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A Review Of The Phytochemical And Pharmacological Characteristics Of Moringa Oleifera

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Abstract: Moringa oleifera, often referred to as the "Miracle tree," is a versatile and resilient plant. It thrives in diverse climates, even in harsh conditions. This plant is notable for its high concentration of various bioactive compounds and is recognized for its potential role in combating malnutrition. Moringa exhibits a range of pharmacological effects, including anti-cancer, anti-diabetic, anti- inflammatory, and antioxidant activities. The pharmacological benefits of Moringa are likely linked to its bioactive constituents, particularly flavonoids. Thisreview aims to consolidate information regarding the bioactive compounds and therapeutic properties of Moringa, thereby serving as a resource for its prospective use as a functional food. This review pro vides a comprehensive overview of Moringa, covering its botanical characteristics, phytochemical composition, and pharmacologicalproperties.

Keywords: Moringa oleifera, Phytochemistry, Health benefits, Pharmacological actions.

1. INTRODUCTION

Medicinal plants have long served as a vital source of biologically active compounds. Many of these compounds exhibit beneficial properties that can enhance human health. One notable example is Moringa oleifera, commonly referred to as Moringa in scholarly literature. This cruciferous plant belongs to the genus Moringa within the family Moringaceae. Historical records indicate that Moringa has been utilized for health-related purposes since 150 B.C. Among the 13 recognized cultivars of Moringa, which include M. arborea, M. rivae, Moringa oleifera, M. longituba, M. stenopetala, M. concanensis, M. pygmaea, M. borziana, M. ruspoliana, M. drouhardii, M. hildebrandtii, M. ovalifolia, and M. peregrina (Mahmood K.T et al., 2010), M. oleifera stands out as the most extensively researched and utilized species due to its significant phytochemical and pharmacological attributes associated with human health. Although Moringa oleifera is indigenous to the Indian subcontinent, it is now cultivated in various regions worldwide, including Africa, Europe, and Asia. This widespread cultivation is attributed to Moringa's adaptability to hot, humid, and arid environments, as well as its ability to thrive in less fertile soils. Additionally, Moringa is commonly known as the 'horseradish tree' or 'drumstick tree. In the 1990s, the popularity of Moringa cultivation surged due to the growing awareness of its utility as a versatile plant. This tree is characterized by its multifunctionality, as every part of Moringa can beutilized for various applications (Kou X et al.,2018). Consequently, Moringa has emerged as one of the most economically significant crops, especially in developing nations, where it serves diverse roles in food production, industry, agriculture, and medicine (Leone et al., 2015). For instance, Moringa plays acrucial role in enhancing food security in regions plagued by hunger, as its flowers, pods, leaves, and seeds are recognized as nutritious food sources (Kou X et.al,2018). The leaves of Moringa, in particular,are abundant in essential nutrients, including proteins and vitamins, making them suitable for consumption either raw or cooked to combat malnutrition in vulnerable populations (Leone et al., 2015). Given its wealth of bioactive compounds and nutritional benefits, there is a growing interest in investigating Moringa's implications for human health. Thus, this review aims to compile informationregarding Moringa, focusing on its pharmacological properties and potential health advantages.

Plant Description. M. oleifera is a slender, deciduous, perennial tree that typically grows to about 10 meters tall. It has drooping, brittle branches covered in corky bark. The leaves are feathery, pale green, and compound, measuring 30–60 cm in length,with many small leaflets that are 1.3 to 2 cm long and 0.6 to 0.3 cm wide. The lateral leaflets are slightly elliptical, while the terminal leaflets are obovate andslightly larger. The tree produces fragrant flowers that are white or creamy-white, around 2.5 cm in diameter, and arranged in clusters. The stamens are yellow, and the pods are pendulous, brown, and triangular. When dry, the pods split lengthwise into three sections and contain approximately 20 seeds embedded in pith. Each pod has nine ribs at both ends, and the seeds aredark brown with three papery wings.


Figure 1- Moringa Plant


Figure 2- Tree and seed pods of Moringa oleifera


Figure 3- Moringa oleifera Pollen


Figure 4- Moringa seeds

The tripinnate compound leaves have feathery, curved leaflets that are green and measure 1 to 4 cm long. This appearance often confuses people into thinking the tree is a legume. The leaves are arranged alternately on the branches, with twice or thrice pinnate leaves growing at the tips. Each leaf has along petiole with 8 to 10 pairs of pinnae. Each pinna has two sets of inverse elliptic leaflets and one additional leaflet at the end. Young leaves can grow to be 20–70 cm long.

The seeds are oval-shaped with three papery wings and a tannish, semi- permeable coating. Most seeds are brown to dark brown, but some may be white if they are not viable. Viable seeds usually sprout within a week. The seeds have three white wings that extend at intervals of about 130 degrees. The flowers are noticeable, have a pleasant smell, and form inflorescences thatare 15–25 cm long. They are mostly white to cream, about 2.5 cm in diameter, and some varieties have a slight pink colour. These fragrant flowers bloom abundantly in axillary, drooping panicles that are 10 to 25 cm long, with a dotted base and white colour. The lanceolate sepals are five-reflexed, and thefive petals are thin. All but the lowest stamen are reflexed, with a total of five stamens and five staminodes.

2. PHYTOCHEMISTRY OF MORINGA OLEIFERA

The metabolites identified in M. oleifera extracts. Numerous studies have concentrated on analyzing both the polar and non-polar extracts of M. oleifera.

2.1 Non-Polar Compounds: Moringa oleifera extracts contain a variety of bioactive compounds, includingfatty acids, alkanes, and essential oils, with diverse applications in medicine, cosmetics, and alternative therapies.

Fatty Acids: M. oleifera leaves and seeds are rich in fatty acids, particularly cis-11-eicosenoic acid (gondoic acid), oleic acid, palmitic acid, and linoleic acid. Gondoic acid, a monounsaturated fatty acid, is the most abundantin leaf extracts. In seed extracts, oleic acid is predominant, followed by palmitic and stearic acids. These fatty acids are essential for the synthesis of omega-3 fattyacids, supporting cellular development and immune regulation. Gondoic acid, oleic acid, and linoleic acid also exhibit antimicrobialproperties, inhibiting biofilm formation of Staphylococcus aureus. The oily fraction from M. oleifera leaves is widely used in cosmeticproducts for skin and hair care.

2.1.1 Alkanes and Derivatives: Alkanes such as nonacosane, octacosane, and heptacosane, alongwith fatty acids like 6-octadecenoic acid (petroselinic acid), are commonly found in M. oleifera extracts. These compounds are integral to the plant's protective epicuticularwax layer, which prevents moisture loss. Phytosterol γ-sitosterol, found in the Chennai variety, is beneficialfor managing type II diabetes. Various alkanes and fatty acids were identified in different M.oleifera varieties, with differences in compound abundance depending on geographic location.

2.1.2 Essential Oils: M. oleifera essential oils, extracted through methods like hydrodistillation and supercritical fluid extraction, contain volatile compounds including terpenes, alcohols, aldehydes, and esters. These oils are known for antibacterial, antioxidant, and anti- inflammatory properties, and are commonly used in alternativemedicine and aromatherapy. Essential oils from the leaves have been shown to disrupt fungalgrowth by damaging cellular membranes.

Notable compounds include phytol, a diterpene alcohol, and small amounts of terpenes like linalool oxide, farnesylacetone, and α- ionone.Moringa oleifera is a rich source of nutrients, with its leaves and seeds containing high levels of proteins, amino acids, glucosinolates, and polyphenolic compounds that offer various health benefits.

2.2 Polar Compounds:

2.2.1 Amino Acids:

M. oleifera leaves are particularly rich in glutamic acid, which is themost abundant amino acid. Methionine is the least abundant amino acid in the Madurai variety,while histidine is the lowest in the Chennai variety. In the seeds, glutamic acid remains the most prevalent, and threonine (Madurai) and valine (Chennai) are the least abundant.

Glucosinolates: M. oleifera contains aromatic glucosinolates, such as glucomoringin,which serve as precursors to isothiocyanates. These compounds exhibit a range of biological activities, including antioxidant, anti- inflammatory, anticancer, and hypoglycemic effects. The presence of rhamnose in M. oleifera glucosinolates enhancestheir stability, making them more durable than those found in othercruciferous vegetables.

Phenolic Compounds: The leaves are rich in polyphenols, including caffeic acid, chlorogenic acid, o-coumaric acid, ellagic acid, ferulic acid, and gallic acid. Flavonoids such as quercetin, kaempferol, and myricetinare also abundant and contribute to the plant's antioxidant, anti- inflammatory, and anticancer properties. Quercetin is the most abundant flavonoid, with a concentration of 16.64 mg/g dried weight. It is noted for its health benefits, including lowering blood pressure, improving dyslipidaemia, andexhibiting antimicrobial activity.

3. HEALTH BENEFITS OF MORINGA OLEIFERA:

Moringa extracts, particularly the flavonoids, have demonstrated potential benefits for cardiovascular health, oxidative stress, hypertension, and fat accumulation. Quercetin, in combination withlactoferrin and hydroxyapatite, has also shown promise as an antimicrobial agent in the food industry.

4. Pharmacological actions

4.1. Leaves:

4.1.1 Cardiovascular Activity

Research teams mainly used hydroalcoholic solvents to extract leaves from M. oleifera, focusing on their potential to help with cardiovascular diseases. Extraction of the alkaloid N, α-L-rhamnosyl vincosamide and studied its protective effects against cardiac toxicity c aused by isoproterenol (ISO) in rats. When given orally at a dose of 40 mg/kg for seven days, this alkaloid significantly lowered the ISO-induced increases in serum cardiac markers like troponin-T, creatine kinase-MB, lactate dehydrogenase, andglutamate pyruvate transaminase, while also decreasing cardiac lipid peroxidation. An increase in cellular antioxidants suggested its ability to protect the heart and scavenge free radicals, which was further supported by an in vitro study. Additionally, rats treated with this compound showed improvements inISO-induced ECG changes and heart tissue health, with a significant reduction inmyocardial necrosis observed using the tri-phenyl tetrazolium chloride (TTC) staining method in isolated pre-treated rats (Panda S et al., 2015).

The impact of bread fortified with M. oleifera leaf powder at 5%, 10%, and 15% concentrations on protecting against hyperlipidemia was investigated. In their study with 32 male albino rats, they found that bread with 10% and especially 15% of the extract, consumed over 45 days, led to significant drops in total cholesterol, triglycerides, low-density lipoprotein, and very-low-density lipoprotein. Kidney function also showed improvement, with marked reductions in serum uric acid, urea, and creatinine levels compared to thecontrol group Halaby (M. S. et al., 2015).

Moreover, the effects of water extracts from M. oleifera leaves on inhibiting alpha-glucosidase and pancreatic alpha-amylase was examining, both linked to diabetes mellitus. Their research also looked into the invitro bile acid binding capacity and inhibition (Adisakwattana S. et al., 2011).

4.1.2 Anti-Inflammatory Activity:

The ethyl acetate extract from fresh M. oleifera leaves, which showed strong phenolic and antioxidant properties. They studied how this extract affects cytokine production in human macrophages when exposed to cigarette smoke, as macrophages and cytokines like TNF are key in lung damage from smoking. Human monocyte-derived macrophages (MDM) treated with different amounts of M. oleifera displayed lower levels of TNF, IL- 6, and IL-8 when exposed to LPS and cigarette smoke extract. This reduction wasseen in both protein and mRNA levels of the cytokines. Additionally, the extract reduced the expression of RelA, a gene involved in the NF-κB p65 signaling pathway related to inflammation. These results demonstrate that M. oleifera can inhibit cytokines (like IL-8) that attract neutrophils to the lungs, as well as others(like TNF and IL-6) that contribute to tissue damage and disease (Kooltheat N et al., 2014).

4.1.3 Antihypertensive Activity:

Dangi et al. 2002 investigated the antihypertensive properties of leaf extracts. Initial findings demonstrated that a water extract from the leaves effectively diminished both the chronotropic and inotropic responses in the isolated frog heart. Alkaloids, which were isolated through extract fractionation and convertedinto their salt forms, were subsequently assessed for their effects on the isolated frog heart. The total alkaloidal salts exhibited a negative inotropic influence on the frog heart. This effect was further elucidated through tests conducted on the isolated guinea pig ileum. Additionally, Bais et al., 2014 examined the anti- obesity effects of a methanolic leaf extract in a rat model. The chronic administration of a high-fat diet (HFD) resulted in hypercholesterolemia in the rats, which was associated with increased body weight, elevated total cholesterol, and triglyceride levels, alongside a reduction in HDL levels. Followinga 49-day treatment period with the leaf extract, significant reductions were observed in liver biomarkers, organ weight, and blood glucose levels in the obese rats.

4.1.4 Radical Scavenging and Antioxidant Activity:

Siddhuraju et al., 2003 investigated the radical scavenging abilities and antioxidant properties of various leaf extracts. All tested extracts demonstratedthe capacity to scavenge peroxyl and superoxyl radicals. Among the three moringa samples analyzed, the methanol and ethanol extracts derived from Indian sources exhibited the highest antioxidant activities, recorded at 65.1% and 66.8%, respectively, within the beta-carotene-linoleic acid system.

Furthermore, an increase in the concentration of all extracts significantly enhanced their reducing power ($p < 0.05$), which may contribute to their overallantioxidant efficacy. The predominant bioactive compounds identified were phenolic compounds, particularly flavonoids such as quercetin and kaempferol. Following this study, additional researchers have reported on the antioxidant properties of leaf extracts. Xu et al., 2021 linked antioxidantactivity to specific flavonoid glycosides, while Wahyuni et al.,2022 associated it with the tannin content. The latter study introduced a novel methodology utilizing HPLC, tandem MS spectrometry (MS-MS), and chemometrics to establish correlations between specific flavonoid glycosides in the extracts and their tested antioxidant activities. Tiloke et al., 2018 explored theantioxidant potential of the extracts through the synthesis of phytonanoparticles, highlighting their significant role as potential antiproliferative agents in cancer treatment. The resulting gold phytonanoparticles have shown promise in

enhancing cancer therapies, leading to improved survival rates and quality oflife.

4.1.5 Anticancer Activity:

1. Khalafalla et al.,2010 conducted an in vitro study examining the effects of various leaf extracts on leukemia and hepatocarcinoma cells. The findings revealed that these extracts were capable of inducing cell death in a substantialproportion of abnormal cells, specifically 70–86% among primary cells obtained from 10 patients diagnosed with acute lymphoblastic leukemia and 15patients with acute myeloid leukemia. Additionally, the extracts demonstrated a 75% lethality rate in cultured hepatocarcinoma cells, with the hot water and ethanol extracts showing particularly pronounced effects.

4.1.6 Anti-Allergic Activity:

The anti-allergic activity of extracts from leaves, seeds, and pods, as well as isolated compounds such as β-sitosterol-3-O-glucosid, glucomoringin, and quercetin, was assessed by Abd Rani et al. ,2019 using rat basophilic leukemia (RBL-2H3) cells to model both early and late allergic reactions. Ketotifen fumarate served as the positive control. The early phase of the allergic reaction was evaluated by measuring the inhibition of beta-hexosaminidase and histamine release, while the late phase was assessed through the inhibition of interleukin (IL-4) and tumor necrosis factor (TNF-α) release. Both the extracts and pure compounds demonstrated significant inhibitory effect, suggesting their potential as anti-allergicdrug candidates.

4.2 Seeds:

4.2.1 Anti-Inflammatory Activity

Wolff et al.,2023 reported that an ethanolic extract of seeds contained high levels of a glucosinolate with an isothiocyanate functional group (MIC-1, 1), a compound known for its anti-inflammatory and antidiabetic effects. Since it was not metabolically characterized, the authors investigated its bioaccessibility usinga human intestinal model and its bioavailability with serum from treated rats. Thefindings indicate that this compound remains largely unaltered during absorption, unlike other isothiocyanates, and demonstrates favorable bioaccessibility and bioavailability for potential therapeutic applications. In rural areas of developing countries, moringa seed extracts are used to purify drinking water due to the presence of lectins——carbohydrate-binding proteins that help reduce water turbidity through their coagulant properties. Araújo et al.,2013 assessed the cytotoxic and anti-inflammatory effects of an aqueous seed extract on cancer cell lines NCI-H292, HT-29, and HEp-2, as well as on murine erythrocytes. The extracts showed anti-inflammatory activity in lipopolysaccharide-stimulated murine macrophages by modulating the production of nitric oxide, TNF-α, and IL-1β. Additionally, the aqueous extract decreased leukocyte migration in a mouse model of carrageenan-induced pleurisy, leading to reduced myeloperoxidase activity and lower levels of nitricoxide, TNF-α, and IL-1β. Histological analysis of the lungs revealed a reductionin leukocyte numbers due to the extract.

4.2.2 Antiviral Activity:

Xiong et al.,2022 extracted eleven compounds from a methanol seed extract, including two novel and nine known compounds. These were identified as one carbamate, three phenylglycosides, four phenol glycosides, two nucleosides, andone flavonoid. The antiviral activity tests indicated that Moringa A, glucomoringin, and vitexin exhibited significant inhibitory effects against the H1N1 virus, with IC50 values of 0.26 ± 0.03, 0.98 ± 0.17, and 3.42

± 0.37 μg/mL, respectively. Additionally, these three compounds reduced levels of TNF-α, IL-6, and IL-1β, which are elevated in hosts due to H1N1 infections.

4.2.2 Anticancer Activity:

Five-Fluorouracil (5-FU) is a potent anticancer drug widely used to treat various malignancies. Famurewa et al. ,2019 investigated whether moringa seed oil couldprotect against 5-FU-induced nephrotoxicity and the underlying mechanisms in Wistar rats. The rats received prophylactic oral treatment with moringa seed oil. The findings suggested that 5-FU induces nephrotoxicity through oxidative stress, increased inflammation, and apoptosis. Moringa seed oil effectively mitigated these changes, highlighting its potential in managing 5-FU nephrotoxicity in cancer patients.

4.2.4 Antioxidant Activity:

Singh et al.,2014 examined the phenolic compounds and the antioxidant and antibacterial activities of defatted seed flour. Results indicated that the extractability of phenolic compounds was significantly higher ($p < 0.05$) in bound phenolic extracts (4173.00 ± 32.22 mg gallic acid equivalents (GAE)/100 g) compared to free phenolic extracts (780.00 ± 14.2 mg GAE/100 g), correlating with higher antioxidant and antimicrobial activities. The IC50 values for DPPH radical scavenging activity were 0.9 ± 0.05 mg/mL for bound phenolic extracts and 14.9 ± 0.07 mg/mL for free phenolic extracts. The bound phenolic extract was more effective against tested bacteria, with minimum inhibitory concentrations (MIC) ranging from 0.06 to 0.157%, compared to 0.117 to 0.191% for free phenolic extracts. This data suggests that moringa seeds could be a valuable source of antioxidants and antibacterials for the foodand pharmaceutical industries.

Finally, Liao et al.,2018 identified β-sitosterol, isolated from M. oleifera stems, asan anti-inflammatory compound in two cell lines——keratinocytes and macrophages——induced by PGN, TNF-α, or LPS. When administered at doses between 7.5 and 30 μM, β-sitosterol, dispersed as nanoparticles with diametersof 50 ± 5 nm, effectively suppressed the secretion of the aforementioned inflammatory factors.

5. CONCLUSION

Moringa oleifera, often called the "miracle tree," has long been celebrated in traditional medicine for its potential health benefits. Recent scientific researchhas begun to unravel the mysteries behind these claims, revealing a treasure trove of bioactive compounds within its leaves, seeds, and pods. In conclusion, this review highlights a significant need for further research into the impact of phytoconstituents of M. oleifera for development of new drugs.

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