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MORINGA OLEIFERA: AN UPDATED REVIEW OF ITS FEATURES, PHYTOCHEMISTRY, PHARMACOLOGICAL ACTIVITIES, AND HUMAN CONSUMPTION

Musfera Emaan[1], Subha Mahmood[*2], Rabia Zulfiqar[*3], Mubashar Mazhar[4], Zafar Iqbal[5]

*[1, *2,*3,5]Department of Pharmacy, The University of Chenab Gujrat, Pakistan.*
[4]Agri Extension Department, University of Agricultre Faisalabad, Depalpur Campus Okara, Pakistan.

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Corresponding Author: *
Subha Mahmood
Rabia Zulfiqar

Abstract

Moringa oleifera, frequently referred to as the miracle tree, is a remarkable plant valued for its wide range of medicinal and practical benefits. For generations, it has been used in traditional medicine to help treat conditions such as persistent pain, various ulcers, skin wounds, and issues affecting the heart and liver. Modern scientific research has validated many of these traditional uses, confirming that extracts from different parts of the tree offer significant anti-inflammatory, liver-protective, and heart-protective properties. Researchers have identified over one hundred active compounds in the plant, including various vitamins, antioxidants, and unique substances like niacin A&B. While this review highlights a strong foundation for its medicinal potential, many traditional applications remain scientifically unproven, pointing to a need for further study to fully understand how these compounds work in the human body.

1. Introduction

Moringa oleifera (*M. oleifera*), the miracle tree, flourishes universally in practically all tropical and subtropical sections, but it is supposed to be inborn to Afghanistan, Bangladesh, India, and Pakistan [1]. The Moringa family includes 13 species (*M. oleifera*, *M. arborea*, *M. rivae*, *M. ruspoliana*, *M. drouhardii*, *M. hildebrandtii*, *M. concanensis*, *M. borziana*, *M. longituba*, *M. pygmaea*, *M. ovalifolia*, *M. peregrina*, *M. stenopetala*), of which *M. oleifera* has become well known for its use in sustenance, biogas production, manure, etc [2]. Moringa has the exclusive property of bearing dearth [3]. Nearly all parts of the tree are used for their crucial nutrients. *M. oleifera* leaves have a high content of beta-carotene, minerals, calcium, and potassium [4]. Desiccated leaves have an oleic acid content of about 70%, which makes them appropriate for making creams [5]. The crushed leaves are used to make many beverages, of which "Zija" is the most popular in India [6]. The bark of the tree is considered very beneficial in the treatment of different disorders such as pustules [7], toothache [8], and hypertension [9] Roots, however, are found to have a character in the action of toothache [8], helminthiasis [10], and paralysis [11]. The flowers are used to treat ulcers, inflamed spleen, and to produce aphrodisiac matters [2]. The tree is thought to have unbelievable properties in treating malnutrition in newborns and lactating mothers [3]. The present review aims to sum up the updated insight regarding the pharmacological activities, worldwide research analysis, toxicological, phytochemical, and ethnomedicinal properties of *M. oleifera*. Lately, *M. oleifera's* been blowing up worldwide for its killer nutrition and health perks. Research is coming out left and right because it's so darn useful and relevant these days, so we gotta pull it all together, check what's solid, and spot the gaps. That'll help frame the new stuff and point

folks in science, docs, and farming toward what to tackle next.

The leaves contain total superstars stuffed with protein, all the must-have amino acids, vitamins A, B-vitamins, C, E, and minerals like calcium, potassium, iron, and magnesium [12].

2. Taxonomy, Botanical and Geographical distribution

2.1. Taxonomy

The taxonomic classification of *M. oleifera* is summarized in Table 1 [3, 13, 14].

Table 1. Taxonomy of *Moringa oleifera* Lam.

Level	Classification
Kingdom	Plantae
Subkingdom	Tracheobionta
Superdivision	Spermatophyta
Division	Magnoliophyta
Class	Magnoliopsida
Subclass	Dilleniidae
Order	Capparales
Family	Moringaceae
Genus	Moringa
Species	Oleifera

2.2. Botanical and Geographical Distribution

M. oleifera has spread far and wide across the globe, but it originally hails from India, Arabia, and the East Indies.it is common in places like Asia, Africa, the Caribbean, Latin America, the Pacific Islands, Florida, Madagascar, Central America, Cuba, the Philippines, Ethiopia, and Nigeria [2, 15]. *Moringa oleifera* is a fast-growing deciduous tree that can reach about 8 meters in height. It has a twisted trunk, smooth bark that ranges from dark gray to yellow, and a broad, umbrella-like crown. Its leaves are compounded and divided into smaller leaflets, which are dark green on top and lighter underneath. The tree also produces fragrant creamy-white flowers in loose clusters. Its fruit is a long, three-sided capsule known as a "drumstick," and it contains light brown seeds that can sprout within a week if conditions are right [16]. It requires tropical and subtropical regions and grows at a temperature of about 25–35 [1]. It grows best in indirect sunlight and in soil that drains well, since standing water can damage the tree. The soil should be slightly acidic to alkaline. The tree usually begins to produce fruit when it is about 6 to 8 months old [17]. It is commercially cultivated in several countries, including Africa, Mexico, Hawaii, and South America. However, because soil conditions vary from one region to another, the nutrient content of the plant may also differ from country to country [3].

2. Morphology

The tree grows rapidly in loamy and well drained sandy soils , preferring a height of 500m above sea level [1]. Normally, the tree is small to medium in size, the leaves are naturally trifoliate, the flowers are born on an inflorescence 10–25 cm long [14], and the fruits are usually trifoliate and commonly referred to as "pods" [3]. The trunk usually grows straight but is occasionally poorly formed, the branches are usually disorganized, the canopy is umbrella-shaped; the brown seeds have a semi-permeable hull, and each tree has a capacity of about 15,000–25,000 seeds per year [9].

Figure 1. Summary of morphological characters of *Moringa oleifera*.

3. Cultivation

Moringa oleifera can be propagated through seeds, hardwood cuttings, or nursery-raised transplants. Under suitable conditions, seeds sown at shallow depths of up to 2 cm typically germinate within two weeks. Similarly, hardwood cuttings (1–2m long,4–16cm thick) taken from mature trees during the rainy season readily establish roots when maintained under moist conditions [18]. Because it grows so quickly, reaching up to 33 m in just three months, *M. oleifera* can support several harvests each year. Pruning or pollarding is often used to encourage side branching, make harvesting easier, and improve regrowth. In particular, moderate pruning has been found to produce significantly more leaf biomass than either light or heavy pruning [19]. Planting density is adjusted according to the intended production goal. For intensive leaf production, plants are usually spaced 10–20 cm apart, with harvesting done every 35–45 days; this system also requires irrigation and fertilization. In semi-intensive systems, spacing is about 50×100 cm, with harvests every 50–60 days and moderate input levels. For agroforestry systems, rows are typically spaced 22–44 m apart to allow low-input integration into broader farming systems.

Yields can vary greatly depending on genotype, climate, and spacing. Intensive plantations may produce between 40 and 580 metric tons of fresh biomass per hectare per year [20]. Shoots are usually harvested when they reach 0.5–11 m in height to encourage regrowth, although picking individual leaves may be quicker, it can reduce plant stamina over time. For seed production, wider spacing of 2.5–33 m is recommended to support pod development. Pods generally mature about three months after flowering and should be harvested promptly to prevent seed loss. Depending on the cultivar and environmental conditions, a single tree can produce 15,000–25,000 seeds per year [21, 22].

4. Human consumption

Moringa is highly valued for its dense concentration of nutrients and minerals, which support overall health and well-being [23, 24] . The pods are typically prepared as a vegetable, finding their way into stews, curries, and soups; when young, they are tender and fiberless, similar in texture to green beans. The leaves are incredibly versatile and can be enjoyed boiled, fried, or incorporated into various cooked dishes. Similarly, the seeds can be boiled or fried like peas when harvested green or roasted and enjoyed like peanuts. Beyond the standard parts,

the roots and seeds are often dried and ground into a seasoning, while the flowers and buds are used in a variety of culinary applications. Dried flowers are also commonly steeped to make tea, and the resin collected from the tree's trunk serves as a natural thickener for sauces. Because Moringa leaves, pods, and seeds are packed with protein, essential vitamins, calcium, iron, magnesium, zinc, and a host of antioxidants like flavonoids and phenolics, they are widely recognized for their ability to support organ function and general health [25, 26]. Dried leaf powder is frequently used as a nutritional supplement, making it an excellent addition to everyday meals. This is especially helpful in communities where diets rely heavily on starches, as Moringa can be easily stirred into side dishes to boost the intake of necessary proteins and micronutrients, thereby improving overall nutritional security. In regions like southern India, the leaves and young pods are staples, frequently eaten like spinach or used to enhance the nutritional value of soups and salads. Furthermore, it is a traditional dietary inclusion for pregnant women, often used to help improve breast milk production [27]. Nutrient content varies with preparation method, leaf and pod age, and harvest season. Due to its ten times higher vitamin A content than carrots, seven times vitamin C than oranges, seventeen times calcium than milk, and fifteen times potassium than bananas, it is known as the miracle plant [28].

5. Nutritional values

M. oleifera leaves are broadly recognized for their brilliant nutritional affluence, comprising over 90 phytonutrients, as well as essential amino acids, proteins, vitamins, and minerals. Among these, vitamins have been widely studied across different leaf forms fresh, dried, and powdered. Leaf powder, commonly presented in health food stores, is typically derived from shade- or sun-dried leaves [29]. All plant parts, especially the leaves and pods of the Moringa tree, are rich in protein, vitamins, minerals, antioxidants, and phytochemicals of nutritional and medicinal value [30]. All parts of Moringa are a good source of nutritionally essential minerals Ca, P, Mn, Zn, and Cr, and the leaves and flowers might be potential sources of Fe supplements for humans and livestock [31]. *Moringa oleifera* oil contains a high level of oleic acid (65.00%), palmitic acid (12.31%), linoleic acid (16.00%), palmitoleic acid (2.10%), and stearic acid (5.10%), respectively [32]. The chemical composition ranged from 19.34% to 22.42% for protein; 1.28% to 4.96% for lipids; 7.62% to 14.60% for ash; and 30.97% to 46.78% for dietary fiber [33]. Calcium and potassium are rich in leaves, and the grains are rich in copper. Leaves and seeds also contain high levels of vitamin E and C [27]. The vitamin content of *M. oleifera* also shows considerable geographical variation. For instance, vitamin C levels range from 0.04% to 0.12%, with the highest values reported in samples from the United Kingdom, Jordan, and South Africa, and undetectable levels in samples from Nigeria[34].

Table 2. Vitamin content in *Moringa oleifera* Lam. Leaves[35]

Vitamin	Raw Leaves (mg/100g)	Dried Leaves (mg/100g)	Leaf Powder (mg/100g)
Vitamin A	1.28	3.63	16.30
Vitamin B1	0.06	2.02	2.64
Vitamin B2	0.05	21.30	20.50
Vitamin C	220.00	15.80	17.30
Vitamin E	448.00	10.80	113.00

Moringa leaves have more protein than peas and more iron than spinach [36]. It contains a rich source of vitamin A, vitamin C, and milk protein. Different types of active phytoconstituents like alkaloids, protein, quinine, saponins, flavonoids, tannin, steroids, glycosides, fixed oil, and fats are present [13]. Glutathione (GSH) plays a leading role in preserving lens pellucidity. It also acts as an antioxidant and stabilizes proteins in minimized form [37, 38].

Table 3. Mineral content in *M. oleifera* Lam. Leaves [39]

Mineral	Fresh Leaves (mg)	Dried Leaves (mg)	Leaf Powder (mg)
Calcium	440.00	2,185.00	2,003.00
Potassium	259.00	1,236.00	1,324.00
Magnesium	42.00	448.00	368.00
Phosphorus	70.00	252.00	204.00
Iron	0.85	25.60	28.20

6. Methods of preserving Moringa

Moringa can be preserved for a long time without loss of nutrients. Drying or freezing can be done to store the leaves. A report by Evison et al., (2015) shows that a low temperature oven used to dehydrate the leaves retained more nutrients except vitamin C than freeze-dried leaves. Hence, drying can be done using economical household appliances like stove to retain a continuous supply of nutrients in the leaves. Preservation by dehydration improves the shelf life of Moringa without change in nutritional value. An overdose of moringa may cause high accumulation of iron. High iron can cause gastrointestinal distress and hemochromatosis. Hence, a daily dose of 70g of moringa is suggested to be good and prevents over accumulation of nutrients [40].

7. Ethnomedicinal/ Traditional uses

People worldwide have included *M. oleifera* in their diet since ancient times because of its vital therapeutic values. Various medicines made from the plant are said to have ethnomedicinal properties for curing diseases and have been used for centuries. Approximately every part (leaf, pod, bark, gum, flower, seed, seed oil, and root) of this plant has been used to treat one disease or another [41]. *M. oleifera* seeds are used as biodiesel, which is recognized to the high yield of *M. oleifera* Lam and Moringa seed oil. It is also used as animal feed owing to its high nutrient levels [42-44]. Traditionally, this plant has long been used in India as part of the holistic Ayurvedic system, thanks to its wide range of pharmacological properties [45]. In Thailand, people mainly use the leaves and pods to help reduce fever and as a natural antidote [46], while in South Asia and India it is valued for its anti-aging effects [15]. Uses of *M. oleifera* are observed in pathological alterations such as antihypertensive [9], anti-anxiety [47] , anti-diarrheal [48], antidiuretic [49]. Moringa is also used to treat dysentery [50] and colitis [51]. The pods treat hepatitis and relieve joint pain [52]. The roots are conventionally used to treat kidney stones [53], liver diseases [54], inflammation [55], ulcers [56], and pain associated with the ear and tooth [57]. The bark of the stem is used to treat wounds and skin infections [58]. Indians use the gum extracted from this plant to treat fever, and it is also used to induce abortions [59]. The seeds of the plant act as a laxative and are used in the treatment of tumors, prostate, and bladder problems [60]. The seeds show promise for the treatment of arthritis by altering oxidative stress and reducing inflammation [61]. Preparations from the plant leaves benefit nursing mothers and malnourished infants and improve the general health of the population. The leaves have been useful for patients suffering from insomnia [62] and treating wounds [63]. Moringa is used incredibly extensively in the cosmetic industry nowadays, and in ancient Egyptian history, it was similarly used for preparing dermal ointments [64].

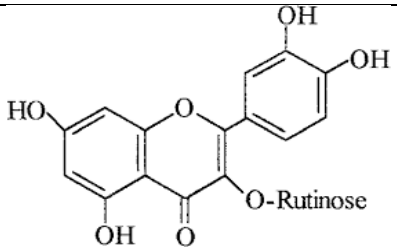
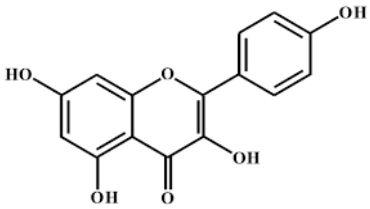
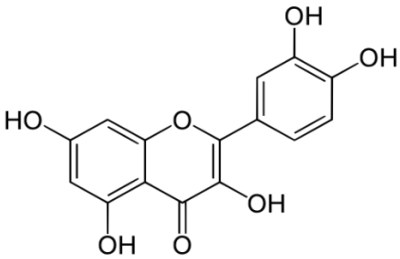
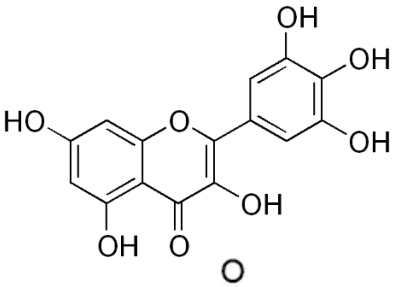
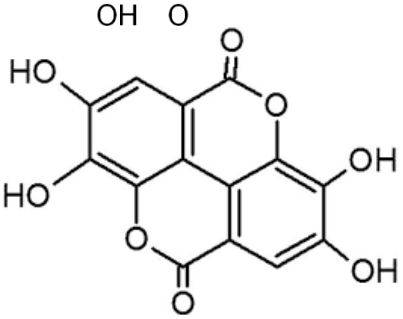
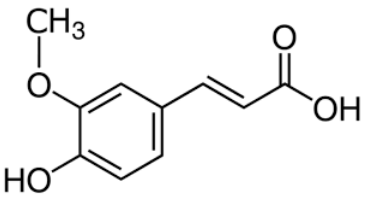
This review highlights how these traditional uses connect with modern scientific findings and brings together evidence on the effectiveness of the chemical components of *M. oleifera* (often referred to as *M. oleifolia* in older texts). It also looks at the plant's importance for agriculture, nutrition, and the rural economy, while summarizing what is known about its potential toxicity. Overall, this work offers fresh perspectives on how *M. oleifera* could be developed into new medicines, agricultural products, or functional health foods.

8. Phytochemistry

Aqueous and alcoholic extracts of leaves, seeds, flowers, roots, and pods have yielded a wide spectrum of secondary metabolites with established or potential bioactivity. The major classes of compounds include flavonoids,

carbamates, glucosinolates, and phenolic acids, each exhibiting organ-specific profiles and contributing to distinct therapeutic effects [65-67].

Table 4. List of phytochemicals of Moringa leaves with their class and chemical structure [12]

Plant part	Compound phytochemical (amount)	Class	Chemical structure
Leaves	Rutin (555.6 µg/g)	Flavonoid	
Leaves	Kaempferol (197.6 µg/g)	Flavonoid	
Leaves	Quercetin (2030.9 µmol/100 g)	Flavonoid	
Leaves	Myricetin (5.804 mg/g)	Flavonoid	
Leaves	Ellagic acid (0.078–0.128 mg/g)	Polyphenol	
Leaves	Ferulic acid (0.078–0.128 mg/g)	Phenolic acid	

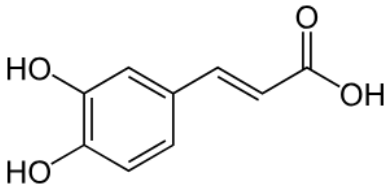
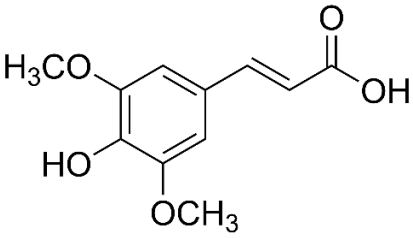
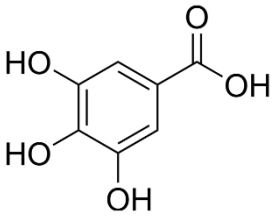
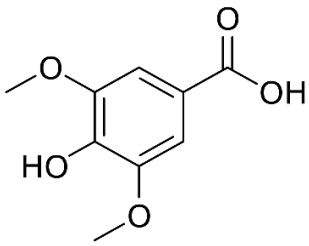
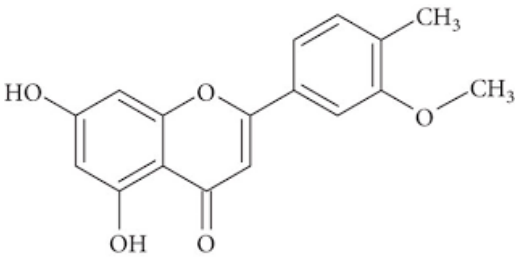
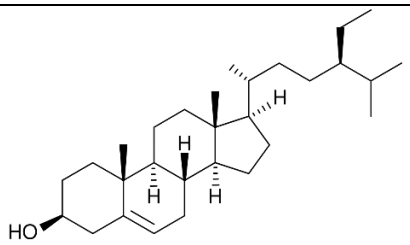
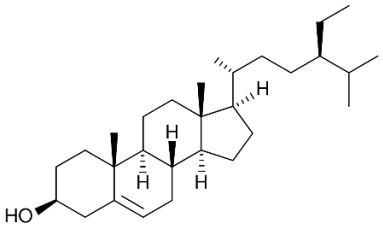
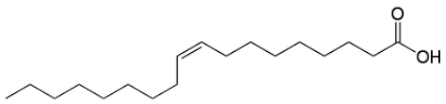
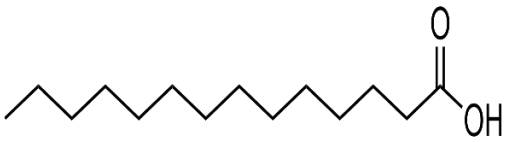
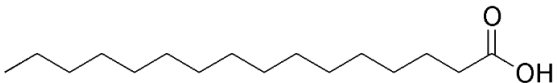
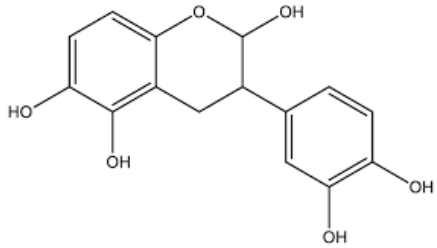
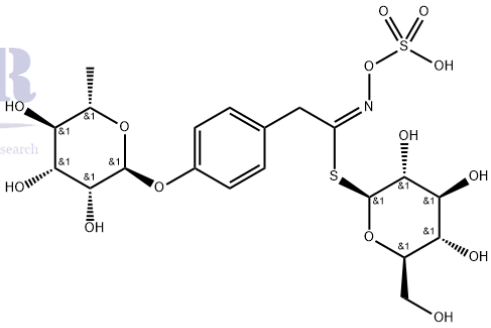
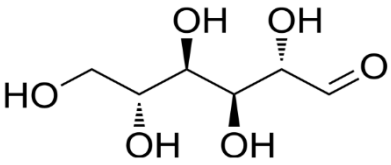
Leaves	Caffeic acid (0.409 mg/g)	Phenolic acid	
Leaves	Sinapic acid (trace)	Phenolic acid	
Leaves	Gallic acid (1.034 mg/g)	Phenolic acid	
Leaves	Syringic acid (trace)	Phenolic acid	
Leaves	Isorhamnetin (0.118 mg/g)	Flavonoid	

Table 5. List of phytochemicals in other parts of Moringa plant with their class and chemical structures [12].

Plant part	Compound	Class	Chemical structure
Stem	β-Sitosterol	Phytosterol	

Seeds	β-Sitosterol	Phytosterol	
Seeds	Oleic acid (70% w/w)	Fatty acid	
Seeds	Myristic acid	Fatty acid	
Seeds	Palmitic acid	Fatty acid	
Seeds	Proanthocyanidin (procyaniadin)	Flavonoid (oligomer)	
Seeds	Glucomoringin	Glucosinolate	 KH
Flower	D-Mannose	Carbohydrate	

9. Pharmacological activities

Recent pharmacological studies have revealed that different extracts of *M. oleifera* exhibit different pharmacological activities, such as antimicrobial [68], antifungal [69], anti-inflammatory [70], antioxidant [71], anticancer [72], fertility [73], wound healing [68], and other pharmacological activities mentioned below.

9.1. Anti-microbial action

Researchers found that the ethanolic root extract of *M. oleifera* contains N-benzylethyl

thioformate (a compound that's basically the aglycone form of deoxyniazimincin). This stuff seems to drive the extract's solid antimicrobial and antifungal punch in contradiction of a wide range of bacteria and fungi [69]. The methanolic leaf extract from M. *oleifera* shows promise in fighting urinary tract infections triggered by both Gram-negative and Gram-positive bacteria, like *Klebsiella pneumoniae*, *Staphylococcus aureus*, *Escherichia coli*, and *Staphylococcus saprophyticus* [74]. Extracts from the leaves, seeds, and stems of M. *oleifera* have shown clear inhibitory effects contrary to various fungal strains, *including Aspergillus flavus*, *Aspergillus terreus*, *Aspergillus nidulans*, *Rhizoctonia solani*, *Aspergillus niger*, *Aspergillus oryzae*, *Fusarium solani*, *Penicillium sclerotigenum*, *Cladosporium cladosporioides*, *Trichophyton mentagrophytes*, *Penicillium species*, and *Pullarium species* [69]. M. *oleifera* seeds contain active compounds like 4-(α-L-rhamnosyloxy) benzyl isothiocyanate, which are thought to drive their antimicrobial effects [75]. M. *oleifera* fruits pack alkaloids, flavonoids, and steroids that inhibit Candida albicans growth. They likely work by denaturing proteins or blocking spore germination, thanks to the steroid rings in their structure [76]. Moringa seed kernel extract showed strong inhibitory effects against *Bacillus cereus*, *Staphylococcus aureus*, Mucor species, and Aspergillus species. It was less effective, though, against *P. aeruginosa and E. coli*. This suggests it could be useful for treating infections from those other bugs, aside from *E. coli and P. aeruginosa* [77].

9.2. Anti-Inflammatory Activity

Different parts of M. *oleifera* like leaves, pods, flowers, and roots exhibited important anti-inflammatory effects. One isolated compound, 4-[2-O-acetyl-α-L-rhamnosyloxy) benzyl] thiocyanate from moringa, repressed nitric oxide and proved effective in Raw264.7 cell lines [78]. Compounds from M. *oleifera* roots—aurantiamide acetate and 1,3-dibenzylurea—were found to inhibit TNF-α production [79]. Active compounds in M. *oleifera* like tannins, phenols, alkaloids, flavonoids, carotenoids, β-sitosterol, vanillin, and moringin have anti-inflammatory properties. The fruit extract lumps nuclear factor kappa B (NF-κB) translocation, while the chloroform extract turned out to be cytotoxic at higher concentrations (500–1000 μg/mL) [80]. M. *oleifera* leaf extract was tested in mice to treat atopic dermatitis in human keratinocytes. It efficiently reduced mannose receptor mRNA, thymic stromal lymphopoietin, and retinoic acid-related orphan receptor γT expression in ear tissues [81].

9.3. Oxidative Stress

Researchers tested M. *oleifera* extract on mice with methotrexate-induced damage to check for potential protective effects. The mice got the extract starting a week before their methotrexate shot, and treatment sustained for 12 days total. Results exhibited it helped shield them from oxidative stress [82]. The ethanolic extract from M. *oleifera* stems protected keratinocytes from H2O2-induced epidermal oxidative stress. Results confirmed its strong antioxidant potential, making it a promising preventive option for such injuries in animal skin [83]. The study explored Moringa leaf extract's antioxidant power against diclofenac sodium-induced liver toxicity in animals. Researchers determined it was highly effective in countering the damage, positioning it as a potential liver protectant [84].

9.4. Cardiovascular Activity

Freeze-dried aqueous and alcoholic extracts of M. *oleifera* provided cardioprotective effects in animals with isoproterenol-induced myocardial infarction. Continuing treatment with M. *oleifera* better hemodynamics from isoproterenol impairment and increased levels of key enzymes like SOD, catalase, lactate dehydrogenase, glutathione peroxidase, and creatine kinase [85]. The butanolic extract proved to be a potent antioxidant source in rats with isoproterenol-induced cardiac necrosis. It also meaningly dropped inflammation and myocardial necrosis, thanks to the compound N-α-rhamnopyranosyl vincosamide [86]. Moringa leaves significantly reduced cholesterol levels while protecting hypertensive rats. The key active compounds behind this effect seem to be niazirmin A, niazirmin B, and niazimincin [59].

9.5. Fertility and Anti-Fertility Activity

Adding to Moringa's long list of benefits, different parts of the plant show fertility and abortion-inducing properties. Aqueous extracts

at 200 and 400 mg/kg doses proved particularly strong for abortifacient and anti-fertility effects [69]. Recent studies on hot and cold leaf extracts of *M. oleifera* suggest that taking Moringa before, during, or after pregnancy could harm fetal development by triggering strong uterine wall contractions [87].

9.6. Hepatoprotective Activity

Moringa is loaded with flavonoids analogous quercetin, kaempferol, isoquercetin, rhamnetin, and others. Quercetin from the flowers, especially, seems responsible for its liver-protective effects [69]. Methanolic extract at low dose showed changes in hepato-renal and hematological profile with noteworthy changes in serum aminotransferase concentration, plasma cholesterol level, alkaline phosphate, bilirubin, and serum LPO levels. However, the higher dose of the extract transformed total bilirubin, blood urea nitrogen, and non-protein nitro gen levels and decreased the clotting time [68]. In Sprague-Dawley rats with acetaminophen-induced liver damage (where silymarin was the standard treatment), Moringa delivered comparable hepatoprotective properties by lowering AST, ALT, and ALP levels [88].

9.7. Analgesic/Antipyretic Activity

Moringa leaf extract demonstrates analgesic effects across nearly all tree parts in both central and peripheral animal models [59]. Various fractions of alcoholic extracts like petroleum ether, n-butanol, ethyl acetate, and dimethyl ether showed strong analgesic activity, outperforming standard aspirin [74]. Ether and ethyl acetate fractions from the seeds were tested in a hyperpyrexia model [89] , using paracetamol (200 mg/kg) as the standard. The extract came out on top with the strongest antipyretic activity of all [89].

9.8. Neuropharmacological Activity

Leaf extract aids reinstate monoamine levels in the brain, making it beneficial for Alzheimer's disease. Meanwhile, the ethanolic leaf extract showed anticonvulsant effects in vitro by prompting dopamine, norepinephrine, locomotor activity, and serotonin (5-HT) levels in the brain during penicillin-induced convulsions [90, 91]. Methanolic root extract in mice induced with pentobarbital sodium and diazepam delivered strong CNS sedative effects by extending sleep duration. The toluene acetate fraction from that extract showed promise as a nootropic agent [89]. Leaves established solid anticonvulsant activity in phenyltetrazoline and maximal electroshock models using male albino mice [90]. Aqueous root extract jammed penicillin-induced epileptic seizures in adult albino rats [91]. Finally, ethanolic leaf extract had anxiolytic effects, backed by behavioral tests on the actophotometer and rotarod respectively [59].

9.9. Anti-Ulcer/Gastroprotective Activity

Researchers found that bisphenols and flavonoids from moringa leaves helped lower the ulcer index, duodenal ulcers, and stress ulcers in a rat model of gastric ulcers triggered by ibuprofen [59]. Moringa extract was shown to significantly reduce free radicals, neutralize the acidic nature of gastric juice, and offer real protection against developing gastric ulcers [92]. Flavonoids in the plant help ward off ulcer formation by ramping up capillary resistance, boosting microcirculation, and limiting cell injury as a result [93].

9.10. Neuropathic Pain

The wide range of plant compounds in moringa leaf extract has prompted researchers to create an herbal option for treating chronic neuropathic pain from nerve constriction. This comes as there's a push to cut back on traditional painkillers for this condition. The study used diabetic rats with neuropathic pain from chronic nerve constriction. Tests before and after treating them with moringa leaves presented a big improvement in their pain condition. It points to reduced oxidative stress as the key mechanism behind this effect, suggesting moringa could be a promising new natural treatment for neuropathic pain [94]. A research team looked into bio-guided fractions from moringa seed extract using a diabetes-induced model of neuropathic pain. They ran a bunch of oxidative stress tests and other experiments on rats with induced pain, both before and after treatment. In the end, the team found that rats treated with the extract had solid blood sugar

control, good pain relief, and strong neuroprotective effects all with a wide safety margin [95].

9.11. Wound Healing Effect

Studies showed a strong effect on wound healing after incision or excision wounds when using ethyl acetate and water extracts from M. *oleifera* leaves at a dose of 300 mg/kg [68].Preclinical research reported that extracts from leaves, seeds, and dried pulp effectively boosted wound closure, increased granuloma breaking strength, and lowered skin breaking strength in the scarred areas [96]. Leaf extracts delivered promising results in diabetic animals by toning down inflammatory markers and ramping up vascular endothelial growth factor levels in the damaged tissue [59]. Compounds in the aqueous extract made a real difference for diabetic foot ulcers by bringing down levels of various inflammatory markers [96]. Researchers ran an in vitro assay to pick out the standardized extract with the highest potency, then turned it into a film for wound healing. The results indicated that the aqueous extract stood out with the best cell proliferation and migration properties compared to the other extracts [97].

9.12. Immunomodulatory Activity

The methanolic extract from the plant includes active compounds like isothiocyanate and glycoside cyanide, which boost immune stimulation and help strengthen overall immunity. A recent review paper points out that various bioactive compounds have been used to tackle immune-related issues like cancer, hypertension, and diabetes, ultimately ramping up the host's immunity [98].

9.13. Hematological Activity

M. oleifera has shown real promise in boosting blood-related functions. A randomized, double-blind study found that aqueous leaf extract effectively raises low hemoglobin levels (8–12 g/dL) in women [99]. Another study exhibited that healthy volunteers who took *M. oleifera* leaves for 14 days saw a significant bump in their platelet counts [59].

9.14. Anti-Obesity Activity

In one study, giving rats with hypercholesterolemia oral doses of *M. oleifera* leaf powder for about 49 days significantly lowered their body mass index (BMI) [100]. The reason behind this seemed to be a drop in mRNA expression for the hormones resistin and leptin, along with an uptick in the regulation of the adiponectin gene in those rats [59]. A recent study shed light on the mechanism for *M. oleifera*'s anti-obesity effects. The plant notably improved the lipid profile by cutting body weight. It also regulated genes tied to adipogenesis, boosted glucose tolerance, and lowered levels of hormones like vaspin, leptin, and resistin [101].

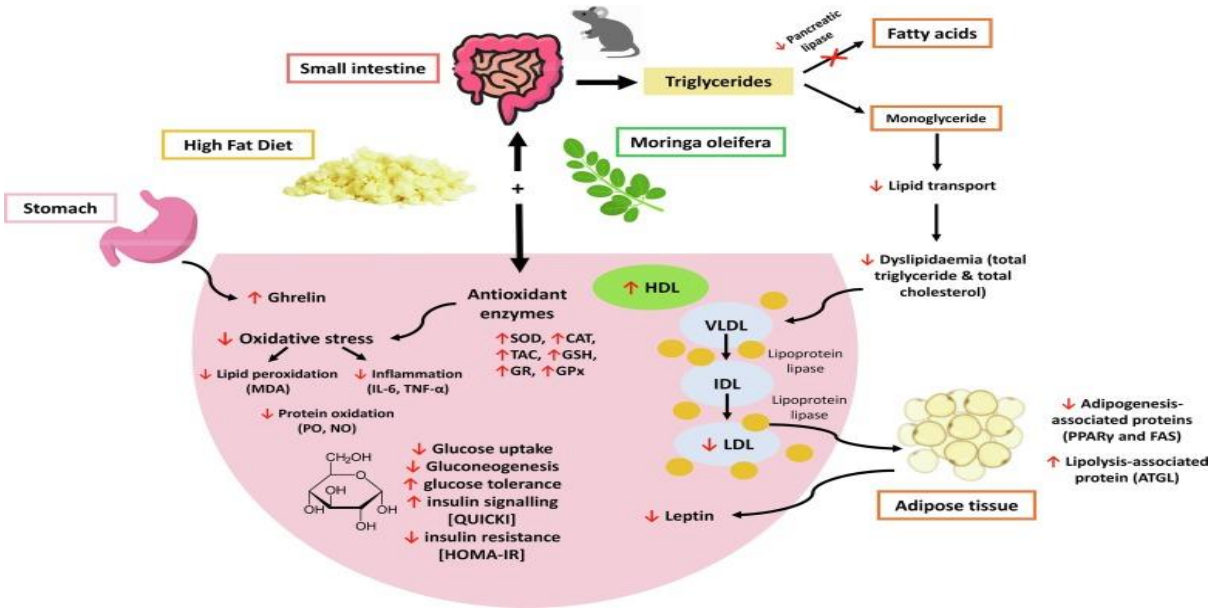


Figure 2. Shows the *M. oleifera* as a promising antidiabetic agent

9.15. Anti-Diabetic Activity

Moringa leaves delivered great results in glucose tolerance tests on Wistar and Goto-Kakizaki rats, while also bringing down their blood glucose levels. The aqueous extract showed antidiabetic effects in rats by managing blood glucose, protein, sugar, and hemoglobin levels [70]. The plant's leaves managed to lower glucose levels within three hours of intake, though not quite as much as the standard drug glibenclamide. When given orally, moringa seeds contain insulin-like proteins with antigenic epitopes similar to insulin, and they exhibit strong antihyperglycemic activity [102]. Leaf extracts from the plant also pack antidiabetic punch they boost CAT and MDA levels, cut down FPG, hemoglobin, LDL-C, and VLDL-C in type 2 diabetic patients, and, crucially, raise insulin levels in healthy folks [103]. The seed extract lowers LPO levels and ramps up antioxidant effects in mice hit with streptozotocin; it also dialed back IgG, IgA, IL-6, and pancreatic β-cell activity. Researchers suggested the key bioactive compounds behind this are quercetin, kaempferol, glucomoringin, chlorogenic acid, and isothiocyanates [104].

9.16. Diuretic Activity

Alcoholic and aqueous root extracts of M. *oleifera* significantly undertook calcium oxalate urolithiasis in male rats. This drop came from minor retention levels of oxalates, calcium, and phosphates, as well as reduced serum urea nitrogen, creatinine, and uric acid [49].

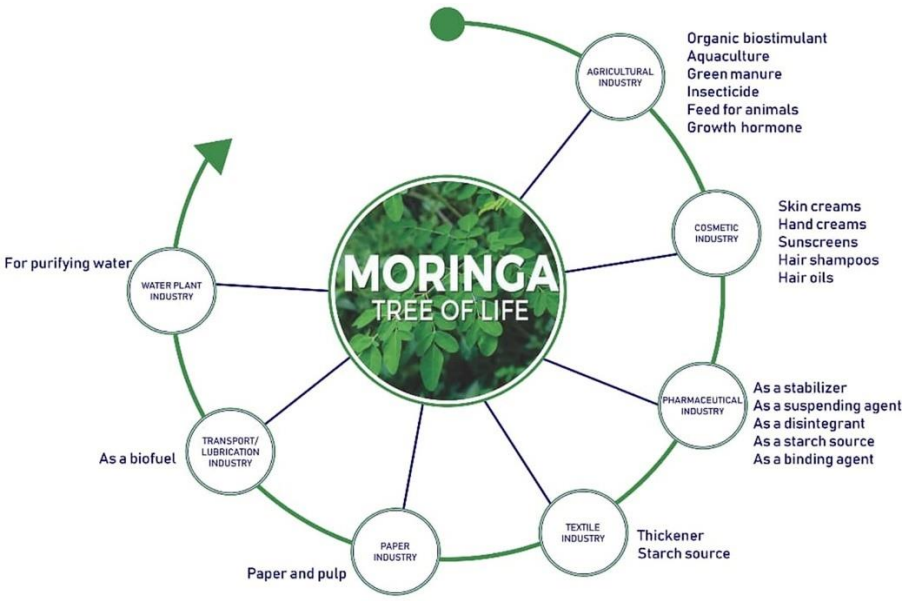


Figure 3. Shows properties of *M. oleifera.*

10. Miscellaneous Uses

Researchers ran a study on M. *oleifera* using an HPLC-based cyclo condensation method, with astragalin and isothiocyanates as marker compounds for standardization. This standardized approach could be a solid way to check the quality when developing cosmetics and natural health products [105].

M. *oleifera* leaf extract proved useful in countering the negative side effects of neem oil, which aquaculture folks use as an insecticide to manage predators and parasites in fish fry. Researchers wrapped up that the moringa extract wiped out the oxidative stress and toxicity triggered by the neem oil [106].

Researchers looked into why okra (*Abelmoschus esculentus*) yields were so low. The main culprits turned out to be pest and insect infestations plus poor soil nutrients. To boost production, folks tried various chemical pesticides, but those just created more environmental headaches. Using M. *oleifera* aqueous leaf extract at concentrations like 1:30 and 1:40 ended up being a real help for okra crops [107].

Researchers tested how well M. *oleifera* leaf and root extracts worked as plant growth regulators

and biopesticides during wheat harvests. They applied different concentrations (5, 10, 12.5, 25% w/w, w/v, or v/v) of the leaf and root extracts at various wheat growth stages. They saw major boosts in plant growth, which led to higher yields and fewer aphids showing up [108].

Moringa oleifera is loaded with macronutrients, micronutrients, vitamins, phytohormones, alkaloids, and flavonoids, turning it into a true multipurpose powerhouse. Recent studies also show its extracts help plants handle both abiotic and biotic stresses, even in tough environmental conditions [109].

Researchers checked out how M. *oleifera* teamed up with praziquantel in rats. They focused on seeds and leaves to see how they affected praziquantel bioavailability and watched the in vivo impact on Taenia crassiceps. The combo delivered way more cyst-killing power than praziquantel alone in the treated rats [110].

M. *oleifera* is packed with all sorts of bioactive goodies like flavonoids and vitamins. A group of researchers ran an in vitro study zeroing in on the bioactive compounds that give the plant its strong nutritional punch. The conclusive statement of the research revealed that the high levels of proteins, lipids, and sulfur-containing amino acids combined with very few toxic components make Moringa an excellent nutritional option for people [111].

Researchers credit palmitic acid the bioactive compound isolated from Moringa leaf extract with a wide range of therapeutic benefits. A team put this isolate to the test against various microbial and fungal strains. The results showed that it created the largest zones of inhibition across both fungal and bacterial targets [112].

11. Phytopharmaceutical formulations

Plant extracts have always caught researchers' eye when it comes to creating all sorts of pharmaceutical products. This usually means developing medicinal products that hit two key marks: first, making something stable that holds up well, and second, something patients will actually stick with. The real edge with Moringa plant extracts is they seem incredibly safe at the typical doses used for real therapeutic results. M. *oleifera* has gained solid traction in research circles, and scientists have tried all kinds of methods to come up with different formulations. Many phytopharmaceuticsl formulations prepared using M. *oleifera* are tabulated below (table 6)

Table 6. Phytopharmaceutical formulations prepared using *M. oleifera* extract

Plant Part Used	Nature of Extract	Formulation	Method of Preparation & Polymers/Excipients Used	Application
Leaves	Ethyl acetate	Polyherbal formulation	Suspending method (carboxymethylcellulose)	Anti-ulcer [113]
Leaves	Aqueous/methanolic	Polyherbal ointments	Water-in-oil mixing (wool fat, hard paraffin, cetostearyl alcohol, PEG4000, PEG400, sorbitol mono-oleate, liquid paraffin, white beeswax, span60, tween60)	Edema [114]
Seed	Oil	Micro-dispersion	Vortexing (Span80, tween80)	Anti-inflammatory [115]
Leaves	Ethanolic	Lozenges	Wet granulation (Polyvinyl-pyrrolidone, magnesium stearate, menthol, vanillin)	Anti-microbial activity [116]
Seed	Oil	Nano-micelle	Microemulsion method (Tween80, Ethanol)	Mitochondrial cancer cell apoptosis [117]

Leaves + fruits (Embelia ribes)	Hydro-alcoholic	Thermo-reversible in-situ nasal gel	Cold method (polyethylene glycol) (PEG400), Pluronic F127, xanthum gum, carbopol934, hydroxypropylmethylcellulose (HPMC K4M))	Allergic rhinitis [118]
Leaves	Aqueous, ethanolic	Film dressing	Solvent casting method (Alginate, pectin)	Wound healing [119]
Leaves	Ethanolic	Effervescent tablets	Wet granulation (70% ethanol, lactose, citric acid, tartaric acid, sodium bicarbonate, aspartame, PEG600)	Anti-anemia [120]
Seed	Oil	Anti-inflammatory cream	Triturating process (Oleic acid, sodium hydroxide, potassium hydroxide, aluminum hydroxide, liquid ammonia, sodium benzoate)	Anti-inflammatory [121]
Leaves	Silver NPs (AgNPs)	-	Shaking method (Silver nitrate)	Anti-fungal activity [122]
Leaves	Aqueous	Hydrocolloid film dressing	Solvent casting method (sodium alginate, pectin)	Wound healing in diabetic condition [123]
Leaves	Hydro-alcoholic	In-situ gel	Cold technique (Pluronic F127, gellan gum, glycerine, Carbopol 934)	Allergic rhinitis [124]
Leaves	Aqueous	Nanofibers impregnated onto Hydrocolloid film	Electrospinning (poly-(ethylene oxide) (PEO), sodium alginate, pectin, glycerol)	Chronic Wound dressing [125]
Leaves	Hydro-alcoholic	Polymeric microparticles (MPs)	Spray dried method (Chitosan)	Exuding wound treatment [126]
Leaves	Aqueous	Iron oxide nanorods	Mixing method (Iron (III) chloride hexahydrate)	Anti-bacterial property [127]
Seed	Oil	Suppositories	Pour molding method (Macrogol, dika fat, liquid paraffin, Polyethylene glycol 1000 & 4000, petroleum ether)	Hemorrhoids [128]
Leaves	Ethanolic	Oral suspension	Stirring method (Sodium carboxymethyl cellulose, propylene glycol, benzoate, sorbitol)	Hepato-protection against Isoniazid [129]

Leaves	Ethanolic	Granules	Wet granulation method (Gum Arabic, HPMC, Methocel K100M CR, magnesium stearate, Avicel PH200, tween 20, 40, 80, span 20, 40, Poloxamer 407, sodium lauryl sulphate)	Anti-inflammatory and anti-arthritic [130]
Leaves	Powder	Chewable gummy tablets (CGT)	Heating and Congealing (Gelatin, high methoxyl pectin, mannitol, sucrose, propylene glycol, citric acid, corn oil, sodium benzoate)	Evaluation of Chewable gummy tablets [131]

12. Clinical trials

So far, 25 clinical studies have looked into M. *oleifera*, with 15 of them wrapped up. Out of those completed ones, nine tested it as part of people's diets, while the rest focused on specific treatments for certain diseases. All in all, the results show moringa can really help with things like malnutrition, chronic kidney disease, HIV, and reproductive health issues [132]. One clinical study really spotlighted M. *oleifera*'s potential as an anti-asthma treatment. Researchers used seed kernels from the plant to tackle bronchial asthma symptoms. They picked participants based on strict inclusion and exclusion rules, tracking respiratory stats and blood samples at the start and after three weeks of treatment. Patients took the extract as a dried powder 3 grams twice a day for three weeks, mixed with water. Symptoms got scored as severe, moderate, or mild on a simple points scale. In the end, both symptoms and breathing issues improved a lot, showing M. *oleifera* seeds could be a solid option for managing bronchial asthma [133].

13. Interactions Between *M. oleifera* and pharmaceutical drugs

13.1. Synergistic Effects

Cancer often comes back because cells get resistant to chemo drugs. That said, certain plant extracts pack antitumor and immune-boosting punch with way less toxicity than harsh meds [134]. Research shows pairing the chemo drug doxorubicin with M. *oleifera* leaf extracts creates a powerful synergy, slamming the brakes on HeLa cell growth. Methanol extracts from the bark also amp up antibiotics, busting through resistance in tough, multidrug-resistant bugs. For example, Vankwani et al. found a big synergistic boost when combining M. *oleifera* stem bark extract with ampicillin against methicillin-resistant S. aureus [135]. Abu-Hussien and colleagues found that mixing essential oil from M. *oleifera* seeds with oils from cinnamon (*Cinnamomum verum*) and black cumin (*Nigella sativa*) ramped up antibacterial power against *Staphylococcus aureus* in a big way. The combo's inhibitory concentrations dropped noticeably lower than what you'd see with any of the oils used solo [136]. Then, in animal studies, blending M. *oleifera* extract with fluoxetine a selective serotonin reuptake inhibitor delivered stronger antidepressant-like results than either one on its own. All this points to some real synergistic potential, though we'll need more human trials to lock it down for sure [137].

13.1. Pharmacokinetic Drug Interactions

1. Antimalarial drugs: An experimental study demonstrated that co-administration of M. *oleifera* leaf extract with chloroquine resulted in antagonistic effects, potentially due to the inhibition of chloroquine absorption. This interaction may reduce the drug efficacy in treating malaria, highlighting the need for caution when combining Moringa with certain antimalarial drugs [138].
2. Cytochrome P450 enzyme inhibition: Lab tests reveal that M. *oleifera* extracts can block these enzymes, especially CYP3A4 and CYP2D6, which handle breaking down a ton of medications. The strength of that inhibition changes based on the extract type and how concentrated it is, but methanolic leaf extracts pack the biggest punch [139].
3. Antihypertensive drugs: In spontaneously hypertensive rats, M. *oleifera* leaf extract on its

own lowered blood pressure about as well as standard meds. But when paired with those drugs, there was no extra boost or synergy. This implies that taking moringa alongside antihypertensives probably won't amp up the benefits [140].

14. Conclusion

Moringa oleifera, known as the miracle tree, stands out for its exceptional nutritional density and versatile applications across nearly all plant parts, including leaves rich in proteins, vitamins (A, B, C, E), minerals (calcium, potassium, iron), and antioxidants like beta-carotene and oleic acid, making it a potent tool against malnutrition, especially in newborns, lactating mothers, and nutrient-poor diets. Its ethnomedicinal uses span treating hypertension, toothaches, ulcers, and paralysis, while phytochemicals such as flavonoids, glucosinolates, and phenolic acids underpin a broad spectrum of pharmacological activities, including antimicrobial effects against bacteria like *Staphylococcus aureus* and fungi like *Aspergillus*, anti-inflammatory and antioxidant properties, cardioprotective benefits, hepatoprotection, antidiabetic action, wound healing, and immunomodulation. Cultivation is straight forward in tropical/subtropical regions with rapid growth, high yields (up to 580 tons/ha fresh biomass), and propagation via seeds or cuttings, supporting uses in food, biodiesel, cosmetics, and agriculture. Clinical trials affirm efficacy in asthma, anemia, and HIV adjunct therapy, with phytopharmaceutical formulations emerging; however, cautions include potential iron overload (limit to 70g/day), anti-fertility effects, and drug interactions like CYP450 inhibition or antagonism with antimalarials. Overall, M. *oleifera's* global research surge validates its multipurpose value, urging focused studies on standardization, toxicity, synergies, and gaps in human trials to harness its full therapeutic, nutritional, and industrial potential.

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