REVIEW ARTICLE

Moringa Root: Comparative Phytochemical Profile, Bioactive, Medicinal Properties, and Agricultural Applications – A Review

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Abstract

The nutritional and medicinal importance of the *Moringa oleifera* Lam. is long-established; however, the root is relatively unexplored irrespective of its unique anatomical and phytochemical properties. The present systematic review summarizes available literature on the comparative phytochemical profile, structural specialization, pharmacological activity, and agro-industrial prospects of roots of the moringa plant. *M. oleifera* has an adapted taproot system with increased storage tissues, which provide drought resistance and the ability to accumulate a wide range of metabolites. Phytochemical studies have recognized various bioactive compounds, which comprise alkaloids, i.e., moringin and moringinine, glucosinolates, isothiocyanates, flavonoids, tannins, phenolic acids, and terpenoids. It has been shown to have important antidiabetic, antioxidant, antimicrobial, anti-inflammatory, anti-ulcer, anticancer, and insecticidal properties exhibiting low levels of toxicity in pre-clinical models. Root extracts have also shown potential in the case of the use of water purification and sustainable control of pests. Although these results are promising, the lack of uniformity in phytochemical profiles and the scarcity of clinical validation highlight the need to standardize extraction processes, develop more sophisticated metabolomic analysis, and to carry out extensive toxicological and mechanistic analyses. *M. oleifera* root is an underutilized but promising bioresource that has a high potential for pharmaceutical and agricultural innovations.

Key words: Bioactive compounds, *Moringa oleifera* root, pharmacological activities, phytochemical profiling, phytomedicine

INTRODUCTION

Moringa oleifera belongs to the family of Moringaceae. The genus Moringa comprises 13 tree and shrub species native to the continents of Africa and Asia, among which *M. oleifera* Lam. is the most extensively cultivated and the scientifically investigated species.[1] The figure 1 illustrates the phylogenetic relationships among the 13 species of the genus *Moringa*.

M. oleifera, native to the Indian subcontinent and widely referred to as the “miracle tree” or the “drumstick tree,” is a quick-growing, drought-resistant plant, which is predominantly distributed across the tropical and subtropical regions of the world. A vast array of nutritional profiles, a diverse phytochemical composition, and numerous agricultural, health, food security, and environmental sustainability initiatives make it a significant crop worldwide. Historically, it has been part of the traditional diets and ethnomedical practices, particularly in Ayurveda and other traditional medical systems.[2,3]

The moringa leaves contain higher levels of proteins, vitamins A, C and E, minerals (calcium, potassium, and

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iron), and all nine essential amino acids. Therefore, it is a good source of essential nutritional value.[4] As an example, on a gram- per-gram basis, moringa leaves have threefold more potassium than bananas, sevenfold more vitamin C than oranges, and fourfold more calcium than milk.[5] Moringa also plays a significant role in addressing malnutrition in the war on malnutrition because of its rich nutrient composition in developing nations, specifically, where malnutrition is a significant concern and danger to the welfare of the community.[6] Based on the clinical trials and field-based studies, the improvements in hemoglobin levels, vitamin A, and other indicators of general development among malnourished infants supplemented with moringa leaf powder were noted.[7]

It also contains numerous anti-oxidant phytochemicals, including more than 40 flavonoids, phenolic acid, tannin, saponin, glucosinolates, and disintegrate into bioactive isothiocyanates, such as moringin.[8] Their pharmacological effect is due to these compounds that have hepatoprotective, cardioprotective, anti-inflammatory, antibacterial, and anti-cancer action.[9,10] In addition, moringa is a powerful source of traditional medicine, in the case of the treatment of diabetes, instead of its extract is capable of modulating important metabolic pathways.[8,11] Moringa has a potent antioxidant activity and also contributes to the prevention of oxidative stress, which is the greatest contributor to ageing and chronic diseases such as neurodegeneration and heart disease.

Beyond its nutritional and medicinal value, *M. oleifera* is also extremely important in the sustainability of agriculture, environmental remediation, and human health. The seeds contain cationic proteins, which are natural coagulants capable of removing the pathogens and suspended solids from turbid water effectively. It is an inexpensive, environmentally-friendly substitute for synthetic chemicals by which the water systems are purified, especially in rural areas and disaster-affected areas.[12,13] Furthermore, seed cake obtained from oil extraction can be used as a biopesticide and organic manure to the benefit of soil fertility, which will lead to a decrease in the use of chemical fertilizers.[14] The fast reproduction, large biomass, and capacity to develop in marginal soils make the plant suitable for reforestation, utilized in agro forestry systems, and also in carbon sequestration so as to mitigating the climatic change.[15]

According to the botanical nature of the plant, the root system of *M. oleifera* is characterized by a prominent taproot that develops into a fleshy, tuberous structure as the plant matures. The water and nutrients present in arid conditions are known to be available to the plant because of the roots that are usually very long, thin, and deep-rooted into the ground. This characteristic is responsible for the plant not suffering from drought.[16] The mature roots are dark brown, thick in cork on the outside, and white or cream colored inside, which emit an odor like horseradish, hence one of its popular names. Such pungency is attributed to the presence of secondary metabolites, specifically, glucosinolates, including glucotropaeolin. These metabolites are broken down to benzyl isothiocyanate, which is a potent biological agent and bitter-tasting compound by enzymes.[17]

In ancient times, the Ayurvedic, African, and Southeast Asian medicines have treated many diseases with the roots of the moringa, including inflammation, joint diseases, including arthritis, microbial infections, as well as diseases affecting the circulatory system.[18] It is noted that moringa roots have a concentrated level of bioactive compounds, which are rare in the aerial parts at the same concentration as has been reported by phytochemical profiling studies. Among them are alkaloids (such as spirochin and moringine), isothiocyanates (such as moringin) and glucosinolates, flavonoids, tannins, saponins, and terpenoids.[19,20] In addition to being able to suppress oxidative stress, pro-inflammatory cytokines, moringin has also demonstrated robust antibacterial, anti-inflammatory, and anticancer effects in preclinical models.[21] These substances mediate the ethnomedical utilization of the moringa root, specifically in Ayurvedic medicine and African folk medicine, as a treatment of circulatory problems, joint pain, and infection.[22,23]

Moreover, recent advancements in analytical techniques have provided the ability to extract and characterize more selective phytochemicals specific to roots. Techniques such as nuclear magnetic resonance spectroscopy, gas chromatography-mass spectrometry, and liquid chromatography-mass spectrometry simplify the structure-activity relationship research to identify new compounds in the roots of moringa.[24] As an example, comparative analyses reveal the presence of tissue-specific synthesis pathways by revealing the presence of a relatively high level of particular phenolic acids and sulfur-containing compounds in roots compared to leaves or seeds.[25] This evidence shows that it is necessary to carry out the plant part-specific studies as compared to the generalization of the applicability of phytochemical information on other components of the plants.

The reasons why moringa roots need to be of interest in a systematic review include that they are not clearly studied, yet are useful pharmacologically and nutritionally, and a range of bioactive chemicals with possible uses in functional foods and medicine. The leaves, seeds, and pods of *M. oleifera* have been the most studied and used commercial parts because of their high nutrient content and easy yield, although they have shown specific phytochemical profiles and strong biological activities, their roots have been comparatively least studied.[19,26] Since roots of plants are frequently storage sites of special compounds engaged in defensive mechanisms, many of which many have therapeutic potential, this knowledge gap provides a vital research prospect in science

ROOT MORPHOLOGY AND ANATOMY OF MORINGA ROOTS

Moringa exhibits diversity in terms of root anatomy and morphologies, which are well aligned with its ecological strategies and life forms. The four main habitats in the genus with various root structure abnormalities are bottle trees, Sarcorhizal tree (species bearing enlarged, fleshy storage roots), thin trees, and tuberous shrubs. Both stem and root secondary xylem in bottle-tree species and *Medicago arborea* have prominent bands of confluent paratracheal parenchyma and alternative bands of libriform fibers that result in regular spatial organization of storage parenchyma and supporting fibers; this same banding of parenchyma-fiber is regularly expressed in roots and enables a large volume of storage living tissue to be available to store water and carbohydrates and to support basic mechanical integrity.[27]

The xylem of the sarcorhizal tree *Moringa ruspolina* also consists of repeated bands of long, slender, parenchymal fibers, which focus on storage yet vary in their fiber shape dramatically.[27] *M. oleifera* possesses a tetrarch main root, and mature roots contain many elements of vessel embedded in xylem parenchyma, representing a hydraulically efficient, yet physiologically sustainable conductive system.[28] In tuberous shrub species, large subterranean storage organs in the form of tubers, predominantly comprised of parenchyma, are survival organs in the face of severe droughts.[27]

Quantitative studies across habitats show that vessel elements are generally broader and the conductive area more advanced in plants in more humid regions. These findings indicate that the xylem of the root and stem of the *Moringa* species are hydraulically adapted to the local water supply and demonstrate substantial developmental plasticity. The presence of tyloses and ergastic deposition in vessels and other cells, and the high growth of storage parenchyma to the detriment of dense mechanical tissues in *M. oleifera*, have both been explained as a trade-off whereby mechanical strength is partly compromised to ensure maximum storage of water and secondary metabolites in root and stem wood.[29] The combination of these properties demonstrates that moringa root systems have evolved toward a balance of hydraulic conductivity, storage, and sufficient (though not optimal) mechanical support by being physically specialized, which promotes the established resistance to drought of the genus and its medicinal importance.[28,29]

PHYTOCHEMICAL PROFILE OF MORINGA ROOTS

All major phytochemical groups associated with the *M. oleifera* are present in its roots, although their concentrations vary in comparison to the aerial portions. The comparative phytochemical screening of the leaves, seeds, and roots indicates that roots contain relatively high concentrations of phenolics and tannins, with tannin (=38.15 mg/100 g) and phenolic acid (=4.01 mg/100 g) having the highest level of concentration among the examined organs. Many types of alkaloids, phenolic acids, flavonoids, tannins, saponins, terpenoids, glucosinolates, and isothiocyanates in different organs, such as roots, have been reported in *M. oleifera.*[30,31] Graph 1 Presents the concentrations of major bioactive compounds in *M. oleifera* roots. According to Panchal *et al*.,[32] the presence of rutin, moringine, and moringinine in *M. oleifera* root extract has been confirmed.

Some of the polyphenols present in the species are gallic, caffeic, chlorogenic, and ferulic acids, flavonoid, and polyphenols such as kaempferol derivatives and quercetin. These compounds are predominantly found in leaves and seeds; however, they have also been detected in root and stem extracts that complement the highly potent antioxidant and insecticidal activities of root methanolic and ethanolic extracts.[12,33,34] In addition, methyl-4-caffeoylquinate, quinic acid isomer, glucomoringin, glucotropaeolin, and benzyl glucosinolate are reported as phytochemicals present in moringa roots.[35] Glucosinolates and their hydrolysis products, isothiocyanates, along with similar thiocarbamates such asniazimin A and B, are recognized as key bioactive constituents. These compounds, either individually or synergistically, contribute to the anti-inflammatory, antihypertensive, and antidiabetic effects.[36,37] Numerous different bioactive compounds have been identified in the plant; more than 100 different bioactive compounds have been identified. These bioactive compounds are responsible for antimicrobial, antioxidant, hypolipidemic, and tissue-protective functions.[36] Nevertheless, the phytochemical composition is highly variable and depends on plant part, genotype, solvent used in extraction, and such environmental factors as climate and altitude.[19,38] In contrast to leaves, which are the richest source of polyphenols and flavonoids, and seeds, which focus their alkaloids, flavonoids and saponins and tannins, the roots are characterized by a tannin- and phenolic-dominated phytochemical matrix, retaining representative levels of alkaloids, saponins, terpenoids, and glucosinolate-derived isothiocyanates, contributing to traditional medicinal use and newly in bioinsecticides and pharmacological preparation, respectively.[30,39] In addition to the moringa seedling roots, which were found to contain ascorbic acid (1.9 mg/g), total carotenoid (29.7 mg/g), and non-structural soluble carbohydrates (258.90 mg/g).[40] The bioactive compounds present in *M. oleifera* roots are illustrated in Figure 2, while the glucosinolates identified in the plant are depicted in Figure 3.

ANTI-DIABETIC PROPERTY OF MORINGA ROOT

The antidiabetic activity of M. oleifera roots was indicated by EC_{50} values of 870.1 ± 12.0 µg/mL and 560.7 ± 7.4 µg/mL for the main and lateral roots, respectively.[41] During ethnobotanical investigations, leaves accounted for 41% of the total reported usage in experiments testing *M. oleifera* anti-diabetic activity, followed by seeds (19%) and roots (19%). In biological and clinical studies of the anti-diabetic effect of moringa, 82% of the plant parts investigated were leaves, 9%

were seeds, and 9% were roots. The administered dosages used in the studies were in the range of 100–800 mg.[42] These results indicate that moringa root exhibits an anti-diabetic activity. Treatment of *M. oleifera* root powder and its methanol extract showed significant increases in the level of insulin when compared to the untreated diabetic group. In the normal group receiving 15 g/kg of *M. oleifera* root powder (16% in diet), the highest insulin concentration was observed (21.72 ± 3.43 µu/mL). Based on the hematological and liver functional indicators, the study revealed that *M. oleifera* root powder and its methanol extract possess hypoglycemic properties and alleviate other undesired diabetic symptoms pre-determined by alloxan-caused diabetes of the experimental rats. The outcomes of the experiment indicate an encouraging opportunity to use this plant to develop a powerful anti-diabetic drug.[32,43] The alcoholic and aqueous root extracts of M. oleifera demonstrated notable antidiabetic and antihyperlipidemic effects in diabetic rat models. The level of the blood sugar was lower in comparison to the diabetes control with both extracts. They both reduced total cholesterol (TC), low-density lipoprotein (LDL), TG, high-density lipoprotein/LDL, and TC/LDL when compared to the diabetic control group. Both extracts increased the bilirubin levels in the diabetic rats when compared to the diabetic control group. The antidiabetic and antihyperlipidemic effect may be explained by the presence of active ingredients such as the alkaloids moringine and moringinine. According to the following studies, the moringa root possesses antidiabetic properties.

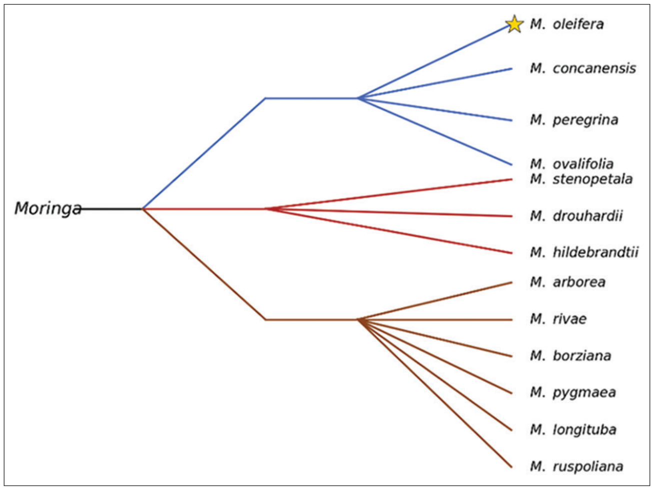


Figure 1: Phylogenetic tree of *Moringa* species

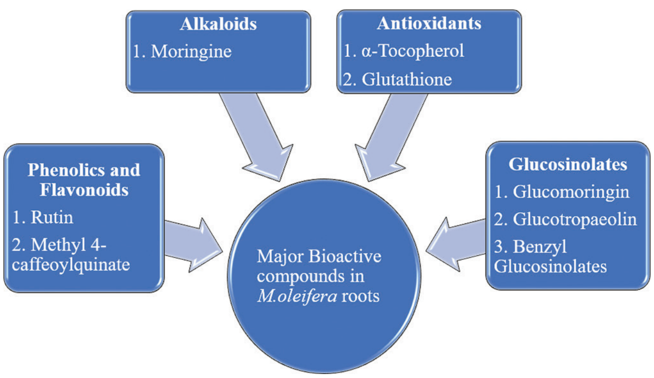


Figure 2: Major bioactive compounds present in *Moringa oleifera* roots

ANTI-OXIDANT PROPERTY OF MORINGA ROOT

Experiment result with 2,2-diphenyl-1-picrylhydrazyl activity (EC_{50}) - 0.057 ± 0.03 µg/mL and 1.23 ± 0.02 µg/mL of main roots and lateral roots, respectively, in the moringa plant. The antioxidant activity of plant material was found

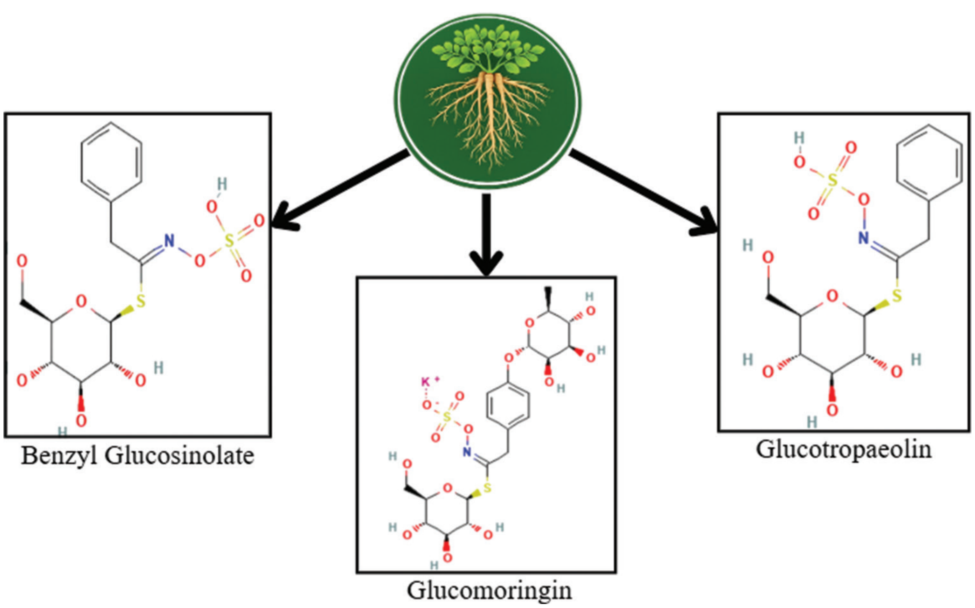


Figure 3: Major glucosinolates present in *Moringa oleifera roots*

to be higher than that of the reference chemical ascorbic acid. The roots have a better capability of being used to get antioxidants compared to the leaves. Lateral roots had higher concentrations of condensed tannins and flavonoids, yet the leaf extracts had the highest concentrations of total phenolics.[41] Root powder extracts (phytochemicals) were analyzed and found to include alkaloids, tannins, flavonoids, cardiac glycosides, saponins, triterpenes, and steroids. Median lethal dose (LD_{50}) was investigated by using oral extracts of *M. oleifera* root powder (hexane, ethyl acetate, and methanol). The LD_{50} was found to be over 5000 mg/kg. The experiments have shown that *M. oleifera* root extracts are virtually non-toxic when administered orally. The groups treated with *M. oleifera* root powder and its methanol extract had much higher levels of oxidative stress indicators such as glutathione peroxidase (GPx), catalase (CAT), and superoxide dismutase (SOD) when compared to the untreated diabetic group. The elevated SOD, CAT, and GPx of this experiment reveal that *M. oleifera* root powder and its methanol extract have the capability of reducing reactive free radicals, which can reduce oxidative damage. It is possibly due to high flavonoid concentration, which is an antioxidant.[43] Some of the phenolic compounds that are found in *M. oleifera* root include polyphenols, flavonoids, and tannins. The capacity of the various extracts to scavenge free radicals, reduce hydroxyl radicals, and decrease the activities of the microsomal lipid peroxidations confirms the existence of various bioactive compounds in *M. oleifera* root. Furthermore, this paper reports that DNA is resistant to damage by hydroxyl radicals. The analysis determined an appropriate solvent to extract the antioxidants and bioactive constituents and differences in antioxidant activity between different solvent extracts.[39] It is the first report of the antioxidant polyphenols in the plant root and stem bark and their possible ability to scavenge free radicals. The concentration of the polyphenols in the leaf and other parts was significantly different from that of the extract of the stem and root bark having different types of procyanidins as compared to that of the leaf. The sections of the plant all showed very good antioxidant and radical scavenging characteristics. The best radical scavenging was realized by the leaves of the plant, and the best antioxidant potential was realized by the root bark extracts of the plant.[44]

ANTI-MICROBIAL PROPERTY OF MORINGA ROOT

Tshabalala *et al*.[41] experimented with the minimum inhibitory concentration of the antibacterial and antifungal action of Moringa leaf, lateral, and main root extracts. Overall, the leaf samples exhibited superior antibacterial activity toward *Bacillus subtilis*, *Escherichia coli*, and *Staphylococcus aureus* compared to the root extracts. The extract of the main and lateral roots demonstrated limited efficacy against *B. subtilis* and *E. coli*. The significant antimicrobial activity observed for the moringa extracts in this study suggests that it has potential use as a feasible alternative against methicillin-resistant *S. aureus*. According to the findings of Dalukdeniya *et al*.,[45] bioactive compounds present in *M. oleifera* (Lam) can be utilized as antibacterial agents against food-borne microbial infections in each of the analyzed sections of the plant. It has been shown that all types of extracts of *M. oleifera* (Lam) have antibacterial activity against Gram-positive *(Listeria monocytogenes*) and Gram-negative (*Salmonella enteritica*, *Vibrio parahaemolyticus*, *E. coli*) microbes; these findings justify the use of the *M. oleifera* (Lam) plant in traditional medicine and show that its potent application for the development of novel therapeutic drugs for food-borne infections. *M. oleifera* (Lam.) roots, petroleum ether extracts of roots inhibit *Pseudomonas aeruginosa*, *S. aureus* and *E. coli*. *P. aeruginosa, S. aureus,* and *E. coli* were all susceptible to the effects of the chloroform extract of moringa root, yet *Proteus mirabilis* was not susceptible to it at any dose. *P. mirabilis* and *S. aureus* were sensitive to the root ethyl acetate extract. Ethanol extract was found to be effective against *P. aeruginosa, S. aureus, E. coli,* and *P. mirabilis*. This research indicates the antibacterial action of the *M. oleifera* roots.[46] The antibacterial activity of different extracts of *M. oleifera* root bark has also been investigated *in vitro* against *P. aeruginosa, Salmonella gallinarum, E. coli*, and *S. aureus*. These observations prove the antibacterial potential across multiple plant parts of *M. oleifera*.

Further *in vitro* and *in vivo* research is necessary to fully use the antibacterial potential of various *M. oleifera* extracts, particularly those of ethyl acetate and acetone extracts, in the treatment of bacterial illnesses in humans and animals.[47] Moringa root powder at the highest concentration (600 mg/L) and a higher initial *E. coli* concentration (50 MPN/100 mL) reduced *E. coli* colonies in the contaminated water by 87%. This suggests that moringa root powder can also be used as a point-of-use water treatment at the household level. Nevertheless, the mechanisms behind the potential existence of bioactive compounds present in the moringa roots that are active against *E. coli* need to be researched further. Additional investigations should also assess the effects of moringa root powder on water quality parameters such as turbidity, pH and palatability and the cost-effectiveness[48,49] cited that the phytochemical screening indicated that all extracts contained alkaloids, flavonoids, saponins, and tannins; however, saponins were absent in root extracts, and tannins were absent in seed extracts. As the outcomes of the antimicrobial study indicated, the *M. oleifera* pod, root, and seed ethanol extracts exhibited antibacterial properties against *Candida albicans*, *S. aureus*, and *E. coli*. The observation that the *M. oleifera* has active phytochemicals with antimicrobial potential is supported by the fact that the ethanol extracts of all the plant components used in this study had varying and significant antimicrobial activity against test pathogens. The most effective extracts in inhibiting the growth of *P. aeruginosa* were the ethyl acetate extracts of roots and leaves and also the ethanolic and methanol extracts of leaves. The most common phenolics and flavonoids that were present in *M. oleifera* were myricetin, quercetin, and hydroxybenzoic acids. These bioactive constituents play a major role in multiple biological processes and are considered key contributors to the antimicrobial and antioxidant effects of the plant.[50]

ANTI-INFLAMMATORY PROPERTY OF MORINGA ROOT

Sashidhara *et al*.[51] isolated 1,3-dibenzyl urea and aurantiamide acetate from the roots of *M. oleifera*. Aurantiamide acetate was significant in inhibiting tumor necrosis factor-α and interleukin (IL)-2 in a dose-dependent manner, and inhibiting IL-2, but not IL-6, whereas 1,3-dibenzyl urea had a potent analgesic effect and significant inhibition of IL-2 but not IL-6. This evaluation implies that these compounds may contribute to the analgesic, anti-inflammatory, and anti-arthritic activities. It also exhibited anti-rheumatic, anti-arthritic, anti-inflammatory, and anti-cancer effects, plus gentisic acid was found at relatively higher concentrations in the roots and seeds.[50] Edema rat paw and rat 6-day air pouch inflammatory models have been used to study the anti-inflammatory properties of a crude methanol extract of the *M. oleifera* Lam. root. The highest level of inhibition was 83.8% and 80.0% at 600 mg/kg, respectively. These results show that the roots of *M. oleifera* exhibit significant anti-inflammatory activity.[52]

ANTI-ULCER PROPERTY OF MORINGA

In their experiment,[53] used two experimental rat models to investigate the antiulcer properties of the ethanolic root-bark extract of *M. oleifera* using gastric lesions induced by ethanol and gastric ulcers induced by pylorus ligation. There was no toxicity or mortality observed in the rats in an acute oral toxicity assessment of the MO. In both cases of antiulcer screening models, a dose-response antiulcer study was conducted using 150, 350, and 500 mg/kg of the extract. Based on the subsequent outcome, MO can possibly be used to cure stomach mucosal lesions and ulcers. It also increases the pH of the gastric juice and reduces its acidity. Such findings indicate that MO possesses antisecretory and antiulcer effects and, therefore, it can be utilized as a source of antiulcer medications in the future. According to Ruckmani *et al.*,[54] fresh leaf juice and root alkali preparation of *M. oleifera* possess powerful anti-ulcer properties. The anti-ulcer effects of moringa have been demonstrated through a dose-dependent reduction in the ulcer scores of the rats. The alkali preparation of the root shows more effectiveness in anti-ulcer activity than the fresh leaf juice. Interestingly, *M. oleifera* is also a strong analgesic and anti-inflammatory. Aspirin and other substances that contain analgesics and anti-inflammatories are known to cause gastric ulcers. It is an impressive scenario to combine analgesic-anti-inflammatory and anti-ulcer activities.

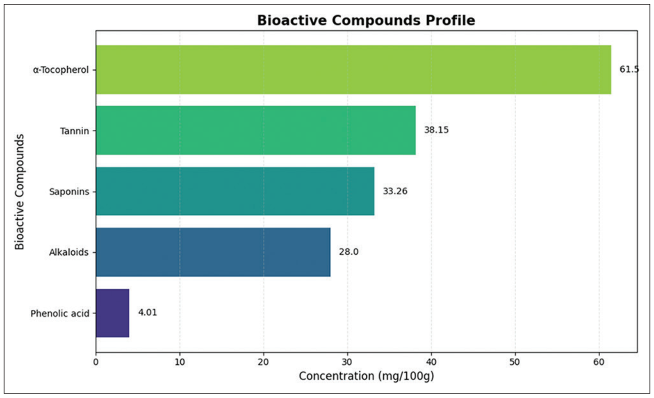
ANTICANCER AND CYTOTOXIC POTENTIAL

Moringa leaf extract, moringa leaf nanoparticle, moringa root core extract, and moringa root outer extract have demonstrated anti-cancer activity against liver hepatocyte HepG2, colon HCT 116 and Caco-2, and breast MCF7 cancer cell lines by decreasing cell proliferation and exhibiting apoptosis-mediated cell death, but the root core extract was capable of sparing the healthy BHK-21 cell line with minimal cytotoxic activity. Moreover, in liver hepatocyte HepG2, this paper paves a path toward examining the action of Moringa extracts on the key signaling pathways that drive cancer cell growth and contribute to the growing body of research indicating their potential to be used as anti-cancer agents.[55]

Roy *et al.*[56] compared the cytotoxic potential and apoptotic induction potential of the ethanolic extract of *M. oleifera* root bark (EMORB) on two human leukemic cells, U937 and K562. The EMORB selectively kills leukemic cells, particularly those of histiocytic lymphoma and erythroblastic cells, by inducing cell death in them through the process of apoptosis. The cytotoxicity induced by EMORB was associated with exposure to phosphatidylserine, which modulated the DNA fragmentation and caspase activation. Thus, their findings provide a completely novel approach to the cell death pathways induced by the root bark of *M. oleifera* and have tremendous potential in the creation of cancer treatment in the future.

INSECTICIDAL EFFECT OF MORINGA ROOT

The ethanolic extracts of *M. oleifera* roots and stems exhibited strong insecticidal activity as they induced dose-dependent death in *Tribolium castaneum* (red flour beetle). The efficacy of the *M. oleifera* root and stem extracts as sustainable bioinsecticides is justified by their high level of activity. Their multi-target mechanisms and better safety profile underscore their potential to replace synthetic pesticides as components of integrated pest control systems. This study illustrates the untapped potential of *M. oleifera* as a sustainable plant to use in integrated pest control. The ethanolic extracts of *M. oleifera* roots and stems exhibited strong insecticidal activity as they induced dose-dependent death in *T. castaneum* (red flour beetle). The efficacy of the *M. oleifera* root and stem extracts as sustainable bioinsecticides is justified by their high level of activity. Their multi-target mechanisms and better safety profile underscore their potential to replace synthetic pesticides as components of integrated pest control systems. This paper illustrates the untapped potential of *M. oleifera* as a sustainable plant to use in integrated pest control. Furthermore, this research provides a novel understanding



Graph 1: Bioactive compounds in *Moringa oleifera* root according to Satish *et al*.[39]

of how to extract phytochemicals with antioxidant and insecticidal properties in the most effective way by systematically assessing the various solvents and plant parts.[34]

Plant-derived extracts had been investigated in consideration of an environmentally friendly alternative to chemical pesticides in termite control. The research found that methanolic *M. oleifera* root extract possesses some insecticidal activity since it was effective in the killing of termites. In this study, the highest rate of termite mortality was 56.67% at 14% concentration after 96 h of exposure to the methanol extract of *M. oleifera* root.[57] According to Alabi and Adewole,[58] all the concentrations of the Moringa root oil extract adversely affected the emergence of teneral adults, which means that disruptive to the development stages of *C. maculatus* (cowpea beetle). Moringa root oil extract affects all concentrations of the extraction and leads to increased mortality, reduced emergence of adults, and seed damage in the contact test and fumigant test. Farmers need to consider moringa root extracts to avoid *C. maculatus* infection and to store cowpea seeds to be used in the next planting season. *M. oleifera* root oil extract can be employed in sustainable pest management to control insect pests that infest stored products.

A comparison of 10% (w/v) moringa root extract and 75% of the recommended concentrations of flupyradifurone or afidopyropen revealed a synergistic effect and a much greater mortality of *Bemisia tabaci* nymphs and adults with the combined doses. Further, the tomato, eggplant, and chilli crops treated with the moringa root extract were identified to have elevated lysyl oxidase pathway volatile organic compounds and elevated peroxidase, polyphenol oxidase, and phenylalanine ammonia-lyase enzyme activities after the *B. tabaci* feeding.[59] Beyond the pest management applications, the root and the seeds can be ground and dried for use as a flavoring agent. In addition, the root bark juice is also anti-tubercular and applied to the tooth cavities as a toothache remedy and earache remedy.[60]

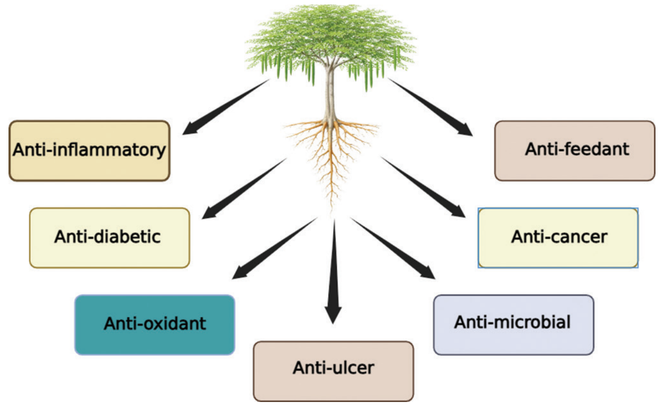


Figure 4: Therapeutic properties of Moringa root

CONCLUSION

The root of the *M. oleifera* is structurally specialized and phytochemically enriched as the organ with a high potential in medicinal and agricultural applications. It is drought-tolerant and has metabolite accumulation due to its deep taproot system and storage tissues. Diverse bioactive compounds such as alkaloids, glucosinolates, isothiocyanates, flavonoids, tannins, and phenolic acids found in the root contribute to the anti-diabetic, antioxidant, antimicrobial, anti-inflammatory, antipyretic, anticancer, and insecticidal effects of the root are illustrated in Figure 4. Experimental studies indicate its possible use in phytomedicine, functional foods, water treatment, and pest management in a sustainable manner, and it is an underexploited but valuable plant resource. Nevertheless, it is necessary to have additional scientific confirmation of its harness to achieve its full potential. The structure-activity relationships need to be explained by standardized methods of extraction, high-tech metabolomic profiling, and systematic mechanistic investigations. Complete toxicology studies and clinical trials are necessary to guarantee safety and efficacy, especially because of strong root-specific substances. Future interdisciplinary research and field-based validation will be critical for translating laboratory findings into practical, scalable applications in health and agriculture.

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AUTHORS CONTRIBUTIONS

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REFERENCES

1. Boopathi NM, Abubakar BY. Botanical descriptions of *Moringa* spp. In: The *Moringa* Genome. Berlin: Springer; 2021. p. 11-20.
2. Dhakad AK, Ikram M, Sharma S, Khan S, Pandey VV, Singh A. Biological, nutritional, and therapeutic significance of *Moringa oleifera* Lam. Phytother Res 2019;33:2870-903.
3. Chopade SP, Patil UN, Garunge VK, Ahire MP, Chaudhari MJ, Ahirrao RA. Review paper on "Moringatree". Int J Pharm Res Applic 2025;10:1346-55.
4. Tiwari N, Singh D. The nutritional profile and therapeutic potential of *Moringa oleifera* (Sahjan): A comprehensive review. Int J Agric Invent 2025;10:179-84.
5. Kushwaha P, Bhatt DK. *Moringa oleifera* (Drumstick Tree): A versatile tree with high nutritive values and industrial use: A review. Flora Fauna 2022;28:171-6.
6. Sundaram D, Babu N. *Moringa oleifera*: A review on nutritive significance and its medicinal application for children. Int J Community Med Public Health 2024;12:610-5.
7. Godinez-Oviedo A, Guemes-Vera N, Acevedo-Sandoval O. Nutritional and phytochemical composition of *Moringa oleifera* Lam and its potential use as nutraceutical plant: A review. Pak J Nutr 2016;15:397.
8. Gupta A, Prasad B, Singh A. Pharmacological active potential of *Moringa oleifera*. Int J Agrochem 2024;10:6-12.
9. Nawale SN. *Moringa oleifera*: A review on medicinal properties and their commercial applications. Asian J Res Pharm Sci 2024;14:125-8.
10. Sharma S, Rani R, Singh AP, Singh AP. Review on *Moringa oleifera* plant. J Drug Deliv Ther 2024;14:210-4.
11. Wang L, Zou Q, Wang J, Zhang J, Liu Z, Chen X. Proteomic profiles reveal the function of different vegetative tissues of *Moringa oleifera*. Protein J 2016;35:440-7.
12. Brilhante RS, Sales JA, Pereira VS, Castelo-Branco DS, Cordeiro RA, De Souza Sampaio CM, *et al*. Research advances on the multiple uses of *Moringa oleifera*: A sustainable alternative for socially neglected population. Asian Pac J Trop Med 2017;10:621-30.
13. Nzeyimana BS, Mary AD. Sustainable sewage water treatment based on natural plant coagulant: *Moringa oleifera*. Discov Water 2024;4:15.
14. Sachan P, Goswami M, Goswami K. *Moringa oleifera* (Moringaceae) an in-depth review of its nutritional classification and therapeutic application. Res Pharm 2024;14:16-24.
15. Devkota S, Bhusal KK. *Moringa oleifera*: A miracle multipurpose tree for agroforestry and climate change mitigation from the Himalayas-a review. Cogent Food Agric 2020;6:1805951.
16. Singh M, Singh S, Verma D. Morphological and pharmacognostical evaluation of *Moringa oleifera* Lam. (Moringaceae): A plant with high medicinal value in tropical and subtropical parts of the world. Pharmacogn Rev 2020;14:138-45.
17. Nazim M, Raza W, Ul Hassan Nasim F, Anjum S, Ullah H, Nawaz A, *et al*. *Moringa oleifera*: A comprehensive review with special emphasis on phytochemistry. Phytochem Rev 2025;25:891-44.
18. Kumar N, Sharma S. Pharmacology, ethnopharmacology, and phytochemistry of medicinally active *Moringa oleifera*: A review. Nat Prod J 2023;13:13-41.
19. Ben-Uwabor P, Olasehinde A, Olawepo G, Lawal A. Comparative phytochemical screening of leaves, seeds and roots of *Moringa* plant (*Moringa oleifera* Lam). Niger J Sci Environ 2025;23:13-26.
20. Muthu Reka S, Vijayanchali S. The role of *Moringa oleifera* pods, seeds, bark and root as functional food. World J Adv Res Rev 2024;21:1937-42.
21. Tshabalala T, Ncube B, Madala NE, Nyakudya TT, Moyo HP, Sibanda M, *et al*. Scribbling the cat: A case of the "miracle" plant, *Moringa oleifera*. Plants (Basel) 2019;8:510.
22. Garima S, Pratibha P, Neelu S, Sharma Mahesh C. *Moringa oleifera*: A review on morphological, phytochemical and pharmacological aspects. Int J Curr Pharml Rev Res 2017;8:163-83.
23. Ojha PS, Tripathi V, Dwivedi P. Antioxidant capacity and radical scavenging activities of *Moringa oleifera*. Acta Sci Agric 2024;8:35-7.
24. Bouchakour M, Nehal F. Advances in phytochemical profiling and extraction techniques of *Moringa oleifera* Lam: Toward its pharmaceutical and nutraceutical applications. S Afr J Bot 2026;188:255-81.
25. Wilcaso P, Landázuri AC, Castelló ML, Ortolá MD. Comprehensive characterization of nutritional, phytochemical, optical, and electrical properties of *Moringa oleifera* Lam. Parts from ecuador. LWT 2025;228:118108.
26. Ayoade ET, Akinyemi A, Oyelere FS. Phytochemical profile of different morphological organs of *Moringa oleifera* plant. J Phytopharmacol 2019;8:295-8.
27. Olson ME, Carlquist S. Stem and root anatomical correlations with life form diversity, ecology, and systematics in *Moringa* (Moringaceae). Botan J Linn Soc 2001;135:315-48.
28. Vyas MK. A contribution on the anatomical characters of *Moringa oleifera* Lamk. And their significance. J Pharmacogn Phytochem 2019;8:576-8.
29. Jayeola A. The sparse development of mechanical tissues in *Moringa Oleifera* linn. Is a trade-off between

strength and storage of secondary metabolites. Ife J Sci 2013;15:75-80.
30. Pareek A, Pant M, Gupta MM, Kashania P, Ratan Y, Jain V, *et al*. *Moringa oleifera*: An updated comprehensive review of its pharmacological activities, ethnomedicinal, phytopharmaceutical formulation, clinical, phytochemical, and toxicological aspects. Int J Mol Sci 2023;24:2098.
31. Xu Y, Chen G, Muema FW, Xiao J, Guo M. Most recent research progress in *Moringa oleifera*: Bioactive phytochemicals and their correlated health promoting effects. Food Rev Int 2024;40:740-70.
32. Panchal M, Murti K, Shah M. Preliminary phytochemical and pharmacognostical studies of *Moringa oleifera* roots. Roman J Biol Plant Biol 2011;57.
33. Divya S, Pandey VK, Dixit R, Rustagi S, Suthar T, Atuahene D, *et al*. Exploring the phytochemical, pharmacological and nutritional properties of *Moringa oleifera*: A comprehensive review. Nutrients 2024;16:3423.
34. Ghada BK, Marwa R, Shah TA, Dabiellil M, Dawoud TM, Bourhia M, *et al*. Phytochemical composition, antioxidant potential, and insecticidal activity of *Moringa oleifera* extracts against Tribolium castaneum: A sustainable approach to pest management. BMC Plant Biol 2025;25:579.
35. Hamza MA, Naimuzzaman M, Roy SK. Health benefits of *Moringa oleifera*: Used as an anti-diabetic agent. Int J Agric Res Innov Technol 2023;13:96-102.
36. Camilleri E, Blundell R. A comprehensive review of the phytochemicals, health benefits, pharmacological safety and medicinal prospects of *Moringa oleifera*. Heliyon 2024;10:e27807.
37. Khan S, Basit A, Hafeez MB, Irshad S, Bashir S, Bashir S, *et al*. *Moringa leaf* extract improves biochemical attributes, yield and grain quality of rice (*Oryza sativa* L.) under drought stress. PLoS One 2021;16:e0254452.
38. Danga JR, Rai IN, Dwiyani R. Morphological characterization and phytochemical analysis of Moringa plant (*Moringa oleifera* L.) different altitudes in Bali. Agro Bali Agric J 2025;8:657-64.
39. Satish A, Reddy PV, Sairam S, Ahmed F, Urooj A. Antioxidative effect and DNA protecting property of *Moringa oleifera* root extracts. J Herbs Spices Med Plants 2014;20:209-20.
40. Tesfay S, Bertling I, Odindo A, Workneh TS, Mathaba N. Levels of anti-oxidants in different parts of *Moringa* (*Moringa oleifera*) seedling. Afr J Agric Res 2011;6:5123-32.
41. Tshabalala T, Ndhlala A, Ncube B, Abdelgadir H, Van Staden J. Potential substitution of the root with the leaf in the use of *Moringa oleifera* for antimicrobial, antidiabetic and antioxidant properties. S Afr J Bot 2020;129:106-12.
42. Fatoumata B, Mohamet S, El HadjiMakhtar B. Antidiabetic properties of *Moringa oleifera*: A review of the literature. J Diabetes Endocrinol 2020;11:18-29.
43. Umar SA, Mohammed Z, Nuhu A, Musa K, Tanko Y. Evaluation of hypoglycaemic and antioxidant activity of *Moringa oleifera* root in normal and alloxan-induced diabetic rats. Trop J Nat Prod Res 2018;2:401-8.
44. Atawodi SE, Atawodi JC, Idakwo GA, Pfundstein B, Haubner R, Wurtele G, *et al*. Evaluation of the polyphenol content and antioxidant properties of methanol extracts of the leaves, stem, and root barks of *Moringa oleifera* Lam. J Med Food 2010;13:710-6.
45. Dalukdeniya D, De Silva K, Rathnayaka R. Antimicrobial activity of different extracts of leaves bark and roots of *Moringa oleifera* (Lam). Int J Curr Microbiol App Sci 2016;5:687-91.
46. Anzano A, De Falco B, Ammar M, Ricciardelli A, Grauso L, Sabbah M, *et al*. Chemical analysis and antimicrobial activity of *Moringa oleifera* Lam. Leaves and seeds. Molecules 2022;27:8920.
47. Dewangan G, Koley K, Vadlamudi V, Mishra A, Poddar A, Hirpurkar S. Antibacterial activity of *Moringa oleifera* (drumstick) root bark. J Chem Pharm Res 2010;2:424-8.
48. Morgan CR, Opio C, Migabo S. Chemical composition of *Moringa* (*Moringa oleifera*) root powder solution and effects of *Moringa* root powder on *E. Coli* growth in contaminated water. S Afr J Bot 2020;129:243-8.
49. Abdulkadir IS, Nasir IA, Sofowora A, Yahaya F, Ahmad AA, Hassan IA. Phytochemical screening and antimicrobial activities of ethanolic extracts of *Moringa oleifera* Lam on isolates of some pathogens. J Appl Pharm 2015;7:4.
50. Prabakaran M, Kim SH, Sasireka A, Chandrasekaran M, Chung IM. Polyphenol composition and antimicrobial activity of various solvent extracts from different plant parts of *Moringa oleifera*. Food Biosci 2018;26:23-9.
51. Sashidhara KV, Rosaiah JN, Tyagi E, Shukla R, Raghubir R, Rajendran SM. Rare dipeptide and urea derivatives from roots of *Moringa oleifera* as potential anti-inflammatory and antinociceptive agents. Eur J Med Chem 2009;44:432-6.
52. Ezeamuzie I, Ambakederemo A, Shode F, Ekwebelem S. Antiinflammatory effects of *Moringa oleifera* root extract. Int J Pharmacogn 1996;34:207-12.
53. Choudhary MK, Bodakhe SH, Gupta SK. Assessment of the antiulcer potential of *Moringa oleifera* root-bark extract in rats. J Acupunct Meridian Stud 2013;6:214-20.
54. Ruckmani K, Kavimani S, Jayakar B, Anandan R. Anti-ulcer activity of the alkali preparation of the root and fresh leaf juice of *Moringa oleifera* lam. Anc Sci Life 1998;17:220-3.
55. Abd-Rabou AA, Abdalla AM, Ali NA, Zoheir KM. *Moringa oleifera* root induces cancer apoptosis more effectively than leave nanocomposites and its free counterpart. Asian Pac J Cancer Prev 2017;18:2141-9.
56. Roy S, Deb N, Basu S, Besra SE. Apoptotic activity of ethanolic extract of *Moringa oleifera* root bark on human myeloid leukemia cells via activation of caspase cascade. World J Pharm Sci 2014;3:1138-56.

57. Omoregie M, Omoregie A, Iloba B. Insecticidal potential of *Moringa oleifera* (Lamarck) root on workers of *Macrotermes bellicosus* (Smeathman). Eur Int J Sci Technol 2018;7:9-16.
58. Alabi O, Adewole M. Essential oil extract from *Moringa oleifera* roots as cowpea seed protectant against cowpea beetle. Afr Crop Sci J 2017;25:71-81.
59. Roy D, Biswas S, Sarkar S, Biswas A, Mondal K, Das P, *et al*. Blending *Moringa* root extract with biorational insecticides: A potential approach for the management of *Bemisia tabaci* through synergistic interactions and induced plant defense. Plant Stress 2025;16:100852.
60. Hossain MF, Numan SM, Khan SS, Mahbub S, Akhtar S. Human consumption, nutritional value and health benefits of *Moringa* (*Moringa oleifera* Lam.): A review. Int J Community Med Public Health 2022;9:3599-604.

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