REVIEW ARTICLE

Potential Benefits of *Moringa oleifera* for Diabetic Foot Ulcers – Future Research and Applications

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ABSTRACT

Diabetic foot ulcers are permanent scars in people with diabetes that result from nerve damage, inadequate blood flow, and infection. The ulcers not only cause significant financial burdens but also remain poorly controlled, necessitating the need for new therapeutic approaches. *Moringa oleifera*, or *Moringa*, has the potential to be more valuable in the treatment of diabetic foot ulcers due to its long-standing and traditional use. Several civilizations, especially in Africa and Asia, have administered the *Moringa* plant for quite a long period of time, due to its medicinal values in curing wounds and infections through traditional medicine. It is precisely the extensive composition of phytochemicals, including vitamins, minerals, flavonoids, and phenolic compounds, that shapes this herb's medicinal potential. Ultimately, these are elements that relate to meaningfully striking antibacterial, anti-inflammatory, and antioxidant impacts. The extracts of *Moringa* are known to carry a pharmacological potential that, importantly, contributes to wound healing. Research indicates that the herb can accelerate wound healing, lower the number of microorganisms, and promote the regeneration of damaged tissue. Some of the basic mechanisms include oxidative stress regulation, promotion of collagen formation, and mitigation of inflammatory reactions, all of which play a crucial role in the improvement of ulcer healing. In the near future, the incorporation of *Moringa* into treatment against diabetic foot ulcers presents substantial hope. Future studies should focus on formulation procedures to improve and understand the long-term consequences of combined applications with traditional therapies. Applying *Moringa's* natural healing abilities to ulcer treatment could potentially transform diabetic foot ulcers treatment into long-lasting plant-based solutions, improving patient outcomes.

Keywords: Diabetic foot ulcers, *Moringa oleifera*, Phytochemistry, Pharmacology, Mechanisms, Wound healing.

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INTRODUCTION

Diabetic foot ulcers (DFU) are chronic, open sores or wounds in the feet of individuals suffering from this disease. Their development may be attributed to neuropathy, poor circulation, or high blood sugar levels. They most commonly occur on parts of the foot that bear weight, i.e., the heels, balls of the foot, or toes.[1] DFUs are a major complication of diabetes, with 15–25% of subjects who have diabetes experiencing a DFU sometime in their lifetime. Rather, the prevalence is very high in those with long-standing diabetes mellitus, poor glycaemia control, and the presence of comorbid conditions.[2] DFUs have a devastating impact on patients' quality of life. The physical symptoms associated with pain, discomfort, and immobility can be quite overwhelming, as well as grossly debilitating to the patient's independent functioning. Patients with diabetic foot ulcers have difficulties while walking, which disables normal activities and social interaction. This further contributes to a sedentary lifestyle that culminates in more serious health issues, such as obesity and cardiovascular diseases.[3]

In addition, ulcers often lead to long periods of treatment, repeated consultations, and treatment in medical institutions, and, in the worst cases, hospitalization and even disability. Such developments have an impact not only on the patient's physical state but also on their mental state, causing them to become depressed or anxious or to lose self-pride. The financial burden is also critical because of medical expenses, drugs, and possibly reduced income from weakened work capacity. DFUs present numerous treatment issues. Factors such as

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poor blood circulation, infection, and high blood glucose level often complicate the process of wound healing. Effective management demands the need to incorporate specialists such as wound care therapists, endocrinologists, and occasionally surgeons. In spite of the numerous advancements in treatment options, like advanced wound dressings, different modes of surgery, and offloading devices it's still doubtful to get many patients to heal completely.[4]

Infection dominates the majority of patient's complications and may cause severe consequences, including gangrene and disability. The presence of antibiotic-resistant bacteria further complicates the treatment. Finally, variations in patient compliance and access to appropriate care resources may manifest as problems with the root causes of DFUs, such as better diabetes management and improved methods or approaches. Despite the progress in understanding and management, we still face challenges in prevention, treatment, and patient support, all aimed at reducing the profoundly detrimental effects on the lives of individuals suffering from DFUs.[5]

Description of *Moringa*

Moringa oleifera Lam. (*M. oleifera*), also known as drumstick or horseradish is commonly used to refer to the genus in the *Moringa*ceae family, amongst the *Moringa* genre.[6] *M. oleifera*, acquainted with "Tree of Wonders", "Tree of Life" and "Diamond of Plants", is widely cultivated for its drought resistance, rapid growth and nutrient-rich properties in African and Asian countries.[7] The most well-known type in this recent variety is *oleifera,* renowned for its qualities as both a food source and a traditional medicinal herb. The other relatives include *stenopetala*, which bears a resemblance to *oleifera* but is typically consumed as part of a high diet in Ethiopia and Kenya, and *Moringa peregrina*, a plant commonly found in the Arabian Peninsula consumable one is peregrina. *Moringa oleifera* has been extensively researched and used. It is a deciduous, fast-growing tree that can reach up to 10 meters in height. Parts of *M. oleifera*, the leaves, seeds, and pods, are nutritious and rich in contents that include, among others, Vitamin A, Vitamin C, Vitamin E, Calcium, Potassium, and proteins. The tree produces small, white, pretty flowers, which are fragrant and carried in thin, long, pod-like structures known as drumsticks.

Apart from *M. oleifera*, there are *Moringa stenopetala* and *Moringa peregrina*, which maintain the same uses adapted to different environments. Traditional medicine and local culinary art, primarily in parts of East Africa, use the larger leaves of *Moringa stenopetala*. It is native to arid regions and serves as a drought-resistant plant with oil-rich seeds.[8]

Geographical Distribution

Moringa is native to the sub-Himalayan regions of India, stretching from India eastwards to Pakistan, Bangladesh, and Afghanistan. It has spread to tropical and subtropical regions all over the world because it is generally adaptable and offers many benefits compared to such considerations as risks and performance records. The plant flourishes in positively hot and arid conditions, and it is widely cultivated in Africa, Southeast Asia, and Latin America. Its hardiness to drought and poor soil conditions make it a plant that seems to contribute a lot to nutrition and economic development at the same time, which is very important in most developing countries. Distribution of *Moringa* products continues to expand, with international acclaim given to its nutritional and medicinal value.[9, 10]

Traditional and historical uses

Different civilizations have used *Moringa* over the centuries. Ancient Indians used it extensively and found its medicinal value in Ayurvedic texts. It was well-known in traditional African medicine for its use in treating infections, malnutrition, and inflammation. In the Philippines, it has gained widespread use as an ingredient in soups and stews due to its claimed benefits. *Moringa* leaves, seeds, and pods have been used to treat gastrointestinal, skin, and respiratory diseases. Such widespread traditional applications are a clear indication that this plant was very vital and versatile under varying cultures.[11] Table 1 provides a brief overview of the traditional historical uses of *Moringa*, highlighting its application in various cultures for similar purposes.

Historical and Traditional Knowledge

Historical use in wound healing

Moringa has a long history of use in wound healing, with both anecdotal and documented evidence. Ancient Ayurvedic medicine reported *Moringa oleifera* as a highly popular wound healing and antiseptic medicine due to its germ-killing and

Table 1: Traditional and historical uses of *Moringa oleifera* across different regions

Aspect	*Description*	*Cultural regions*	*Uses*
Historical Use in Wound Healing	Application of *Moringa* leaves and seeds in treating wounds and infections.	Ancient India, Africa, and the Philippines.	Poultices and topical applications to accelerate healing and prevent infections.
Traditional Medicinal Practices	Utilization of *Moringa* in traditional medicine for various ailments.	India, Africa, Southeast Asia.	Remedies for digestive issues, skin conditions, and respiratory problems.
Traditional Preparations	Different methods of preparing *Moringa* for medicinal use.	India: Leaf pastes; Africa: Leaf poultices; Philippines: Boiled leaf solutions.	Topical treatments for wounds, infusions for general health, and dietary supplements.
Folklore and Indigenous Knowledge	Beliefs and practices surrounding the spiritual and healing properties of *Moringa*.	Africa: Spiritual protection and health maintenance; India: Ayurvedic healing practices.	Used in rituals and ceremonies, and believed to provide protection and promote vitality.

anti-inflammatory activities. The treatment includes *Moringa* leaves and oil poultices. Most African traditional medical practices use the leaves and seeds of the *Moringa* tree to prepare poultices, which aid in the healing of wounds and ulcers among the sick. For instance, Uganda and Nigeria utilize a significant amount of *Moringa* leaves to create pregnancy and wound poultices, which they then apply topically to ensure proper and effective healing without infection. Recent research has also confirmed those traditional uses and showed that *Moringa* contains antimicrobial and antioxidant features that contributed to faster healing and anti-inflammatory action.[12]

Traditional practice

Traditional practice involves preparing the *Moringa* tree in various cultural medicinal areas and methods. For instance, in India, people commonly prepare the leaf as a paste with other herbs and apply it externally to wounds, rashes, or skin infections. In the Philippines, people boil the leaves and apply them topically to cuts and bruises.

Moringa is an important aspect of folklore and indigenous knowledge. For instance, it was believed among some African communities that the tree possesses spiritual properties, safeguards them from evil spirits, and works towards restoring health. Traditional knowledge further confirms the tree's role in maintaining overall health and vitality. Rituals and special ceremonies intended to enlist the supposed protective and healing powers of *Moringa* always reinforce the need for its use in indigenous practices.[13]

These are some of the historical and cultural practices that demonstrate deep belief in the effectiveness of *Moringa* and its incorporation into traditional medicinal systems globally.

Moringa's Phytochemistry

Major Phytoconstituents

It is believed that *Moringa* oleifera's phytochemicals are the primary source of nutritional and therapeutic underpinnings.

- *Vitamins and Minerals*

Moringa leaves contain numerous essential vitamins and minerals. It is a great source of beta-carotene, or Vitamin A, Vitamin C, Vitamin E, and several B vitamins, such as Vitamin B6 and folate. Additionally, *Moringa* enjoys high rates of minerals - calcium, iron, magnesium, potassium, and zinc. All of these have an impact on the immune system's function, bone viability, and cell capture processes.[14]

- *Antioxidants*

As a plant rich in antioxidants, they effectively protect against free radicals by counterbalancing oxidative stress. Vitamin C, vitamin E, and beta-carotene are considered to be among the most prominent antioxidants. Such compounds provide protection from cellular damage and reduce the risk of chronic diseases like cardiovascular disease and cancer.[15]

- *Flavonoids and phenolic compounds*

The leaves and seeds of this plant contain flavonoids, such as quercetin, kaempferol, and chlorogenic acid, all attributed to be anti-inflammatory, antioxidant, and neuroprotective in function. Other phenolic compounds, like caffeoylquinic acid, contribute to the ability of this plant to fight against both oxidative stress and inflammation.[16,17]

Table 2 depicts the majorly present phytochemicals in *Moringa* and their categories, functions, and impact on health, with a particular emphasis on the manner in which they synergies to provide the therapeutic benefit derived from *Moringa* oleifera.

Bioactive components

The bioactive compounds within *Moringa* are responsible for its wide-ranging health benefits. In summary, the bioactive compounds in *Moringa* serve the following functions:

Antioxidants

Moringa antioxidants, particularly Vitamin C and E, act in a way that scavenges free radicals and decreases or reduces

Table 2: Principal Phytochemicals in *Moringa oleifera*

Phytochemical	*Type*	*Key Functions*	*Impact on Health*
Vitamins	Nutrients	Essential for various bodily functions. Includes Vitamin A, C, E, and several B vitamins.	Supports immune function, skin health, antioxidant defense, and overall cellular health.
Minerals	Nutrients	Includes calcium, iron, magnesium, potassium, and zinc.	Promotes bone health, oxygen transport, muscle function, and enzyme activity.
Beta-carotene	Carotenoid (Antioxidant)	A precursor to Vitamin A with strong antioxidant properties.	Protects cells from oxidative stress, supports vision, and boosts immune function.
Quercetin	Flavonoid	Has anti-inflammatory and antioxidant effects.	Reduces inflammation, supports cardiovascular health, and alleviates allergy symptoms.
Kaempferol	Flavonoid	Exhibits antioxidant and anti-inflammatory properties.	Enhances cellular protection, reduces inflammation, and may help in cancer prevention.
Chlorogenic Acid	Phenolic Compound	Known for antioxidant and anti-diabetic effects.	Regulates blood sugar levels, reduces oxidative stress, and supports metabolic health.
Benzyl Isothiocyanate	Isothiocyanate	Provides antimicrobial and anti-inflammatory effects.	Helps control infections and reduces inflammation in chronic wounds.
Caffeoylquinic Acid	Phenolic Compound	Has antioxidant and anti-inflammatory properties.	Supports overall health by reducing oxidative damage and inflammation.

oxidative damage to the cells. Such an action is helpful in protecting against chronic diseases and age-related disorders. Another powerful antioxidant is beta-carotene, which plays a pivotal role in the maintenance of eyes and immunity.[15]

Flavonoids

Quercetin and kaempferol in *Moringa* express potent anti-inflammatory and antioxidant activities. Quercetin has the ability to modify immune system functions, which reduces inflammation and allergic responses. Studies have demonstrated that Kaempferol lowers oxidative stress, maintains cardiovascular health by enhancing endothelial function, and lowers blood pressure.[16]

Phenolic Compounds

These plant compounds, such as chlorogenic acid, provide the *Moringa* plant's anti-inflammatory and anti-diabetic activity. Chlorogenic acid regulates blood sugar—it inhibits glucose absorption in the intestines and increases insulin sensitivity. The presence of phenolic compounds also accounts for the antimicrobial activity, supporting potent wound healing and overall immune defense.[18]

Moringa's diverse phytochemical composition enhances its traditional use in health promotion and disease prevention, underscoring its value as a functional food or medicinal plant.

Pharmacology of *Moringa*

Pharmacokinetics and Pharmacodynamics

Comprehensive human data are still scarce, although the pharmacokinetics and pharmacodynamics of *Moringa oleifera* have been the subject of various studies. According to existing research, here are the basics: [14]

Absorption

Most of the key compounds in *Moringa* are vitamins, minerals, and bioactive phytochemicals. Their bioavailability depends on the form and presence of other nutrients. When consumed, the gastrointestinal lancet fairly absorbs nutrients from *Moringa* at appropriate doses. For instance, combining *Moringa* with a high vitamin C diet enhances the absorption of minerals like calcium and iron.

Distribution

Once absorbed, the blood circulation distributes the active principles of *Moringa* throughout the body. The body distributes vitamins A, C, and E to wide tissues, where they impose antioxidant activities. Similarly, reports suggest that flavonoids and phenolic compounds circulate into the blood stream, reaching various organs and tissues of the body to participate in anti-inflammatory and anti-microbial events.

Metabolism

The liver primarily metabolizes the phytochemicals in *Moringa*, transforming them into their multiple metabolites. For instance, the liver metabolizes flavonoids and phenolic compounds into conjugated forms that may be more extractable or possess a distinct biological activity. Metabolic pathways of *Moringa* components are complicated and tend to involve conjugation reactions like sulfation and glucuronidation.

Excretion

Most of the metabolites resulting from *Moringa*'s constituents are excreted in urine and feces. The kidneys clear water-soluble vitamins and their metabolites, while bile excretes some fat-soluble compounds and their conjugated forms. Individual metabolic rates and overall health can modify the rate and efficiency of excretion.

Table 3 briefly shows the effect of *Moringa*'s pharmacokinetics and pharmacodynamics on potential therapeutic action in diabetic foot ulcer management.

Clinical Efficacy

Moringa oleifera is clinically effective in wound healing, anti-inflammatory, and antimicrobial activities.

Wound healing

Clinical studies have indicated the effectiveness of *Moringa* in wound healing. Studies have shown that treating subjects with *Moringa* leaf extracts significantly reduces wound healing time. For instance, a study in the Journal of Ethnopharmacology revealed that *Moringa* leaf extract speeds up wound healing in diabetic rats by boosting collagen production and reducing oxidative stress. Another study demonstrated that ointments of *Moringa* plant extracts in wound repair and regeneration actively facilitated repair by causing epithelialization and reducing inflammation.

Numerous research studies have evaluated *Moringa* for its anti-inflammatory properties. Evidence from clinical studies indicates that it can bring down inflammatory markers like

Table 3: *Moringa oleifera's* pharmacokinetics and pharmacodynamics

Aspect	*Description*	*Relevance to DFU Management*
Absorption	*Moringa*'s nutrients and bioactive compounds are absorbed through the gastrointestinal tract. Vitamins and minerals are absorbed efficiently, while compounds like flavonoids may have variable bioavailability.	Effective absorption is crucial for delivering therapeutic benefits to the wound site and systemic health support.
Distribution	Active compounds are distributed throughout the body via the bloodstream. Vitamins such as A, C, and E, and flavonoids circulate to various tissues.	Ensures that *Moringa*'s therapeutic compounds reach the wound site and other affected tissues.
Metabolism	*Moringa*'s phytochemicals are metabolized primarily in the liver through conjugation reactions, including sulfation and glucuronidation.	Metabolism can influence the duration and intensity of *Moringa*'s effects on inflammation and healing.
Excretion	Metabolites are excreted through urine and feces. Water-soluble vitamins and their metabolites are excreted via the kidneys, while fat-soluble compounds are excreted in bile.	Efficient excretion is important for minimizing potential toxicity and maintaining optimal levels of active compounds.

CRP and pro-inflammatory cytokines. The Journal of Clinical Biochemistry and Nutrition published one such study, which showed that supplementing with *Moringa* significantly reduced the levels of inflammatory markers in arthritis patients. *Moringa*'s high content of flavonoids like quercetin and kaempferol, which inhibit inflammatory pathways and reduce the production of inflammatory mediators, is responsible for these effects.[12]

Antimicrobial Properties

Moringa possesses phenomenal antimicrobial activity against a variety of pathogens, such as bacteria, fungi, and viruses. Clinical studies have reported that *Moringa* leaf extracts can inhibit the growth of bacterial strains in both Staphylococcus aureus and Escherichia coli. For instance, Phytotherapy Research published a study that demonstrated the strong activity of *Moringa* leaf extracts against common wound-infecting bacteria. The antimicrobial properties of *Moringa* extend to fungal pathogens, making it a broad-spectrum compound with activity justifiable by its traditional use in treating infections.

To put it another way, although *Moringa*'s pharmacokinetics preclude proper absorption and distribution of its active compounds, the pharmacodynamics produce curative potential with seriously interesting therapeutic implications for wound healing, inflammation, and activity against microorganisms, among other things.[19]

Mechanisms of Action on Management of DFU

DFUs are recurrent, chronic lesions that pose a major challenge to treatment and often succumb to chronic inflammation, infection, and poor healing. Recently, *Moringa* oleifera has appeared as adjunctive therapy with multifaceted mechanisms of action in the management of DFUs. Here is an insight into how *Moringa* aids in the management of DFUs through its anti-inflammatory, antimicrobial, and wound-healing properties.

Anti-inflammatory

Moringa's anti-inflammatory properties would be important in the management of DFUs, where inflammation has often disrupted healing processes. Key pathways and impacts include (Figure 1).

Pro-inflammatory Cytokines Inhibition

The bioactive components of *Moringa*, which include flavonoids like quercetin and kaempferol, and phenolic acids like chlorogenic acid, are known to reduce the production of pro-inflammatory cytokines like tumour necrosis factor-alpha (TNF-A) and interleukins like IL-1 and IL-6, which are important markers of the inflammatory response and contribute to the development of chronic wounds.[20]

Modulation of the NF-kB Pathway

The *Moringa* components may modulate the nuclear factor-kappa B (NF-KB) signaling pathway. Activation of this transcription factor induces several inflammatory genes. *Moringa* inhibits this pathway, thereby reducing the ensuing inflammatory response and aiding in the control of chronic inflammation in DFUs.[21]

Reduction of Oxidative Stress

Moringa's antioxidant properties have been linked to compounds such as Vitamin C, Vitamin E, and beta-carotene. It helps balance oxidative stress by counteracting free radicals. Less oxidative stress results in fewer inflammations, creating a more conducive environment for wound healing.[14]

Targeting such inflammatory pathways, *Moringa* helps reduce the inflammatory burden of DFUs, thus making it more conducive for repair and regeneration.

Antimicrobial Properties

Infection is a major complication in DFUs, and *Moringa*'s antimicrobial properties play an important role in infection control (Figure 2).

Activities that stop bacteria

Moringa extracts are very good at killing common bacteria that cause DFU infections, like S. aureus, Escherichia coli, and Pseudomonas aeruginosa. Its antimicrobial mechanism consists of benzyl isothiocyanate and other phenolic compounds, causing damage to bacteria's cellular walls and inhibiting bacterial growth.[22]

Fungal and Viral Activities

Moringa also holds antifungal and antiviral activity and is generally said to exert a broad spectrum of antimicrobial

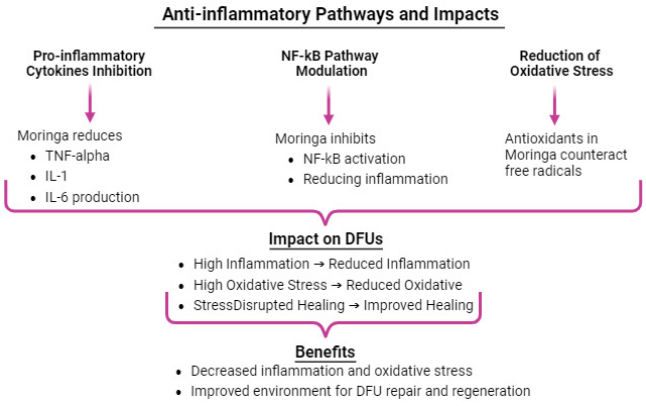

Figure 1: Anti-inflammatory pathways and impacts

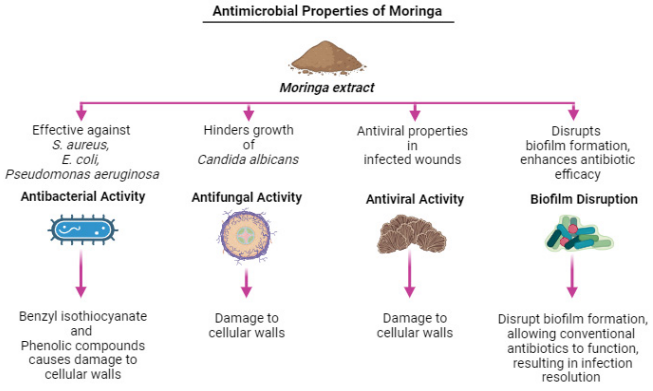

Figure 2: Antimicrobial properties of *Moringa* in managing Diabetic Foot Ulcers (DFUs)

activity. It hinders the growth of fungi such as Candida albicans, and studies have also demonstrated its antiviral properties in those who have infected wounds.[23]

Biofilm Disruption

Bacteria that colonies in chronic wounds can develop biofilms on the surface, which inhibit treatment. *Moringa* is known to disrupt biofilm formation, allowing conventional antibiotics to function, resulting in infection resolution.[24]

Moringa aids in further effective DFU management by fighting against the microbial pathogen and preventing biofilm formation, which helps to maintain a cleaner wound ecology.

Promotes Wound Healing

Moringa supports all phases of the wound healing process, which are essential for the management of DFUs (Figure 3).

Collagen Synthesis

Collagen is a fundamental component of the extracellular matrix and is particularly important for wound strength and structure. Results have indicated that *Moringa* increases collagen formation in the wound bed, which consequently increases the tensile strength in the wound and leads to faster closure. Some of the other results are those shown by the *Moringa* extracts, which induce fibroblasts to further prepare collagen with its associated organizational role in the structure of repairing tissue.[25]

Cellular Regeneration

Moringa enhances cellular regenerations with its various cell types, such as keratinocytes and fibroblasts, which are responsible for the repair process. *Moringa*'s bioactive compounds stimulate cell proliferation and migration into the wound area. This further stimulates and paces the process of epithelization and tissue fixation. According to reports, the proliferation of these cells, which contribute to faster wound closure, has increased.[26]

Angiogenesis

This process of wound repair constitutes the formation of new blood vessels, including the supply of oxygen and nutrition. *Moringa* promotes angiogenesis by modulating growth factors, such as vascular endothelial growth factor (VEGF). The process enhances blood supply to the wound area, thus supporting repair and tissue regeneration.[27]

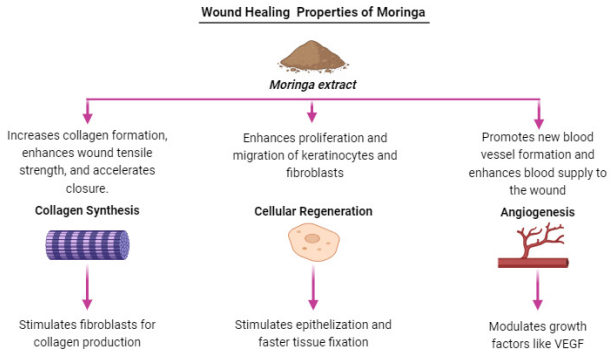

Figure 3: *Moringa's* Role in Wound Healing for Diabetic Foot Ulcers (DFUs)

Moringa channels its manifold mechanisms of action: its anti-inflammatory, wound-healing effects, and antimicrobial properties come together to make it a valuable adjunct in the management of diabetic foot ulcers. *Moringa* plays a crucial role in addressing inflammation, infections, and tissue repair, all of which are crucial factors that contribute to a patient's optimal outcomes during the treatment of chronic diabetic foot ulcers.

Table 4 elaborates on how *Moringa*'s different mechanisms of action lead to effective management of DFUs and hammers, highlighting its potential as an adjuvant in wound care.

Future Perspectives

Despite the great promise, there are significant research gaps that severely hinder the use of *Moringa oleifera* in diabetic foot ulcer management:

Large-Scale Clinical Trials

Early studies and small-scale clinical trials involving *Moringa* for wound healing have yielded positive results, so there is a need for well-designed original clinical trials in this area to capture all of these findings. Small sample sizes and short durations limit the majority, preventing them from fully capturing the benefits and safety profile of *Moringa*.[12]

Extraction Standardization

It's hard to compare studies because *Moringa* extracts are made from different parts of the plant (leaves, seeds, and pods), and the methods used to make the extracts are also different. Standardized extracts, specifically those with a well-defined concentration of the active compound, are necessary for this purpose to guarantee reproducible and reliable therapeutic outcomes.

Mechanistic Understanding

Notwithstanding the documentation of *Moringa*'s anti-inflammatory effects, antimicrobial action, and wound-healing properties, their molecular-level mechanisms require further elaboration. In-depth research focused on interactions of bioactive compounds within *Moringa* at the cellular and molecular pathways would perhaps increase the plant's therapeutic uses and, in particular, assist in developing more targeted treatments.

Long-term Safety and Efficacy

The real long-term impact of *Moringa* supplementation or topical application, especially in individuals suffering from chronic diseases such as diabetes, is not well known. An elaborate safety assessment and long-term efficacy study will go a long way towards determining the role of *Moringa* in the management of DFU in a sustained way.[28]

Clinical Integration Potential

There are several opportunities to incorporate *Moringa* into clinical practice for the management of DFUs.

Adjunctive Therapy

Standard treatment of DFUs can include *Moringa* as an adjunctive therapy. *Moringa*'s anti-inflammatory,

Table 4: The mechanism of action of *Moringa* Oleifera in the management of diabetic foot ulcers

Mechanism	*Description*	*Impact on DFU Management*
Anti-inflammatory Effects	Inhibition of pro-inflammatory cytokines (e.g., TNF-α, IL-1β) and modulation of NF-kB pathway.	Reduces chronic inflammation, creating a more favorable environment for wound healing.
Oxidative Stress Reduction	Antioxidant activity through compounds like Vitamin C, Vitamin E, and beta-carotene.	Decreases oxidative damage, supports cell function, and aids in tissue repair.
Antimicrobial Properties	Antibacterial, antifungal, and antiviral effects from compounds such as benzyl isothiocyanate and phenolic acids.	Controls infections, reduces microbial load, and prevents complications associated with chronic wounds.
Biofilm Disruption	Disruption of biofilm formation by bacteria in wounds.	Enhances the effectiveness of antibiotics and improves wound healing by preventing persistent infections.
Promotion of Collagen Synthesis	Stimulation of fibroblasts to increase collagen production.	Strengthens wound tissue, improves wound tensile strength, and accelerates healing.
Cellular Regeneration	Enhancement of keratinocyte and fibroblast proliferation and migration.	Facilitates epithelialization and overall tissue repair.
Angiogenesis	Upregulation of vascular endothelial growth factor (VEGF).	Promotes new blood vessel formation, improving blood supply to the wound area and supporting healing.

antimicrobial, and wound-healing properties make it conform to standard, conventional protocols for wound treatment. For instance, adding *Moringa* to conventional treatment can enhance healing rates and prevent infections.[29]

Nutritional Supplement

Given the rich nutrient profile of *Moringa*, it can serve as a suitable nutritional supplement to the diet, promoting overall health and accelerating wound healing. For diabetic patients, nutritional supplementation with *Moringa* powder or capsules becomes significant, as it increases the likelihood of being nutrient-sufficient, thereby improving wound healing outcomes.[30]

Tailored Formulations

Future formulations of *Moringa* extract will be tailored to specific needs, such as an advanced wound dressing, gel formulation, or topical cream. We can optimize these for improved absorption and effectiveness in managing DFU.

Sustainable and Innovative Applications

The future for *Moringa* in DFU management also includes sustainable and novel applications:

Formulation Strategies

Innovative formulation strategies may improve *Moringa*'s effectiveness in wound care. For instance, adding these *Moringa* extracts to hydrogels, nanocarriers, or any other advanced delivery system will stop the breakdown and improve the bioavailability and targeted delivery of the active components of *Moringa* to the wound site. This will improve the healing effects and make the *Moringa* product more useful for clinical use.[31-34]

Sustainable Cultivation

Moringa has an underlying resilience and adaptability, making it one of the plants chosen for sustainable agricultural practices. This is evident in sustainable plant growing practices such as organic farming and agroforestry, which ensure a continued good supply of *Moringa* while also being environmentally friendly.

Bioengineering Applications

The ongoing advancements in bioengineering have the potential to unlock new applications for *Moringa* in wound-care. For example, incorporating *Moringa* extracts into bioengineered skin substitutes or scaffolds would provide added therapeutic benefit and positively contribute to tissue regeneration in DFUs.

The promotion of *Moringa* cultivation in regions reporting a high incidence of DFU will have a positive economic impact on the community. In this case, the local farmers and the community as a whole, through the cultivation of this crucially important plant, benefit not only from the easy availability of recognized natural resources but also from the boost to their local economies. Additionally, it could aid in addressing global health issues such as diabetes and wound care.[32-34]

To fully harness *Moringa*'s potential in DFU management, it must help bridge certain research gaps and foster innovative applications. *Moringa*, which focuses on comprehensive clinical studies and advanced formulation development for sustainable practice, may become an important contributor to improving outcomes with diabetic foot ulcers.

CONCLUSION

Moringa oleifera offers a promising supplementary therapy for management of diabetic foot ulcers (DFUs) owing to its numerous therapeutic properties. The anti-inflammatory, antibacterial, and wound-healing properties of this substance efficiently address the major problems associated with DFUs, such as chronic pain, infection management, and regeneration of tissue. To fully assess its safety and efficacy, it is essential to conduct more comprehensive and precisely designed clinical trials. It is necessary to standardize extracts, explore molecular mechanisms, and create new formulations in order to enhance the therapeutic value of *Moringa* in medical applications. As research advances, introducing *Moringa* into DFU treatment strategies might significantly enhance patient satisfaction and contribute to more efficient and long-lasting wound care solutions globally.

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