunostimulatory,^[61] neuroprotective, anti-inflammatory, antioxidant, anti-cancer, and antidiabetic activities. Two key processes in wound healing are angiogenesis and the synthesis of VEGF (vascular endothelial growth factor), both of which are promoted by terpene and saponins.^[62] Mechanism of action research indicates that *P. notoginseng* flower extracts inhibit NF-KB signaling which influences the synthesis of inflammatory cytokines such as IL-6, which are implicated in the formation of keloid.^[63]

Rosmarinus *officinalis*

Rosemary, or *Rosmarinus officinalis* L., is part of the family Lamiaceae. The *Salvia* and *Rosmarinus* genera have become united, according to recent evolutionary studies. Rosemary is a fragrant herb with needle-like leaves cultivated worldwide that is used in traditional medicine.^[64,65,66] The cosmetics and pharmaceutical industries have been using rosemary for its anti-inflammatory and antioxidant activities, contributed mainly by the presence of carnosol/carnosic and ursolic acids. Its other possible uses in treating non-pathological dermatoses like aging and sun damage, wound healing, skin cancer, and mycoses have also been explored. The flavonoids reported in rosemary are hesperidin, diosmin, isoscutellarein 7-O-glucoside, hispidulin 7-O-glucoside, eriocitrin, luteolin 3'-O-D-glucuronide, and genkwanin.

These flavonoids have been found in some areas of the plant since the earliest times. The comparison between the group treated with rosemary essential oils and the control group in an *in vivo* experiment showed that the

former had improved a lot in angiogenesis, granulation tissue development, and healing. Topically treated rats with or without diabetes using 10% *R. officinalis* oil experienced quick healing of the wounds, according to another research.^[67]

Stone Apple (Bael)

The bael tree, or *Aegle marmelos*, is a medium-sized, aromatic tree that is 95–125 cm in diameter and 7.0–8.5 meters tall. It is a member of the Rutaceae family. Its natural habitat is the deciduous forests of India. Strong antioxidant properties and antigenotoxic properties are found in bael leaf extracts, which are used topically to promote wound healing.^[68] The active components of *A. marmelos* root extract include coumarins, terpenoids, phenolic acids, tocopherols, essential vitamins like C and A, minerals, and carotenoids, as well as two alkaloids called omethylhalfordinol and isopentylhalfordinol that support healing and strengthen the area that has been treated. Additionally, Bael fruit pulp promotes wound healing by reducing inflammation and regulating collagen formation.^[69]

Linn. Sesamum Indicum

One of the oldest cultivated plants in history, *Sesamum indicum* Linn. of family Pedaliaceae, is mostly sown for its delicious, oil-rich seeds. The seeds possess a strong antioxidant effect as they are rich in sesamol. Sesame seeds have been traditionally used to heal burn wounds especially. Treatment with oil and seeds significantly increased the hydroxyproline content of the granulation tissue, dry weight, and breaking strength of the wound in the dead space model. These results indicate that the *S. indicum* oil and seeds can enhance healing of wounds when given orally or applied topically.^[70]

Tulsi

Labiaceae family comprises Tulsi (*Ocimum sanctum*), commonly referred to as Tulasi, which is native to tropical and subtropical regions of India.^[71] Plant constituents have, for decades, been in use in siddha and ayurvedic medicine to treat a range of diseases including skin, liver, and infection.^[72] Through active involvement in immunological reactions including antibody formation, release of mediators in hypersensitivity reactions, and tissue response to the same, *O. sanctum* is of fundamental importance in the process of wound healing. The plant is rich in eugenol, linalool, β -caryophyllene, thymol, camphor, ocimene, linolen, anethol, pinene, cineol flavonoids with antioxidant activity as predominant active metabolite, which further helps in fostering wound healing activity.^[73] The wound healing activity of *O. sanctum* L. aqueous extract was tested in rats by Shetty *et al.* Because of the higher percentage of wound contraction, researchers studied the wound-breaking strength in the incision wound model, time of epithelization, and percent wound concentration in the excision wound model. The pathologic healing, such as keloids and hypertrophic scars, might be treated with the application of *O. sanctum* L. Dexamethasone-

repressed healing and normal wound healing were compared to an ethanolic extract of *O. sanctum* L. leaves. Aside from a substantial increase in weight of wet and dry granulation tissue and breaking strength of granulation tissue, the extract also substantially improved wound contraction, rate of wound epithelialization, and breaking strength of the wound. In every model of wound healing, the extract also substantially suppresses dexamethasone's anti-healing activity.^[74]

Turmeric

Turmeric, derived from *Curcuma longa* rhizomes, belonging to the ginger family Zingiberaceae, has been in use for a long time in Ayurvedic medicine for its therapeutic properties. It is used in different forms—local application, oral ingestion, and inhalation—to treat a wide range of conditions. It has been a natural medicine for centuries in various cultures. The main bioactive compound found in turmeric, curcumin, is known for its strong wound-healing properties, as well as its anti-allergic, antioxidant, anti-cancer, and anti-coagulant effects. Curcumin facilitates wound healing through affecting several phases of the repair process, which range from increasing wound contraction to collagen synthesis, granulation tissue formation stimulation, and tissue remodeling. Curcumin is also frequently used in Traditional Chinese Medicine to alleviate abdominal pain. Being one of the most well-studied nutraceutical compounds, curcumin has been used traditionally by various ethnic populations for decades. Its broad-spectrum biological activity acts at multiple levels of gene and protein regulation—ranging from transcriptional, translational, to post-translational processes. Curcumin acts on a number of major biological pathways, including proinflammatory cytokines, NF- κ B, cyclooxygenase-2 (COX-2), 5-lipoxygenase (5-LOX), STAT3, C-reactive protein, prostaglandin E2, cellular adhesion molecules, phosphorylase kinase, transforming growth factor- β (TGF- β), and a number of biochemical markers like triglycerides, endothelin-1 (ET-1), creatinine, heme oxygenase-1, AST, and ALT. Both *in vitro* and *in vivo* animal studies have established that curcumin's therapeutic effects mainly occur through the reduction of the cellular environment and extracellular matrix.

Table 2: A short description of the therapeutic herbs utilized in wound recovery.

Sr. no.	Medicinal plants	Primary Uses	Parts used	Key Metabolites	Reference
1	Turmeric (<i>Curcuma Longa</i>)	Long term wound recovery	Rhizomes, stem	Curcumin, curcuminoids, vitamin A	[64]
2	Liquorice (<i>Glabra Glycyrrhiza</i> Linn)	Recurrent or acute wound recovery	roots	Glycyrrhetic acid, glabridin, isoliquirtin, glycyrrhizin	[65]
3	Gotu Kola (<i>Centella asiatica</i>)	Healing of an incisional wound	leaf	Asiatic acid, apigenin, catechin, asiaticoside	[66,27]
4	Mimosatenuiflora	Burn, ulcerative wound care	Bark, stem	Mimosine, sitosterol, tannins, linoleic acid, polyphenols, lupeol	[67]
5	<i>Apis Mellifera</i> or Honey	Wound dressing agent	Secretion from hive	5Hydroxyimidaclopid, α tocopherols, tannins	[68]
6	Theaceae (<i>Camellia Pubipetala</i>)	Healing of excision or incision, diabetic wounds	Leaves	Flavonoids, theanine, catechins, caffeine	[69]
7	Forest Champa (<i>Spermadictyon suaveolens</i>)	Prolonged wound closure management	Roots, leaves, stem or bark	Triterpenes, eugenol, sesquiterpenes, alkaloids	[70]
8	Neem (<i>Azadirachta indica</i>)	Surface or non occlusivewound repair	All parts	nimbin, nimbidin Azadirachtin, azadirone,	[71]
9	Sesame seeds (<i>Sesamum indicum</i> Linn.)	Wound infections, skin lesions	Seeds, oil	Vitamin E and C, sesamol, sesamolin sesamolinal	[50]
10	Trumpet tree (<i>Cecropia peltata</i>)	Closed wound Healing illness	Leaves, bark	Flavanoids, terpenes phenols, alkaloids, sterols, waxes, cecropins, coumarins, tannins.	[72]
11	Kencur (<i>Kaempferia galanga</i>)	Incision wound Healing such as bruises, cuts and burns	Rhizomes, oils	Kaempferol, camphor, cineole cardiac glycosides	[73]
12	Druce (<i>Prosopis cineraria</i>)	Enhanced wound closure	Leaves	Patulitritin, diketones, stigmasterol, hentriacontane, octasanol	[67]
13	Maidenhair (<i>Ginkgo biloba</i>)	Closed wound Healing	Leaves and seeds	Flavonoids, proanthocyanidins ginkgolic acid	[74]
14	Indian mulberry or Noni (<i>Morinda citrifolia</i>)	Diabetic wound Healing, long term wound care	Leaves, bark and fruit	Iridoids, Anthraquinones, polyphenol, sterols, alkaloids, and terpenoids	[75]
15	Club Moss (<i>Lycopodium Serratum</i>)	Ulcerative wound infections	whole plant, Spores	Alkaloids such as lycopodine, steroids, triterpenoids, sterols	[76]
16	Catharanthus roseus or Madagascar periwinkle	Acute or chronic Parasitic, diabetic Wound infections	Leaves, flowers	Monoterpenoids alkaloids, vinblastine, saponins, Vincristine	[77]
17	Euphorbia hirta (<i>asthma weed</i>)	Chronic wound healing	Leaves	Terpenoids, phorbic acid, quercetin, tannins	[78]
18	Pterocarpus sandalinus, or red sandalwood	Acute or chronic wound healing	Bark wood	Petrocarpol, santalin A, B and C	[79]
19.	Aloe (<i>Aloe vera</i>)	Healing of an open wound, skin ailments	Gel or latex obtained from leaves	Acemannan, saponins, anthraquinones	[23,8]
20	Bhramhi (<i>Bacopa monnieri</i>)	Wounds, burns management	Whole plant, leaves, stem	Bacosides, steroids, triterpenoids, Flavonoids, alkaloids	[80]

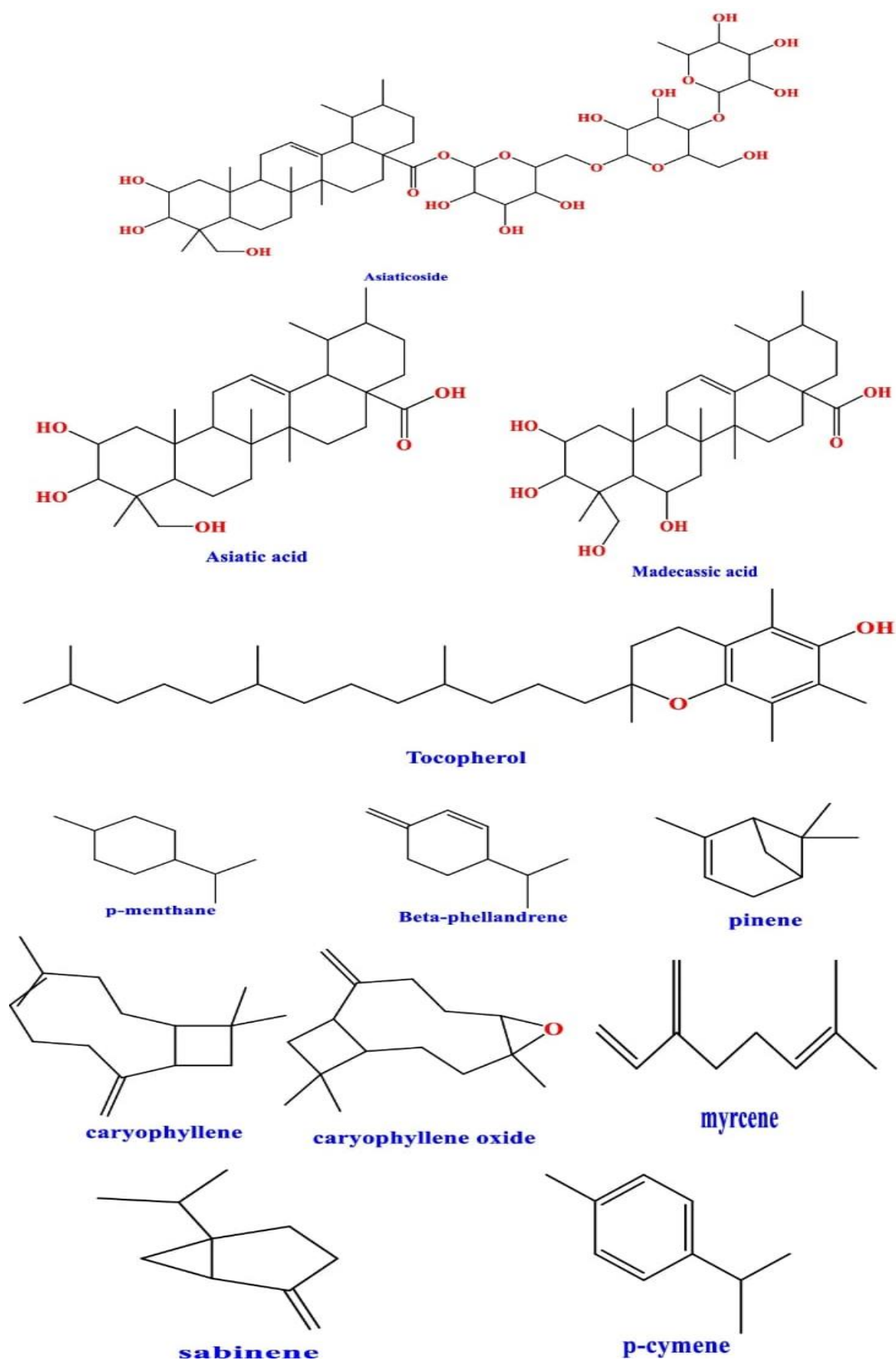
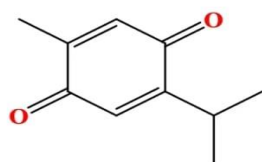
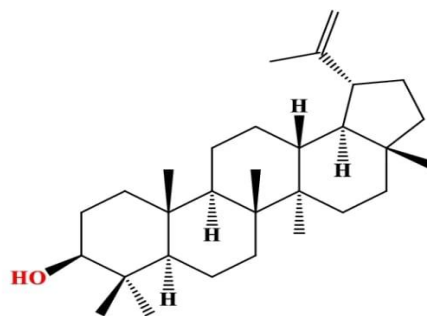


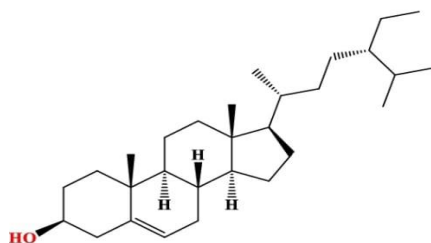
Fig. 2: Structure of chemical constituents present in various plant material.



Thymoquinone



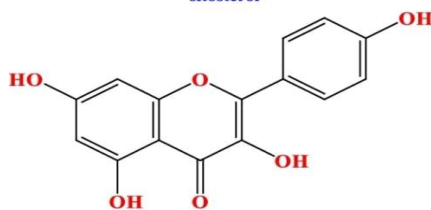
Lupeol



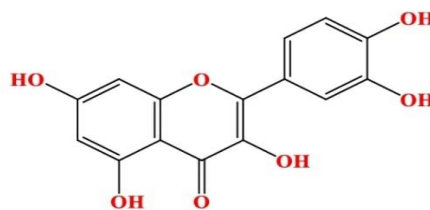
sitosterol



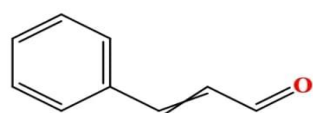
Artocarpin



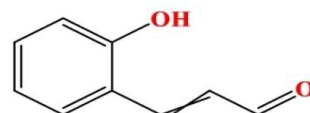
Kaempferol



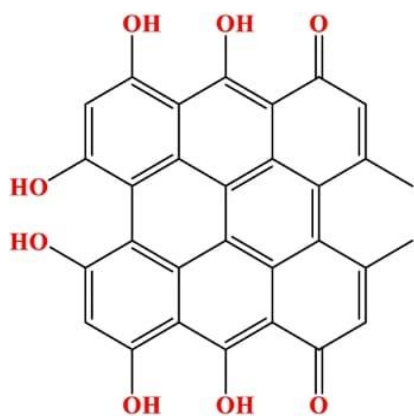
Quercetin



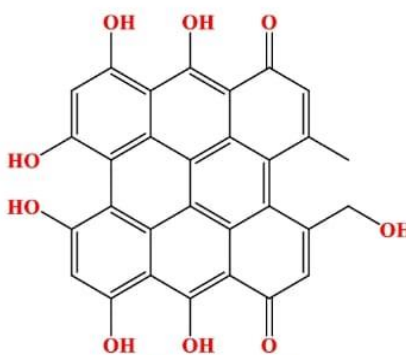
Cinnamaldehyde



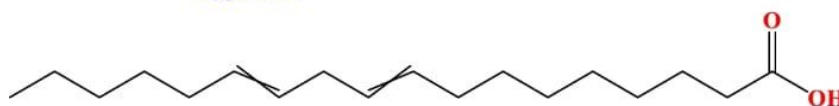
2-hydroxyl cinnamaldehyde



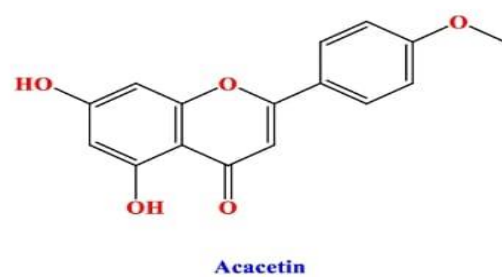
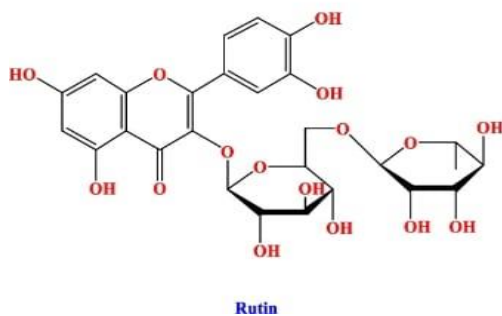
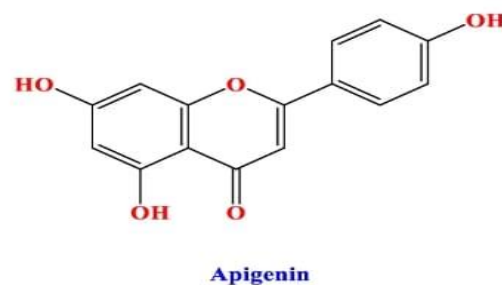
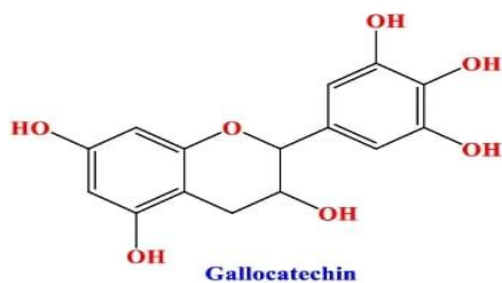
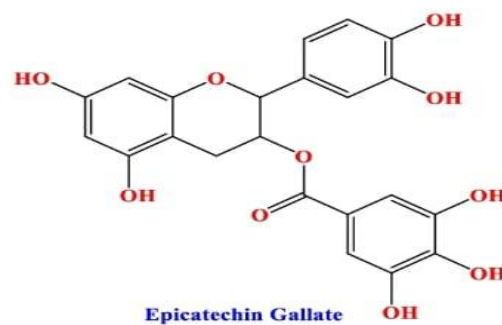
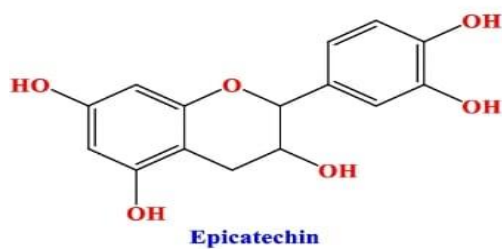
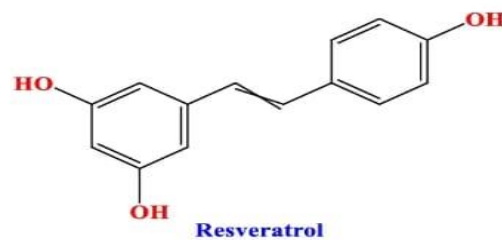
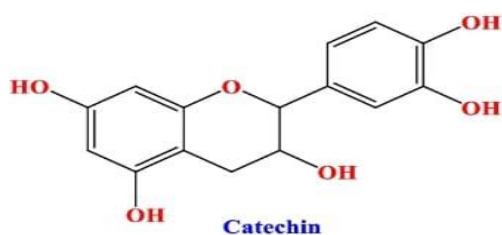
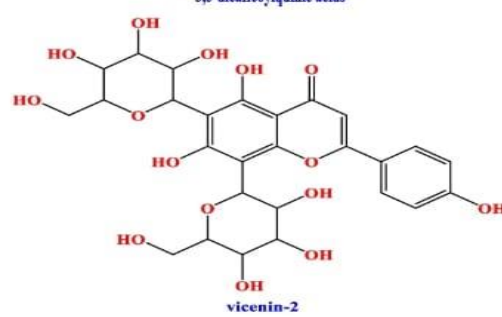
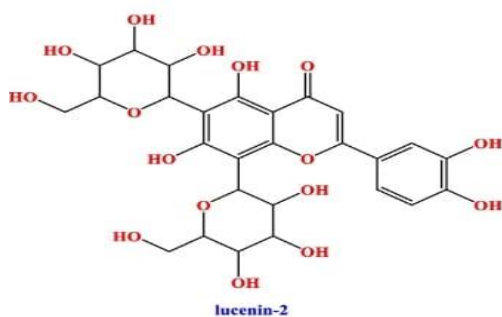
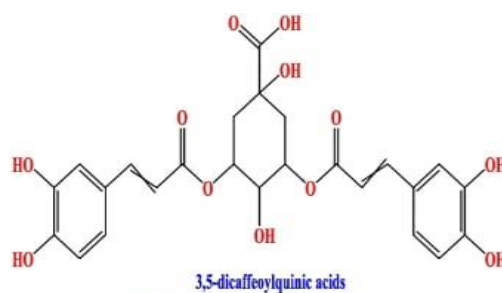
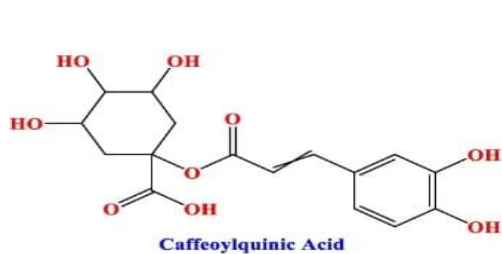
Hypericin



Pseudohypericin



Linoleic acid



PATENTED HERBAL FORMULATIONS FOR THE TREATMENT OF WOUNDS

In recent years, there has been growing interest in utilizing diverse natural materials for repairing human skin damaged by burns and wounds. Driven by the

significant biomedical potential of these materials, researchers have increasingly opted to file patents for the methods used in creating bioactive wound dressings. Table 3 showcases several noteworthy patented innovations:

Table 3: Herbal compositions patented for wound care applications.

S No.	Patent No.	Title	Composition used	Indications	Reference
1.	US 20130209592	A gel forming agent containing at least one of hydroxyethyl cellulose and xanthan gum with sugarcane plant extract	It includes gelling agents such as hydroxyethyl cellulose, xanthan gum, and sugarcane extract	wound repair ,burns treatment	[81]
2.	EP 2704729B1	Silver hydrogel antimicrobial preparation to treat burns and wounds	Aloe vera gel with medical grade silver salt	Antibacterial wound dressing composition	[82]
3.	WO/2014/066968	Formulation incorporating rice oil	Rice oil	Boosts wound healing mechanism	[83]
4.	EP 2586450	Herbal balm for Burns	Comprises of agents like virgin olive oil, beeswax, peeled chestnuts, elderberry bark	No signs of wound scars, improve wound recovery	[84]
5.	WO/2014/075157	Composition incorporating coffee oil	Coffee oil	Enhanced topical wound healing , skin diseases	[85]
6.	US 20130052289	A medication for diabetic patients that includes ficusmicrocarpa extracts for alleviating their wounds	Herbal extract of Ficus microcarpa	Improved ulcerative wound healing capacity in diabetic patients	[86]
7.	WO/2013/056514	Wound healing effect of Rhizoma arisaematis herbal extract	Rhizoma arisaematis extract	Enhanced wound healing effect	[87]
8.	EP 2570124	Compositions based on Oleuropein for wound recovery in diabetics or elderly person	Oleuropein composition	Wound healing effect in elderly patient	[88]
9.	US 8741353	Ointment for burns and wounds	Incorporation of sesame seeds oil, honey, potassium alum, myrrh, curcumin, mukul	Burns or wound healing dressing	[89]
10.	US 11071617B2	Biomedical patches featuring fiber alignment	silk derived composition	Accelerates wound healing process	[90]
11.	RU2736214C1	Ointment for wound healing	Herbal mixture of hypercium perforatum, arctium, veronica officinalis, stem of lilium candidum, bee wax, pork fat, egg oil, grape seed oil	wound healing, burns and antibacterial activity	[91]
12.	WO201712224A1	Nanobiocomposite formulation for wound healing and preparation thereof	Nanobiocomposite consist of silver nanoparticles and cellulose nanocrystals	Wound healing	[92]
13.	EP2895209B1	Wound healing composition consist of microspheres	Polystyrene microspheres	Accelerates healing of wound process	[93]

14.	US20200330543A1	wound healing formulation for topical use	Herbal mixture consisting of gotu kola, plantago, figwort, yarrow, tabebuia, impetiginosa.	Anti-inflammatory, antimicrobial activity, wound healing, skin disorders like eczema	[94]
15	IN349393	Nanocomposite formulation for wound healing and preparation thereof	Nanofibrous film and ointment composed of matrix of cellulose nanocrystals (CNCs) impregnated with silver nitrate filler and leaves of <i>S. cumini</i> .	Anti-inflammatory, rapid angiogenesis and collagen formation, enhanced reepithelization.	[95]

FUTURE PERSPECTIVE

Herbal plants have huge potential in wound treatment with their antimicrobial, anti-inflammatory, antioxidant, and tissue-regeneration capabilities. With increased interest in traditional remedies, the future focus should be on scientifically confirming conventional wisdom through the discovery and activity testing of active constituents in such plants. Standardization of herbal preparations is essential in order to provide consistency, safety, and efficacy, as preparation variability can result in variable healing responses. Modern therapies such as nanogels, hydrogels, and bioactive dressings may be utilized to enhance the delivery and uptake of herbal substances at wound sites. Well-conducted clinical trials are also needed to establish the therapeutic potential of herbal medicines to comply with international regulatory requirements. The co-administration of herbs with conventional therapies may provide a more effective wound healing, particularly in chronic and infected wounds. Secondly, personalized medicine strategies with artificial intelligence and genetic profiling may assist in adapting herbal treatments to the individual case. In conclusion, the convergence of herbal medicine with conventional science can transform wound healing in the future.

CONCLUSION

When injury activates the body's healing process, scarring usually ensues, so current wound management emphasizes minimizing risks and accelerating healing. Phytotherapeutic agents—whether administered topically or systemically—are being more commonly utilized for resistant or chronic ulcers as a result of their higher bioavailability and reduced risk of adverse effects. Most traditional societies continue to practice plant medicines that support the body's own healing mechanisms, and contemporary science is combining this age-old wisdom with sophisticated methods to develop more effective, safer wound therapies. However, to be licensed as wound care products, plant-based therapies first have to go through demanding procedures such as standardization, toxicity assessment, and clinical testing. More clinical evidence—e.g., trials with *Centella asiatica*, *Aloe vera*, and polyherbal preparations demonstrating benefits—indicates the viability of scientifically substantiated herbal wound products. Therefore, ongoing exploration of herbal preparation for burn and wound healing is

warranted, based on their significant therapeutic potential in supporting secure and effective skin regeneration.

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