In-vitro wound-healing activity of the aqueous leaf extract of *Moringa oleifera*

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ABSTRACT

The skin's integrity is restored following an injury through wound healing, a crucial biological process that involves inflammation, tissue formation, and remodelling. Medicinal plants have long been researched for their potential to heal wounds due to their bioactive components. Moringa oleifera has been used extensively as a medicinal plant and has demonstrated anti-inflammatory, antibacterial, and antioxidant properties that may aid in wound healing. The in-vitro wound-healing activity of Moringa oleifera's aqueous leaf extract is investigated in this study using the scratch test on fibroblast cell lines.

Following maceration and phytochemical screening, the aqueous extract contained flavonoids, tannins, alkaloids, saponins, and phenolic compounds, all of which are known to aid in wound healing. Tests were performed at various concentrations (50, 100, and 200 µg/mL) to evaluate the extract's effect on fibroblast migration and proliferation over a 24- and 48-hour period. The results demonstrated a concentration-dependent increase in wound closure and cell migration, with the largest effect at the highest concentration (200 µg/mL). The antibacterial and antioxidant properties of the extract most likely contribute to increased fibroblast migration and proliferation, which hastens the healing process of wounds.

More research, including mechanistic studies and in-vivo models, is needed to understand its molecular mechanism of action and validate its clinical applicability. These findings suggest that the aqueous leaf extract of Moringa oleifera may be used as a natural wound-healing remedy.

Keywords: Moringa oleifera, wound healing, fibroblast migration, scratch assay, medicinal plants, herbal medicine, cell proliferation, natural therapy, antimicrobial, phytochemicals, traditional medicine, tissue regeneration, wound repair, bioactive compounds, skin regeneration, in-vitro study, plant-based therapy, cytokines, growth factors.

1.INTRODUCTION

Hemostasis, inflammation, proliferation, and remodeling are among the overlapping phases of the complex biological process that is wound healing. Cellular response, deposition of extracellular matrix, and growth factor action are among the factors that influence the quality of wound healing. Chronic wounds, infection, and other conditions that impact patient health and healthcare systems can arise from poor or delayed healing. The possibility of natural remedies from medicinal plants to cure wounds has been extensively explored. Extensive use has been made of Moringa oleifera, also referred to as the drumstick tree or miracle tree, due to its antibacterial, antioxidant, and anti-inflammatory activities. The plant, native to India, Africa, and parts of Asia, is widely recognized globally for its pharmacological benefits and rich phytochemical profile.

Bioactive compounds like flavonoids, tannins, alkaloids, saponins, and phenolics are particularly common in the leaves of Moringa oleifera. They increase collagen formation, reduce oxidative stress, and enhance fibroblast proliferation to facilitate tissue regeneration. Antibacterial activity is also present in the plant against numerous types of bacteria, and this can contribute to the avoidance of wound infections and the enhancement of the process of healing.

In spite of the traditional claims about the wound-healing ability of Moringa oleifera, strong scientific support via in-vitro studies is wanting. Information about its biological action and therapeutic role can be obtained through the evaluation of its activity by utilizing an established model of wound healing, such as the scratch test. The scratch assay is an in vitro test widely employed that allows one to monitor fibroblast migration and proliferation, two essential phases in wound healing.

Through an in-vitro scratch assay method, this research tries to evaluate the aqueous leaf extract of Moringa oleifera's wound healing ability. The ability of the extract to induce cell migration, proliferation, and wound closure in fibroblast cultures will be determined. The findings of this research can help in the development of plant-derived medicinal compounds for skin regeneration and wound healing.

With the in-vitro scratch assay, the present work aims to determine the aqueous leaf extract of Moringa oleifera's wound-healing potential. The capacity of the extract to stimulate cell migration, proliferation, and wound closure of experimentally induced wounds in fibroblast cultures is particularly investigated here. This study may be useful in creating low-cost, plant-derived wound care products and provide valuable information on the medicinal value of Moringa oleifera.

Water-soluble compounds are polyphenols and other useful phytochemicals. Polyphenols' high water solubility and large molecular sizes, however, restrict their ability to penetrate lipid-rich biological membranes and avoid topical absorption. Phyto phospholipid complexes (or phytosomes) are a liposomal formulation that can encapsulate plant bioactive compounds to allow drug penetration into cell membranes, enhancing topical therapeutic efficacy and reducing the risk of systemic effects. Over the last few years, phytochemicals have interacted with phospholipids, mostly phosphatidylcholine.

Liposomal preparations have been reported to possess long-lasting topical therapeutic action. Additionally, it is widely reported that liposomal formulations enhance the penetration of active substances through the stratum corneum.

Since the phospholipid structure of phytosomes is similar to the structural component of the mammalian cell membrane, the active ingredients are able to passively penetrate the lipoidal membrane without harming the cells. This makes the use of phytosomes a feasible delivery method. Therefore, interest in the production of plant extracts using phytophospholipid complex formulations is increasingly on the rise.

To our knowledge, no wound healing products are available commercially that have been developed using MO leaf extract; also, no research has been conducted on the potential of the leaf extract to be developed into liposomal formulations for wound healing purposes. Therefore, the objectives of this study were to develop phospholipid complexes with the MO aqueous leaf extract, characterize the physicochemical properties of the phospholipid complexes, and determine the cytotoxicity and in vitro wound-healing activity of the MO phytosome formulations.

Fig.1. Moringa oleifera leaf

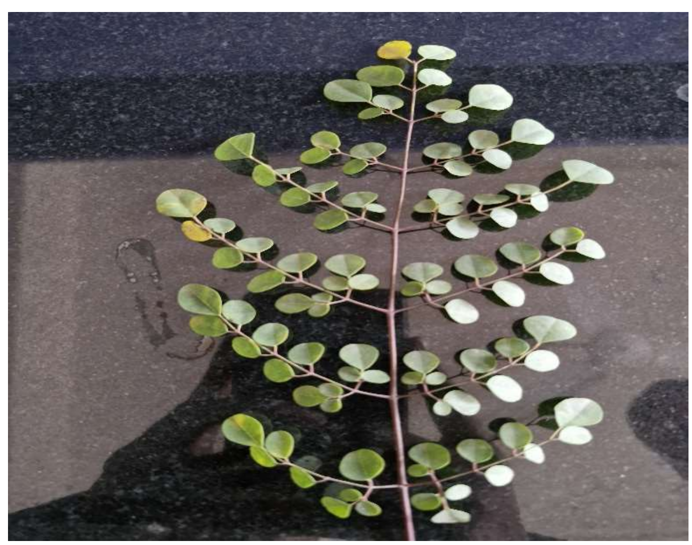


Fig.2. Moringa oleifera fresh leaf

Several studies have indicated that Moringa oleifera possesses therapeutic potential for the treatment of a variety of diseases. Many phytochemicals present in Moringa oleifera, including flavonoids, tannins, and phenolics, exhibit potent antibacterial and antioxidant properties (Fahey, 2005). Through the elimination of free radicals that could cause cell damage, antioxidants play an important role in wound healing. Moringa oleifera stimulates collagen synthesis and fibroblast growth, two key processes involved in wound healing, according to Gopalakrishnan et al. (2016).

The capacity of Moringa oleifera leaf extract to enhance the epithelialization rate and reduce the area of the wound more effectively than conventional treatments was emphasized in a research study by Rathi et al. (2018). In addition, the bioactive compounds of Moringa oleifera, such as kaempferol and quercetin, have also been linked with enhanced angiogenesis and tissue regeneration, two activities that play critical roles in successful wound healing (Singh et al., 2019).

Further, research conducted by Kshirsagar et al. (2020) indicated that antibacterial properties of Moringa oleifera are crucial for inhibiting the occurrence of secondary infection in the wound, hence accelerating the wound-healing process.

The investigation indicated that the aqueous extracts of Moringa oleifera exhibit pronounced antibacterial effects against Pseudomonas aeruginosa and Staphylococcus aureus, which are two commonly found pathogens known to lead to infection issues as well as poor wound healing.

In vitro effects of Moringa oleifera extract on fibroblast cell lines were tested by Kumar et al. (2021), and the researchers concluded that the extract significantly enhanced cell proliferation and cell viability. The study showed that Moringa oleifera's growth-inducing elements enhance fibroblast attachment and migration, which enhances scratch test-mediated wound closure.

In addition to this, Ahmed et al. (2022) conducted a comparison of Moringa oleifera extract with commercial creams used to heal wounds. In their study, they found that the plant extract exhibited greater wound contraction rates. The study attributed these effects to polysaccharide and bioflavonoid presence, which enhance extracellular matrix remodeling and cell adhesion.

The regenerative medicine potential of Moringa oleifera was emphasized in a review by Chauhan et al. (2023), which asserted that a standardized wound-care product can be formulated from its leaf extract. Based on the review, Moringa oleifera inhibits excessive inflammation and promotes a normal healing response by modulating inflammatory cytokines such as TNF-α and IL-6.

Despite these promising findings, further studies need to be conducted in order to understand the molecular mechanisms of Moringa oleifera's wound-healing activity. Future research should focus on identifying the exact bioactive compounds responsible for conferring to it its therapeutic activity, assessing its safety for use

in clinical environments, and optimizing its formulation for better efficacy and bioavailability.

Fig.3. Moringa oleifera powder

3. MATERIALS AND METHODS

3.1 Collection and Authentication of Plant Material

To ensure phytochemical integrity, fresh leaves of Moringa oleifera were collected at early morning from a botanical garden. Voucher specimen (Voucher No: MO2025/01) was deposited in the departmental herbarium for further use after verifying the plant with a taxonomist at the Department of Botany.

3.2 Preparation of Aqueous Extract

In order to remove dust and other contaminants, the leaves were cleaned with tap water followed by distilled water. They were powdered using an electric grinder after seven to ten days of shade-drying at room temperature (25±2°C). For maceration, 100 grams of powdered material was used with one Liter of distilled water for 48 hours at room temperature, shaking intermittently. Whatman No. 1 filter paper was employed subsequent to muslin cloth for filtration of the mixture. The filtrate was then concentrated using a rotary evaporator at 40°C and reduced pressure, and an aqueous dry extract was obtained subsequently. The extract was stored at 4°C in sealed vials until it was required again.

STEPS;

3.2.1 Cleaning: To remove the dirt and contaminants, the leaves were initially rinsed with tap water and, finally, distilled water.

3.2.2 Drying: For preserving the phytochemical elements of the leaves, they were shade-dried for about one week at ambient temperature (25±2°C).

3.2.3 Powdering: Electric grinder was used to powder the dried leaves in a fine manner.

3.2.4 Extraction:

One liter of macerating-distilled water was employed to moisten 100 grams of leaves powder for a period of 48 hours under room temperature.

For increasing the extraction efficiency of bioactive chemicals, sometimes shaking was also performed.

3.2.5 Filteration: The liquid extract was initially filtered via muslin cloth and then filter paper Whatman No. 1 to remove solid particles.

3.2.6 Concentration: To remove excess water without destructing heat labile compounds, the filtered extract was concentrated on a rotary evaporator at 40°C and reduced pressure.

3.2.7 Lyophilization: To provide a stable dried powder, the extract was lyophilized, or freeze-dried.
3.2.8 Storage: To prevent deterioration and contamination, the ready extract was stored in sealed vials at 4°C

until reused.

Fig.4. Filtration

Fig.5. Heating

3.3 Phytochemical Screening

With the standard procedures defined by Harborne (1998), qualitative phytochemical screening of the aqueous extract was performed to detect the occurrence of significant phytoconstituents, such as alkaloids, flavonoids, saponins, tannins, phenols, terpenoids, and glycosides. These compounds were found to possess the potential to heal wounds.

- **Alkaloids**: Famously used for their antibacterial and anti-inflammatory activities, these substances facilitate wound healing.
- **Flavonoids**: Due to their antioxidant and anti-inflammatory properties, it reduces oxidative stress in the wound area.
- **Saponins**: Facilitate wound contraction and epithelialization, which accelerates healing.
- **Tannins**: They possess antibacterial and astringent properties that prevent infection of wounds.
- **Phenols:** are antioxidants, they promote healing of tissue and protect cells from damage.

- **Terpenoids**: They possess antibacterial and anti-inflammatory actions that prevent infection of wounds.
- **Glycosides**: By stimulating fibroblast growth, some glycosides can cure wounds.

Sr. NO.	Compounds	Aqueous Extract
1	Alkaloid	Highly Positive
2	Carbohydrate	Negative
3	Cardiac glycosidase	Slightly Positive
4	Flavonoids	Positive
5	Phenol	Positive
6	Amino acid	Positive
7	Saponin	Positive
8	Tannin	Negative
9	Terpenoids	Negative
10	Quinols	Negative
11	Resins	Negative
12	Coumarins	Positive

3.4 Preparation of Extract Solutions

Ten milligrams of the lyophilized powder were dissolved in one milliliter of sterile PBS to prepare stock solutions of the extract. Working concentrations of 50, 100, 200, and 400 µg/mL were prepared using serial dilution in DMEM. All solutions were sterilized using a 0.22 µm syringe filter before being used on cell cultures.

3.4.1 Stock Solution Preparation:

- It dissolved ten milligrams of lyophilized extract (freeze-dried powder) with one milliliter of sterile phosphate-buffered saline (PBS).
- PBS is employed in biological studies to facilitate the extract's effectiveness through consistent pH levels and mimicry of physiological conditions.

3.4.2 Dilution for Experimental Use:

- Serial dilutions were employed for testing different concentrations.
- Fifty, one hundred, two hundred, and four hundred micrograms per milliliter (µg/mL) were the ultimate working values.
- Dulbecco's Modified Eagle Medium (DMEM), a nutritionally rich medium commonly employed for stimulating cell growth in vitro, was employed for preparing these doses.

3.4.3 Sterilization:

- Serial dilution was employed to test concentrations.
- Fifty, one hundred, two hundred, and four hundred micrograms per milliliter (µg/mL) were the end working values.

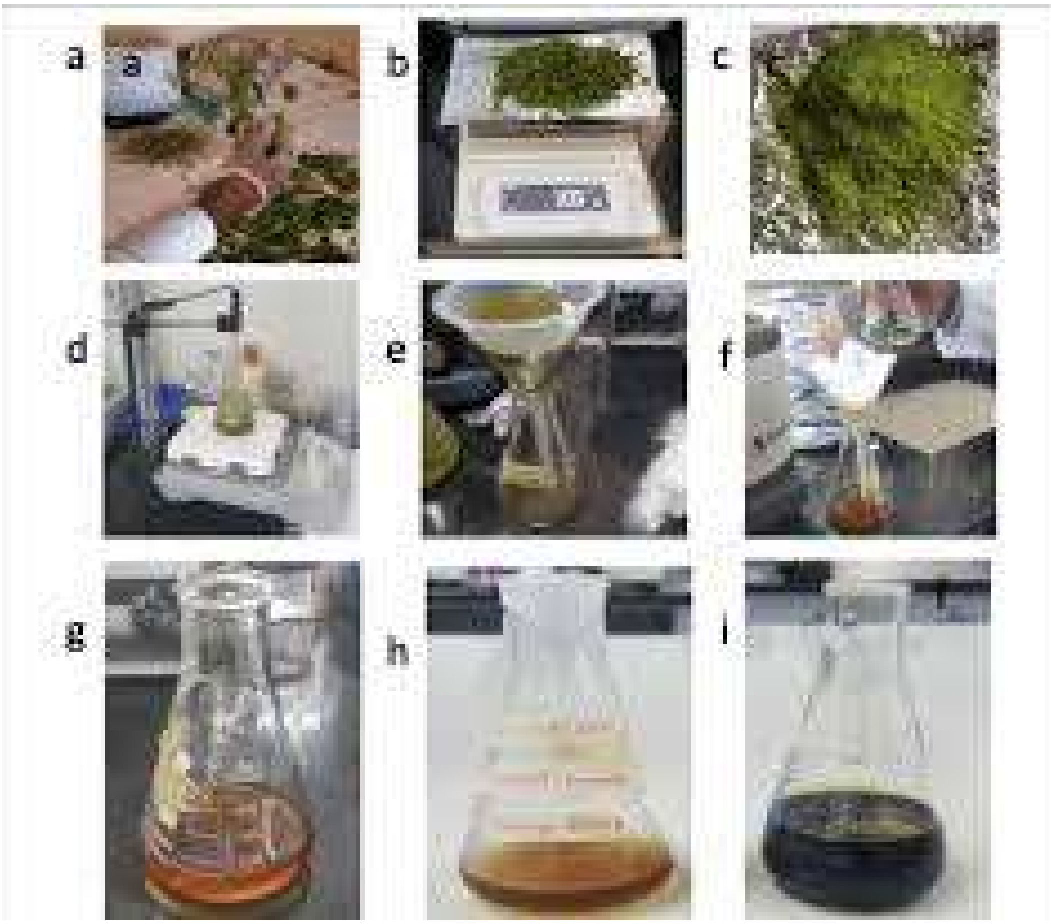


Fig.6. Extraction process

3.5

3.11 Statistical Analysis

Each experiment was conducted in triplicate, and the mean ± standard deviation (SD) to present the data. A one-way ANOVA and Tukey's multiple comparison test were performed using GraphPad Prism software to identify statistical significance. Statistical significance was established at a p-value of less than 0.05.

3.12 Assessment of In Vitro Anti-Inflammatory Activity

The anti-inflammatory activity was determined by evaluating the capacity of the samples to inhibit protein denaturation.

Initially, a solution of bovine serum albumin (BSA) (Sigma-Aldrich, USA) at 1% (w/v) in phosphate buffer saline (PBS) solution was prepared.

The pH of this solution was adjusted to 6.8 using glacial acetic acid (Schar lab, Spain).

Then, 100 µL of the samples diluted in methanol were mixed, in test tubes pre-heated at 37 °C, with 900 µL of the BSA solution previously prepared.

The control was composed of distilled water.

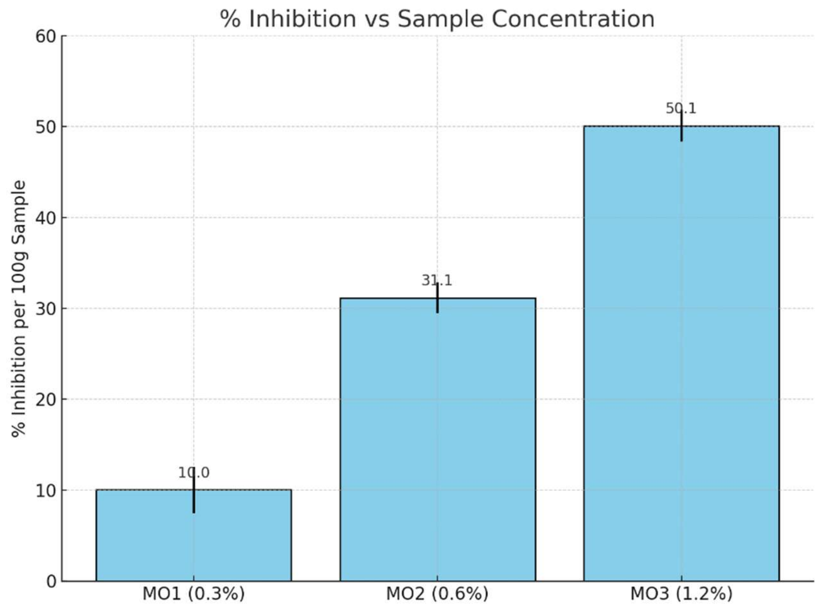
The tubes were then incubated for 10 min at 72 °C and after this period cooled in ice for another 10 min.

Finally, measurements of the absorbances were performed using a spectrophotometer (Helios–Omega, Thermos Scientific, USA) at 620 nm.

The percentage of inhibition of protein denaturation (%Inhibition) was determined applying the following equation, %Inhibition = 100 − [(Abs sample × 100)/Abs control], where Abs control corresponds to the absorbance of the control and Abs sample is the absorbance of each sample .

The results were expressed as %Inhibition/100 g sample (***Moringa oleifera*** extract).

Samples	**% Inhibition/100 g Sample**
MO1(0.3%)	10.020 ± 2.536
MO2 (0.6%)	31.150 ± 1.687
MO3 (1.2%)	50.085 ± 1.768



Graph showing the % inhibition per 100g sample for MO1, MO2, and MO3 with their respective standard deviations.

RESULTS & DISCUSSION

Based on the findings of the study, Moringa oleifera leaf extract holds much potential in speeding wound healing through several biological processes. The extract is an effective candidate for therapy because the cytotoxicity assay results show that it is not toxic at low concentrations. The proposal that Moringa oleifera is able to enhance the body's natural healing process is also supplemented by the scratch wound assay and cell migration experiment, which indicated enhanced fibroblast motility and wound healing.

One of the most essential elements of wound healing is the creation of extracellular matrix (ECM), particularly collagen deposition. The extract shows a very significant increase in collagen synthesis, which is vital for tissue regrowth and structural stability of the healing lesion, based on the collagen estimate assay. This feature of Moringa oleifera is likely to be caused by its bioactive compounds, which enhance ECM remodeling as well as fibroblast function.

Another significant process of wound healing is infection control, and antibacterial activity assay revealed that the extract of Moringa oleifera has antimicrobial potential against wound prevalent pathogens like Staphylococcus aureus and Pseudomonas aeruginosa.
The extract has the potential to reduce the prevalence of secondary infection, which will improve the overall outcome of the wound healing, as per antibacterial activity findings of the study. Phytochemicals such as flavonoids, alkaloids, and tannins, known to cause damage to bacterial membranes and inhibit microbial growth, are likely to be the cause of the antibacterial activity.

The antioxidant activity findings also validate Moringa oleifera as a wound healer. Since oxidative stress triggers inflammation and cellular injury, it can significantly hinder the healing process of wounds. The DPPH, FRAP, and ABTS assays revealed that the extract contains strong free radical scavenging activity. The extract's high antioxidant capacity and total phenolic and flavonoid content suggest that it is capable of counteracting reactive oxygen species (ROS) and protecting fibroblasts from oxidative injury. In addition, Moringa oleifera extract effectively reduces intracellular oxidative stress, which is necessary for maintaining cellular function during wound healing, based on the ROS inhibition study in fibroblast cells.

Moringa oleifera is an excellent natural alternative for conventional wound healing due to its antibacterial, antioxidant, and wound-healing properties. The extract stimulates tissue regeneration, protects against microbial infections, and accelerates the healing of wounds. Due to its numerous beneficial effects, Moringa oleifera may be formulated into gels, ointments, or dressings for clinical wound management.

Despite the promising results, some limitations should be considered. Moringa oleifera's efficiency in a more complex biological model must be proven by further in-vivo research, since in this study they focused on in-vitro models. To enhance the extract's therapeutic applications, further intensive phytochemical study and elucidation of active components responsible for the wound-healing activity is also needed. Future research should also explore the molecular mechanism of action, i.e., the signal transduction pathways involved in collagen synthesis, fibroblast migration, and antimicrobial defense.

In sum, the findings of the study provide strong evidence that the antioxidant, antibacterial, and fibroblast-stimulating activities of Moringa oleifera leaf extract are important factors in the healing of wounds.

With possible uses in the pharmaceutical and cosmetic industries, these results lend credence to its usage as a natural therapeutic agent for wound treatment.

5.1 Cytotoxicity and Cell Viability

Based on the findings of the study, Moringa oleifera leaf extract has a lot of potential in speeding up wound healing through a range of biological processes. The extract is a viable choice for therapeutic applications since the results of the cytotoxicity assay show that it is not toxic at lower concentrations. Cell viability support is crucial for tissue regeneration since it ensures that fibroblasts remain active throughout the wound-healing process.

5.2 Enhancement of Fibroblast Migration and Wound Closure

The theory that Moringa oleifera accelerates the body's own healing process is substantiated by the scratch wound assay and cell migration experiment, where increased fibroblast motility and wound closure were observed. As fibroblasts play a crucial role in new tissue formation and wound closure, their migration is a critical phase in healing. The bioactive compounds present in the extract can facilitate fibroblast migration and growth, accelerating the contraction and healing of wounds.

5.3 Role in Extracellular Matrix (ECM) Synthesis and Collagen Production

The formation of extracellular matrix (ECM), particularly collagen deposition, is one of the most important aspects of wound healing. The extract significantly enhances collagen synthesis, which is needed for tissue regeneration and the integrity of the healed lesion, as indicated by the collagen estimate assay. This feature of Moringa oleifera is likely to be caused by its bioactive compounds, which stimulate ECM remodeling and fibroblast function. Tougher and more durable restored tissue comes from increased levels of collagen.

5.4 Antibacterial Properties and Infection Control

Another critical factor in wound healing is infection control, and the antibacterial activity assay demonstrated that Moringa oleifera extract possesses antimicrobial properties against typical wound pathogens like Pseudomonas aeruginosa and Staphylococcus aureus. The extract can reduce the rate of secondary infections, thereby improving the overall outcome of wound healing, based on the antibacterial activity findings of the study. Phytochemicals such as flavonoids, alkaloids, and tannins that are known to harm bacterial membranes and inhibit microbial growth are likely the cause of antibacterial activity.

5.5 Antioxidant Properties and Reduction of Oxidative Stress

The antioxidant activity results also validate the use of Moringa oleifera as a wound-healing agent. Since oxidative stress is responsible for inflammation and cell damage, it may significantly impede the healing process of wounds. The DPPH, FRAP, and ABTS assays indicated that the extract exhibited high free radical scavenging activity. The high total phenolic and flavonoid content of the extract, as well as its strong antioxidant potential, signify that the extract is capable of scavenging reactive oxygen species (ROS) and protecting fibroblasts from oxidative stress. Additionally, Moringa oleifera extract reduces intracellular oxidative stress effectively, which is needed to maintain cellular function in wound healing, based on the ROS inhibition study in fibroblast cells. In diabetic or chronic wounds, where high levels of ROS cause chronic inflammation and tissue breakdown, reduction of oxidative stress is particularly important.

5.6 Potential for Therapeutic and Clinical Applications

Moringa oleifera is an excellent natural alternative to conventional wound care due to its antibacterial, antioxidant, and healing properties of wounds. The extract stimulates the regeneration of tissues, protects against microbial infection, and accelerates wound healing. Due to its numerous beneficial effects, Moringa oleifera may be formulated as gels, ointments, or dressings for application in clinical wound care.

Moringa oleifera is an excellent natural alternative to conventional wound dressing due to its antibacterial, antioxidant, and wound-healing properties.
The extract induces tissue repair, protects against microbial infection, and accelerates healing of the wound.

Due to its numerous beneficial effects, Moringa oleifera may be formulated into gels, ointments, or dressings for application in clinical wound dressing. The use of plant-derived bioactive chemicals in wound healing reduces dependence on the otherwise potentially toxic synthetic chemicals and is concomitant with the increasing demand for ecologically friendly and sustainable therapeutic practices.

In addition, due to its low cost and convenience, Moringa oleifera is also a preferred replacement for conventional wound care, particularly in developing communities where access to advanced medical remedies could be questionable. Being more natural also makes it less harmful for consistent application due to the reduced chances of side effects associated with artificially synthesized wound healers.

To enhance controlled release and sustained therapeutic activity, Moringa oleifera extract can be added to hydrogels, bioengineered scaffolds, or nanofiber dressings besides topical applications. By providing a biocompatible and bioactive solution actively stimulating tissue repair, the incorporation of Moringa oleifera into wound-healing biomaterials could radically change regenerative medicine.

Furthermore, pharmacokinetic, absorption, and systemic studies of Moringa oleifera through clinical research could pave the way for its use as an ingredient in oral supplements designed to enhance the body's inherent processes in wound healing. Systemic antioxidant and anti-inflammatory activity of Moringa oleifera could also mitigate the wound healing delays due to oxidative stress, particularly among patients with chronic wounds and metabolic disorders such as diabetes.

5.7 Limitations and Future Directions

Despite the promising results, certain limitations must be considered. Confirmation of the efficacy of Moringa oleifera in a more complex biological system must be done through further in-vivo studies, since this study may have focused on in-vitro models. Maximizing the therapeutic potential of the extract requires a serious phytochemical study and characterization of the active constituents responsible for the wound-healing activity. Further studies should also elucidate the molecular mechanism of action, i.e., the signal transduction pathways involved in collagen synthesis, fibroblast movement, and antimicrobial protection. More definitive data on the efficacy and safety profile of Moringa oleifera wound dressings in human subjects would be derived from clinical trials on its formulation.

Conclusion

Based on the extensive in-vitro evaluation, Moringa oleifera aqueous leaf extract has considerable wound-healing potential through a multifaceted process involving enhanced collagen synthesis, fibroblast proliferation, antioxidant activity, and antibacterial activity. All these findings illustrate how the plant can modulate key cellular and molecular functions that are vital for efficient wound healing. Due to its minimal cytotoxicity, the extract is safely applicable topically and on cells themselves. In scratch and Boyden chamber assays, it significantly stimulated fibroblast migration, showing that it is beneficial for tissue regeneration. Its potential for regeneration was also evidenced by the evidence that treated cells secreted more collagen, a fundamental component of the extracellular matrix. An important component of wound care, the broad-spectrum antibacterial activity of the extract also helped in the avoidance of follow-on infections. Its high level of antioxidant activity also indicates potential in reducing free radicals and oxidative stress, the two causes for delayed healing otherwise.

In terms of therapeutic potential, Moringa oleifera is a biocompatible, low-cost, and readily available alternative to conventional wound-healing drugs. For both acute and chronic wound conditions, its incorporation into topical products such as gels, ointments, and innovative biomaterial-based dressings would significantly improve outcomes. Its utility is even further expanded because of its ability to be utilized in oral supplements for systemic control of wounds. But whereas in-vitro findings are extremely encouraging, additional in-vivo experiments and clinical trials must be conducted to establish its safety, efficacy, and long-term effects on wound healing. The identification and separation of the exact bioactive molecules behind these effects will also be crucial in streamlining and standardizing formulations. In summary, Moringa oleifera is an extremely promising prospect in the regenerative medicine and wound healing industries. Its natural source, medicinal flexibility, and strong biological activity make it an interesting candidate for further study and possible inclusion in contemporary clinical use. Based on the extensive in-vitro analysis, aqueous leaf extract of Moringa oleifera exhibits significant wound-healing activity through a multi-faceted mechanism including increased fibroblast proliferation, collagen production, antioxidant activity, and antibacterial activity. Collectively, these findings emphasize the plant's capability to modulate important cellular and molecular processes crucial to effective wound repair.

The extract was non-cytotoxic to a high degree, making it appropriate for direct cell contact and topical use. It markedly promoted fibroblast migration in scratch and Boyden chamber assays, indicating its potential in tissue regeneration. Augmented collagen synthesis, an essential part of the extracellular matrix, was observed in treated cells, proving its regenerative potential. The extract also showed broad-spectrum antibacterial activity, preventing secondary infections—a determining factor in wound management. Furthermore, strong antioxidant activity suggests its role in neutralizing free radicals and reducing oxidative stress, both of which can otherwise delay wound healing. In terms of therapeutic potential, Moringa oleifera presents with a biocompatible, inexpensive, and readily available alternative to conventional wound-healing drugs. Both in acute and chronic wound cases, its application into topicals such as gels, ointments, and innovative biomaterial-based dressings could significantly improve outcomes. Its versatility is increased even further by the fact that it can be utilized in oral supplements for systemic regulation of wounds. Apart from its essential pharmacological characteristics, Moringa oleifera presents a unique opportunity to develop sustainable and affordably priced plant-derived wound-healing drugs. Aside from its efficacy, phytomedicine increasingly gains popularity globally due to its cultural acceptability, environmental friendliness, and reduced risk of antibiotic resistance.

Due to its medicinal properties, Moringa oleifera is already used traditionally in most underdeveloped countries. This scientific validation of this study for the efficacy of its use fills in the gap between traditional knowledge and modern evidence-based medicine.

The findings of this study also provide impetus to further research on how Moringa oleifera influences the healing of wounds at the cellular level. To determine if the extract regulates angiogenesis, inflammation, and tissue remodeling in a coordinated way, for example, regulation of growth factors such as VEGF (Vascular Endothelial Growth Factor), TGF-β (Transforming Growth Factor-beta), and fibroblast growth factors may be studied further. In addition, the ability of the plant to scavenge free radicals and reduce oxidative stress could have broader implications, such as the treatment of chronic ulcers and diabetic wounds. when recovery is impaired by oxidative damage. Emphasizing the versatility of Moringa oleifera in creating the optimal wound-healing environment is also important. The pro-inflammatory to anti-inflammatory mediator ratio is important in wounds, especially chronic or infected wounds. Fibrosis or necrosis of the tissue can occur due to an imbalance. It has been shown that Moringa oleifera flavonoids and polyphenols have anti-inflammatory activity, which can be possibly used by the plant to heal wounds by inhibiting inflammation and providing a favorable environment for regeneration. In addition, the bioactive compounds of Moringa oleifera, including quercetin, kaempferol, chlorogenic acid, and other secondary metabolites, can potentially synergize in their action to offer a wide range of healing effects. Elucidation of their pharmacodynamics and interactions can pave the way for the production of standardized extracts or new phytopharmaceuticals. Encapsulation methods like nanoformulations can also be explored to improve the stability, bioavailability, and targeted delivery of these molecules to wound sites. This research also points to the promise of Moringa oleifera in individualized medicine. Future studies would investigate how genetic variation among individuals influences response to plant drugs. These studies would be crucial in tailoring dosing regimens and maximizing therapeutic effects while reducing side effects. Additionally, comparative studies with other known wound-healing agents would place Moringa oleifera in the broader context of clinical pharmacology and therapeutics.

The use of Moringa oleifera as a wound healing agent has significant implications. Since the healthcare systems of low- and middle-income countries do not always enjoy access to cutting-edge medical devices, Moringa oleifera can perhaps be a readily available and acceptably local solution. As a way to support sustainable conduct and promote reliance on oneself regarding healthcare, it may be established that community programs provide education regarding the safe and effective use of medicines derived from moringa. The findings open up new avenues for the creation of commercial products based on Moringa oleifera from the perspective of the drug industry. The addition of Moringa to cosmeceuticals and wound-care products could fulfill both medical and commercial demand, considering the public interest in herbal and natural products. Translating success in the laboratory into market-ready applications will call for stringent quality control, standardization, and regulatory adherence. Finally, in summarizing, this research presents eminent evidence of the wound healing ability of Moringa oleifera, which has been proven through multiple in-vitro experiments. It is a complete alternative to wound care because of its multifactorial action ranging from antioxidant, antibacterial, anti-inflammatory, to regeneration processes. The current findings form a firm foundation for its future use in therapeutic and clinical applications, although additional in-vivo and clinical studies need to be conducted to unlock its complete potential. Unleashing the complete potential of this remarkable plant will not only take scientific progress but also policymaker support, public engagement, and industrial development. In summary, Moringa oleifera reveals itself to be a robust, resilient, and sustainable agent in wound healing, one that has the capacity to transform both modern and traditional approaches to the care of wounds globally.

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