Moringa oleifera: Phytochemical Constituents, Extraction Approaches, Mechanisms of Action, and Therapeutic Applications

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ABSTRACT
Moringa oleifera, a Moringaceae family member, is one of the most recognized medicinal plants with considerable nutritional and therapeutic value. The different parts of the plant, especially leaves and seeds, have been found to be rich in different types of bioactive compounds like flavonoids, phenolic acids, alkaloids, glucosinolates, tannins, and saponins. The bioactive compounds in *Moringa oleifera* have been found to be responsible for numerous pharmacological activities. The antioxidant, antimicrobial, anti-inflammatory, anti-diabetic, hepatoprotective, and cardioprotective effects have been scientifically proven in *Moringa oleifera* through experimental studies. The plant has attracted interest for its potential applications in pharmaceutical and nutraceutical formulations, owing to its favorable safety profile and biological effectiveness. In this review article, the major bioactive compounds identified in *Moringa oleifer*a have been discussed in detail and the therapeutic potentials of it have been critically discussed in relation to available scientific evidence. The findings highlight the relevance of this plant in traditional medicine and support its continued investigation for the development of plant-based therapeutic agents.
Keywords:
Moringa oleifera, phytochemical constituents, antioxidant activity, antimicrobial activity, medicinal plants, herbal therapeutics.

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1. Introduction
Moringa oleifera, belonging to the family Moringaceae, is a fast-growing deciduous tree that is commonly cultivated in tropical and subtropical regions. The tree is also known by the names drumstick tree, horseradish tree, or miracle tree, owing to the high nutritional and medicinal significance of the tree. The indigenous origin of the tree is the Indian subcontinent. The tree is commonly cultivated in different parts of Asia, Africa, and South America. In Ayurvedic medicine, different parts of the tree have been employed for the treatment of inflammatory conditions, infections, digestive problems, and metabolic disorders. Phytochemical screening of the tree has revealed the presence of bioactive compounds such as flavonoids, phenolic acids, alkaloids, glucosinolates, isothiocyanates, tannins, and saponins (*Anwar et al., 2007; Leone et al., 2015*). The leaves of the tree are rich in quercetin and kaempferol derivatives, which have antioxidant properties. In addition, the presence of glucosinolates and their hydrolysis products, such as isothiocyanates, have contributed to the anti-inflammatory and antimicrobial properties of the tree (*Fahey, 2005*).
In the past few decades, there has been a significant scientific interest in *Moringa oleifera*, and its demand has been on the rise in view of the growing interest in plant-based therapeutic agents, nutraceuticals, and functional foods (*Pareek et al., 2023; Arshad et al., 2025*). The experimental studies on *Moringa oleifera* have shown a number of significant pharmacological activities, and its potential benefits in treating diseases include antioxidant, antimicrobial, anti-diabetic, hepatoprotective, cardioprotective, and anti-inflammatory activities (*Mbikay, 2012; Vergara-Jimenez et al., 2017; Pareek et al., 2023; Arshad et al., 2025*). The biological activities are generally attributed to its phytochemicals.
Moringa oleifera has gained significant importance in pharmaceutical research, nutraceuticals, and plant-based therapeutic agents in view of its significant therapeutic potential, nutritional value, and safety profile

(*Pareek et al., 2023*). The main objective of the review is to discuss the major phytochemicals found in *Moringa oleifera* and its therapeutic potential based on scientific evidence.

2. Botanical Description and Distribution

2.1 Taxonomy

Moringa oleifera is a member of the Moringaceae family, which consists of a small number of species that have adapted to arid to semi-arid environments. The genus *Moringa* consists of different species, but *Moringa oleifera* is the most cultivated and economically important species (*Leone et al., 2015*). The classification of the plant is as follows:

- **Kingdom:** Plantae
- **Order:** Brassicales
- **Family:** Moringaceae
- **Genus:** *Moringa*
- **Species:** *Moringa oleifera* Lam.

2.2 Morphological Characteristics

Moringa oleifera is described as a fast-growing tree with drought resistance and deciduous characteristics with a height of 5 to 12 meters. The tree has soft whitish-gray corky bark and a deep taproot system to facilitate survival during drought (*Anwar et al., 2007*). The tree has alternate tripinnate leaves with feathery characteristics. The leaves have small oval-shaped leaflets with dark green coloration on the upper portion. The flowers have a creamy white color with a sweet fragrance and are in loose panicles. The flowers are bisexual and zygomorphic in nature to facilitate cross-pollination.

The fruit has a long, pendulous three-sided capsule with a common name “drumstick.” The fruit may vary in length between 20 to 60 cm with numerous dark brown winged seeds. The seeds are round in shape with “ben oil” characteristics to facilitate nutritional and cosmetic uses (*Leone et al., 2015*).

2.3 Geographical Distribution

Moringa oleifera is a plant native to the foothills of the Himalayan region in northwestern India but is now cultivated in many parts of the world in tropical and subtropical regions (*Fahey, 2005*). It can thrive in many countries in South Asia, Southeast Asia, Africa, Central and South America, and parts of the Middle East. It can also thrive in warm climates where temperatures range from 25–35°C and can tolerate a variety of soils, from sandy to loamy soils. It is promoted as a sustainable crop in arid regions owing to its adaptability to drought and poor soils (*Vergara-Jimenez et al., 2017*). The extensive cultivation of *Moringa oleifera* is mainly because of its nutritional, medicinal, and economic values.

3. Phytochemical Constituents

Moringa oleifera is known for its high content of various phytochemicals. Various parts of *Moringa oleifera*, especially leaves and seeds, contain a wide range of primary and secondary metabolites that are responsible for its pharmacological properties. These compounds have been shown to contribute to its antioxidant, antimicrobial, anti-inflammatory, and metabolic properties (*Leone et al., 2015; Pareek et al., 2023*).

3.1 Primary Metabolites

The major metabolites found in *M. oleifera* include proteins, carbohydrates, lipids, vitamins, and minerals. The leaves have a high concentration of proteins with essential amino acids, thus providing a valuable nutrient-rich food source in some developing countries (*Pareek et al., 2023*). The leaves also have a high concentration of vitamins such as vitamin A, vitamin C, and vitamin E, which play a role in antioxidant defense mechanisms (*Anwar et al., 2007*).

Calcium, potassium, iron, and magnesium are minerals found in high concentrations. These micronutrients increase the nutritional and therapeutic value of *M. oleifera*, especially in addressing malnutrition and micronutrient deficiencies (*Vergara-Jimenez et al., 2017*).

3.2 Secondary Metabolites

Secondary metabolites are primarily responsible for the medicinal properties of *M. oleifera*.

3.2.1 Flavonoids

Flavonoids are one of the most common phytochemicals present in *M. oleifera* leaves. The common flavonoids present in its leaves are quercetin and kaempferol. Flavonoids are powerful antioxidants that can scavenge free radicals and prevent lipid peroxidation (*Sreelatha & Padma, 2009*). Quercetin is also known to have anti-inflammatory and cardio-protective properties.

3.2.2 Phenolic Compounds

Phenolic acids like chlorogenic and gallic acids have been reported to be present in *M. oleifera*. Phenolic acids have been reported to have antioxidant properties and have been linked to the prevention of diseases caused by oxidative stress (*Leone et al., 2015*). The total phenolic content has been reported to have a positive correlation with the free radical scavenging potential of the plant (*Pareek et al., 2023*).

3.2.3 Glucosinolates and Isothiocyanates

The *Moringa oleifera* plant is also known for the presence of glucosinolates, primarily in the leaves and seeds of the plant. The hydrolysis of the glucosinolates results in the formation of isothiocyanates, which are biologically active compounds known for their antimicrobial and anti-inflammatory properties (*Fahey, 2005*). These biologically active compounds have also been studied for their chemopreventive and anti-inflammatory properties in different experimental models (*Waterman et al., 2014; Arshad et al., 2025*).

3.2.4 Alkaloids

Alkaloids are nitrogen-containing compounds identified in different extracts of the *M. oleifera* plant. These have been identified as contributing to the antimicrobial and analgesic properties of the drug. Although these are present in smaller quantities than flavonoids, it is possible that they have a synergistic effect with other phytochemicals (*Anwar et al., 2007*).

3.2.5 Saponins and Tannins

The presence of saponins in the *M. oleifera* drug has been identified with the hypocholesterolemic and immunomodulatory properties of the drug. Tannins have antimicrobial and astringent properties. These compounds increase the therapeutic properties of the drug, which can be used for the healing of wounds (*Leone et al., 2015*).

3.2.6 Sterols and Fatty Acids

The seeds of the *M. oleifera* plant have large quantities of fixed oils that have oleic acid, palmitic acid, and behenic acid. Sterols such as beta-sitosterol have anti-inflammatory, lipid-lowering, and cardio-protective properties (*Pareek et al., 2023*).

4. Extraction Methods

The extraction of bioactive compounds from *Moringa oleifera* is an important step in determining the yield and content of phytochemicals. Various factors affect the selection of an extraction method for *Moringa oleifera*. The selection of a suitable method for extracting bioactive compounds is usually based on the type of compounds and their use.

4.1 Solvent Extraction

The most commonly used technique for extracting phytochemicals from *M. oleifera* is solvent extraction. Organic solvents like ethanol, methanol, acetone, and chloroform, along with aqueous solvents, are used for extracting phytochemicals from *M. oleifera*. Polar solvents like ethanol and methanol are found to be effective in extracting phenolic compounds and flavonoids (*Leone et al., 2015*).

Traditionally, aqueous solvents have been used to extract water-soluble compounds like tannins and saponins. However, organic solvents have been found to have better antioxidant activity (*Sreelatha & Padma, 2009*).

4.2 Soxhlet Extraction

Soxhlet extraction is a type of hot extraction technique used to improve the efficiency of extraction by reusing the solvent in a cyclic manner. This method has been found to be effective in extracting phenolic compounds and flavonoids using ethanol or methanol (*Anwar et al., 2007*).

4.3 Maceration and Traditional Methods

Maceration involves extracting the bioactive compounds by immersing the plant material in the chosen solvent at room temperature with occasional shaking. It is simple, economical, and suitable for heat-sensitive compounds. Infusion and decoction are commonly used in traditional medicine but have low extraction efficiency (*Vergara-Jimenez et al., 2017*).

4.4 Seed Oil Extraction

M. oleifera seeds possess fixed oil, known as ben oil, which can be extracted by cold pressing or solvent extraction. The cold-pressed oil retains significant amounts of antioxidants, showing good oxidative stability, which can be attributed to the high oleic acid content of the oil (*Anwar et al., 2007*).

4.5 Advanced Extraction Techniques

In recent years, advanced extraction technologies have been increasingly applied to improve the recovery of bioactive compounds from *Moringa oleifera*. Ultrasound-assisted extraction (UAE) uses ultrasonic waves to disrupt plant cell walls, thereby enhancing the release of intracellular phytochemicals into the solvent. This method significantly improves extraction efficiency and reduces extraction time and solvent consumption compared to conventional techniques (*Leone et al., 2015; Azwanida, 2015*). Similarly, microwave-assisted extraction (MAE) utilizes microwave energy to rapidly heat the solvent and plant matrix, which accelerates the diffusion of bioactive compounds such as phenolics and flavonoids. MAE has been reported to yield higher concentrations of antioxidant compounds from *M. oleifera* leaves while requiring shorter processing times (*Azwanida, 2015; Vergara-Jimenez et al., 2017*).

Another promising method is the use of supercritical fluid extraction (SFE) technique, which mostly uses carbon dioxide as an extraction solvent under a high-pressure and high-temperature condition. This method has been found to be environmentally friendly as it avoids the use of organic solvents and can extract non-polar bioactive compounds such as lipids and essential oils. The SFE technique has been found to have potential applications for obtaining pure bioactive compounds from *M. oleifera* seeds and other plant materials, including thermolabile compounds (*Leone et al., 2015; Meireles et al., 2020*). However, the use of modern extraction techniques has been hindered by the need for expensive equipment.

4.6 Influence of Solvent on Biological Activity

The selection of extraction solvent is of prime importance in defining the chemical composition and biological activities of *Moringa oleifera*. The polarity of the solvent greatly affects the nature of the bioactive compounds solubilized from the plant material. Polar solvents like methanol, ethanol, and water have been found to be more efficient in extracting phenolic, flavonoid, and other polar bioactive compounds responsible for antioxidant potential (*Sreelatha & Padma, 2009*; *Azwanida, 2015*). Among these solvents, ethanolic and methanolic extracts of *Moringa oleifera* leaves have been reported to exhibit higher antioxidant and antimicrobial potential compared to other solvents, because of their higher capacity to solubilize phenolic compounds.

On the other hand, less polar solvents such as chloroform and hexane can be used for the extraction of lipophilic compounds such as fatty acids and alkaloids. Research findings indicate that variations in solvent system can cause substantial differences in biological activities such as antimicrobial, anti-inflammatory, and cytoprotective activities of the plant extracts (*Vergara-Jimenez et al., 2017; Meireles et al., 2020*). Hence, the choice of the extraction solvent is crucial for enhancing the recovery of target phytochemicals for maximum therapeutic potential of *Moringa oleifera* plant extracts.

5. Therapeutic Potential of *Moringa oleifera*

Moringa oleifera is known for the variety of pharmacological properties it displays, which are generally ascribed to the high content of phytochemicals, flavonoids, phenolic acids, alkaloids, glucosinolates, and isothiocyanates. Its therapeutic potential has been investigated through numerous in vitro and in vivo studies.

5.1 Antioxidant Activity

M. oleifera exhibits strong antioxidant activity due to the presence of quercetin, kaempferol, chlorogenic acid, and other phenolic compounds. These bioactive constituents scavenge free radicals and reduce oxidative stress, which is implicated in aging and chronic diseases. Several studies have reported high DPPH and ABTS radical scavenging activity in leaf extracts (*Sreelatha & Padma, 2009; Xu et al., 2019; El-Sherbiny et al., 2024*). The antioxidant potential protects against cellular damage.

5.2 Antimicrobial Activity

The antimicrobial potential of *M. oleifera* has been demonstrated for Gram-positive bacteria, e.g., *Staphylococcus aureus*, Gram-negative bacteria, e.g., *Escherichia coli*, and fungi, e.g., *Candida albicans* (*Rahman et al., 2009; Arora & Onsare, 2014; El-Sherbiny et al., 2024*).

The major bioactive compounds responsible for the antimicrobial potential of *M. oleifera* have been reported to be phenolic compounds, flavonoids, alkaloids, and isothiocyanates.

Among the bioactive compounds, the isothiocyanate derivatives of glucosinolates have been reported to play a crucial role in the antimicrobial potential of *M. oleifera*. These compounds disrupt microbial cell membranes, alter permeability, and interfere with intracellular enzyme systems (*Waterman et al., 2014*). The ethanolic and methanolic extracts of *M. oleifera* have been reported to exhibit higher antimicrobial activity compared to the aqueous extract of the plant, owing to the solubility of the bioactive compounds (*Rahman et al., 2009*).

Studies using agar well diffusion and minimum inhibitory concentration (MIC) assays have demonstrated dose-dependent inhibition of bacterial growth (*Arora & Onsare, 2014*). The broad-spectrum antimicrobial activity supports the application of *M. oleifera* in topical formulations, wound healing preparations, and anti-acne products.

5.3 Anti-Inflammatory Activity

Inflammation is known to play a significant role in the causation of different chronic diseases. The bioactive constituents found in *M. oleifera*, such as isothiocyanates and flavonoids, are known to inhibit pro-inflammatory agents like nitric oxide and cytokines (*Parente et al.,2025*). Experimental studies on animal models reveal that there are significant anti-inflammatory activities (*Waterman et al., 2014*).

5.4 Antidiabetic Activity

M. oleifera has been extensively investigated for its hypoglycemic activity. The leaf extracts have been found to decrease blood glucose levels and improve insulin response in diabetic animal models. The mechanism is believed to be mediated by the inhibition of enzymes responsible for carbohydrate digestion and the stimulation of pancreatic beta-cell function (*Jaiswal et al., 2009; Mbikay, 2012*).

5.5 Cardioprotective and Hepatoprotective Effects

The plant has shown protective activity against cardiovascular and liver disorders. The antioxidant and anti-inflammatory properties of the plant have been shown to reduce lipid peroxidation and lipid profiles. It has been shown to have hepatoprotective activity against chemically induced liver damage (*Fakurazi et al., 2008*). It also shows lipid-lowering activity in cardiovascular diseases (*Mbikay, 2012*).

5.6 Wound Healing and Dermatological Applications

Due to its antimicrobial, antioxidant, and anti-inflammatory properties, *M. oleifera* is increasingly explored in topical formulations. Extracts promote wound contraction, collagen formation, and tissue regeneration in experimental models (*Rathi et al., 2006*). These properties support its application in herbal gels and cosmetic preparations.

6. Mechanisms of Action of *Moringa oleifera*

The varied therapeutic properties of *Moringa oleifera* can be attributed to different biochemical and molecular mechanisms. The pharmacological properties of the plant can be attributed to the different bioactive components such as flavonoids (quercetin, kaempferol), phenolic acids (chlorogenic acid), glucosinolates, isothiocyanates, alkaloids, vitamins, and carotenoids, which show synergistic activity by modulating oxidative stress, inflammatory responses, microbial viability, and metabolic pathways.

6.1 Antioxidant Mechanisms

The antioxidant mechanism of *M. oleifera* involves both direct and indirect pathways. Phenolic compounds and flavonoids present in the leaves act as free radical scavengers by donating hydrogen atoms or electrons to neutralize reactive oxygen species (ROS), thereby preventing oxidative damage to lipids, proteins, and nucleic acids. In addition to radical scavenging, these compounds chelate transition metal ions such as iron and copper, reducing the generation of hydroxyl radicals through Fenton reactions (*Sreelatha & Padma, 2009*).
Beyond direct antioxidant activity, *M. oleifera* enhances endogenous cellular defense systems. Experimental studies indicate that its extracts upregulate antioxidant enzymes including superoxide dismutase (SOD), catalase (CAT), and glutathione peroxidase (GPx), while restoring reduced glutathione levels (*Fakurazi et al., 2008*). Emerging evidence suggests that these effects may be mediated through activation of the Nrf2 signaling pathway, which regulates antioxidant response elements (ARE) and promotes cytoprotective gene expression (*Xu et al., 2019*). This dual antioxidant mechanism contributes to its protective role against oxidative stress-related disorders.

6.2 Antimicrobial Mechanisms

The antimicrobial properties of *M. oleifera* can be attributed to the presence of isothiocyanates, flavonoids, tannins, and other secondary metabolites. The isothiocyanates, which are derived from the breakdown of glucosinolates, have been identified as the primary antimicrobial agents of *M. oleifera*. These antimicrobial agents work by disrupting the integrity of the cell membranes of the target microorganisms, thus increasing the permeability of the membranes and causing the leakage of cellular components. The agents may also inhibit the vital enzymes of the target bacteria by interacting with the thiol groups in proteins (*Waterman et al., 2014*).
Phenolic compounds also play a role by binding to bacterial cell walls and membranes, which affects their structural integrity and nutrient uptake. Flavonoids have also been shown to have an inhibitory role on nucleic acid synthesis and biofilm formation, leading to a decrease in microbial virulence (*Rahman et al., 2009*). All these properties of these bioactive compounds contribute to the broad-spectrum activity of *M. oleifera* against Gram-positive bacteria, Gram-negative bacteria, and certain fungal species.

6.3 Anti-Inflammatory Mechanisms

The anti-inflammatory effects of *M. oleifera* are mediated through modulation of key inflammatory signaling pathways. Bioactive isothiocyanates and flavonoids have been shown to suppress the activation of nuclear factor kappa B (NF-κB), a transcription factor that regulates genes involved in inflammation. Inhibition of NF-κB activation results in decreased expression of pro-inflammatory mediators such as tumor necrosis factor-alpha (TNF-α), interleukin-6 (IL-6), inducible nitric oxide synthase (iNOS), and cyclooxygenase-2 (COX-2) (*Waterman et al., 2014*).
Experimental studies demonstrate that *M. oleifera* extracts reduce nitric oxide production and attenuate inflammatory cytokine release in activated macrophages. Furthermore, its antioxidant activity indirectly supports anti-inflammatory effects by limiting oxidative stress-induced inflammatory signaling cascades (*Mahajan & Mehta, 2010*). Thus, *M. oleifera* has considerable potential in managing chronic inflammatory conditions.

6.4 Metabolic and Cytoprotective Mechanisms

In the case of metabolic disorders, *M. oleifera* has been shown to produce positive effects by acting on carbohydrate-digesting enzymes, such as α-amylase and α-glucosidase, to decrease postprandial hyperglycemia. Moreover, the presence of polyphenolic compounds has been shown to improve insulin sensitivity and protect the beta cells in the pancreas from oxidative stress (*Mbikay, 2012*). Hepatoprotective activity has also been linked to reduced lipid peroxidation, restoration of antioxidant status, and stabilization of cellular membranes in toxin-induced liver injury models (*Fakurazi et al., 2008*).

Overall, these multi-target mechanisms highlight the pharmacological versatility of *Moringa oleifera* and support its therapeutic applications in oxidative stress, microbial infections, inflammatory disorders, and metabolic diseases.

7. Pharmaceutical Applications of *Moringa oleifera*

Moringa oleifera has attracted considerable interest in the field of pharmaceutical research owing to its wide array of pharmacological activities. The therapeutic potential of the plant has been largely attributed to its rich content of flavonoids, phenolic acids, glucosinolates, isothiocyanates, vitamins, and essential fatty acids, which play a crucial role in its antioxidant, antimicrobial, anti-inflammatory, and metabolic activities.

In metabolic disorders, the leaf extracts of *M. oleifera* have exhibited notable hypoglycemic activities, increasing insulin sensitivity while regulating carbohydrate metabolism. The polyphenolic constituents of *M. oleifera* inhibit enzymes responsible for carbohydrate metabolism, while their antidiabetic activities reduce oxidative stress associated with diabetes, making them suitable for use as adjunct therapy for diabetes management (*Mbikay, 2012*). The plant's ability to reduce serum cholesterol levels while preventing lipid peroxidation makes it suitable for cardioprotective activities.

The hepatoprotective activities of *M. oleifera* have also been noted with animal studies indicating that the plant extracts can restore levels of antioxidant enzymes, reduce lipid peroxidation, and protect against liver toxicity (*Fakurazi et al., 2008*). This makes *M. oleifera* suitable for use as part of nutraceutical formulations for the prevention of liver toxicity.

Moreover, antimicrobial properties of *M. oleifera* extracts have been reported to exhibit inhibitory activity against different types of bacterial and fungal pathogens. Bioactive isothiocyanates and phenolic compounds interfere with microbial cell integrity and metabolism. Such properties can be applied in oral formulations for infection management (*Rahman et al., 2009*). All these pharmacological properties make *M. oleifera* a candidate for a complementary medicine.

8. Topical and Dermatological Applications of *Moringa oleifera*

Moringa oleifera has received considerable attention for its potential applications in dermatological and cosmetic fields due to its high content of bioactive compounds such as flavonoids, phenolic acids, vitamins, and essential fatty acids. These bioactive compounds are responsible for strong antioxidant, antimicrobial, and anti-inflammatory properties, which are beneficial for skin care and treatment of various skin conditions. According to recent studies, its leaves and seeds can be used to formulate topical products such as creams, gels, and ointments for skin care and protective effects against environmental stressors (*Baldisserotto et al., 2023*).

The role of the antioxidant properties of *M. oleifera* in the protection of the skin from damage by ultraviolet radiation and pollution is significant. The phenolic and flavonoid content of the *Moringa* plant has been found to exhibit antioxidant properties, which can neutralize free oxygen radicals and reduce cellular damage, thus providing anti-aging benefits to the skin (*Baldisserotto et al., 2023*). Furthermore, the antimicrobial properties of *Moringa* have been proven to be effective in the management of skin infections by skin-associated microorganisms, such as *Staphylococcus epidermidis*, thus providing benefits in the management of acne.

In addition, the seed oil of *M. oleifera*, commonly known as ben oil, has been found to possess potential wound healing and anti-inflammatory activities. It has been found that the topical application of formulations containing this seed oil enhances wound contraction, reduces inflammation, and increases collagen synthesis, thereby indicating its potential in wound healing and skin regeneration. More recently, research has been conducted on the use of advanced topical delivery systems such as hydrogels and microemulsions, containing *Moringa* extracts for better skin penetration and activity. The above observations indicate the potential value of *Moringa oleifera* as a significant component in dermatological and cosmeceutical formulations.

9. Limitations

Even though *Moringa oleifera* has shown significant pharmacological potential, there are still some limitations that need to be addressed. The phytochemical content in *Moringa oleifera* varies depending on the geographical location, cultivation conditions, and processing methods, which might affect its biological activities (*Anwar et al., 2007; Leone et al., 2015*). Moreover, the differences in extraction solvents and methods make it difficult to compare the results and standardize the extraction process.

The majority of the claims of the therapeutic effects of the herbs have been based on in vitro and animal studies, but the number of well-designed human clinical trials is still limited (*Mbikay, 2012; Vergara-Jimenez et al., 2017*). In the toxicological studies, the herbs have generally been considered safe at moderate doses, but the long-term studies and drug-herb interaction studies are limited (*Asare et al., 2012*). Thus, additional standardized and clinically validated studies are needed to support its clinical application.

10. Future Perspectives

The recent progress in the field of phytochemistry and pharmacology has identified the increasing prospect of *Moringa oleifera* as a promising source of significant therapeutic agents of the future. The contemporary studies have underscored the significance of the investigation of new bioactive compounds such as isothiocyanates, flavonoids, and phenolic compounds that contribute to the antioxidant, anti-inflammatory, and neuroprotective properties of the *Moringa oleifera* plant. The emerging trends in the field of *Moringa oleifera* research also reveal that the role of the bioactive compounds of the plant may be significant in the prevention of chronic health conditions such as neurodegenerative, metabolic, and inflammatory disorders (*Worku & Tolossa, 2024; Arshad et al., 2025*).

In addition, there has been a focus on the research and development of novel pharmaceutical and nutraceutical formulations from *M. oleifera*. Advances in extraction technologies, nano-formulations, and drug-delivery systems may improve the bioavailability and effectiveness of its bioactive compounds. Moreover, molecular and computational research has shown that some of the phytochemicals from *M. oleifera* may be promising lead compounds in drug discovery, especially in the management and treatment of neurodegenerative diseases and cancer (*Ezeorba et al., 2025*).

Therefore, future studies should focus on the design of clinical trials, the standardization of the extraction process, as well as the characterization of the active compounds so that the mechanism of action of the pharmacological effects of the drug can be understood. These studies will play an integral role in the safe use of the traditional as well as experimental knowledge of *Moringa oleifera* in the field of modern medicine (*Mukhtiar et al., 2025*).

11. Conclusion

Moringa oleifera has been recognized as a significant medicinal plant owing to its substantial content of phytochemicals and its unique pharmacological properties. Various research has confirmed the presence of a number of significant bioactive compounds, such as flavonoids, phenolic acids, glucosinolates, alkaloids, and vitamins, in *Moringa oleifera*, which are responsible for its antioxidant, antimicrobial, and therapeutic activities, among others. The properties and traditional use of *Moringa oleifera* in the management and treatment of a number of health conditions make it a significant medicinal plant and a potential source of bioactive compounds for pharmaceutical and nutraceutical purposes.

Recent research has also confirmed the potential of *M. oleifera* in the formulation of topical and pharmaceutical products such as creams, gels, and functional health products with the objective of improving skin health and preventing oxidative stress disorders. The presence of nutritionally important compounds and favorable safety profiles has also created considerable interest in its use as a multi-functional herb for therapeutic and preventive purposes.

Though promising biological activities have been demonstrated by *Moringa oleifera* in experimental studies, it is still necessary to conduct further studies on standardized extraction methods, the bioactive constituents with highest activity, and their mechanisms of action using well-designed clinical studies. Further scientific investigations will be essential to fully explore the therapeutic potential of *Moringa oleifera* and to utilize it extensively for pharmaceutical, nutraceutical, and dermatological applications in the near future.

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