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Review Article

Moringa oleifera: A comprehensive review on pharmacology, phytochemistry, and clinical applications

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ABSTRACT

Moringa oleifera, commonly referred to as the "tree of life" or the "miracle tree," holds wide spectrum of medicinal and non-medicinal benefits, and so it is valuable herbal plant. *M. oleifera* has been traditionally use for treating various disease conditions such as wounds, pain, ulcers, liver disease, heart disease, cancer, and inflammation. Pharmacological studies have substantiated the hepatoprotective, cardioprotective, and anti-inflammatory potential inherent in extracts derived from various parts of the *Moringa oleifera* plant. Notably, bioactive constituents have been identified in every part of the plant, with over one hundred compounds characterized to date. The plant is rich in alkaloids, flavonoids, anthraquinones, vitamins, glycosides, and terpenes, among other things. Furthermore, the discovery of novel chemicals in the plant, such as niazimin A&B and muramoside A&B, has revealed potent hepatoprotective, anticancer, antihypertensive, antioxidant, and nutritional qualities.

This current review underscores the traditional and remarkable advantages of Moringa, delving into its pharmacological characteristics, phytopharmaceutical formulations, clinical examinations, toxicity profile, and various other applications. Additionally, it aims to shed light on the plant's commercial and phytopharmaceutical applications with the intention of fostering further research. Despite this comprehensive exploration, the review acknowledges that many conventional uses of Moringa still lack scientific investigation. Consequently, the study advocates for further research to unravel the plant's mechanistic pathways, aiming to pinpoint and isolate the active or synergistic compounds accountable for its medicinal properties.

1. Introduction

Moringa oleifera, recognized as the "miracle tree," commonly found in tropical and subtropical regions worldwide, with its presumed origin in Asian countries including Afghanistan, Bangladesh, India, and Pakistan. The Moringa family encompasses 13 species, and *M. oleifera*, in particular, has gained prominence for its multifaceted uses in nutrition, biogas production, and fertilizer. Notably, Moringa exhibits a unique resilience to drought. Research indicates that *M. oleifera* stands out as an economical and dependable option for achieving optimal nutrition. Virtually all parts of the tree are utilized for their essential nutrients.[1,2] The leaves of *M. oleifera* are rich in β-carotene, minerals, calcium, and potassium. Dried leaves, boasting an oleic acid content of approximately 70%, which having application in the formulation of moisturizers. The powdered leaves use for the production of various beverages, with "Zija" being particularly popular in India.[3,4] The tree's bark is esteemed for its efficacy

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in addressing diverse ailments such as ulcers, toothaches, and hypertension. Roots play a role in treating toothaches, helminthiasis, and paralysis. Moringa flowers are utilized in the treatment of ulcers, enlarged spleens, and the production of aphrodisiac substances. The tree is renowned for its remarkable properties in addressing malnutrition in infants and lactating mothers.[5]

The current review aims to present a comprehensive summary of current understanding of *M. oleifera's* pharmacological activity, worldwide research analysis, toxicological characteristics, phytochemical composition, and ethnomedicinal attributes.

2. Morphology and Taxonomy

The tree displays rapid growth in loamy and well-drained sandy soils, with a preference for elevations around 500 meters above sea level. Typically, it attains a small to medium size, featuring naturally trifoliate leaves and flowers borne on an inflorescence measuring 10–25 cm in length. The fruits, commonly referred to as "pods," are usually trifoliate. While the trunk typically grows straight, occasional poor formation is observed. Branches tend to be disorganized, forming an umbrella-shaped canopy. The brown seeds possess a semi-permeable hull, and each tree yields approximately 15,000–25,000 seeds annually.[6,7]

Table 1: Taxonomical classification

1.	Kingdom	Plantae
2.	Sunkingdom	*Tracheobionta*
3.	Super division	*Spermatophyte*
4.	Division	*Magnoliophyta*
5.	Class	*Magnoliopsida*
6	Subclass	*Dilleniidae*
7.	Order	*Capparales*
8.	Family	*Moringaceae*
9.	Genus	*Moringa*
10.	Species	*Oleifera*

M. oleifera has been a staple in diets worldwide since ancient times due to its significant therapeutic values. Various medicines derived from the plant have been recognized for their ethnomedicinal properties and have been utilized for centuries in treating various diseases. Practically every part of the plant, including leaves, pods, bark, gum, flowers, seeds, seed oil, and roots, has been employed in the treatment of different ailments. The plant's uses extend to addressing conditions such as antihypertension, anti-anxiety, anti-diarrhea, and diuresis. Moringa has proven effective in treating dysentery and colitis, with poultices made from its leaves providing quick relief for inflammatory conditions like glandular inflammation, headaches, and bronchitis.[8]

The pods are utilized to treat hepatitis and alleviate joint pain, while the roots conventionally address concerns such as kidney stones, liver diseases, inflammation, ulcers, and ear and tooth pain. Stem bark is applied to wounds and skin infections. In Indian traditional medicine, gum extracted from the plant is used to treat fever and induce abortions. The seeds function as a laxative and find application in treating tumors, prostate issues, and bladder problems. Their potential in treating arthritis by modifying oxidative stress and reducing inflammation is recognized. Preparations from the plants leaves benefit nursing mothers, malnourished infants, and contribute to the overall health of the population. Historically, the leaves have been used to address insomnia and wound treatment. In contemporary times, Moringa is extensively utilized in the cosmetic industry, a practice reminiscent of its use in ancient Egyptian history for preparing dermal ointments.[9]

3. Phytochemistry Overview

Extensive research has been conducted on various parts of *Moringa oleifera,* as well as its isolated synthetic compounds. The genus Moringa boasts the identification of over 90 compounds with significant therapeutic potential. These isolated synthetic compounds possess a diverse array of categories, including proteins and amino acids, phenolic acids, carotenoids, alkaloids, glucosinolates, flavonoids, sterols, terpenes, tannins, saponins, fatty acids, glycosides, and polysaccharides.[10–12]

Moringa oleifera leaves, in particular, exhibit a notable concentration of phenolic acids and flavonoids. Phenolic acids such as cinnamic acid, sinapic acid, syringic acid, gentisic acid, gallic acid, ferulic acid, protocatechuic acid, vanillin, caffeic acid, o-coumaric acid, p-coumaric acid, and epicatechin are present, while flavonoids including quercetin, catechin, myricetin, and kaempferol demonstrate excellent therapeutic activity.[11] Lutein, a carotenoid, is found in substantial quantities in *M. oleifera* leaves. The therapeutic efficacy of the plant is attributed to the active constituents present in its leaves, as revealed by gas chromatography–mass spectrometry analysis, identifying key compounds like palmitoyl chloride, cis-vaccenic acid, 5-O-acetyl-thio-octyl, pregna-7-dien 3-ol-20-one, γ-sitosterol, β-l-rhamnofuranoside, and tetradecanoic acid.[13]

The leaves also yield two new alkaloids, marumoside A and marumoside B, along with aurnatiamide acetate from the roots. Moringin and moringinine, two alkaloids, are identified in the plant's stem. *M. oleifera* emerges as a rich source of glucosinolates, with glucomoringin being the most abundant. β-sitosterol, a sterol isolate, is found in both seeds and leaves, while β-sitosterol-3-O-β-D-galactopyranoside, another sterol glycoside, is extracted from the bark. The leaves contain diterpenes and terpenes, with phytol being a major diterpene alcohol. Trace amounts of terpenes and their derivatives are also present.[14,15]

4. Pharmacological/Therapeutic activities:

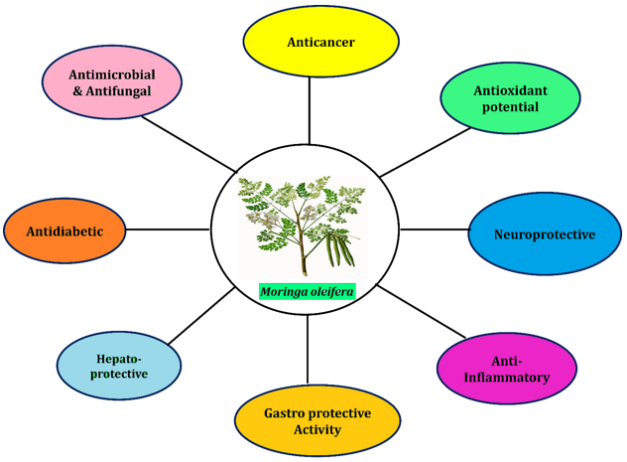

Figure 1: Therapeutic potential of *moringa oleifera* plant

4.1. Antimicrobial and antifungal activity

Moringa, abundant in bioactive compounds, demonstrates the capacity to hinder the proliferation of pathogenic bacteria and fungi, especially those producing toxins. The plant encompasses antimicrobial components like alkaloids, amino acids, cardiglycosides, flavonoids, saponins, steroids, terpenoids, and tannins. Pterygospermine, an antibiotic compound derived from flowers, exhibits notable antimicrobial properties.[16] Root extracts of moringa adversely affect the growth of *E. coli, P. aeruginosa, and S. aureus* bacteria. The fresh leaves of *M. oleifera*, in both juice and hydroalcoholic extracts, exhibit antimicrobial potential against both Gram-negative and Gram-positive bacteria.[17–19] Alcoholic extracts also demonstrate biological activity against Candida albicans. Methanolic extracts significantly inhibit the growth of *Aspergillus flavus* fungi and *Trichoderma harzianum* **.** Extracts of *M. oleifera*'s leaves, seeds, and stems have been proven to suppress a number of fungus species, including *Fusarium solani, Aspergillus niger, Aspergillus flavus, Aspergillus terreus, and Aspergillus nidulans. M. oleifera* fruit contains alkaloids, flavonoids, and steroids that inhibit Candida albicans growth by either denaturing proteins or blocking spore germination via the steroid ring.[20] Moringa seed kernel extract exhibits substantial inhibitory effects against *Bacillus cereus*, *Staphylococcus aureus*, Mucor species, and Aspergillus species, but is less efficient against *P. aeruginosa* and *E. coli*. A recent study highlights that single extract from *M. oleifera* seeds demonstrates antimicrobial potential over Gram +ve bacteria.[18,19]

4.2. Anti-inflammatory activity

Various components of *M. oleifera*, including leaves, pods, flowers, and roots, demonstrated a noteworthy anti-inflammatory effect. Specifically, an isolated compound, 4-[2-o-Acetyl-alpha-l-rahamnoslyloxy) benzyl] thiocynate from Moringa, exhibited inhibitory activity on nitric oxide and proved effective in Raw264.7. The study explores the anti-inflammatory properties of the *Moringa oleifera* ethyl acetate fraction in RAW264.7 cells. It found that the fraction downregulated iNOS, COX-2, and NF-κB expression, while increasing IκBα levels. This suggests a potential therapeutic avenue, as agents that disrupt NF-κB activation have shown efficacy in treating inflammation-associated diseases. The study also found that the ethyl acetate fraction's anti-inflammatory potential is linked to suppressing NF-κB activation, preventing IκBα degradation and NF-κB p65 protein translocation.[21] Aurnatiamide acetate and 1, 3-dibenzylurea, derived from the roots of Moringa oleifera, were identified as supplementary compounds with inhibitory effects on tumor necrosis factor (TNF-α) production. Tannins, phenols, alkaloids, flavonoids, carotenoids, β-sitosterol, vanillin, and moringin forms the active chemical constituents were identified for their anti-inflammatory properties..[22]

The extract from *M. oleifera* fruit was observed to impede the translocation of nuclear factor kappa B (NF κB), and the chloroform extract exhibited cytotoxicity at higher concentrations (500–1000 μg/mL).[23] In an experimental mice model, the application of *Moringa oleifera* leaf extract emerged as an efficacious treatment strategy for atopic dermatitis in human keratinocytes. This treatment strategy was accompanied by a significant decrease in the ear tissues' expression levels of retinoic acid-related orphan receptor γT, thymic stromal lymphopoietin, and mannose receptor mRNA.[24,25]

In addressing urinary tract infections, *Moringa oleifera* bark extract has exhibited notable efficacy, achieving a complete cure rate of 66.67% within three weeks. When lipopolysaccharide (LPS) and cigarette smoke extract (CSE) are added to human monocyte-derived macrophages (MDM), the extract shows modulatory effects. Its effect is demonstrated by the control it exerts on the inflammatory markers TNF-α, IL-6, and IL-8, as well as the inhibition of RelA expression, a crucial gene involved in the NF-κB p65 signaling cascade.[26] In rat models with acetic acid-induced acute colitis, oral administration of *M. oleifera* seeds results in a reduction in distal colon weight, ulcer severity, and thus themucosal inflammation,[27] This underscores the potential of *M. oleifera* in mitigating inflammation-related conditions through a multifaceted approach.

4.3. Neuroprotective and antioxidant effect in neurodegenerative disorders

Moringa is recognized for its neuroprotective effects, attributed to its ability to enhance blood supply to the brain. This is crucial in preventing cerebral ischemia and reducing the ROS formation. The plant significantly reduces ROS, inducing an antioxidant response that protects the brain. Notably, *Moringa* reduces brain infarct volume in cortical and subcortical areas significantly.[28] It also increases superoxide dismutase (SOD) activity in rodent hippocampus and striatum. The ethyl acetate fraction of *Moringa* has been studied for its impact on the molecular mechanisms of inflammation. Treatment with this fraction results in the downregulation of iNOS, COX-2, and NF-κB expression, while upregulating IκBα levels. These findings suggest a potential therapeutic strategy, as interference with NF-κB activation has shown efficacy in treating inflammation-associated diseases. Studies further reveal that *Moringa* seed extract effectively manages cognitive impairment by improving the cholinergic system and neuron synthesis in the hippocampus.[21] *Moringa* administration reverses scopolamine-induced reductions in phosphorylated extracellular signal-regulated protein kinase (ERK1/2), AK strain transforming (Akt), and cAMP response element-binding protein (CREB) in the hippocampus.[29]

Long-term *Moringa* treatment improves spatial memory, decreases escape latency, and lowers oxidative stress, restoring acetylcholine levels and halting the progression of Alzheimer's disease (AD). The neuroprotective effects extend to dementia, where *Moringa* treatment reverses dementia-like conditions via decreasing MDA, cholinesterase, nitric oxide (NO), and amyloid levels while increasing glutathione levels. *Moringa* has a positive influence on neuronal health by promoting neurite outgrowth and neuronal differentiation in embryonic neurons. Research demonstrates its efficacy in restoring spatial memory and neurodegeneration in various hippocampal regions. Additionally, *Moringa* exhibits neuroprotective effects in models of Alzheimer's disease, restoring neurotransmitter levels and monoamine balance in the brain.[30]

Parkinson's disease (PD) is a hypokinetic neurological illness caused by dopaminergic neuron degeneration in the substantia nigra pars compacta.[31] In the context of Parkinson's disease (PD), *Moringa* is implicated in reducing oxidative stress, ROS formation, mitochondrial damage, and apoptosis. Sulforaphane, a component of *Moringa*, has been shown to protect against PD by directing interventions towards the transcription factor Nrf2 with the aim of enhancing the longevity of dopaminergic neurons.[32] *Moringa*'s anti-inflammatory properties extend to the reduction of proinflammatory cytokines in PD models.[33]

For Huntington's disease (HD), *Moringa* treatment preserves normal parameters and prevents the elevation of glutamate and dopamine levels observed in the HD group. However, its effectiveness is limited against specific induced demyelination and protein aggregations in certain brain areas of the HD rodent model.[34]

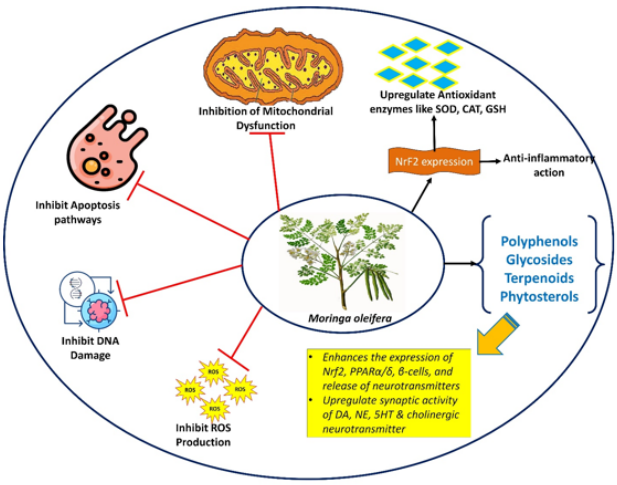

Figure 2: Neuroprotective mechanism of *moringa oleifera*

Neuronal degeneration is a significant contributor to oxidative stress, a leading factor in neurological disorders like mitochondrial dysfunction. Mitochondria, vital for cellular functions such as energy metabolism, synthesis regulation, ATP production, and ROS scavenging, become dysfunctional in various neurodegenerative disorders. Non-mitochondrial ROS generation leads to mitochondrial ROS and disrupts chelation balance within cells.[35] The study conducted by Muhammed et al. in 2020 revealed that *Moringa* exerted a protective influence against mitochondrial dysfunction by modulating the activities of mitochondrial nicotinamide adenine dinucleotide (NADH) dehydrogenase and ATPase enzymes. This underscores the plant's intrinsic neuroprotective activity, which plays a key role in averting ROS generation and mitigating oxidative damage.[36]

4.4. Antidiabetic activity

Moringa leaves exhibited notable efficacy in augmenting glucose tolerance in Wistar and Goto-Kakizaki rats, concurrently eliciting a reduction in blood glucose levels. The aqueous extract demonstrated pronounced antidiabetic effects by modulating key parameters, including blood glucose levels, protein, sugar, and haemoglobin, in rat models.[37] Consumption of the plant's leaves resulted in a discernible reduction in glucose levels within a three-hour timeframe, although without surpassing the efficacy exhibited by the standard drug glibenclamide. Orally

administered *Moringa* were found to harbor insulin-like proteins possessing antigenic epitopes to insulin, thereby manifesting notable antihyperglycemic activity.[38]

Administration of the aqueous extract obtained from *M. oleifera* leaves at a dose of 100 mg/kg resulted in improvements in insulin sensitivity, an increase in total antioxidant capacity, and enhancements in immune tolerance. These findings align with concurrent research suggesting the ameliorative potential of *M. oleifera* in addressing glucose intolerance. Noteworthy antidiabetic properties inherent in the plant's leaf extracts were evidenced by heightened levels of catalase and malondialdehyde, coupled with diminished fasting plasma glucose, hemoglobin, low-density lipoprotein cholesterol, and very low-density lipoprotein cholesterol in individuals with type 2 diabetes.[39] Most notably, these extracts induced elevated insulin levels in healthy subject. Furthermore, the seed extract from *M. oleifera* demonstrated a reduction in lipid peroxidation levels, concomitant with an augmentation of the antioxidant effect in mice subjected to streptozotocin-induced conditions. This seed extract was also effective in diminishing parameters such as immunoglobulin G, immunoglobulin A, and interleukin-6, along with mitigating pancreatic β-cell activity. The compounds deemed responsible for these effects were proposed to include quercetin, kaempferol, glucomoringin, chlorogenic acid, and isothiocyanates.[40] Furthermore, recent investigations underscored the pivotal role of *M. oleifera* leaf extract administration over a six-week period in alleviating diabetic complications. This encompassed a protective effect against diabetes-induced renal damage and inflammation in a streptozotocin-induced diabetes rat model. Administration of *M. oleifera* seed powder exhibited ameliorative potential for diabetic nephropathy, culminating in the restoration of normal histology in both renal and pancreatic tissues, particularly in comparison with a diabetic-positive control group.[41]

These findings suggest that *M. oleifera* leaf extract and seed powder may have therapeutic potential in managing diabetic complications, particularly in terms of renal and pancreatic health. Further research is warranted to elucidate the underlying mechanisms and explore their potential as adjunct therapies for diabetes management.

4.5. Anticancer activity

Cancer is a major cause of death globally and the second leading cause of death in the United States. Several epidemiological studies have found a link between cruciferous vegetable consumption and an increased risk of developing breast, lung, and colon cancer.[42] Extracts obtained from leaves and bark of *M. oleifera* downregulate the tumor growth in pancreatic, breast, and colorectal cancer cell proliferation. Alsamari and colleagues conducted gas chromatography-mass spectroscopy analysis, identifying 12 distinct compounds in *M. oleifera* extract, with three potentially possessing anticancer properties.[43] The precursor form of the potent anticancer compound isothiocyanates, glucosinolates, naturally occurs in the intact plant.[44] Extensive research has focused on their anticancer efficacy, revealing that both androgen-dependent and androgen-independent human prostate cancer cells are inhibited in development by allyl isothiocyanates. When benzyl isothiocyanates were administered to mice harboring BxPC-3 tumor xenografts, it shows a significant 43% decrease in tumor development. By blocking AKT, phenyethyl isothiocyanates have shown promise in slowing the progression of cancer.[45]

Although investigations into *Moringa* isothiocyanates are limited, existing studies on other isothiocyanates suggest the potential for this compound to usher in novel avenues in cancer therapeutics. The *Moringa* plant has been shown to have anti-cancer properties in several portions of the plant; specific chemicals such as isothiocyanate and thiocarbamate have been shown to inhibit tumor cells. In a mouse model of melanoma, alcoholic and hydro-methanolic extracts from fruits and leaves have shown a substantial reduction in tumor development. According to a recent computational modeling research, rutin in *M. oleifera* has the highest affinity for binding to BRCA-1.[46]

4.6. Analgesic/antipyretic activity

Numerous pre-clinical investigations on rats have documented the analgesic and anti-inflammatory properties of *Moringa*, and it has been suggested that *Moringa* reduces inflammatory indicators. An alcoholic extract of moringa seed and leaves showed a comparative analgesic efficacy between aspirin and indomethacin.[47] According to these researches, *Moringa* is equivalent to the common medication's aspirin and indomethacin, which is widely recognized to have an analgesic effect.[48] In a carrageenan-induced model of paw edema, Anti-inflammatory activities of moringa leaf extract have been demonstrated and it is might be mediated via neutrophils and the c-Jun N-terminal kinase pathway.[22,49]*Moringa'*s anti-inflammatory active ingredients include vanillin, hydroxymellein, moringine, moringinine, -sitostenone, and 9-octadecenoic acid.[50] *Moringa* leaf extract's antipyretic effectiveness was shown in experimental albino rats, where it decreased pyrexia caused by yeast and, in a dose-dependent way, maintained normal body temperature. *Moringa* leaf extract was shown to be an excellent antipyretic in experimental albino rats by significantly reducing fever caused by yeast. Moreover, the extract exhibited a dose-dependent response, effectively maintaining normal body temperature in the tested subjects.[51]

4.7. Hepatoprotective

M. oleifera's hepatoprotective activity is associated to the abundance of bioactive substances found in its aqueous leaf extracts, which include high quantities of phytochemicals such as flavonoids, phenolic acids, and carotenoids. These chemicals work together to provide therapeutic effect and for its possible health advantages, *M. oleifera* should be consumed on a daily basis.[52] However, excessive intake may lead to iron accumulation, causing gastrointestinal distress and hemochromatosis. To prevent nutrient over-accumulation, a daily dose of 70 g of *M. oleifera* is suggested.[53]

The antioxidant-rich characteristics of *M. oleifera* aqueous leaf extract are demonstrated in in vivo experiments, and this is an important defense against illnesses brought on by oxidative stress. According to in vitro studies, *M. oleifera* hepatoprotective qualities against a range of medications, including acetaminophen, pyrazinamide, gentamicin, and rifampicin, are mostly ascribed to its leaves.[54] Determining a half-maximal inhibitory concentration is frequently necessary in order to assess the efficacy *M. oleifera* as a protective agent in vitro. In vitro models such as the HepG2 cell line are often used to evaluate hepatatoxicity and the protective effects of aqueous leaf extracts by mimicking the natural in vivo environment.[55]

The hepatoprotective properties of *M. oleifera* against oxidative stress are remarkable. *M. oleifera's* antioxidant action reacts to elevated ROS. *M. oleifera* releases Nrf2 via activating the Nrf2-Keap1 complex in the presence of oxidative stress. Antioxidant response elements (ARE) are bound by the phosphorylated version of Nrf2 (p-Nrf2), which then translocates to the nucleus and stimulates the transcription of antioxidant genes. By upregulating antioxidants and downregulating ROS, this cascade efficiently reduces oxidative stress.[56]

5. Immunomodulatory Activity

The extract derived from *Moringa oleifera* leaves, particularly rich in isothiocyanates, has exhibited the ability to impede both gene and protein expression of interleukins IL-1β and IL-6 in lipopolysaccharide stimulated RAW 264.7 cells.[57] Furthermore, the ethyl acetate fraction of *M. oleifera*, characterized by its phenolic content, demonstrated inhibition of macrophage activation induced by LPS or cigarette smoke. This resulted in a notable decrease in gene and protein expression of pro-inflammatory cytokines, including IL-6, IL-8, and TNF-α.[58,59]

Active ingredients such isothiocyanate and glycoside cyanide, which have immunostimulatory action and efficiently boost immunity, are present in the plant's methanolic extract. According to a recent review study, a number of bioactive substances have been employed to treat immune-related conditions like diabetes, cancer, and hypertension, which has improved host immunity. Several substances obtained from *M. oleifera*, such as the polysaccharide isolated from the root of *M. oleifera* and the isothiocyanates-enriched seed extract showed similar anti-inflammatory properties. These substances were discovered to inhibit phosphorylation of Rel A(p65), phosphorylation of I$\kappa\beta$, and nuclear translocation of NF-$\kappa\beta$, resulting in decreased mRNA expression of COX-2, TNF-α, iNOS, IL-1, and IL-6.[60] Furthermore, it has been demonstrated that extracts from *Moringa oleifera* leaves boost unstimulated macrophage proliferation and pinocytic activity in addition to secreting more ROS. Certain elements, such *Moringa oleifera* seed resistant protein, stimulated the growth of murine splenocytes and the macrophages' generation of nitric oxide (NO). Peripheral blood mononuclear cells were exposed to water-soluble lectins, which caused the production of several cytokines TNF-α, IL-2, IL-6, IL-10 and NO.[2]

These findings underscore the versatile the efficacy of plant extracts from *Moringa oleifera* in reducing inflammation in activated immune cells, suggesting therapeutic applications in immunity disorders, organ transplantation and immunocompromised conditions like acquired immune deficiency syndrome (AIDS) and HIV/AIDS. In summary, *Moringa oleifera* has context-dependent immunomodulatory effects on immune cells that activate resting or unstimulated cells while suppressing stimulated cells. Furthermore, it has been shown that the ethanolic leaf extract of *Moringa oleifera* can protect immune cells from the cytotoxicity caused by melamine, a common food adulterant and contaminant.[60,61]

6. Toxicity and Phytopharmaceutical Formulations

Moringa oleifera, recognized for its nutritional and medicinal properties, has undergone extensive scrutiny to elucidate its toxicological aspects. In a particular investigation, the oral administration of an aqueous methanol solution from *Moringa*, at a dosage of 2000 mg/kg, manifested no lethal effects in female rats.[77] Similarly, a parallel examination involving Sprague-Dawley rats revealed an absence of deleterious or lethal consequences associated with the consumption of *Moringa* leaves. The seeds of *Moringa oleifera* exhibited acute toxicity at a dose of 4000 mg/kg, with observed mortality at 5000 mg/kg.[78] Despite this, the seed extract was determined to be suitable for nutritional purposes. Subsequent subacute toxicity tests conducted at diverse dosage levels unveiled a lethal dose of 1585 mg/kg, which, notably, did not induce significant deviations in sperm quality, biochemical parameters, or hematological indices.[79] Findings from an acute toxic study at 5000 mg/kg and subacute investigations ranging from 40 to 1000 mg/kg indicated an absence of adverse reactions. However, heightened levels of ALT and

Table 2: Phytopharmaceutical applications of *moringa oleifera*

Sr.no	Type of extract	Formulation	Therapeutic Application	References
1	Ethanolic extract of Leaves	Lozenges	Anti-inflammatory	62
2	Ethanolic extract of Leaves	Effervescent Tablets	Anti-anemia	63
3	Seed Oil	Cream	Anti-inflammatory	64
4	Ethanolic extract of Leaves	Ag-Nps (Silver nanoparticles	antimicrobial	65
5	Hydro-alcoholic extract of Leaves + Fruits	In-Situ Nasal Gel	Allergic rhinitis	66
6	Ethanolic extract of Leaves	Suspension	Hepato-protection against Isoniazid	67
7	Ethanolic extract of Leaves	Granules	Anti-inflammatory and anti-arthritic	68
8	Seed Oil	Suppositories	Hemorrhoids	69
9	Aqueous, ethanolic extract of Leaves	Film Dressing	Wound healing	70
10	Hydro-alcoholic extract of Leaves	In-Situ Gel	Allergic rhinitis	66
11	Hydro-alcoholic extract of Leaves	Micro-Particles	Exuding wound treatment	71
12	Aqueous extract from Leaves	Film Dressing	Wound healing in diabetic condition	72
13	Aqueous/methanolic extract from Leaves	Ointments	Edema	73
14	Seed Oil	Nano-Micelle	Mitochondrial cancer cell apoptosis	74
15	Leaves	Nanorods	Anti-bacterial property	75
16	Seed Oil	Micro-Dispersion	Anti-inflammatory	76

ALP, coupled with decreased creatinine levels, prompted the recommendation that daily *Moringa* consumption should not surpass 70 gm/day to avert cumulative toxicity.[80]

The collective data underscore the importance of adhering to recommended daily limits, given the generally safe nature of *Moringa* consumption, even though potential adverse effects were observed at higher doses. To augment the current understanding of *Moringa*'s safety profile, further scientific inquiry is warranted. Below are the list of Phytopharmaceutical formulations prepared using *M. oleifera* extract.

7. Conclusion, Current Status, and Future Prospects

Moringa stands out as a versatile plant, offering a myriad of benefits across diverse applications. The current assessment of its status indicates its potential in various pharmacological activities, biomedical applications, and animal husbandry, as evidenced by extensive research conducted in key regions like India, Nigeria, Brazil, and China between 2019 and 2022. This wealth of research serves as a valuable repository for global researchers.

The comprehensive study of *M. oleifera* reveals its multifaceted contributions to human well-being. Rich in nutrients and phytoconstituents, the plant is not only suitable for human consumption but also finds applications in various formulations owing to its potent antioxidant properties. These formulations range from wound healing to anti-cancer and anti-aging solutions. Moreover, *M. oleifera* extracts serve as effective fertilizers. Despite its numerous benefits, it is crucial to note potential toxic and abortifacient effects associated with excessive consumption. The comprehensive review delves into various facets of *Moringa oleifera*, spanning global research, ethnopharmacology, pharmacological activities, phytochemistry, phytopharmaceutical formulations, clinical studies, toxicology, and miscellaneous parameters. Noteworthy compounds like alkaloids, phenolic acids, glycosides, sterols, glucosinolates, flavonoids, terpenes, and fatty acids contribute significantly to the medicinal properties of *M. oleifera*. Furthermore, the plant emerges as a prolific source of vitamins, micronutrients, and carotenoids, augmenting its medicinal worth and positioning it as a superfood.

Pharmacological studies underscore the plant's effectiveness in treating various diseases, including neuropathic pain, cancer, hypertension, and diabetes. However, there is a need for further exploration of phytochemicals for potential therapeutic benefits. Beyond clinical applications, *M. oleifera* serves as a cost-effective biostimulant for farmers. While preclinical research has been prolific, future endeavors should prioritize extensive clinical studies, particularly in addressing life-threatening diseases such as coronavirus outbreaks, AIDS, and various cancers. Mechanistic studies are also recommended to unravel the plant's active or synergistic compounds. In summary, *M. oleifera*, aptly named the "Miracle tree," emerges as a promising phytopharmaceutical and functional

food. Regular consumption holds the potential to address a spectrum of chronic diseases, presenting itself as a safer alternative for medical practitioners in diverse therapeutic applications.

8. Source of Funding

None.

9. Conflict of Interest

None.

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