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Medicinal Uses and Pharmacology of Moringa Oleifera: A Review

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Abstract

Moringa oleifera Lam. is a nutritionally supplemented tropical plant whose leaves, seeds, bark and roots has been traditionally used in traditional medicine. The research of the modern period (2015-2025) has reported its various pharmacological activities such as antioxidant, anti-inflammatory, antihyperglycemic, antihypertensive, antimicrobial, anticancer and others. These properties are due to the great concentration of vitamins (A, C, E), minerals (Ca, K, Fe), flavonoids, glucosinolates/isothiocyanates and other phytochemicals. Preclinical models (in vitro, animal) establish that M. oleifera extracts induce antioxidant defenses (through Nrf2/ HO-1) and inhibit pro-inflammatory processes (NF-kB, TGF-b/ Smad) in tissues. The in vitro/in vivo mechanism has shown a positive response in glucose metabolism (a-glucosidase inhibition, enhanced b-cell function), lipid profile and blood pressure (endothelium-dependent vasodilation, ACE inhibition), bone remodelling and neuro protection. There is still limited human clinical evidence: a meta-analysis of 9 RCTs (N ≈ 650) found no effects on glycemic or lipid outcomes (except a small but significant diastolic BP reduction, SMD -0.41) with Moringa supplementation, but a recent 3-month RCT in women with type 2 diabetes in Saharawi showed a significant reduction in HbA1c (-0.59%) in the group receiving Moringa supplementation. According to the mechanistic studies, M. oleifera supports its action through various pathways: the inhibition of carbohydrate-digesting enzymes and SGLT1 (reduction in glucose absorption), the stimulation of endothelial nitric oxide and endothelium EDHF release (vasorelaxation), the blockage of vascular Ca2+ channels, and the production of ACE-inhibitory peptides. The available evidence, in general, points to a promising pharmacological role of M. oleifera in metabolic, cardiovascular, neurodegenerative as well as in infectious and inflammatory disorders, yet, well-designed clinical trials and preparation standardization are required to prove effectiveness and safety.

Introduction

Moringa oleifera Lam. (Moringaceae) is a rapid tree that has its native habitat in South Asia, yet is grown across the world. It is nicknamed as the miracle tree since almost all its parts (leaves, seeds, pods, flowers, bark, roots) are consumed as food and in folk remedies (1). The leaves themselves are extremely rich in nutrients (high in protein, b-carotene, vitamins (A, C, E, B-complex), mineral (Ca, K, Fe) (1, 2). Some ethnobotanical applications are in the treatment of malnutrition, diabetes, high blood pressure, inflammatory diseases, and healing wounds, infections and others. M. oleifera has been identified to contain over 100 phytochemicals (flavonoids such as quercetin/kaempferol, phenolic acids, glucosinolates/isothiocyanates, alkaloids, vitamins, terpenes, etc.) with numerous with high bioactivities (1). Recent pharmacological studies have verified that M. oleifera extracts have antioxidant, anti-inflammatory, anti-microbial, anti-cancer, hypoglycemic, hypotensive, hepatoprotective, and other effects (1, 3). Most available evidence is however preclinical. The review is a systematic search of the current (last 5-10 years) preclinical and clinical evidence of the M. oleifera medicinal properties systematized according to the therapeutic effects and mechanism of action (4).

Methods of Literature Search

We have made a thorough literature search (2015-2025) of databases such as PubMed, Scopus, Web of Science and Google Scholar using such keywords as: Moringa oleifera pharmacology, Moringa oleifera clinical trial, Moringa oleifera mechanism etc (1, 2) . English as well as other peer-reviewed publications were taken into account. Appropriate in vitro, in vivo and human research were filtered and information on pharmacological action, dosage, models, and mechanisms were harvested. Reviews on the subject matter were also looked into to determine important compounds and pathways. The sources used below are mostly of good quality journals and contain clinical trials, meta-analyses and high quality preclinical studies.

Pharmacological Effects by Indication

Anti-Inflammatory and Antioxidant Actions

M. oleifera is a source of antioxidant and anti-inflammatory phytochemicals (flavonoids, phenolics, glucosinolates, etc.). Extracts are always found to decrease oxidative stress and pro-inflammatory cytokines in cell and animal models. As an example, oral administration of moringa seed-derived isothiocyanate MIC-1 (4-[(a-L-rhamnosyloxy)benzyl]isothiocyanate) at the dose of 80 mg/kg reduced inflammatory mediators (TNF-a, IFN-a, IL-1b, IL-6) in liver, kidney, spleen and colon, and splenomegaly was prevented in LPS-induced sepsis mice(3). Simultaneously, MIC-1 treatment stimulated the nuclear Nrf2 (activation of antioxidant gene expression) and reduced nuclear NF-kB in macrophages (3), which led to a decrease of intracellular ROS and the recovery of mitochondrial activity. Likewise, M. oleifera seed extract in vivo prevented NF-kB and TGF-b1/Smad2/3 signatures (inflammatory and fibrotic pathways) and promoted the Nrf2/ HO-1 antioxidant pathway in diabetic nephropathy rats, which resulted in reduced renal inflammation and fibrosis (5). Concisely, M. oleifera compounds have both anti-inflammatory and antioxidant effect through major pathways (NF-kB inhibition, Nrf2 activity) (6).

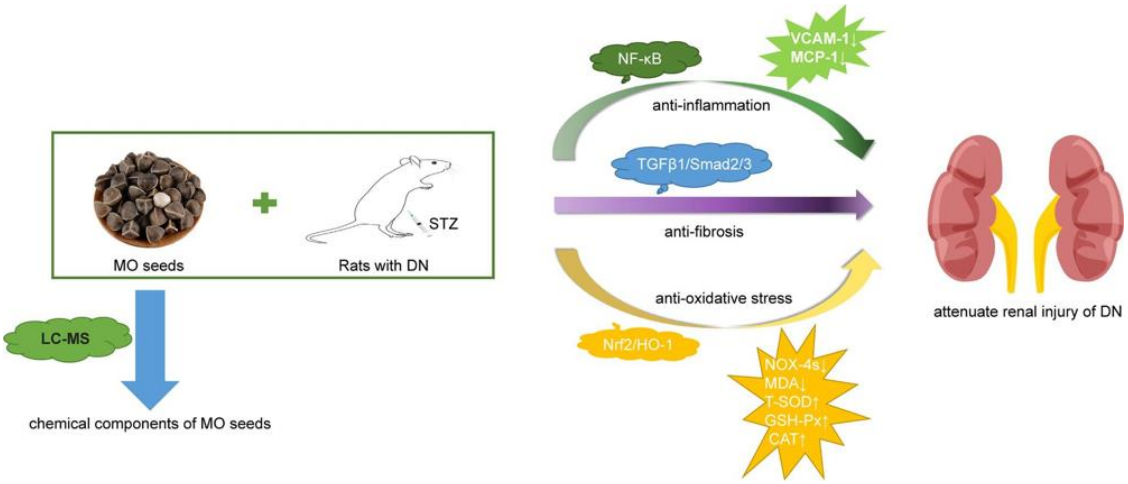

Figure 1. Moringa seed extract stimulates Nrf2 and suppresses NF-kB/TGF-b pathway in diabetic rat kidneys, which suppresses the inflammation and fibrosis (5). The graphical abstract (by He et al., 2022) shows how M. oleifera alleviates diabetic nephropathy by changing the ratio in favor of anti-fibrotic and antioxidant mechanisms.

Other moringa compounds (flavonoids such as quercetin, kaempferol; phenolic acid; vitamins C/E) add to the effects of MIC-1. As an example, the leaf extract of M. oleifera suppresses LPS-induced cytokines (IL-6, TNF-a) in macrophages and enhances the oxidative stress indicators in different tissues. A water extract of a leaf reduced the inflammatory cytokines (IL-6, MCP-1) and blocked the NF-kB pathway in human adipocytes(3, 5). M. oleifera therefore is a strong natural anti-inflammatory/antioxidant and thus its application in traditional medicine on inflammatory disorders is justified.

Antidiabetic and Metabolic Effects on Animal, in vitro: M. oleifera has been demonstrated to enhance glycemic regulation in diabetic animals in several studies. Fasting glucose, insulin sensitivity and pancreatic b-cells are all improved in diabetic rats treated with moringa leaf powder or extracts. The suggested mechanisms comprise the inhibition of carbohydrate degrading enzymes and transporters: M. oleifera leaf flavonoids (a-naphthoquinone glycosides) interact with and prevent pancreatic a-amylase and intestinal a-glucosidase (5). This slows starch breakdown. Also, the glucose absorption is decreased by high intestinal competitive blockage of SGLT1 by the high dietary fiber and chlorogenic acid of leaves (5). Alterations in additional mechanisms have also been shown to occur in the rat, such as enhanced uptake of glucose in muscle through AMPK activation and enhanced anti-oxidant coverage of b-cells.

Animal evidence: M. oleifera leaf supplementation significantly decreased body weight gain and adiposity, and lipid profiles in a rat model diet high in fats. As an illustration, 5 percent (g/w) moringa leaf (12 weeks) in diet reversed obesity and dyslipidemia resulting in the use of high-cholesterol diets . Similar to the above case in diabetic nephropathy rats, moringa seeds also relieved hyperglycemia and kidney dysfunction as well as renal protection (4).

Human trials: There is rare and confusing clinical data. A meta-analysis (2025) of 9 RCTs (341 treated, 308 placebo) in patients with type 2 diabetes or prediabetes did not observe any significant outcome of M. oleifera supplement on fasting glucose, HbA1c or the majority of lipid endpoints[5][6]. The only borderline result was the

slight decrease in diastolic BP (SMD -0.41, 95%CI -0.77 to -0.04) (2). All were rated by low-very low certainty caused by heterogeneity and small samples[19][20]. Conversely, a 3-month, unblinded, RCT in poorly controlled female diabetes in Saharawi (n ≈ 50) showed that 5 g/day of moringa leaf powder reduced HbA1c by 0.59% (9.09% to 8.50, p<0.001) in the moringa group, but not the controls (5). The difference between groups was not substantial (p=0.056) but indicates a positive change in glycemic. Secondary outcomes (fasting glucose, lipids) were also not significantly altered. Altogether, although preclinical evidence is always encouraging, there has been evidence of only mild or intermittent positive effect on glucose metabolism in the human trials to date (2, 5).

Cardiovascular and Antihypertensive Action.
M. oleifera is commonly used as a traditional medicine used for treatment of hypertension and heart health (7). Examples of bioactive compounds implicated are nitrile glycosides, flavonoids as well as peptides. There are experimental studies that show a vasorelaxant and diuretic effect. The isolated rat artery assays demonstrate that M. oleifera leaf extract causes intense, endothelium-dependent vasodilation through nitric oxide (NO) and endothelium- derived hyperpolarizing factors (EDHFs) (5). The relaxation due to the extract was mostly NO-mediated (inhibited by L-NAME) but also required EDHF/K+ channels in mesenteric arteries of hypertensive rats (7). Also, Moringa extract have a direct action in preventing the vascular smooth muscle Ca2+ influx: it blocks voltage- and receptor-operated calcium channels in vascular smooth muscle cells, decreasing intracellular calcium and thereby cell vessel contractility (7).

The renin-angiotensin system peptide inhibitors were also found: enzymatic hydrolysates of moringa leaf protein (enzymatically digested <1 kDa fraction) demonstrated over 84 percent ACE activity inhibition and approximately 44 percent renin inhibition. ACE had IC50 [?]0.3 mM with two isolated tetrapeptides (Leu-Gly-Phe-Phe, Gly-Leu-Phe-Phe). In addition, some flavonoid glycosides (e.g. quercetin-3-O-glucoside) have dose-dependent ACE inhibition (~75% inhibition at 28 mg/mL) (7).

Evidence: Moringa extracts (leaf/fruit) have a modest blood pressure-lowering effect in hypertensive animal models, which is usually matched by low dose captopril. Chronic (45 days) administration of ethanolic moringa leaf extract by one rat study showed a significant blunting of L-NAME induced hypertension. There is a lack of human trials: the RCT results showed that an acute meal of 20g fresh moringa leaves lowered postprandial systolic BP in healthy individuals. Nonetheless, in diabetic or prediabetic adults, other RCTs found no significant changes in blood pressure in their 4-12 weeks moringa supplementation (7). The latest meta-analysis only reported a slight decrease in diastolic BP (2).
Besides blood pressure, M. oleifera is able to positively regulate lipids in animals. The rat studies usually show a decrease in the total cholesterol and triglycerides. Human studies (in healthy or dyslipidemic subjects) have shown small LDL reducing effects, but here too there are conflicting results (2). M. oleifera, in general, has several vasoprotective (NO-enhancers, Ca-channel blockers, ACE-inhibitors) and cardiovascular support properties, but the prospects of clinical validation are still strong.

Antimicrobial and Antiparasitic Effect.
Many in vitro experiments show that M. oleifera extracts prevent bacteria, fungi and parasites. Leaf, seed or root extracts are susceptible to a wide variety of gram-positive and gram-negative bacteria (e.g. E. coli, S. aureus, Salmonella, etc.); antifungal activity against Candida and Botrytis also has been described (8). An example is that the ethanolic root extract has an isothiocyanate derivative (N- benzyl ethyl thiocarbamate) which exhibits a broad antimicrobial and antifungal activity (1). Antimalarial activity is also demonstrated with seed and leaf preparations: others report that the moringa leaf compounds have an antimalarial effect of inhibiting the growth of Plasmodium falciparum and also control the activation of monocytes in malaria models (9). Conventional applications involve purification of water with crushed seeds as well as treatment of parasitism. There is no clinical evidence about the use of antimicrobials, whereas the phytochemical evidence is high. Probably the antimicrobial effects are the disruption of the cell membrane by isothiocyanates and tannins, as well as the chelation of the metal ions by phytates. Due to the emergence of antibiotic-resistance, M. oleifera is under investigation as a repository of novel antimicrobials (including delivery mediated by nanoparticles).

Anticancer and Antiproliferative Effects. Investigations into M. oleifera indicate a possible antiproliferative action. Leaf and seed extracts (in particular seeds) have been demonstrated as inhibitory of several types of cancer cells in vitro (breast, colon, lung). Some of the mechanisms suggested are induction of apoptosis, cell cycle arrest and antiangiogenic. As an illustration, compounds obtained by hydrolyzing seeds (such as niazimicin) induce cell death in colon cancer cells, and leaf flavonoids induce cell death in breast cancer cells. In vivo, there are few murine studies that have documented that oral M. oleifera extract has the ability to prevent tumor growth in transplant models (e.g. Ehrlich ascites tumor). Nonetheless, there are no strict human tests. Current studies are identifying individual bioactive components (e.g. moringa isothiocyanates) to anticancer pathways (e.g. p53 activation, NF-kB inhibition) (3). The findings are preliminary and not yet accepted clinically as a cancer treatment but M. oleifera should be investigated more due to these findings as an adjunct or preventive agent.

Hepatoprotective and Organ Protection. M. oleifera extracts prevent liver damage in various models of drug or toxin-induced liver damage. An example would be the effect of moringa leaf/seed extract on rat models of acetaminophen or streptozotocin toxicity in which moringa leaf/seed extract preserved liver enzymes, decreased oxidative damage, and improved histology. Aqua regia moringa leaf extract alleviated antiretroviral induced cytotoxicity in human liver HepG2 cells in a cell culture study, much through antioxidant mechanisms. Likewise, there is also renal protection with decrease in BUN/ creatinine and better kidney structural appearance (e.g. gentamicin or diabetic nephropathy models). Once again, the protective actions focus on anti-inflammatory/antioxidant actions - the activation of Nrf2/antioxidant genes and inhibition of NF-kB/fibrosis pathways as shown in the model of diabetic nephropathy (5). Therefore, M. oleifera is regarded as possessing cytoprotective effects on liver and kidney which justify its ancient application in liver disease and poisoning. There have been no significant human experiments of organ protection yet.

Neuroprotective Effects Recent reviews indicate that M. oleifera has a neuroprotective potential. It has a high level of flavonoid and isothiocyanate, which are good antioxidants and anti-inflammatory factors in the brain. Moringa extracts have been used in animal models of neurodegeneration (e.g. stroke, rodent models of Alzheimer) to enhance cognitive performance, inhibit neuronal apoptosis and decrease signs of oxidative stress. The mechanisms are neutralization of free radicals in neural tissue, downregulation of neuroinflammatory cytokines (IL-1b, TNF-a) and the regulation of neurotransmitters. As an example, moringa leaf supplementation in aging rats elevated serotonin and dopamine and lowered acetylcholinesterase implying improvement of mood and cognition (10). The review conducted by Worku et al. in 2024 concluded that M. oleifera enhances the antioxidant defense actions of the brain, lowers inflammation, and increases the levels of neurotransmitters (10). The authors highlight its potential in the neurodegenerative diseases (Alzheimer, Parkinson) and request clinical trials (10). Overall, the data on preclinical neuroprotection is promising, probably, the same anti-oxidative/anti-inflammatory actions are listed in the system.

Impact on Bone and Mineral Homeostasis. There is an emerging evidence of the use of M. oleifera in the treatment of bones. According to preclinical studies (2024-2025), moringa extract prevents bone loss in osteoporotic models. In rodents M. oleifera supplementation inhibited bone deterioration caused by glucocorticoid- or estrogen-deficiency, enhancing trabecular thickness and raising osteoblast-activity markers (11). A single study reported that moringa treatment increased serum alkaline phosphatase and procollagen type I N-terminal propeptide, which indicates that there was increased bone formation (8). Moringa mechanistically controlled bone remodeling signals: it enhanced BMP2 and PI3K/Akt signaling (osteoblasts) and inhibited RANKL/RANK (osteoclasts) (11). These results represent a solid basis on which they could be used in the management of osteoporosis (11). There are no clinical bone trials on M. oleifera, but it has a great deal of calcium and anabolic effects in animals, so it might be a valuable bone health dietary supplement.

Other Effects (Nutrition, Fertility, etc.) The moringa leaf powder is a nutritional supplement to malnutrition and anemia due to its nutrient content. Human trials on small groups have indicated that the consumption of M. oleifera leaves could increase hemoglobin levels in anemic children and enhance milk production in the mother after childbirth. In a report of 2023, it was reported that pregnant women taking moringa experienced increased birth weights (by ≈ 116 g) and improved hemoglobin status and no contraindications were reported (8). Probably these effects are caused by the iron, vitamin A and C of the leaves. Moringa has also been examined concerning antimicrobial resistance, mental health (depression symptoms alleviation, possibly through serotonergic activity), as well as even as a cosmetic ingredient (high oleic oil in the seeds). **Safety and Toxicology** M. oleifera is also considered to be safe in normal levels of consumption. There are few adverse effects and traditional use (herbal teas, cooked leaves) is reported to have little adverse effects and modern trials show that it has few adverse effects. Animal tests of acute and sub-chronic toxicity did not show any harmful effects at a dose level of up to 1 g/kg body weight (8). Another interesting human test used 0.5-2 g/day of leaf powder (including pregnant women) without ill effects (12). In one of the reviews, it was stated that the safe dosage of moringa leaf is 2 g/day even in pregnancy. It should be avoided only in root bark and large amounts of seeds which contain mild toxic alkaloids. All in all, the antioxidant and vitamin content is very high indicating a large safety margin (12), yet controlled clinical studies on long-term usage are still required.

Conclusion

In the past ten years, Moringa oleifera has received a lot of scientific attention due to the so-called multi-nutraceutical properties (13). Its extracts demonstrate broad-spectrum pharmacological responses in cell and animal models: antioxidant/anti-inflammatory effect (through the Nrf2 and NF-kB pathways), metabolic benefits (glucose and lipid control), cardiovascular benefits (vasorelaxation, ACE inhibition), and organ protection (hepatic, renal, neural) and so on. These have the potential to be used in the treatment of diabetes, hypertension, obesity, cancer and neurodegeneration among others. Nonetheless, there is still preliminary human clinical evidence. Although small studies have found some evidence of moderate metabolic effects (e.g. small changes in HbA1c or BP), bigger, more prolonged and more controlled studies are required. Recent quality meta-analysis found that existing RCTs of moringa in metabolic disease are inconclusive (2).

Future outlook: Reproducible research will be important in the future through standardization of M. oleifera preparations (e.g. defined extracts or isolated compounds). There are new delivery systems (nanoparticles, fortified foods) that could be used to improve bioavailability. Mechanistic research is elucidating therapeutic options like SGLT1, Ca 2+ channels, and particular signaling pathways (see Table 1). The clinical trials are also supposed to be homogeneous, placing efforts on well-defined endpoints (glycemic control, blood pressure, inflammatory biomarkers). Due to its antioxidant and nutrient composition, moringa can particularly be helpful as a supplementary therapy or preventive supplement.

To conclude, Moringa oleifera is an interesting medicinal tree whose pharmacological effects are multifaceted and justified by the modern science. It is influenced by its rich phytochemistry which is the basis of anti-inflammatory, antioxidant, metabolic and organ-protective (Table 1). Existing evidence indicates an encouraging response to therapy, although clinical validation and mechanism is still an area of research.

Table 1. Summary of key pharmacological effects of Moringa oleifera**

Effect / Indication	Active Components	Evidence (Model)	References
Anti-inflammatory	Isothiocyanates (e.g. MIC-1), flavonoids (quercetin, etc.)	In vitro macrophage ↓TNF-α/IL-6, NF-κB suppression; LPS mouse model ↓cytokines, ↑Nrf2	(5, 6)
Antioxidant	Polyphenols, vitamins C/E	In vitro free radical scavenging; ↑antioxidant enzymes (SOD, CAT) in diabetic/nephropathy rats	(5)
Antidiabetic	Fiber, chlorogenic acid, flavonoids	Rodent diabetes models: ↓glucose, ↑insulin sensitivity; Inhibits α-amylase/α-glucosidase and SGLT1	(5)
Antihypertensive	Nitrile glycosides, peptides	Rat studies: endothelium-dependent vasodilation (↑NO, EDHF) ACE/renin inhibition by peptides; ↓BP in some animal models	(7)
Hypolipidemic	Fiber, flavonoids	Rodents: ↓TC, TG, ↑HDL	(2)

Effect / Indication	Active Components	Evidence (Model)	References
		with leaf/seed extracts; Human data inconclusive	
Antimicrobial	Benzyl thiocarbamates, glucosinolates	In vitro: broad antibacterial/fungal activity (e.g. root extract with N-benzyl thiocarbamate)	(1)
Hepatoprotective	Polyphenols, isothiocyanates	Toxin models: normalized ALT/AST, improved histology; protects HepG2 cells from drug-induced oxidative stress	(5)
Neuroprotective	Flavonoids (rutin, quercetin etc.)	Animal neurodegeneration models: ↑antioxidant enzymes in brain, ↓neuroinflammation; improves cognition and neurotransmitters	(10)
Bone health	Calcium, vitamin D analogs? (proposed)	Rodents (osteoporosis models): ↑BMD, trabecular thickness; ↑osteoblast markers (ALP, procollagen I)	(11)

Note: TC = total cholesterol; TG = triglycerides; BMD = bone mineral density; ALP = alkaline phosphatase.

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