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REVIEW

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Exploring the pharmacological potential of *Moringa oleifera* folium in health applications: A review

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Abstract: This review synthesizes current knowledge on the therapeutical potential of *Moringa oleifera* leaf extract in health. *M. oleifera* has transitioned from traditional medicine to the forefront of scientific investigation due to its exceptional phytochemical diversity and pharmacological versatility. Evidence supporting cardiovascular, metabolic, and renal benefits is assessed, highlighting mechanisms including nitric oxide modulation, anti-adipogenic effects, protein glycation inhibition, and renoprotection in diabetic conditions. The anti-inflammatory properties of *M. oleifera* are examined across gastrointestinal, neurological, and pulmonary systems, with significant findings in inflammatory bowel disease models, microglial enzyme modulation, and cancer suppression. Recent research on specific bioactive fractions, molecular targets, and signaling pathways provides mechanistic insights into *M. oleifera*'s therapeutic actions. While substantial preclinical evidence supports *M. oleifera*'s potential, it identifies critical research gaps, particularly in clinical validation, standardization, and pharmacokinetics. *M. oleifera* represents a promising sustainable resource for addressing global health challenges, especially in chronic disease prevention and management.

Keywords: moringa oleifera, antioxidant, anti-inflammatory, cardiovascular, neuroprotection, diabetic nephropathy

Introduction

Moringa oleifera, commonly known as the "miracle tree" or "drumstick tree," has emerged as one of the most versatile medicinal plants in the global pharmacopeia. Native to the sub-Himalayan regions of India, Pakistan, Bangladesh, and Afghanistan, this fast-growing deciduous tree has spread across tropical and subtropical regions worldwide, becoming an integral part of traditional medicinal systems in Asia, Africa, and Latin America [1]. The remarkable nutritional profile and therapeutic potential of *M. oleifera* have positioned it as a subject of intense scientific investigation in recent decades.

The leaves of *M. oleifera* represent a particularly rich in bioactive compounds with diverse pharmacological activities. Phytochemical analyses have identified a wide array of constituents, including flavonoids, phenolic acids, alkaloids, isothiocyanates, tannins, saponins, and essential vitamins and minerals [2,3]. This biochemical diversity underpins the plant's multifaceted therapeutic potential, with antioxidant properties forming the cornerstone of its health-promoting effects.

M. oleifera exhibits a spectrum of biological activities that have attracted significant scientific attention, including anti-inflammatory, antidiabetic, hepatoprotective, antimicrobial, anticancer, and neuroprotective effects [1,4]. The global healthcare landscape faces mounting challenges from the increasing prevalence of non-communicable diseases, antibiotic resistance, and the economic burden of synthetic pharmaceuticals. In this context, *M. oleifera* represents an attractive therapeutic option due to its accessibility, sustainability, and favorable safety profile [5].

Although preclinical studies support the therapeutic potential of *M. oleifera*, several key areas require further investigation before it can be fully integrated into modern healthcare systems. These include elucidation of specific molecular mechanisms, standardization of extraction methods, optimization of dosage regimens, and comprehensive clinical validation across diverse populations and health conditions [6,7].

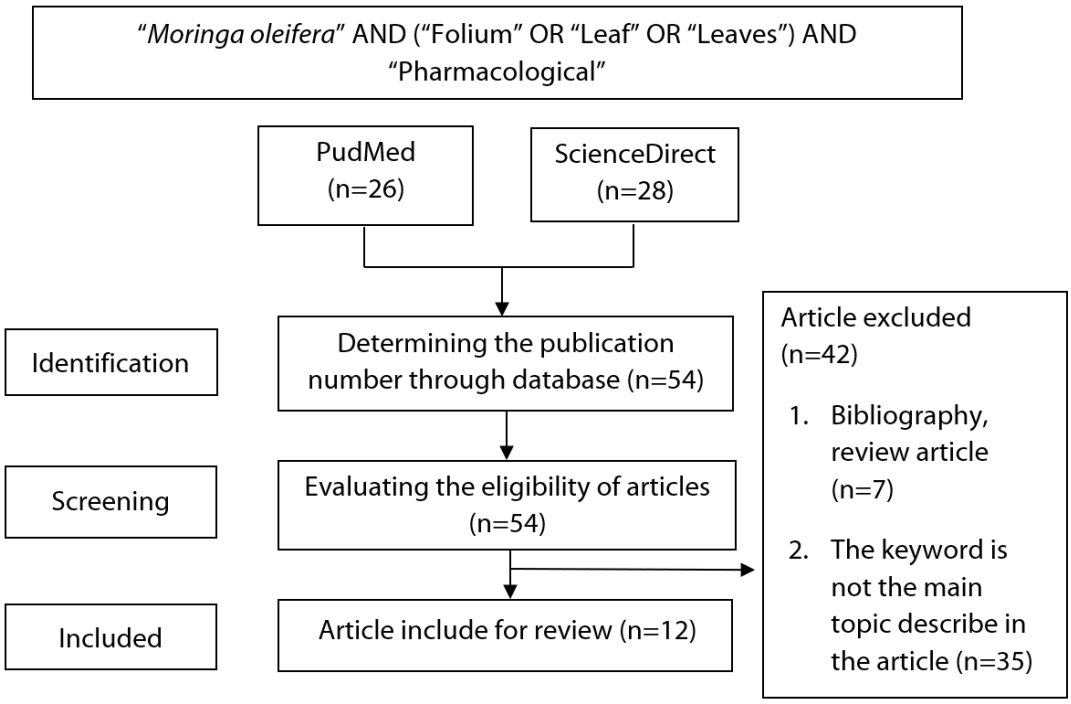

Figure 1. PRISMA diagram related to the analysis of the pharmacological potential of Moringa Leaf

This review synthesizes current evidence regarding the pharmacological applications of *M. oleifera* leaves, with particular emphasis on their antioxidant, cardiovascular, metabolic, neurological, gastrointestinal, and anticancer properties. By examining the bioactive constituents, molecular mechanisms, and therapeutic applications, this review aims to provide an evidence-based foundation for future research and development of standardized Moringa-derived products.

Methods

This study used a narrative review to investigate the pharmacological potential of *M. oleifera* leaves, with an emphasis on therapeutic effects and healthcare applications. Literature searches were conducted using PubMed (https://ww.ncbi.nlm.nih.gov/) and ScienceDirect (https://www.sciencedirect.com/) databases with the search string "Moringa oleifera" AND ("Folium" OR "Leaf" OR "Leaves") AND "pharmacological," limited to publications from 2019-2024 (as of November 18, 2024).

The selection process adhered to PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines to ensure systematic and transparent article collection and screening [8]. PRISMA methodology guided the identification, screening, eligibility assessment, and final inclusion of relevant literature. This structured approach identified 12 articles meeting all inclusion criteria for comprehensive analysis. The complete selection workflow is illustrated in Figure 1.

The included articles were systematically analyzed to extract preclinical (in vivo and in vitro) data and clinical evidence of *M. oleifera* leaves' pharmacological activities. The analytical results, including core experimental findings from each publication, were compiled in Table 1, revealing diverse pharmacological properties supported by various testing methodologies.

Antioxidant properties and protective effects

Moringa oleifera leaves demonstrate remarkable antioxidant capacity, which underpins many of their health-promoting properties. Recent research has identified numerous bioactive compounds responsible for these effects, including polyphenols, flavonoids, and other phytoconstituents with free radical scavenging abilities [2]. The antioxidant potential of *M. oleifera* leaf extracts has been confirmed through multiple assays, including DPPH, hydrogen peroxide, and iron reduction tests, with the ethanolic extract showing particularly potent activity at concentrations as low as 0.28 mg/mL, comparable to established antioxidants like ascorbic acid and butylated hydroxytoluene [2].

Table 1. Key therapeutic applications of *Moringa oleifera* leaf extracts

Therapeutic category	Extract type	Study model	Key findings	Active compounds	Reference
Antioxidant & protective	Ethanolic extract	In vitro assays	Significant free radical scavenging activity at 0.28 mg/mL, comparable to ascorbic acid and BHT.	Flavonoids, phenolic compounds	[2]
	Aqueous extract	Male Wistar rats exposed to lead	*M. oleifera* (250 mg/kg) + ascorbic acid (50 mg/kg) normalized liver enzymes and reduced malondialdehyde.	Not specified	[9]
	Methanol extract	Male Wistar rats treated with carbamazepine	Protected against alterations in hematological parameters, liver enzymes, and thyroid function.	Phytochemical constituents	[10]
Cardiovascular	Aqueous extract	Anesthetized rats & arterial beds	Dose-dependent reduction in mean arterial pressure through enhanced endothelial NO production.	Not specified	[11]
Metabolic & anti-diabetic	Dichloromethane extract	Zebrafish on high-fat diet	Reduced visceral adipose tissue accumulation by inhibiting early adipogenesis.	Hexane:EtOAc fraction	[12]
	Ethanolic extract	Streptozotocin-induced diabetic rats	Prevented protein glycation, improved glucose tolerance, reduced lipids, and protected kidney function	Not specified	[13]
Bone health	Leaf powder	Ovariectomized rats	Increased bone mineral density, improved bone microstructure via gut microbiota modulation	MAPK pathway modulators	[14]
Gastrointestinal	Aqueous extract	DSS-induced colitis in mice	Protected intestinal organoids, reduced colonic damage, downregulated inflammatory cytokines	Quercetin-3-galactoside, isoquercitrin	[15]
	Aqueous extract	Acetic acid-induced colitis in rats	Decreased colon weight/length ratio, reduced oxidative stress markers	Not specified	[16]
Neurological	Aqueous extract	BV-2 microglial cells	Maintained cell viability, modulated cholinergic and purinergic enzymes	Chlorogenic acid, rutin, quercetin derivatives	[17]
	Aqueous extract	Acetic acid-induced colitis in rats	Anxiolytic effects, reduced oxidative stress in brain tissue	Not specified	[16]
Anticancer	Leaf extract	Urethane-induced lung cancer in rats	Prevented development of papillary adenocarcinoma, restored normal lung histology	Not specified	[18]

Abbreviations: BHT - butylated hydroxytoluene; NO - nitric oxide; DSS - dextran sulfate sodium; MAPK - mitogen-activated protein kinase

The protective effects of *M. oleifera* extend to mitigating heavy metal toxicity. An investigation comparing *M. oleifera* extract with ascorbic acid in lead-exposed rats revealed substantial benefits in individual and combined treatments. Significantly, administration of *M. oleifera* (250 mg/kg) combined with ascorbic acid (50 mg/kg) provided superior protection against lead-induced alterations in liver enzymes and oxidative stress markers compared to higher doses or single treatments [9]. The extract effectively normalized critical enzyme activities, including alanine aminotransferase, aspartate aminotransferase, alkaline phosphatase, creatine kinase, and lactate dehydrogenase, which were disrupted by lead exposure.

Beyond heavy metal toxicity, *M. oleifera* protects against pharmaceutical-induced adverse reactions. The methanol leaf extract has demonstrated considerable mitigative potential against chronic carbamazepine toxicity in animal models. When administered at 200 mg/kg alongside carbamazepine (20 mg/kg), the extract significantly ameliorated alterations in hematological parameters, liver biochemical enzymes, and thyroid function over 15 weeks [10]. These protective effects were attributed to the extract's rich nutritional profile and phytochemical constituents, which protect both the vascular system and the hypothalamic-pituitary axis from drug-induced damage.

The antioxidant mechanisms of *M. oleifera* involve multiple pathways at the cellular and molecular levels. Research has demonstrated that the extracts can modulate oxidative stress biomarkers in different tissues, suggesting systemic protection. The therapeutic potential of *M. oleifera*'s antioxidant properties extends to addressing conditions characterized by excessive oxidative damage, with applications that will be explored in subsequent sections focusing on specific organ systems and disease states.

Cardiovascular, metabolic and renal effects

Moringa oleifera leaf extracts demonstrate significant benefits for cardiovascular health through several mechanisms, particularly regarding blood pressure regulation. Aqueous extracts of *M. oleifera* leaves have been shown to cause dose-dependent reductions in mean arterial pressure when administered intravenously (1-30 mg/kg) to anesthetized rats. This hypotensive effect appears primarily mediated through enhanced endothelial nitric oxide production, as evidenced by the substantial reduction in *M. oleifera* extract's hypotensive action following pretreatment with NO-synthase inhibitors [11]. Investigations of isolated mesenteric arterial beds further support this mechanism, suggesting its potential development as a natural antihypertensive supplement.

The metabolic benefits of *M. oleifera* extend to adipose tissue regulation and anti-obesogenic effects. Research utilizing zebrafish obesogenic testing has identified specific anti-adipogenic fractions within *M. oleifera* leaf extracts. The dichloromethane extract and its hexane fraction effectively reduced visceral adipose tissue accumulation in young zebrafish consuming high-fat diets. Gene expression analysis revealed that these fractions downregulate key adipogenesis-associated genes, including CCAAT/enhancer-binding proteins beta and delta, which function during the early stages of fat cell development [12]. These findings suggest *M. oleifera* contains bioactive components that may help combat visceral obesity, a significant risk factor for metabolic disorders.

M. oleifera also demonstrates remarkable renoprotective effects, particularly in diabetic conditions with common kidney damage. The ethanolic extract of *M. oleifera* leaves has been found to effectively prevent protein glycation—a critical pathological process in diabetic complications. In streptozotocin-induced diabetic rats, *M. oleifera* leaf extract treatment (100 mg/kg) for eight weeks substantially improved glucose tolerance and body weight while reducing serum triglycerides and total cholesterol levels. The extract ameliorated renal dysfunction markers and enhanced kidney morphology by suppressing diabetes-associated inflammatory responses and reducing renal ROS levels [13].

The beneficial effects of *M. oleifera* on bone health represent another important aspect of its metabolic influence. Research has demonstrated that *M. oleifera* leaf powder can attenuate osteoporosis in ovariectomized rats by increasing bone mineral density, improving bone metabolism indicators, and enhancing bone microstructure. These effects appear partly mediated through positive alterations in gut microbiota composition and enhanced intestinal barrier function. Molecular investigations identified the MAPK signaling pathway as a key mediator of these effects [14].

These findings demonstrate *M. oleifera*'s multifaceted benefits for cardiovascular, metabolic, and skeletal health through interconnected pathways. The plant's

ability to simultaneously target multiple aspects of metabolic health highlights its potential as a holistic therapeutic agent for complex metabolic conditions.

Anti-inflammatory, gastrointestinal, neurological, and anticancer properties

Moringa oleifera leaf extracts demonstrate significant anti-inflammatory effects that benefit multiple body systems. Recent research with dextran sulfate sodium (DSS)-induced colitis in mice revealed that aqueous *M. oleifera* leaf extract effectively mitigates intestinal damage. The extract protected intestinal organoids from tumor necrosis factor (TNF-α) damage while significantly downregulating inflammatory cytokine expression. Oral administration ameliorated DSS-induced colon damage, reducing colonic shortening, preserving goblet cells, and normalizing cellular architecture. LC/MS analysis identified quercetin-3-galactoside and isoquercitrin as key anti-inflammatory components, with network pharmacology predicting their involvement in oxidative stress response and PI3K-Akt signaling pathways [15].

Similar gastrointestinal benefits have been documented in acetic acid-induced colitis models. *M. oleifera* leaf aqueous extract (25-100 mg/kg) administered for 20 days before colitis induction demonstrated significant therapeutic effects. The extract (100 mg/kg) decreased colon weight/length ratio to 112.29 ± 9.46 compared to 185.93 ± 5.28 mg/cm in control groups, indicating reduced inflammation. Beyond intestinal effects, the extract exhibited anxiolytic activity, reducing head dipping behavior and duration in open arms during behavioral testing, highlighting the important gut-brain connection in inflammatory conditions [16].

The neurological benefits of *M. oleifera* extend to cellular protection in the central nervous system. Investigation of its effects on BV-2 microglial cells—resident immune cells in the brain—demonstrated that aqueous extracts (0.1-100 μg/mL) maintained cell viability while modulating cholinergic and purinergic enzyme systems. Phytochemical analysis identified several phenolic compounds, including chlorogenic acid, rutin, quercetin pentoside, kaempferol derivatives, and quercetin derivatives [17]. Since microglial activation can harm neuronal survival, this modulation suggests a potential therapeutic strategy for managing inflammation-mediated neurodegenerative diseases.

Beyond inflammatory conditions, *M. oleifera* demonstrates promising anticancer properties. In a urethane-induced lung cancer rat model, *M. oleifera* leaf extracts showed remarkable therapeutic anticancer effects compared to standard chemotherapy. Treatment with the extract significantly decreased the elevated lung index in cancer-bearing rats while improving oxidative stress markers. Molecular analysis revealed a 50% increase in EGFR-mRNA expression after extract treatment. Microscopic examination confirmed that extract treatment prevented the development of papillary adenocarcinoma in terminal bronchioles and restored normal lung histology [18]. The extract also ameliorated changes in mucin and PCNA-positive cells in lung tissue, suggesting potential as an alternative to conventional chemotherapy with fewer toxic effects.

These findings collectively demonstrate *M. oleifera*'s therapeutic versatility across interrelated pathological processes. Its ability to modulate inflammatory pathways, protect against cellular damage, and regulate responses in diverse tissues suggests shared underlying mechanisms that could be leveraged for targeted therapeutic development.

Future directions and conclusion

Future research on *M. oleifera* should prioritize several key areas to maximize its therapeutic potential. Clinical trials are urgently needed to validate the promising preclinical findings, particularly for metabolic disorders, hypertension, inflammatory bowel disease, and neurodegenerative conditions. Extraction methods and bioactive compound profiles must be standardized to ensure consistency in research and product development. Advanced pharmacokinetic and pharmacodynamic studies are required to determine optimal dosing regimens, bioavailability, and potential drug interactions. Additionally, investigating synergistic effects between *M. oleifera* compounds and conventional pharmaceuticals could open new avenues for integrative medicine approaches. Novel delivery systems to enhance the stability and targeted action of *M. oleifera* bioactive represent another promising research direction, as does exploring genomic and proteomic approaches to identify molecular targets with greater precision.

The extensive of evidence supports *M. oleifera*'s therapeutic versatility and its potential as a sustainable resource for addressing global health challenges. Its wide-ranging biological activities are attributed to a diverse of array of bioactive compounds that act on multiple physiological systems. The plant's

accessibility, favorable safety profile, and environmental sustainability contribute to its relevance as a natural therapeutic agent. Although substantial scientific progress has been made in elucidating the health benefits of *M. oleifera*, further systematic research is needed to bridge the gap between traditional uses and evidence-based applications. With continued research investment and scientific rigor, *M. oleifera* may be integrated into modern healthcare, particularly in the prevention and management of chronic diseases across diverse populations.

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Declaration of interest

The authors declare that there are no conflict of interest related to the publication of this article.

Author contributions

KRDY was responsible for the conceptualization, literature search, and initial drafting of the manuscript. KTW contributed to literature analysis, manuscript editing, and review. GBO was involved in literature analysis, manuscript editing, and critical review. LW contributed to literature analysis, manuscript editing, and review.

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