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## An updated review on Phytochemical constituent and pharmacological properties of *Moringa oleifera* Lam

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#### ABSTRACT

*Moringa oleifera* is a widely distributed plant of the *Moringaceae* family. Nearly, every portion of this tree has extraordinary qualities for food, medicine, or other industrial uses. This study is to gather an overview of global research, pharmacological activity, phytochemical and medicinal updates of *M. oleifera*, and give insight into its industrial and phytopharmaceutical uses to aid exploration. *Moringa* species have long been recognized for their antioxidant, anti-inflammatory, anticancer, and anti-hyperglycaemic properties. Most of their biological action is due to their high presence of flavonoids, glucosides, and glucosinolates. Furthermore, after analyzing the current *M. oleifera* research, we conclude that the majority of current research focuses on the plant's leaves and seeds, and the most concerned feature of *M. oleifera* is focused on its therapeutic potential. Yet more research is required to understand the molecular processes underlying its many features.

**Keywords:** *Moringa oleifera*, Medicinal uses, Pharmacological activity, Phytochemistry, Toxicity, Phytopharmaceutical.

## INTRODUCTION

The "tree of life" or "wonder tree" *Moringa oleifera* Lam. is an important herbal plant because of its numerous therapeutic advantages. The herb has historically been used to treat ulcers, hepatic, cardio, carcinoma, and inflammatory disorders. This review primarily focuses on introducing the bioactive components and uses including its leaves, seeds, pods, flowers, root barks and gum in order to make it easier for investigators throughout the globe to concentrate on each component of this glorious plant. The hepatoprotective, cardioprotective, anti-inflammatory and other therapeutic properties of bioactive chemicals from the various plant sections are confirmed by the pharmacological research. Alkaloids, flavonoids, anthraquinones, vitamins, glycosides and terpenes have all been described thus far from various portions of the *M. oleifera* plant.

Moreover, unique isolates with powerful antioxidant, anti-cancer, anti-hypertensive, hepatoprotective, and nutritional properties have been found in the plant including muramoside A & B and niazimin A & B. The current study acknowledges the traditional usage of *Moringa*, as well as its phytopharmaceutical activities, clinical investigations, toxicological profile and a number of other uses. Most of the previous studies have been focused on extracts and isolates and their potential effects in medicinal and pharmaceuticals. The bioactive constituents of *M. oleifera* have been identified in almost all parts of the plant. The specific constituents isolated from plants mainly detailed in **Table 1** include flavonoids, glucosinolate and isothiocyanate, phenolic acid, alkaloids and sterols, and terpene.

#### Botanical Description and Classification of M. oleifera

The *Moringa* family contains 13 species out of which *M. oleifera* has become well known for its various uses in nutrition, medicinal and industrial sectors, etc. <sup>[1,2]</sup>. *M. oleifera* is among the most affordable and trustworthy options for food and wholesome nourishment, according to studies <sup>[3]</sup>. Almost all of a tree's components are utilized for their vital nutrients. Beta-carotene, minerals, calcium, and potassium are abundant in *M. oleifera* leaves <sup>[4]</sup>.

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Figure 1: Moringa oleifera (MORINGA - BOTANISTRY, 2022)

#### Classification

Kingdom: Plantae

Sub-kingdom: Tracheobionta

Super division: Spermatophyta

Division: Magnoliophyta

Class: Magnoliopsida

Subclass: Dilleniidae

Order: Capparales

Family: Moringaceae

Genus: Moringa

## Different varieties of M. oleifera

The *M. oleifera* different varieties PKM1, PKM 2 and ODC 3 analysis will be used for each organ of the plant. The quantitative ones recorded were; height, stem, diameter, number of leaves, number of branches, number of flowers, leaf length, leaf width, petiole length, and leaflet length. Leaf length is influenced by relative humidity and average annual precipitation. Phenotype characteristics are affected by edaphic factors and result in epigenetic changes <sup>[5]</sup>. Moringa leaves these three varieties consumed for their high nutrient values <sup>[6]</sup>. Therefore, the size, color and number of leaves represent an important characteristic to produce biomass, nutritional content and genetic improvement. The largest diameter at a height of 10 cm from the ground will be observed with an average value of 43.22 mm, and the

lowest value corresponded to 25.61mm at 250 days after transplantation. The most frequent stem colors were grey and whitish grey <sup>[7]</sup>.

The tree prefers to propagate at an elevation of a height of 500 m and grows quickly in loamy, well-drained sandy soils. The tree is typically small to medium-sized with naturally trifoliate leaves, flowers that are born on inflorescences 10 to 25 cm long and trifoliate fruits that are often referred to as "pods" <sup>[2]</sup>. The canopy is umbrella-shaped, the branches are typically unorganized, and the trunk typically grows straight <sup>[8]</sup>.

## **Botanical and Geographical Distribution**

Although *M. oleifera* is found all over the world, it is native to India, Arabia, and the East Indies <sup>[1]</sup>. According to the plant's history, *M. oleifera* was first carried to Africa, Southeast Africa, and the Philippines from India in antiquity (**Figure 1**). It needs tropical and subtropical climates, and it grows best between 25 to 35°C <sup>[9]</sup>. *M. oleifera* is a species of deciduous tree that is often planted worldwide in tropical and subtropical climates <sup>[10]</sup>. It benefits from indirect sunlight, dry soil, and a pH range of slightly acidic to alkaline. At 6 to 8 months of age, the tree starts to produce fruit <sup>[11]</sup>. Commercially, it is grown in a number of locations, including Africa, Mexico, Hawaii, and South America, but because each location has a distinct type of soil, the amount of nutrients differs from place to place <sup>[2]</sup>.

The tree is thought to offer amazing healing abilities for breastfeeding women and infants who are malnourished <sup>[2]</sup>. The powdered leaves are used to make many beverages, out of which "Zija" is the most popular in India <sup>[12]</sup>. The bark and blossoms of *M. oleifera* are employed for treating different disorders such as ulcers, spleen enlargement <sup>[11]</sup>, dentalgia <sup>[13]</sup>, and hypertension <sup>[8]</sup>. Roots are found to have a role in the treatment of toothache, helminthiasis <sup>[14]</sup>, and paralysis <sup>[15]</sup>. The present review aims to sum up the insight and attempts to compile the recent information of global research analysis on the pharmacological actions, phytochemical, medicinal qualities, and toxicological properties of *M. oleifera*.

## Phytochemistry of M. oleifera

Almost every component of M. oleifera and its isolates has been researched. More than 90 chemicals from the genus Moringa were identified according to the scientific information gathered, most of which possess medicinal properties due to having various phytochemicals and secondary metabolites which is highly used in various field. The phenolic acids and flavonoids found in M. oleifera have larger concentrations than those found in other plants. They include nizaminin, moringin, niazirin, glucomorigin, quarcetin, kaempferol, cinnamic acid, syringic acid, vitexin, stigmasterol, caffeic acid, isothiocynate, and gentisic acid. Contrarily, the flavonoids quercetin, catechin, myricetin, and kaempferol [16, 17, 18] which have been considered to have excellent therapeutic efficacy. The active ingredients found in plant leaves are liable for the plant's therapeutic efficacy. By using gas chromatography-mass spectrometry, the plant's leaves revealed nearly 35 compounds. Among the 35 isolated compounds, out of some important ones isolated from the leaves were quercetin, bis (isothiocyanatomethyl) benzene, hexadecanoic acid, 3hydroxy-β-ionone, and essential oils, present in the plant's stem. The most abundant glucosinolate present in the M. oleifera species is 4-O-(a-L-rhamnopyranosyloxy)-benzyl glucosinolates, also known as glucomoringin <sup>[19]</sup>. The  $\beta$ -sitosterol, quercetin-3-O glucoside, bis (isothiocyanatomethyl) benzene, hexadecanoic acid, 3-hydroxy-βionone, essential oils, niaziminin A & B were found in seeds and leaves of this species <sup>[20, 21]</sup>. Another type of sterol glycoside,  $\beta$ -sitosterol-3-O- $\beta$ -D-galactopyranoside was extracted from *M. oleifera* bark <sup>[22]</sup>. *M. oleifera* leaves occur in a major interesting group of terpenes and hexahydro-farnesyl. At the same time, terpenes and their derivatives such as linalool oxide, farnsylacetone, isolongifolene  $\alpha$ -

ionene, and  $\alpha \& \beta$ -ionones are found in fewer amounts. Tannins and saponins, which are responsible for a variety of pharmacological effects, are commonly found in *M. oleifera* seed oil <sup>[18]</sup> along with saponins various fatty acids like arachidic acid, octacosanoic acid, oleic acid, palmitic acid, stearic acid, linolenic acid, behenic acid and paullinic acid are also found in seeds <sup>[23]</sup>.



Figure 2: Schematic illustration of bioactive compounds of M. oleifera (Structure source: https://pubchem.ncbi.nlm.nih.gov).

A novel compound niazirin and niazirinin was extracted from plants <sup>[21]</sup>. <sup>[24]</sup> scientist investigated the ethanolic extracts of the seeds of Moringa oleifera and isolated a new compound O-ethyl-4-(alpha-Lrhamnosyloxy) benzyl carbamate together with seven known compounds, 4(alphaL-rhamnosyloxy)-benzyl isothiocyanate, niazimicin, niazirin, beta-sitosterol, glycerol-1-(9-octadecanoate), 3oleoyl-beta-D-glucopyranosyl)-beta-sitosterol 0-(6'-0 and betasitosterol-3-O-beta-D-glucopyran. [25] Researchers isolated two new compounds from the ethanolic extract of whole pods of Moringa oliefera, O-[2'- hydroxy-3'-(2"-heptenyloxy)]-propyl undecanoate and Oethyl-4- [(alpha-L-rhamnosyloxy)-benzyl] carbamate along with the known substances like methyl phydroxybenzoate and beta-sitosterol. <sup>[26]</sup> Also isolated niazirinin, a thiocarbamate from the leaves of Moringa oleifera. The structure of some of the key phytoconstituents isolated from *M. oleifera* is shown in Figure 2.

#### Medicinal/ Traditional Importance of M. oleifera

All portions of the *Moringa* plant have been claimed to have therapeutic properties. Table 1 lists the traditional therapeutic applications of *Moringa* species. *Moringa* species are extremely nutritious, which helps humans by giving daily nutritional supplements and enhancing their immune systems. According to *Moringa* leaves contain vitamin C, A, and a large amount of amino acids <sup>[27, 28]</sup>. *M. stenopetala* can be obtained across every household in the Gamo Gofa zone <sup>[29]</sup>. *Moringa* leaves are extremely nutritious, according to <sup>[30]</sup> Mathur, with reported a higher protein, vitamin A, vitamin C, and potassium <sup>[31]</sup> Researchers reported *M. oleifera* includes a high level of zeatin, which has been utilized as a natural growth enhancer and helps to raise agricultural yields <sup>[32]</sup>.

Humans have been using *M. oleifera* in their diet since ancient times because of its crucial healing properties (Table 1). Many plant-based medications are reported to have ethnomedicinal properties for treating a variety of ailments and have been employed for generations. Basically, every component of this plant (leaf, pod, bark, gum, flower, seed, seed oil, and root) has been administered to treat a wide range of diseases, either alone or in combination with other plant supplements.

A clinical study was conducted to analyze the effect of *M. oleifera* leaf cookies (50 grams) consumption on breast milk production and nutrient content. In the intervention group, fats, carbohydrates, and vitamin A in breast milk were found to be increased as well as, protein levels enhanced and enhance the quality of breast milk <sup>[33]</sup>. A singleblind randomized control trial investigated the *M. oleifera* leaf powder efficiency on HIV patients. At 6 months' follow-up, patients in

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extract-treated groups (30 patients) significantly increased in body mass index and albumin. These observations suggested that powder supplementation of this plant might be taken as a local solution to improve the nutritional status of HIV patients <sup>[34]</sup>.

*M. oleifera* is used to treat dysentery, colitis, heart diseases <sup>[35]</sup> (Kritikar et al., 1999), blood disorders <sup>[36]</sup> (Rao, 2011) and cancer <sup>[37]</sup> (Manandhar, 2002). Infusion improved memory, tingling and treated numbness circulatory tonic <sup>[38, 39]</sup> and pyrexia.

A *Moringa* leaf poultice is an effective treatment for inflammatory disorders such as glandular irritation, headache, and bronchitis <sup>[13]</sup>. The pods are treated hepatitis and relieve joint pain <sup>[10]</sup>. The roots are conventionally used to treat kidney stones, liver diseases <sup>[40]</sup>, inflammation <sup>[41]</sup> (Ghasi et al., 2000), ulcers <sup>[42]</sup>, and pain associated with the ear and tooth <sup>[43]</sup>.

Table 1: Medicinal importance of *M. oleifera* and its formulation in human welfare

Part used	Nature of Extract/Formulations	Diseases		References
Whole plant	-	Anorexia	Appetite	[44]
	-	Immunity	Auto-immune diseases	[45]
	-	-	Blood disorders	[46, 47]
	-	Cardio-vascular disorders	Heart diseases, troubles	[48 ,35]
	-	-	Cancer	[45]
	-	-	Cholera	[44]
	Infusion	Dental and gum ailments	Alleviate toothache, pyorrhea	[49, 48]
	Infusion	-	Dyslepsia	[35]
	-	General debility	Improve memory, tingling and treat numbness circulatory tonic	[38, 39]
	-	Hair & scalp problems	Baldness	[35]
	<i>Embelia ribes</i> and <i>M. oleifera</i> decoction mixed with honey	-	Helminthiasis	[50]
	-	Hypertension	Alleviate hypertension	[51]
	-	-	Hysteria	[52]
	Juice mixed with salts and asafoetida	-	Urograha	[53]
	-	Venereal diseases	syphilis	[44]
	-	Peptic ulcer	Ulcer	[54, 55]
	Oil		Ieprous ulcers	[56]
	-	Lockjaw	Tetanus	[50]
	-	Obesity	Obesity	[57]
	-	Oral disorders	Mouth stiffness	[58]
	Infusion	Spasm	Relieve spasms	[49]
	Infusion	-	Earache	[38]
	Infusion	Partum problems	Expedite delivery	[59]
	-	Musculoskeletal disorders	Muscular diseases	[48]
	-	Gaseous tumor	Gulma	[58]
Whole plant	Infusion	Pyrexia	Intermittent fever	[35, 60]
Leaf	juice with pepper and ginger		Fever	[60]
Seeds	-	Male Fertility & Genital disorders	Erectile dysfunction	[61]
Whole plant	-	Neurological disorders	Neuralgia	[56]
Root Whole plant/	-	Rheumatoid arthritis	Paralysis Chronic rheumatism, joint pain, arthritis	[48, 62]
Seed oil		Kilcullatold artifilits	emonie meunausii, joint pain, arunnus	
Whole plant	Infusion	Respiratory disorders	Influenza cough, spasmodic affections of bronchitis, and dry cough	[35, 59]
Flower	Juice mixed with buttermilk		Asthma	[63]
Root	Decoction			[35]
Bark	Lukewarm paste	Herpes	Glandular herpes	[50]
Bark	Decoction	Inflammations	Inflammation	[54, 52]
Leat Whole plant	Paste Infusion		Reduce glandular swellings Dropsy due to liver disease	

Fruit	Mixed with Errhine	-	Lymphadenitis	[46]
	deodara pounded with sour gruel		Aneviating tymphademitis	
Flower	Juice	Agalactorrhea	to improve the quality and flow of mother's milk at the time of breastfeeding	[63]
Flowers	Boiled in milk	Reproductive disorders	Improve sexual potency, fertility of both male and female reproductive organs	[63]
Latex	Mixed with sesame oil		Otalgia	[50]
Leaf	Juice with carrot juice	Renal disorders	Kidney troubles	[63]
Warmed leaves	-	-	Hydrocele	[64]
Tender leaves	Juice mixed with honey	Eye's disorders	Acute eye diseases and pain	[50]
Root Seeds	Paste mixed with Ghrita		Relieve on thalmitis watery discharge	[65, 52]
Secus	Juice mixed with honey		pain	
	-		Acute eye diseases, pain	
Leaf	Paste/juice mixed with honey	Conjunctivitis	Dimness of eyes Kapha-associated conjunctivitis/	[66]
Loui	ruste, juleo mixed with honey	Conjunctivitis	ophthalmic diseases	
Leaf	A tablet made from rock salt, Tañkaṇa and Zingiber	Gastro-intestinal	Abdominal pain	[66]
	officinale in equal amounts triturated with <i>M. oleifera</i> inice	disorders		
Bark	-		Stomach diseases	[66]
Leaf	Juice with carrot juice		Constipation	[66]
Flower	Juice mixed with butter milk		Indigestion	[49, 60]
Leaf Whole plant	Juice and Sarjarasa	Viral infections	Smallpox herpes and measles	[49,00]
Leaves	Soup	-	Hiccough & dyspnea	[67]
Seed	Soup prepared from salt, Yavakşāra and <i>Piper nigrum</i> powder			
Leaf	Juice mixed with honey, tender and coconut water	Hepatic disorders	Jaundice	
Root	Decoction		Treatment of liver troubles and enlarged liver	[52, 42]
Root	Juice mixed with Gingiber officinale, Piper nigrum and Mucuna pruriens		Expelling out the earworms	[66]
	Rice with mustard processed with <i>M. oleifera</i> decoction	Abscess	Suppurated abscess	[46]
	Paste	-	Snakebites	[49]
	Decoction or paste	Calculi	Kidney stone	[50]
	Decoction			[45]
Root	Decoction	Throat disorders	Hoarse throat	[56, 45]
Whole plant			Pharyngodyma	[65]
Root bark	Fumes of powder mixed with Ghirta and oil		coryza	[68]
	Juice mixed with honey, oil and rock sait	Ear disorders	Otalgia	[50]
	<i>M. oletjera</i> and <i>Crataeva nurvala</i> mixed with Dhānyāmla	Gouty arthritis	Gout	[50]
Root	Infusion combined with nitrate and alum	Gynecological disorders	Leucorrhoea	[59]
Stem bark	Dried tuber of Ampelocissus latifolia, leaves of		Leucorrhoea	[59, 55]
	Abutilon indicum, flowers of Butea monosperma, M.			
	with water			
Root and bark Whole plant	Decoction with jaggery	Menstrual problems	Menstrual disorders	[44]
Root bark	-	Urinary disorders	Useful in the flow of urine	[66, 63]
Loof	Inice along with correct inice		and urinary diseases	
Root and	Root juice and tender leaves mixed with jaggerv/	Cephalgia	Headache	[69]
leaves/Whole	infusion	·r· 8		
plant	Deste		Dia anno 197	[53]
Root bark Whole plant	Paste M. oleifera and Schleichera oleoides	Skin disorders	Kingworms	[22]
- F	Oil		Aleviating leprosy	[46]
Leaf	Paste		Heal minor cuts, injuries, eczema	[61]

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Leaf	Juice boiled in sesamum oil to make ointment		To cure eczema and itching	
Root	Decoction or paste	Diabetes	Maintained high blood glucose level	[70]
Bark, Leaves	juice			
Fruit	-			
Seed	Equal part of Nymphaea nouchali, M. oleifera and	Hypersomnia	Used as collyrium to treat hypersomnia	[66]
	Mesua ferrea prepared suppository		or drowsiness	
	Paste prepared from an equal quantity of Brassica	-	Tumors	[66]
	campestris, M. oleifera, Crotalaria juncea seed, Linum			
	usitatissimum, Hordeum vulgare and Raphanus sativus			
	pounded with buttermilk			
	Paste prepared from eqal quantity of Brassica	-	Goitre	[66]
	campestris, M. oleifera Crotalaria juncea, Linum			
	usitatissimum, Hordeum vulgare and Raphanus sativus			
	pounded with buttermilk			

## Mechanical insights into the pharmacological and therapeutic profile of *M. oleifera*

Several studies on the pharmacological properties of *M. oleifera* compounds were discovered in the existing literature. These pharmacological studies provided scientific evidence for some of this plant's ethnomedicinal uses. Table 2 and Figure 3 show a brief overview of *M. oleifera's* biological activities as well as mechanistic insights into these activities. This plant is extensively utilized as a nutritional herb and contains valuable pharmacological action such as anti-diabetic, hepatoprotective, anti-inflammatory, anti-cancer, antimicrobial, anti-oxidant, cardioprotective, neuroprotective, neuroprotective, anti-allergic, analgesic, etc which shown in table 1. Some of them are described below:

## Anti-adipogenic activity

In order to combat metabolic conditions including hyperlipidemia and insulin resistance that are related to obesity, the plant compounds could be used to treat the metabolic disorders. <sup>[71]</sup> Scientist depicted that the 4-( $\alpha$ -L-rhamnosyloxy) benzyl isothiocyanate isolated from *M. oleifera* seeds, inhibited the intracellular lipid accumulation during adipocytes differentiation.

## Anti-allergic activity

The isolated compounds from leaves, seeds and pods such as quercetin, kaempferol,  $\beta$ -sitosterol-3-O-glucoside, oleic acid and stigmasterol suppressed the both early and late stages of allergic responses. Thus, these compounds might be used as anti-allergic agents <sup>[19]</sup>.

## Anti-cancer activity

The quercetin-3-O glucoside and bis (Isothiocyanatomethyl) benzene found in leaves as well as moringin presence shown in seeds were investigated to treat various types of carcinoma cell lines during MTT assay <sup>[72]</sup>. Its potential application as a therapeutic formulation for the treatment of cancer, therefore it can be determined by extrapolating its activity further.

## Anti-diabetic activity

One of the main factors that contribute to end-stage renal disease is diabetic nephropathy (DN). The isothiocyanate of *M. oleifera* seeds

controlled some of the pathways/genes stimulated by high glucose, which may help to identify potential therapeutic targets and functions for DN  $^{\left[73\right]}$ .

## Anti-inflammatory activity

Compounds such as Isothiocyanate-1 & vitexin (Seeds), 3-hydroxy- $\beta$ ionone (leaves) and aurantiamide acetate (roots) of *M. oleifera* decreased the inflammatory cytokines using macrophages (*in vitro*) and mice/rats (*in vivo*) models. Moreover, compounds inhibited inflammation through the regulation of the NF- $\kappa$ B pathway, which leads to downregulating the inflammation processes via decreasing of pro-inflammatory mediators <sup>[74]</sup>. Thereby, it was suggested that those compounds have extensive potential for the treatment of metabolic cartilage disorders.

## Anti-microbial activity

Leaves and seeds essential oils as well as, some derivatives of isothiocyanate from seeds of Moringa, which showed the antibacterial and anti-fungal effects toward extensive diffusion and dilutions methods of microbial strains; *S. epidermidis*, *E. coli*, *B. cereus*, *Candida spp.*, etc <sup>[75]</sup>.

## Anti-oxidant activity

*M. oleifera* was reported to be a strong anti-oxidant evident by various studies. Leaves and seeds contain quercetin-3-O glucoside, niazirin, and oils present in seeds of *M. oleifera* were assessed for anti-oxidant potential using DPPH, ABTS & FRAP assays <sup>[75]</sup>. Thus, plants might be utilized for the production of antioxidant-rich products that would be helpful to combat oxidative stress-mediated disorders.

## Cardioprotective effect

The seed oil of *M. oleifera* depicted cardiotoxicity induced by Dichlorvos inhalation in rats. This study improves our comprehension of cardiotoxicity by restoring fat degradation and necrosis in the myocardial layer <sup>[76]</sup>.

## Hepatoprotective effect

The seeds compound 1-O-(4- hydroxymethylphenyl)- $\alpha$ -L-rhamnopyranoside of this plant has liver-protective activities against CCl<sub>4</sub>-induced hepatotoxicity in cells and mice and it has the potential to be developed into a beneficial functional food additive or medication for the treatment of hepatic injury <sup>[77]</sup>.

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#### Locomotor effect

#### Neuroprotective effect

The Kaempferol and oil component elevated the GABAA receptors in the hypothalamus of the mice model. By regulating GABAA-ergic systems, this compound may enhance sleep and promote additional clinical studies to treat insomnia <sup>[78]</sup>.

ROS, including hydrogen peroxide, are distinguished by their induction of oxidative stress, which is linked to a number of neurodegenerative disorders. The glucomoringin-isothiocyanate of M. *oleifera* seeds protected the integrity of neuron cells against oxidative stress-related cytotoxic action <sup>[79]</sup>.



Figure 3: Mechanistic insights into the biological potential of M. oleifera bioactive compounds.

## TOXICOLOGICAL STUDIES

The methanolic leaf extract of *M. oleifera* was tested for acute and sub-chronic toxicities in rats. There was no mortality at 2,000 mg/kg dose observed during acute toxicity. In sub-chronic toxicity, extract (150, 300 & 600 mg/kg) showed no apparent changes in physiology and behavior during 90 days of study in both sexes while, a decrease in body weight, cholesterol, low-density lipoproteins and increase in platelet count <sup>[80</sup>. The stem bark extract of this plant did not have any hazardous effects during acute and sub-acute toxicity up to 2000 mg/kg. The sub-acute toxicity using *M. oleifera* was performed for 60 days in the animal model. In comparison to the control group, the results showed that the lethal dose of the plant was 1585 mg/kg without any appreciable changes in sperm quality, biochemical or

hematological markers <sup>[81]</sup>. The results of *M. oleifera* in sub-acute (40-1000 mg/kg) and acute (5000 mg/kg) toxic investigations did not reveal any adverse reactions while, the levels of ALT, ALP, and creatinine increased in rats or mice. Hence, it might be said that consumption is safe, but to avoid cumulative toxicity, intake shouldn't exceed 70 g/day <sup>[82]</sup>.

#### Moringa as a biocontrol agent

*Trichoderma* IITA 508 (isolated from a diseased cowpea stem, Cotonou, Benin), *Trichoderma* Kd 63 (Dr. M. Morris, Plant Health Products, Pietermaritzburg, South Africa) and *B. subtilis* (Prof P. L. Steyn, Stimuplant CC, Mooiplaats, Pretoria, South Africa) were used. Trichoderma Kd 63 and *B. subtilis* were each in powder formulation with 109 colony forming units (cfu) g)1 powder. Trichoderma IITA 508 had shown in vitro inhibitory action against *S. rolfsii* in a previous study <sup>[83]</sup> and was used in the current study in millet seed inoculum formulation. Trichoderma Kd 63 or *B. subtilis* were used at 5 g powder per liter of distilled water, as recommended by the manufacturer.

## Miscellaneous applications of M. oleifera

The study's decisive finding raises the possibility that the standard method could be effective for evaluating the efficacy of the creation of cosmetic and natural health products. The negative effects of neem oil, which is employed in aquaculture as an insecticide to reduce predators and parasites of fish fry, were successfully eliminated by the extract of *M. oleifera* leaves. According to the researcher's concluding statement, moringa is an excellent nutritional supplement for people because of its high concentration of proteins, lipids, and amino acids that include sulfur as well as its relative lack of harmful components [84].

The bioactive isolate palmitic acid from *Moringa* leaf extract has been linked to a variety of medicinal advantages. This isolate was tested against a variety of microbial and fungal strains by a research team. It exhibited the maximum zone of inhibition for both fungal and microbial strains, according to the findings <sup>[85]</sup>. As a drug carrier, *Moringa* extract was incorporated using nanoparticle technology. In addition to being widely used to prevent and treat a variety of human diseases, *Moringa* is also known for its many non-medicinal applications, chief among them its use for poultry, particularly in the treatment of viral infections (such as the Newcastle Disease Virus)

and other parasitic and bacterial diseases that result in animal mortality <sup>[86]</sup>.

The plant is also a vital growth booster for farmers growing tomatoes, peanuts, corn, and wheat in their early vegetative phases. This plant produces environmentally beneficial biopesticides, which are inexpensive and widely available, and aid in the treatment of different plant diseases <sup>[87]</sup>. *M. oleifera* aqueous extract contains a variety of nutrients and growth stimulants (indole acetic acid, gibberellins, cytokines). As a result, it can be utilized as an effective plant biostimulant, providing a simple alternative to the market's chemical fertilizers and pesticides.

The plant's potential to tolerate dryness is attributed to the plant hormone zeatin, therefore plants exposed to such climatic conditions when sprayed with Moringa methanolic extract showed enhanced growth characteristics as compared to well-watered plants. The tree is effective at eliminating water hardness and is utilized by African tribes as a low-cost alternative to chemical softeners <sup>[88]</sup>. It has also been demonstrated to be an effective treatment for turbidity, alkalinity, and dissolved organic carbon. *Moringa* has been proposed as a possible replacement for chemical alum in the removal of water turbidity.

*Moringa* is an excellent source for treating plant diseases and may be a viable choice for biopesticides. *Pythium debaryanum*, a pathogen responsible for damping-off disease, can be healed by adding leaves to the soil because it affects the plants <sup>[89]</sup> (Akinyeye et al., 2014). Almost every plant part (fruits, flowers, leaves, seeds, roots) is thought to have various characteristics that help spiritually and psychologically heal the body <sup>[90]</sup> (Figure 4).



Figure 4: Other miscellaneous uses of M. oleifera parts in various sectors.

Table 2: Important parts of *M. oleifera* and their applications in horticultural, food, phytochemistry, fodder, and veterinary.

Type of Use	Plant Part	Other Miscellaneous Uses	Reference
Horticultural	Whole plant	Living fence in home gardens	[91]
Food	Leaves, Fruits and	Cooked as vegetable, soups and sauces; salad, condiment, spice,	[92])
	Flowers	flavoring, agents	
	Seeds	Roasted seeds are eaten like groundnut	[93]
	Roots	Tuberous root cores are used as a replacement for horseradish	[92]
	Bark	Infusion taken as a drink	[94]
Phytochemistry	Seeds	To purify water, oil used in cooking, hair-dressing, perfumes & lubricant	[95]
	Leaves	As an antibiotic, bacteriostatic, and fungistatic to purify water	[96]
Fodder	Leaves	Eaten by pigs, camels, donkeys and goats and livestock	[27]
Veterinary	Leaves	Fresh: to treat pigs' diseases	[92]

#### **Current Status**

*Moringa* is a widely distributed species with numerous advantages, and its current status implies that it has significant potential for pharmacological activities and is associated with formulations, biomedical applications, cattle, poultry, and fish production. Tremendous study undertaken in India, Nigeria, Brazil, and China from 2019-2022 has created an immense resource for researchers globally. An extensive study of this plant revealed that *M. oleifera* has developed to help people in a variety of ways. This plant contains a high concentration of minerals and phytoconstituents, making it acceptable for human and animal consumption. Due to its extensive anti-oxidant abilities, it has become a pharmaceutical alternative to formulations such as wound healing, anti-cancer, anti-aging and others. It is valuable not for human consumption, but also as a fertilizer made from *M. oleifera*.

#### **CONCLUSIONS AND FUTURE PERSPECTIVE**

The review highlights different features of M. oleifera, such as its global research, pharmacological activities, phytochemistry, phytopharmaceutical formulations, clinical findings, toxicology, and other variables. Alkaloids, phenolic acid, glycosides, sterols, glucosinolates, flavonoids, terpenes, and fatty acids are abundant and widely employed in a range of applications. Furthermore, M. oleifera is high in substances including vitamins, minerals, and carotenoids, which improve its medical potential and use as a superfood. Pharmacological investigations reveal that the plant's active ingredients have effectively healed a variety of ailments including neuropathic pain, cancer, hypertension, diabetes, and obesity. Numerous phytochemicals are yet to be investigated for potential therapeutic advantages. Aside from its clinical applications, the plant is also employed as an excellent biostimulant in farmers' fields and has proven to be a cost-effective alternative. According to a review of the literature, substantial preclinical research has been conducted in recent years. Further clinical trials will be needed in the future to study the plant's efficacy in life-threatening conditions such as coronavirus outbreaks, acquired immunodeficiency syndrome (AIDS), and other malignancies. Furthermore, additional mechanism-based research is planned to investigate the plant's mechanistic approach to identifying and isolating active or synergistic chemicals. Overall, M. *oleifera* appears to be a phytopharmaceutical and functional food that, if ingested on a daily basis, has the ability to treat numerous chronic diseases in humans and might be used by medical practitioners as a safer option to treat various ailments.

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#### Author's contribution

SY and JM conceptualized and drafted the manuscript. SY prepared the tables with input from both authors. JM promoted, oversaw, and investigated the outcomes of this review article.

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The authors declare no conflict of interest.

#### Ethics approval and consent to participate

Not applicable

## **Consent for publication**

The authors have consent for publication.

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