



A Review of Medicinal Plant Extracts for the Treatment of Antibiotic-Resistant Wounds

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Abstract:

Rising as one of the most serious worldwide health emergencies of the twenty-first century is antibiotic resistance (ABR). The terrifying speed at which pathogenic bacteria are developing resistance to extensively used antibiotics seriously compromises the ability of healthcare systems all around to control infectious diseases. When thinking about chronic wounds—including diabetic foot ulcers, pressure ulcers, and venous leg ulcers—this issue is particularly clear-cut. Chronic wounds, like diabetic foot ulcers, pressure ulcers, and venous leg ulcers, are marked by ongoing inflammation and slow healing, and they are often infected by multidrug-resistant (MDR) bacteria such as *Escherichia coli*, *Pseudomonas aeruginosa*, and *Staphylococcus aureus*. Apart from complicated clinical treatment of these wounds, the existence of such infections raises the possibility of systemic infections, morbidity, and medical costs. This paper will review in whole the therapeutic opportunities of medicinal plant extracts in the treatment of wounds contaminated with antibiotic-resistant bacteria. Through disturbance of bacterial cell walls, inhibition of quorum sensing, and interference with biofilm formation, it investigates the processes of action by which phytochemicals produce their antimicrobial effects. Emphasizing remarkable candidates who have advanced to preclinical or clinical evaluation, the review also addresses the clinical relevance of these results. Emphasizing the need for multidisciplinary research including alternative treatments in mainstream clinical practice, we also address the difficulties and constraints associated with the standardization, formulation, and regulatory approval of plant-based therapies.

Keywords: Medicinal Plants, Antibiotic Resistance, Antimicrobial, Chronic Wounds, Natural Antimicrobials

Introduction

Diabetic ulcers, pressure ulcers, and venous ulcers are among the main worldwide health issues affecting people. Usually with long healing times, bacterial infections aggravate these wounds. Apart from prolonged healing, continuous chronic

infections compromise recovery and add to the general load on health. A particularly alarming aspect of chronic wound infections is the increasing frequency of antibiotic-resistant bacteria (1). Long use of antibiotics for different diseases has resulted in the development of resistance in many



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How to Cite this Article:

S. Khosravi Ghareh Cheh " A Review of Medicinal Plant Extracts for the Treatment of Antibiotic-Resistant Wounds", Advanced Therapies Journal, vol. 7, no. 23, pp.44-54, 2025.

bacterial strains to several antibiotic classes, so complicating treatment and reducing its efficacy (2). Pathogens linked to chronic wound infections such as *Staphylococcus aureus*, *Pseudomonas aeruginosa*, *Klebsiella pneumoniae*, and *Escherichia coli*—usually provide great challenges since they can survive many antibiotics. This opposition demands the quick application of alternative therapeutic modalities since traditional medications reduce their efficacy. The emergence of multidrug-resistant infections (3) has stimulated the need for creative approaches to wound healing. The growing crisis has attracted a lot of attention to the therapeutic applications of natural plants. Because of their several medicinal qualities, plants have long been used in traditional medicine. Medicinal plants are under review as a sensible source of alternative therapies in view of the growing problem presented by antibiotic resistance (4). Among other bioactive elements, plant extracts abound in antibacterial, anti-inflammatory, antioxidant, and wound-healing ones. Particularly those resulting from antibiotic-resistant bacteria, these characteristics make medicinal plants rather successful in treating infections in chronic wounds (5). Though the concept of treating infections with medicinal plants is not novel, their potential is underlined more and more in view of the rise in antibiotic resistance. Many studies on the antibacterial properties of these plants have verified their efficiency in treating resistant diseases. This review aims to identify medicinal plants that may effectively treat wounds resistant to antibiotics, explore how they work, and evaluate the clinical evidence that supports their use as practical alternatives or additions to standard antibiotic treatments. This study clarifies the therapeutic benefits of these plants, so improving knowledge of the important role natural medications could play in preventing the growing problem of antibiotic-resistant infections in chronic wounds.

Antibiotic Resistance and Chronic Wounds

Antibiotic Resistance: A Global Health Crisis

Antibiotic resistance emerges as a major worldwide health concern of the twenty-first century. This phenomenon is the ability of bacteria to resist and maintain proliferating even in the presence of antibiotics used to once basically eradicate them or stop their growth. Mostly resulting from the overuse, abuse, and incorrect administration of antibiotics in human health as well as their great use in agriculture and cattle management, the alarming rise of antibiotic-resistant bacteria is a complex and multidimensional problem (7). In many different parts of the world, antibiotics are used preventively in farming to increase animal growth; these actions combined exert great selective pressure on microbial

populations. They also come without a prescription. By means of strategies to circumvent the effects of these drugs, bacteria create strains resistant to traditional treatment modalities. The development of antibiotic resistance poses significant difficulties in managing chronic wounds because of their prolonged exposure and poor healing capacity, which makes them naturally prone to recurrent infections (8). Often serving as hosts for pathogenic organisms, chronic wounds, including venous leg ulcers, pressure sores, and diabetic foot ulcers, provide a perfect environment for bacterial colonization and infection. Many of the microorganisms causing severe infections have evolved resistance to several drugs under such circumstances; hence, the efficacy of traditional antibiotics is much lower. This not only slows down the healing process but also increases the risk of consequences ranging from local tissue damage and longer hospital stays to life-threatening systemic infections such as sepsis or the need for limb amputation in advanced cases (9). One main factor making management of continuous wound infections challenging is the development of bacterial biofilms. Enclosed in a self-generated matrix of extracellular polymeric molecules, a biofilm is a sophisticated assembly of cells. Covering tissue and medical tools, this matrix clearly adheres to biotic and abiotic surfaces. Persistence and chronicity of infection in chronic wounds depend on the development of biofilm (10). Acting as a significant physical barrier, the biofilm mostly prevents drug penetration and shields microorganisms from the immune system of the host. Furthermore, the microorganisms in a biofilm often show a much lower metabolic rate, which reduces their sensitivity to antibiotics influencing fast-growing cells. Moreover, horizontal gene transfer among bacteria in biofilms can distribute genetic material, including resistance genes, so aggravating and increasing the problem of antibiotic resistance among different bacterial species and strains (11). In chronic wound infections, *Staphylococcus aureus*—especially methicillin-resistant *Staphylococcus aureus* (MRSA)—and *Pseudomonas aeruginosa* are the most often identified antibiotic-resistant organisms. Being resistant to methicillin and other beta-lactam antibiotics, MRSA is a well-known infection that makes treatment of this challenging in both hospital-acquired and community-acquired settings. Its presence in chronic wounds usually causes long-standing infection and alters the course of treatment. Gram-negative *P. aeruginosa* is known for its natural resistance systems and ability to survive in hostile conditions. It shows resistance to carbapenems, aminoglycosides, fluoroquinolones, and many other antibiotics (12). Moreover, its mastery of biofilm development aggravates its

elimination, making *P. aeruginosa* infections extremely tenacious and prone to recurrence rather aggressively. Apart from aggravating chronic wound infections, biofilms improve their therapy resistance. Polysaccharides, proteins, and DNA make up the biofilm matrix, and each adds to its durability. This structural complexity limits immune cell access and prevents the dispersion of antimicrobial drugs, so providing a haven for infections to survive and spread (13). Furthermore improving their resistance are the altered gene expression and phenotypic traits of the biofilm's bacteria. These slow-growing or latent traits enable them to withstand antibiotics meant to be effective against actively proliferating cells. As a result, the management of infections connected to biofilms usually calls for extended treatment courses comprising either advanced wound care techniques, surgical debridement, or combination antibiotic medication. In extreme cases, should the infection be resistant to all currently used drugs, systemic issues with fatal results could follow (14). Given the growing threat of antibiotic resistance and its effects on the treatment of chronic wounds, new therapeutic strategies are much needed. Research projects increasingly center on developing new antibiotics with creative modes of action able to overcome present resistance. Furthermore, alternative approaches such as bacteriophage therapy which uses viruses that specifically target and destroy bacteria—are attracting more interest again (15). Phages have been successful in destroying biofilms and especially attacking resistant bacteria while maintaining the helpful bacteria in the host. Using medicinal plant extracts and natural compounds with antimicrobial action many of which have shown efficacy against resistant strains and biofilm-associated bacteria in first trials is another fascinating strategy (16). Furthermore, under research for their ability to treat infection and promote wound healing are antimicrobial peptides, nanoparticles, and immunomodulatory drugs. Modern medicine finds great challenge in the interaction between antibiotic resistance and ongoing wound infections. The interaction of resistant bacterial strains, biofilm development, and limited treatment options emphasizes the great need for continuous research, global stewardship projects to control antibiotic use, and the development of creative therapeutic approaches. Resolving this conundrum calls for a multidisciplinary approach involving doctors, pharmacologists, microbiologists, and public health officials working together to keep present antibiotics effective and to create fresh treatments for the future (17).

The Role of Biofilms in Chronic Wound Infections

Comprising mostly bacteria, biofilms are extracellular polymeric compound (EPS)-covered communities of microorganisms adhering to surfaces. For bacteria inside the biofilm, extensive cellular polymeric compounds—polysaccharides, proteins, and nucleic acids—form a protective milieu. Acting as a barrier, this matrix protects the bacteria from environmental hazards, including physical elimination, immunological reactions, and antimicrobial drugs. Particularly in hostile environments, biofilm generation is a common survival tactic for bacteria that enables them to resist demanding conditions that would otherwise lead to their death (18). Regarding chronic wounds, the development of biofilm seriously disturbs the appropriate treatment. The dense matrix of these bacteria found there reduces sensitivity to antibiotics since therapeutic drugs cannot pass through biofilms. Apart from the changed metabolic condition of bacteria in biofilms, the reduced antibiotic penetration helps infections to exist (19). In contrast to actively growing, metabolically active planktonic bacteria, bacteria residing in biofilms typically exhibit lower growth rates and altered gene expression, which increases their resistance to antimicrobial treatments (20). Microorganisms associated with biofilms demonstrate greater resistance to antimicrobial treatments, even at typically high concentrations that are effective against planktonic bacteria. The components contributing to this tolerance include dietary restrictions, increased efflux pump production, and changes in gene expression that enable resistance mechanisms. As such, diseases connected to biofilms are usually chronic and difficult to eradicate (21). Moreover, the existence of biofilms in chronic wounds causes a prolonged inflammatory reaction. Treating the biofilm as an alien object, the immune system causes continuous inflammation to fight the disease. This ongoing inflammation can damage tissues, hinder wound healing, and initiate a negative cycle that prevents tissue development. In chronic wounds, biofilms can lead to delayed healing, an increased risk of complications, and prolonged infections, which complicate treatment and management (22).

Medicinal Plant Extracts in Wound Healing

Mechanisms of Action of Medicinal Plant Extracts

Medicinal plants are a wide spectrum of bioactive substances with great impact on the management of bacterial infections and the wound-healing process. These natural substances include alkaloids, flavonoids, terpenoids, phenolic compounds, essential oils, and saponins, each contributing to therapeutic efficacy through distinct biochemical pathways. Three main areas can help to classify their several modes of action: anti-inflammatory activity,

antioxidant activity, and antibacterial and antifungal action (23).

Antibacterial and Antifungal Efficacy

Medicinal plant extracts have antibacterial and antifungal properties from many angles, interfering with microbial viability and pathogenic progress: Among other molecules derived from plants, alkaloids, terpenoids, and saponins compromise the structural integrity of microbial cell membranes. These molecules break down the lipid bilayer, so influencing membrane potential loss, intracellular contents to leak out, and finally microbial cell lysis and death (24). Flavonoids and phenolic compounds are well known to stop the bacterial synthesis of proteins. Attaching to bacterial ribosomes (25), they stop the translation process—needed for bacterial survival and replication. Especially targeted in terms of inhibition by some plant extracts are crucial bacterial enzymes, including RNA polymerase and DNA gyrase. Blocking these enzymes disrupts bacterial DNA transcription and replication, thereby slowing bacterial growth (26). The ability of bacteria to create biofilms is one of the main causes of their resistance to antibiotics and immune evasion. Phytochemicals have demonstrated the ability to prevent biofilm development and disrupt existing biofilms, thereby enhancing bacterial sensitivity to therapeutic interventions and host immune responses, particularly those associated with essential oils such as tea tree oil (*Melaleuca alternifolia*) and thyme (*Thymus vulgaris*).

Anti-Inflammatory Efficacy

Chronic or persistent inflammation is one characteristic of non-healing wounds; it may aggravate tissue damage and delay tissue healing. Strong anti-inflammatory agents found in medicinal plants can modify inflammatory pathways and accelerate healing of wounds. Among the key systems are Curcumin from turmeric stops the release and activity of important pro-inflammatory cytokines, such as tumor necrosis factor-alpha (TNF- α), interleukin-1 beta (IL-1 β), and interleukin-6 (IL-6). These cytokines define the development and maintenance of inflammatory responses (28). Medicinal plants also help to regulate the activities of immune cells. Some plant compounds, for example, affect macrophage polarization and neutrophil activity, so lowering too strong inflammatory responses and encouraging tissue regeneration. This double effect facilitates the start of the cascade of wound healing as well as the reduction of inflammation (29). One aspect of non-healing wounds that can cause delayed tissue recovery and more tissue damage is either persistent or chronic inflammation. Strong anti-inflammatory chemicals found in medicinal plants can alter inflammatory pathways and accelerate

healing of wounds. Curcumin from *Curcuma longa* (turmeric) stops key pro-inflammatory cytokines, like interleukin-1 beta (IL-1 β), interleukin-6 (IL-6), and tumor necrosis factor-alpha (TNF- α), from being released and activated. These cytokines define the development and maintenance of inflammatory reactions (28). Medicinal plants also help to regulate the activities of immune cells. Some plant compounds, for example, affect macrophage polarization and neutrophil activity, so lowering too strong inflammatory responses and encouraging tissue regeneration. This double effect reduces inflammation and helps the wound-healing cascade to start (29).

Antioxidant Efficacy

Effective wound healing is greatly hampered by oxidative stress brought on by an imbalance between the body's antioxidant defenses and the generation of reactive oxygen species (30). ROS, including hydroxyl radicals (\bullet OH), superoxide anions (O_2^-), and hydrogen peroxide (H_2O_2), oxidize proteins, lipids, and DNA, so generating major cellular damage (31). Chronic wounds' low collagen synthesis, tissue necrosis, and elevated inflammation all help to explain poor healing and are generally linked with ongoing oxidative stress. Excess ROS can throw off cellular signaling systems in charge of regulating angiogenesis, extracellular matrix deposition, cell proliferation, and inflammation resolution. Reducing these negative effects and encouraging healing thus depend on an antioxidant intervention (32). Redox balance is restored, and ROS is neutralized in great part by plant-based antioxidants. Among the many very significant medications and herbs are

- *Camellia sinensis*, green tea: From catechins, particularly epigallocatechin gallate (EGCG), strong anti-inflammatory and antioxidant effects abound. EGCG scavenges radicals, so reducing cellular damage; it also raises the activity of endogenous antioxidant enzymes, including catalase (33) and superoxide dismutase (SOD).
- The *Panax ginseng* are the ginsengs. Main active components in ginseng, ginsenosides, significantly boost the antioxidant capacity of the plant. By lowering ROS accumulation and supporting significant wound-healing mechanisms, including fibroblast proliferation, collagen synthesis, and angiogenesis, they so strengthen the body's natural defenses (34). These phytochemicals help cells regenerate, shield tissues from oxidative damage, and aid in the repair of the extracellular matrix, so fostering wound healing. Furthermore, since oxidative stress is obviously connected with immune suppression and higher risk of infection, antioxidants can help in wound healing and resistance against infections (35).

Using antioxidant-rich plant extracts, including green tea, ginseng, wound-healing treatments helps to augment traditional medicine. These botanical agents provide better therapeutic results with fewer complications in the treatment of acute and chronic wounds by directly attacking molecular pathways limiting tissue regeneration (36).

Medicinal Plants with Potential in Treating Antibiotic-Resistant Wounds

Aloe Vera—*Aloe barbadensis* Miller

Traditional medicine has been healing wounds with aloe vera for millennia. Among other bioactive components, anthraquinones, polysaccharides, and enzymes give aloe vera gel antibacterial and anti-inflammatory action. Extracts of aloe vera have shown promise in reducing bacterial load in wounds, encouraging cell migration, and hastening tissue regeneration. Research on wounds infected with *Staphylococcus aureus* and *Pseudomonas aeruginosa* indicates aloe vera may be especially beneficial (37).

Curcuma longa, the turmeric

The bioactive component of turmeric, curcumin, has been exhaustively studied for its anti-inflammatory, antibacterial, and wound-healing properties. By lowering inflammation, encouraging collagen synthesis, and increasing the synthesis of growth factors necessary for tissue regeneration, curcumin has shown the capacity to stop the spread of antibiotic-resistant bacteria, including MRSA, and help heal chronic wounds (38).

Melaleuca alternifolia oil

Long known for its antimicrobial qualities particularly in connection to *Staphylococcus aureus*, *Pseudomonas aeruginosa*, and other multidrug-resistant infections tea tree oil has been shown to permeate the skin and help to heal wounds by lowering bacterial load, so reducing inflammation, and so promoting tissue regeneration (39). Ayurvedic medicine has long made use of neem (*Azadirachta indica*) for its anti-inflammatory, antifungal, and antibacterial properties. Neem compounds have antibacterial action against many antibiotic-resistant species, including MRSA and *Pseudomonas aeruginosa*. Furthermore, helping wounds heal is neem's ability to lower inflammation, boost collagen synthesis, and induce angiogenesis the development of new blood vessels (40).

Garlic (*Allium Sativum*)

Sulfur-containing compounds make up garlic; most famously, allicin exhibits strong anti-inflammatory and antibacterial action. Studies have revealed that garlic extract can lower inflammation, stop the spread

of antibiotic-resistant bacteria, and promote healing of wounds. Regarding MRSA-induced infections, garlic has shown rather amazing potency (41).

Manuka Honey *Leptospermum scoparium*

Especially for treating long-lasting wounds from antibiotic-resistant bacteria, manuka honey—made from the nectar of the *Leptospermum scoparium* plant found in New Zealand—has impressive antibacterial and healing abilities. Manuka honey's unique ingredients—hydrogen peroxide and methylglyoxal (MGO)—increase its strong antibacterial action. Studies have demonstrated the effectiveness of Manuka honey against several multidrug-resistant bacteria, such as *Escherichia coli*, *Pseudomonas aeruginosa*, and MRSA (42). Apart from its antibacterial properties, Manuka honey promotes tissue regeneration, reduces inflammation, and raises angiogenesis, so helping to heal wounds. Additionally helps to maintain a hydrated wound environment, which is necessary for good healing of wounds. In treating chronic wounds, manuka honey has shown effectiveness in lowering bacterial load, shrinking wound size, and accelerating the healing process. Furthermore, its use can help to prevent infections and minimize scarring in wounds, so complementing wound management (30).

Lavender (*angustifolia lavandula*)

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Curcuma longa, the turmeric

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Lavender (*angustifolia lavandula*)

Lavender is well known for its medicinal properties, especially its ability to help wounds heal. It also smells great. Against many diseases, including antibiotic-resistant bacteria, the essential oil derived from *Lavandula angustifolia* shows antibacterial action. By upsetting bacterial cell membranes, lavender oil shows antibacterial action, so stopping microbial growth. Apart from its antibacterial properties, lavender oil has anti-inflammatory and antioxidant effects that improve its capacity for healing wounds. Research shows lavender oil can speed up wound healing,

boost tissue regeneration, and reduce pain connected to the healing of wounds. It is also known for helping to synthesize collagen, a crucial mechanism for healing damaged tissue (43).

Calendula (officinalis calendula)

For millennia, traditional medicine has used calendula—often known as marigold—to help heal wounds. Calendula extracts—including triterpenoids, saponins, and flavonoids—which have antibacterial, anti-inflammatory, and antioxidant properties—show evidence of bioactive action. By encouraging granulation tissue development, enhancing collagen deposition, and so promoting angiogenesis, calendula has shown the capacity to speed wound healing (44). Studies have demonstrated the effectiveness of calendula extracts against *Staphylococcus aureus*, *Pseudomonas aeruginosa*, and *Candida albicans*, among other infections. Calendula's antibacterial qualities come from its ability to destroy bacterial cell walls and stop biofilm development. For those with chronic wounds, calendula has shown effectiveness in reducing pain and inflammation; hence, it is a beneficial alternative for wounds unresponsive to conventional drugs (45).

Echinacea Purpurea

Renowned medicinal plant echinacea has been investigated exhaustively for its immune-boosting properties. Often used to cure or prevent the common cold, echinacea extracts also show antibacterial and anti-inflammatory action, which helps to manage chronic wounds. All of which are vital for wound healing, echinacea is known to increase white blood cell production, improve phagocytosis, and stimulate macrophage activity (46). Many studies have shown Echinacea's antibacterial action against antibiotic-resistant bacteria, including *Pseudomonas aeruginosa* and *Staphylococcus aureus*. Extracts from echinacea have the power to reduce inflammation, boost collagen synthesis, and speed tissue regeneration. Echinacea can boost the immune response, so it supports faster healing of resistant wounds and helps to fight ongoing infections (47).

Gotu Kola, Centella asiatica

Prominent in traditional medicine, particularly for treating skin conditions and promoting wound healing, *Centella asiatica*, sometimes known as Gotu Kola, is Triterpenoids such as asiaticoside and madecassoside, which help to explain *Centella Asiatica*'s wound-healing action, make up several bioactive components. Important for the healing of damaged skin, collagen and extracellular matrix components are produced in part by these compounds (48). Against several infections, including *Staphylococcus aureus* and *Pseudomonas aeruginosa*, *Centella*

asiatica shows antibacterial action. It has anti-inflammatory properties, which help to lower the chronic inflammation sometimes linked to infections resistant to antibiotics in wounds. Apart from its anti-inflammatory and antibacterial qualities, *Centella Asiatica* speeds up healing by encouraging angiogenesis and hence enhancing tissue regeneration (49).

Challenges in the Use of Medicinal Plant Extracts in Wound Treatment

Despite the many challenges that still exist in their clinical use, medicinal plants have enormous potential to heal antibiotic-resistant wounds. The challenges run in the following:

Verification and Standardization of Quality

Using therapeutic plant extracts presents a great difficulty mainly related to their lack of standardization. The various plant species, growing conditions, harvesting methods, and extraction technologies enable modifications to the composition and potency of plant extracts. This variety can influence the homogeneity and effectiveness of the therapy. Standardizing 50 plant extracts guarantees their constant therapeutic potency.

Side Effect and Toxicity

While many therapeutic herbs are considered safe, some plant extracts could have side effects, particularly if taken over long periods or at high dosages. Among the multiple side effects are skin irritability, hypersensitivity reactions, and organ poisoning. Moreover, several plant extracts could interact with other medications and produce side effects. Thus, thorough toxicological studies and clinical trials define the safety profile of medicinal plant extracts (51) for wound treatment.

Bioavailability and Systems of Transmission

The use of medicinal plant extracts presents still another difficulty given the bioavailability of the active components. Many of the bioactive compounds in plant extracts have low solubility, stability, and absorption, which limits their efficacy whether given topically or systemically. Advanced drug delivery systems like nanoparticles, liposomes, and hydrogels are being developed to improve how well plant-based compounds are transported and absorbed, aiming to address these problems. Maximum therapeutic efficacy of these technologies depends on stability, controlled release, and plant extract infiltration into the wound site (52).

Legal and Policy Guidelines

Different legal statuses across countries may prevent the extensive application of therapeutic plant

extracts in clinical practice. Plant-based drugs have raised concerns about their effectiveness and safety because their testing and approval procedures are sometimes less rigorous than those for conventional drugs. Therefore, the development of open regulatory frameworks and quality control criteria defines the safe and effective use of medicinal plants in wound healing (53).

Prospective Developments in the Application of Medicinal Flora for Antibiotic-Resistant Wounds

Antibiotic-resistant wounds challenge the global health scene more and more; thus, research of medicinal plant extracts becomes a necessary route for complementary and alternative medicine. Still, many research and development routes have to be explored if these plant-based treatments are to be included in standard clinical practice (54).

Advancement in Drug Delivery Systems

Clinical application of therapeutic plant extracts is much influenced by the bioavailability of active compounds. Among other bioactive substances in plant extracts, terpenoids, flavonoids, and alkaloids show poor solubility and stability, so restricting their efficacy in wound treatment. Thus, the development of sophisticated drug delivery systems is essential to improve the absorption, stability, and targeted distribution of these bioactive compounds (55). By means of nanoparticles, liposomes, hydrogels, and microspheres, investigating approaches will help to encapsulate and protect these compounds, so ensuring their effective transport to the infection site. By means of regulated and continuous release, these technologies maximize over time the therapeutic effects of plant extracts. Furthermore, these delivery systems can assist in increasing the penetration of plant-derived compounds into biofilm-forming bacteria, which are rather difficult to treat with traditional antibiotics (56).

Clinical research and evidence-based studies

Preclinical studies of medicinal plants have demonstrated their antibacterial, anti-inflammatory, and wound-healing qualities, while data from clinical trials still shows a great depletion of them. Most of the present data comes from laboratory research or animal models; more comprehensive and well-organized clinical trials are needed to ascertain the safety, efficacy, and ideal dosage of these plant extracts for the therapy of antibiotic-resistant wounds in humans (57). This research should mostly concentrate on the direct antibacterial properties of plant extracts as well as their capacity to support the general healing process. For the application of these treatments in clinical environments, analyzing parameters of wound healing—such as closure length, reduction of

infection rate, and tissue regeneration will provide important knowledge. Moreover, included in clinical research have to be side effects, drug interactions, and any long-standing issues with the implementation of plant-based treatments (58).

Standardization and Problems of Quality Control

The absence of standardization in their use and preparation greatly reduces the application of medicinal plants in modern medicine. Variance in the chemical content of plant extracts resulting from species, environmental conditions, harvest timing, and extraction techniques can generate differences in their potency and medicinal efficacy. Globally approved recommendations for the manufacturing, testing, and quality control of medicinal plant extracts will help to guarantee their safety and efficacy (58). Plant extractive active chemical content is measured in part by mass spectrometry and high-performance liquid chromatography (HPLC). This would ensure consistent therapeutic effects (59), thereby facilitating the development of formulations that meet accepted criteria.

Ethical Buying and Environmentalism

Treating antibiotic-resistant wounds with medicinal plants raises serious ethical and environmental issues as well as questions about source. Thus, overuse of some plant species could endanger biodiversity and cause the loss of natural resources. Moreover, the production of medicinal plants usually depends on specific growing conditions; hence, climate change could change these factors, so reducing the availability (60). Clearly important is the environmentally sustainable acquisition of plant resources. This covers the application of sustainable agricultural methods, the development of plants in controlled surroundings (such as botanical gardens or greenhouses), and the collecting of plants in a way that preserves biodiversity. Moreover, ethical sourcing rules have to guarantee fair trade benefits and pay for local people working on plants (61).

Harmonious Integration with Classical Therapies

Incorporating medicinal plants into current healthcare systems is crucial for their widespread acceptance in treating antibiotic-resistant wounds. This means creating mixed treatments combining conventional therapies, including antibiotics and antiseptics, with medicinal plants' antibacterial and wound-healing properties. Combining phytotherapy with conventional antibiotics could have synergistic effects, boosting the efficacy of both treatments (62). Moreover, essential for allowing plant-based treatments to be included in accepted wound care protocols are interactions among doctors, chemists,

botanists, and regulatory authorities in several disciplines. This all-encompassing approach can help to translate studies on medicinal plants into beneficial effects for patients, so reducing the worldwide load of antibiotic-resistant diseases (63).

Conclusion

One of the main worldwide health issues is the growing frequency of wounds resistant to antibiotics. Conventional antibiotics are losing their potency; thus, alternative treatment approaches are much needed. With many plants showing antimicrobial, anti-inflammatory, and wound-healing qualities, medicinal plant extracts present a beneficial answer. Treatment of antibiotic-resistant infections and chronic wounds has shown tremendous promise from plants, including aloe vera, turmeric, tea tree oil, neem, garlic, and manuka honey. Medical plant extracts' inclusion into clinical practice does, however, present several difficulties, including problems with standardization, toxicity, bioavailability, and regulatory approval. Overcoming these obstacles by means of standardized, safe, and successful plant-based treatments should be the main emphasis of the next studies. Furthermore, improving the therapeutic possibilities of medicinal plants could be the use of modern delivery systems. All things considered, natural and sustainable means of treating antibiotic-resistant wounds, medical plant extracts offer a beneficial addition to conventional treatments.

Funding

This study results from independent research conducted without financial support.

Ethics approval and consent to participate

Not applicable.

Conflict of Interest

No conflicts of interest were disclosed.

Consent for publication

Not Applicable

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