Pharmacological Potential of Moringa oleifera: A Comprehensive Review of Its Therapeutic Applications

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***Abstract*—Moringa oleifera, commonly referred to as the drumstick tree or miracle tree, is a highly versatile plant valued for its nutritional, medicinal, and industrial applications. It is cultivated in tropical and subtropical regions worldwide, particularly in India, Africa, and Southeast Asia. Rich in essential nutrients, vitamins, minerals, and bioactive compounds, nearly every part of the tree—including its leaves, seeds, roots, bark, and flowers—offers therapeutic benefits. Scientific studies have demonstrated its pharmacological properties, including anti-inflammatory, antimicrobial, antioxidant, hepatoprotective, and anticancer effects. Additionally, it has been shown to aid in treating diabetes, asthma, ulcers, and hyperlipidemia, along with enhancing wound healing and milk production. Its high nutritional value and therapeutic potential make it a significant plant for addressing malnutrition and various health issues, particularly in developing regions.**

***Index Terms*—Scientific Classification, Phytochemicals, Pharmacological Activities, Health Applications, Other Names**

I. INTRODUCTION

Moringa oleifera belongs to the family Moringaceae. Moringa oleifera is considered one of the most versatile trees in the world, with nearly every part of the tree being utilized for food, medicinal, and industrial purposes.(1) Moringa oleifera is a local medicinal herb from India that has become widely known in tropical and subtropical countries.(2) Commercial cultivation occurs in India, Africa, South and Central America, Mexico, & Hawaii, as well as throughout Asia and Southeast Asia.(3) It is commonly known as Drumstick tree Ben oil tree, Miracle tree, and "Mother's Best Friend".(1)

Often referred to as "one of the most amazing trees God has created," the drumstick tree's nearly every part—bark, root, fruit, flowers, leaves, seed, and gum—serves as a rich source of proteins, vitamins, and minerals, including potassium, calcium, phosphorus, iron, folic acid, and β-carotene.(4) Moringa is regarded as one of the most valuable trees in the world, with nearly every part of the tree being useful for food or possessing other beneficial properties.(5) It is a short, fast-growing plant that is easy to cultivate and retains its leaves even during the dry season. Its leaves are highly nutritious & rich in amino acids, vitamins, minerals, and natural antioxidants. This was noted in the *Charaka Samhita* over 5000 years ago and is also widely recognized in African folk medicine. (6)

Figure 1. Moringa oleifera

When the fresh and dried leaves of moringa were compared based on nutrition with common foods per 100 grams it showed the following results: Carrot contain 1.8mg of vitamin A whereas fresh leaves contain 6.8 mg and dried leaves contain 18.9mg. The

milk contains 120mg of calcium whereas fresh leaves contain 440 mg and dried leaves contain 2003 mg. The fresh leaves have 259 mg of potassium and dried leaves have 1324 mg while the banana contains 88 mg of potassium. Yogurt has 3.1 gm of protein while the fresh leaves contain 6.7 gm and dried leaves have 27.1 gm. 30 mg of vitamin C is present in oranges while 220 mg and 17.3 mg are present in fresh and dried leaves respectively. [1] The term "Moringa" comes from the Tamil word "muringa," which translates to "twisted pods."

Figure 2. Drumstick plant

Meanwhile, the genus name originates from two Latin words: "oleum," meaning "oil," and "ferre," meaning "to bear.". [7] The M. oleifera tree is renowned worldwide for its economic and medicinal significance. The National Institutes of Health (USA) named it "Botanical of the Year 2007." In Africa, it is commonly referred as the "never die" or "miracle tree" due to its remarkable resilience and health benefits. [8]

Taxonomical classification-:[9]

Table 1. Taxonomical classification

Kingdom	Plantae
Sub kingdom	Tracheobionta
Super Division	Spermatophyta
Division	Magnoliophyta
Class	Magnoliopsida
Subclass	Dilleniidae
Order	Capparales
Family	Moringaceae
Genus	Moringa
Species	Oleifera

A. Morphological characters -:

Moringa oleifera is a small, rapidly growing tree, either evergreen or deciduous, typically reaching heights of 10 to 12 meters. It features a broad, open crown with drooping, delicate branches, feathery tripinnate leaves, and thick, cork-like, whitish bark. [10]

Leaves-: The leaves are alternately arranged, with twice or thrice pinnate structures clustered at the ends of the branches. They have long petioles with 8-10 pairs of pinnate leaves, each containing two pairs of opposite, elliptic, or obovate leaflets. These leaflets are rounded or slightly notched at the edges, entire, and dull green on both sides. Initially, they are covered with short grey pubescence, eventually becoming glabrous.[11]

Figure 3. Leaves of Moringa oleifera

Fruit-: The fruits are pendulous (hanging), linear, three-sided pods with nine longitudinal ridges. They typically measure 20 to 50 cm in length, though they can occasionally reach up to 1 meter or more, and are 2.0 to 2.5 cm in width. The pods, which typically contain up to 26 seeds, are dark green during development and take about 3 months to mature after flowering. Upon reaching maturity, they turn brown and split open longitudinally along the three angles, releasing the dark brown, trigonous seeds. [1]

Figure 4. Moringa oleifera fruit

Root **-:** The seedlings form a swollen, tuber-like white taproot that gives off a distinct strong odor, accompanied by only a few scattered lateral roots. Trees that grow from seeds develop a strong, deep taproot, along with a broad network of thick, tuberous lateral roots. Trees propagated from cuttings do not develop taproots. [10]

Flowers -: The flowers are pleasantly fragrant, bisexual, and oblique, with long stalks. They grow in erect, axillary, many-flowered drooping panicles that are 10-25 cm long and densely pubescent, with a width of about 2.5 cm. The flowers are either white or cream-colored, featuring yellow spots at the base. The five reflexed sepals are shaped like linear-lanceolate. The five petals are narrow and spatula-shaped, yellowish-white with a greenish base. There are five stamens, with the hindmost being the longest and the others much shorter. The ovary is stalked, terete, with three longitudinal furrows, one cell, and three placentas bearing double rows of ovules. The style is thin, curved, white, shortly pubescent, and hollowed at the apex. [10] The flowers are white and fragrant, arranged in large axillary drooping panicles. The pods are pendulous and ribbed, while the seeds are 3-angled. [9]

Figure 5. Flowers of Moringa oleifera

Bark and wood -: The bark is thick, soft, fissured, and warty or corky, with a whitish-gray color that becomes rough over time. When the bark is wounded, it releases a gum that starts white but turns reddish-brown or brownish-black upon exposure. The wood is soft and light, with a density ranging from 0.5 to 0.7 g/cm^3.[10]

B. Nutritional composition-:

The Moringa oleifera tree is a nutrient-dense plant, packed with essential proteins, fiber, and minerals that contribute significantly to human nutrition. [12] Moringa leaves are a rich source of easily digestible nutrients and can be consumed fresh, cooked, or dried into powder. They have been widely recommended for nutritional and therapeutic purposes in many developing regions around the world. Additionally, Moringa holds significant potential in enhancing nutrition and boosting the immune functions of poultry and livestock. [13] It is said to be a rich source of six key nutrients: carbohydrates, especially dietary fibers; proteins; vitamins; minerals; lipids; and water. The leaves of M. oleifera are known to contain a variety of essential amino acids and are also a rich source of alpha-linolenic acid. Additionally, they are recognized for their high concentrations of vitamins A, C, and E. [8]

Research has revealed that Moringa contains a wide range of essential nutrients, including vitamins, minerals, amino acids, beta-carotene, antioxidants, anti-inflammatory compounds, and omega-3 and omega-6 fatty acids. [2] Research indicates that immature Moringa pods have approximately 46.78% fiber and about 20.66% protein. The pods contain 30% amino acid content, while the leaves have 44%, and the flowers contain 31%. [14] In addition, Moringa oleifera (MO) is rich in terpenoids, anthraquinones, and glycosides. [15] Moringa seeds are high in sweet oil, making up 30–40% of the seed's weight, and contain about 76% polyunsaturated fatty acids. Moringa oleifera leaves and seeds are rich in protein, iron, calcium, ascorbic acid (vitamin C), vitamin A, and antioxidants like carotenoids, flavonoids, vitamin E, and phenolics. [13] In addition to the notable presence of proteins, lipids, and carbohydrates, M. oleifera seeds are also a good source of vitamins A and B1. The seeds of M. oleifera can be classified as oilseeds due to their lipid content, which ranges from 13% to 46%. [16]

C. Phytochemical components -:

Phytochemicals are plant compounds that, although not providing nutrition, help protect against and prevent diseases. Over 40 natural antioxidants have been identified in Moringa.[1] It is a rich source of various compounds, including key ingredients such as carotenoids, tocopherols (α, γ, δ), flavonoids, phenolic acids, folate, polyunsaturated fatty acids, and a range of minerals.[6] Other significant compounds found include benzyl glucosinolates, 4-

(4-O-acetyl-α-L-rhamnopyranosyloxy) benzyl thiocyanate, and 4-(α-L-rhamnopyranosyloxy) benzyl isothiocyanate.[13]

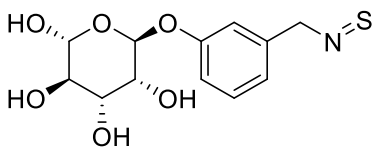
A gas chromatography–mass spectrometry analysis of the plant's leaves identified a total of 35 compounds. Notable compounds isolated included n-hexadecanoic acid, tetradecanoic acid, cis-vaccenic acid, octadecanoic acid, palmitoyl chloride, beta-l-rhamnofuranoside, 5-O-acetyl-thio-octyl, gamma-sitosterol, and pregna-7-diene-3-ol-20-one. E-lutein was found to be the most prevalent carotenoid in the leaves. The plant's radicle contains 4-(α-l-rhamnopyranosyloxy)-benzylglucosinolate and benzylglucosinolate. In addition, spirochin and anthonine are present in the roots. The peduncle of the plant contains beta-sitosterone, vanillin, 4-hydroxymellein, β-sitosterol, and octacosanoic acid, while its crust is composed of 4-(α-l-rhamnopyranosyloxy)-benzylglucosinolate.[6] The flowers contain amino acids, sucrose, d-glucose, trace amounts of alkaloids, and wax. Flavonoids present include quercetin, kaempferol, isoquercitrin, rhamnetin, and kaempferitrin. Additionally, the flowers are rich in minerals such as potassium and calcium.[4] The seeds contain a variety of compounds, including O-ethyl-4-(α-L-rhamnosyloxy)benzyl carbamate, 4-(α-L-rhamnosyloxy)benzyl isothiocyanate, 4-(α-L-rhamnosyloxy)benzylglucosinolate, niazimicin, 3-O-(6’-O-oleoyl-beta-D-glucopyranosyl)-β-sitosterol, β-sitosterol-3-O-β-D-glucopyranoside, niazirin, β-sitosterol, glycerol-1-(9-octadecanoate), isothiocyanates, thiocarbamates, and flavonoids.[6]

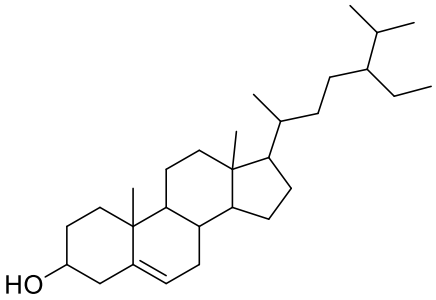
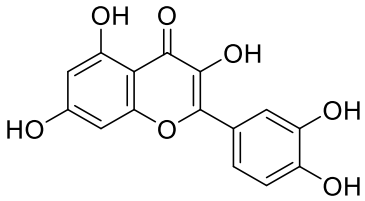
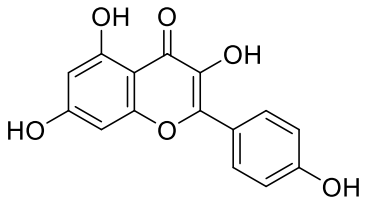
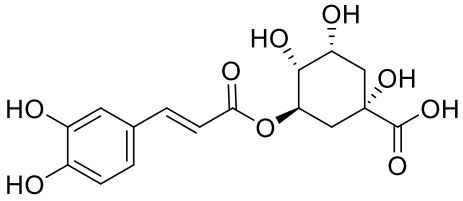
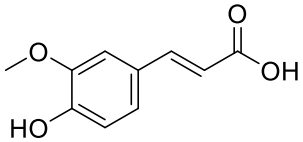
The pods contain glycosides such as thiocarbamate and isothiocyanate, along with two new compounds: O-[2'-hydroxy-3'-(2''-heptenyloxy)]-propyl undecanoate and O-ethyl-4-[(α-L-rhamnosyloxy)-benzyl] carbamate. Methyl p-hydroxybenzoate and β-sitosterol have also been extracted. Additionally, a water-soluble polysaccharide was extracted from the aqueous extract of Moringa oleifera pods. This polysaccharide consists of d-galactose, 6-O-Me-d-galactose, d-galacturonic acid, l-arabinose, and l-rhamnose. Plant hormones, including auxins and cytokinins, are also present. [4] Moringa oleifera seed contains phytosterols, with β-sitosterol, stigmasterol, and campesterol being the most abundant. [17]

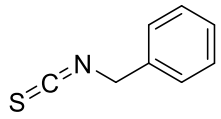
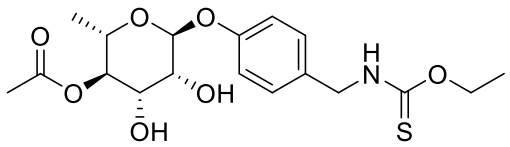
Figure 6. Pods

II. STRUCTURE OF PHYTOCONSTITUENTS:

Table 2. Structure of phytoconstituents

Moringinine	 (2R,3R,4R,5R,6R)-6-(3-(thionitrosomethyl) phenoxy) tetrahydro-2H-pyran-2,3,4,5-tetraol

β-Sitosterol	 17-(5-Ethyl-6-methylheptan-2-yl)-10,13-dimethyl-2,3,4,7,8,9,11,12,14,15,16,17-dodecahydro-1H-cyclopenta[a]phenanthren-3-ol
Quercetin	 2-(3,4-dihydroxyphenyl)-3,5,7-trihydroxy-4H-chromen-4-one
Kaempferol	 3,5,7-trihydroxy-2-(4-hydroxyphenyl)-4H-chromen-4-one
Chlorogenic acid	 (1S,3R,4R,5R)-3-{[(2E)-3-(3,4-dihydroxyphenyl) prop-2-enoyl] oxy}-1,4,5-trihydroxycyclohexane-1-carboxylic acid
Ferulic acid	 (2E)-3-(4-hydroxy-3-methoxyphenyl) prop-2-enoic acid.

Benzyl isothiocyanate	 (isothiocyanatomethyl)benzene
Niaziminin	 [(2S,3R,4S,5R,6S)-6-[4-[(ethoxycarbothioylamino)methyl] phenoxy]-4,5-dihydroxy-2-methyloxan-3-yl] acetate

III. CULTIVATION AND PLANTATION -:

Moringa oleifera is a fast-growing, deciduous tree.[13] The ideal annual rainfall for Moringa ranges from 700 to 2200 mm, though it can thrive in areas with annual rainfall between 250 and 3000 mm.[1] M. oleifera can be grown in any tropical or subtropical region globally.[14] It thrives best in areas where the average maximum daily temperature ranges from 25 to 35°C, although it can endure summer temperatures of up to 48°C for short periods and is also tolerant of winter frosts.[1] The direct seeding method is preferred due to its high germination rates.[14] This tree thrives in a wide range of soils but prefers well-drained, sandy, or loamy soils. While Moringa can grow in clay soils, it cannot withstand prolonged waterlogging. It also flourishes in alkaline conditions, with a pH tolerance of up to 9. [1] Flowering begins within the first six months after planting. [13]

A. Pharmacological activities -:

1. Anti- Inflammatory -:

Inflammation is a physiological response that helps protect the body against infection and facilitates the repair of tissue injury. However, prolonged chronic inflammation can contribute to the development of various chronic inflammation-associated diseases and disorders, including diabetes, cancer, autoimmune diseases, cardiovascular diseases, sepsis, colitis, and arthritis. Inflammatory cytokines, such as interleukin-1 beta (IL-1β) and tumor necrosis factor-alpha (TNF-α), can increase the production of nitric oxide (NO) and prostaglandin E2 (PGE-2). This, in turn, activates or enhances the activity of inducible nitric oxide synthase (iNOS), cyclooxygenase-2 (COX-2), and microsomal PGE synthase-1 (mPGES-1) in target cells. M. oleifera has been shown to not only reduce the production of TNF-α, IL-6, and IL-8 in response to lipopolysaccharide (LPS) and cigarette smoke extract (CSE)-stimulated human monocyte-derived macrophages (MDM), but also to inhibit the expression of RelA, a gene involved in nuclear factor-kappa B (NF-κB) p65 signaling during inflammation. [18]

The research indicates that an aqueous root extract exhibits anti-inflammatory action in rats weighing between 120 and 160 grams. At a dose of 750 mg/kg, M. oleifera treatment significantly decreased oedema formation by 53.5%, 44.6%, and 51.1% at 1, 3, and 5 hours, respectively. Increasing the M. oleifera dose to 1000 mg/kg did not enhance the inhibitory effect on oedema development at 1 and 3 hours; however, it exacerbated the oedema at 5 hours. Indomethacin treatment significantly reduced oedema formation at 1, 3, and 5 hours, with reductions of 49.1%, 82.1%, and 46.9%, respectively. These results indicate that an aqueous root extract of M. oleifera at 750 mg/kg decreases carrageenan-induced oedema to a level comparable to the powerful anti-inflammatory drug indomethacin. [19]

Bark extracts of Moringa oleifera demonstrated anti-inflammatory activity comparable to diclofenac in the carrageenan-induced paw oedema model. The root's anti-inflammatory properties have also been documented. The mechanism underlying the anti-inflammatory activity may be attributed to the modulation of neutrophils and the c-Jun N-terminal kinase (JNK) pathway. The active ingredients contributing to the anti-inflammatory properties include tannins, phenols, alkaloids, flavonoids, carotenoids, β-sitosterol, vanillin, hydroxymellein,

moringine, moringinine, β-sitostenone, and 9-octadecenoic acid. (6)

2. Anti-Bacterial -:

The various extracts from Moringa's morphological parts, including seeds, cotyledons, seed coats, stem bark, leaves, and root bark, have been reported to exhibit antimicrobial potential. Previous research has shown that the antimicrobial activity of *Moringa oleifera* was evaluated using the Kirby-Bauer disc diffusion method. The study found that the 50% ethanolic extract demonstrated antibacterial activity, although it was only minimal. (2) The fresh leaf juice and aqueous extract from the seeds were found to inhibit the growth of *P. aeruginosa*, *S. aureus*, and *B. subtilis*. (4) The antimicrobial activity of the root extract is also attributed to the presence of 4-α-L-rhamnosyloxybenzyl isothiocyanate. The antibacterial exertion was attributed to the aglycone of deoxy- niazimicine (N- benzyl, S- ethyl thioformate), which was uprooted from the chloroform bit of an ethanol excerpt of the root bark. Additionally, juice from the stem bark exhibited antibacterial effects against *Staphylococcus aureus*. The fresh leaf juice was found to inhibit the growth of microorganisms, specifically *Pseudomonas aeruginosa* and *Staphylococcus aureus*, which are pathogenic to humans. (20)

The ethanolic extract of the leaf demonstrated antimicrobial activity against all the bacteria tested. The chloroform extract exhibited activity against pathogens such as *Salmonella typhi*, *Pseudomonas aeruginosa*, *Escherichia coli*, and *Vibrio cholerae*. Ethanolic extracts of the root and bark exhibited antifungal activity against Aspergillus niger, Neurospora crassa, Rhizopus stolonifer, and Microsporum gypseum, along with inhibitory effects against Leishmania donovani. Many studies suggest that seed extracts could be a promising option for purifying water sources, as they inhibit bacterial growth in both agar and nutrient media. Flavonoids, tannins, steroids, alkaloids, saponins, benzyl isothiocyanate, and benzyl glucosinolate were linked as the composites responsible for antimicrobial exertion.(6) The aqueous and ethanolic extracts from the leaves of Moringa oleifera demonstrate notable antibacterial properties, exhibiting strong inhibitory effects on Gram-positive bacteria like Staphylococcus aureus and Enterococcus faecalis, while showing relatively weaker activity against Gram-negative bacteria such as Escherichia coli, Salmonella, Pseudomonas aeruginosa, Vibrio parahaemolyticus, and Aeromonas caviae.(18)

The ethanolic extract of seeds, leaves, and flowers exhibited antimicrobial activity against E. coli, P. aeruginosa, Enterobacter species, K. pneumoniae, S. aureus, Proteus mirabilis, Salmonella typhi A, Streptococcus, and Candida albicans. (21) The aqueous extract of the seeds and the fresh juice from *Moringa oleifera* leaves have been found to be effective against infectious skin bacteria, such as *Staphylococcus aureus* and *Pseudomonas aeruginosa*. The roots and seeds of *Moringa oleifera* are potent antibacterial agents due to the presence of active ingredients such as isothiocyanates and glucomoringin.(22) The seeds have been found to exhibit antimicrobial properties against both Gram-positive and Gram-negative bacterial cells. Additionally, the seeds can inhibit bacteriophage replication. (23)

3. Anti-Ulcer-:

The leaf extract significantly reduced the ulcer index in both the ibuprofen-induced gastric ulcer model and the pyloric ligation test, and it also led to a notable reduction in cysteamine-induced duodenal ulcers and stress ulcers. (6) The study found that the aqueous extract of *Moringa oleifera* leaves protected rats from gastric ulcers induced by indomethacin in a dose-dependent manner. The extract's protective effects were attributed to its tannins and flavonoids. Tannins, with their protein-precipitating and vasoconstrictive properties, may form a protective barrier over the ulcer site, preventing damage from toxic substances and proteolytic enzymes. Flavonoids were thought to enhance capillary resistance and improve microcirculation, making cells more resilient to ulcer-inducing factors. The combination of tannins and flavonoids in the leaf extract appears to reduce both the initiation and progression of ulcers, suggesting that *Moringa oleifera* has potential as an antiulcerogenic agent, supporting its traditional use in medicine. (19) The methanolic flower bud extract resulted in a reduction of the ulcer index in rats with aspirin-induced gastric ulcers. The potential mechanism underlying the ulcer-protective effect may involve an increase in EC cell count and 5-HT levels. (4)

3. Hepatoprotective -:

The research shows that treatment with *Moringa* was found to exhibit hepatoprotective effects against hepatocellular injury by preventing the increase in two serum enzymes, aspartate aminotransferase (AST) and alanine aminotransferase (ALT), which are key indicators of liver health. [2] Various studies have reported that the ethanolic extract of *Moringa oleifera* seeds and leaves possesses hepatoprotective effects. The root and flower extracts also exhibited antihepatotoxic activity.[4] Both aqueous and alcohol extracts of *Moringa* flowers were found to have significant hepatoprotective effects, likely due to the presence of quercetin, a well-known flavonoid with hepatoprotective properties.[20] The hepatoprotective activity was found to be attributed to the presence of alkaloids, quercetin, kaempferol, flavonoids, ascorbic acid, and benzyl glucosinolate.[6] *Moringa oleifera* plays an important role in protecting the liver from damage, oxidation, and toxicity due to the high concentrations of polyphenols found in its leaves and flowers. *Moringa oleifera* oil may assist in bringing liver enzymes back to normal levels, decreasing oxidative stress, and boosting protein levels in the liver.The flowers and roots of the *Moringa oleifera* plant contain a compound called quercetin, which is known for its liver-protective properties. Other compounds in *Moringa oleifera* with liver-protective activity include β-sitosterol, quercetin and its glycosides, rutin, and flavonoids, all of which help prevent lipid oxidation [17] The aqueous and alcohol extracts of *Moringa oleifera* flowers contain quercetin, a well-known flavonoid, which may contribute to their significant hepatoprotective effect. [23]

4. Hypolipidemic -:

The study showed that the methanolic root extract and column fractions of Moringa oleifera exhibited antihyperlipidemic activity, as indicated by a reduction in total cholesterol and triacylglycerides.[23] The crude extract of Moringa leaves exhibits a significant cholesterol-lowering effect in the serum of rats fed a high-fat diet, which may be attributed to the presence of the bioactive phytoconstituent, β-sitosterol. Moringa fruit has been shown to reduce serum cholesterol, phospholipids, triglycerides, low-density lipoprotein (LDL), very low-density lipoprotein (VLDL) cholesterol-to-phospholipid ratio, and atherogenic index lipids. Additionally, it lowers the lipid profile in the liver, heart, and aorta of hypercholesterolemic rabbits, while also increasing fecal cholesterol excretion. [20] Albino Wistar rats were given a methanolic extract of M. oleifera (150, 300, and 600 mg/kg, orally) and simvastatin (4 mg/kg, orally), along with a hyperlipidemic diet, for 30 days to assess their hypolipidemic effects. It was observed that M. oleifera and simvastatin reduced serum cholesterol, triacylglycerides, VLDL, LDL, and the atherogenic index, while increasing HDL levels, compared to the high-cholesterol diet group (control). M. oleifera was also found to enhance the excretion of fecal cholesterol. Thus, it can be concluded that M. oleifera exhibits a hypolipidemic effect. [19]

5. Anti Diabetic -:

Alpha-glucosidase and alpha-amylase, two key enzymes associated with type 2 diabetes, are involved in the hydrolysis of polysaccharide (starch) molecules into monosaccharides (glucose). Indeed, alpha-glucosidase functions by hydrolyzing polysaccharide molecules into glucose, while the alpha-amylase enzyme catalyzes the hydrolysis of the α-1,4-D-glucosidic bonds in the starch molecule. Both enzyme inhibitors decrease glucose absorption, leading to a reduction in postprandial hyperglycemia in the plasma. Polyphenols, particularly flavonoids, phenolic acids, and tannins, exhibit an inhibitory effect on the two key enzymes, alpha-amylase and alpha-glucosidase, which are associated with type 2 diabetes. Thus, the inhibitory effects of moringa extracts on alpha-amylase and alpha-glucosidase were tested. These results demonstrated that the leaf extracts of *Moringa oleifera* exhibit a stronger inhibitory effect against alpha-amylase and alpha-glucosidase compared to the standard drug acarbose, a potent inhibitor of both enzymes. [25] Glucomoringin, phenols, flavonoids, quercetin-3-glucoside, fiber, and other phenolic compounds have been reported to contribute to antidiabetic activity. [6]

6. Wound healing activity-:

The extracts from the leaves, dried pulp, and seeds of Moringa oleifera caused a notable increase in hydroxyproline levels, wound healing speed, granuloma-breaking strength, and granuloma dry weight. Additionally, they reduced scar area and skin-breaking strength in incision, excision, and dead space wound models in rats. Studies on the effect of leaf extract on wound healing in diabetic animals demonstrated improved tissue regeneration, reduced

wound size, downregulation of inflammatory mediators, and upregulation of vascular endothelial growth factor in wound tissues. Additionally, the extract exhibited notable antiproliferative and anti-migratory effects on normal human dermal fibroblasts. [6] Both the aqueous extract of *M. oleifera* leaves and the ethyl acetate extract of dried leaves were found to possess significant wound-healing potential. [23]

7. Anti-cancer-:

Cancer ranks as the second leading cause of death in the United States and is a major cause of death globally. [18] MO holds promise as an anticancer agent for the treatment of various types of cancer. The leaf extract of MO inhibited cell viability in hepatocellular carcinoma, acute lymphoblastic leukemia, and acute myeloid leukemia. The inhibition was attributed to the bioactive compounds niazimicin, β-sitosterol-3-O-β-D-glucopyranoside, and 4-(α-L-rhamnosyloxy) benzyl isothiocyanate. Thus, the study demonstrated that MO leaves inhibited the growth of pancreatic cancer cells. [15] The anticancer activities of MO leaves are attributed to compounds such as glucosinolates, niazimicin, and benzyl isothiocyanate. Niazimicin, a bioactive compound derived from Moringa leaves, has demonstrated potential anticancer activity. There is a direct relationship between Reactive Oxygen Species (ROS) and cell death. Benzyl isothiocyanate has also been shown to be associated with cancer. Research has shown that Benzyl isothiocyanate (BITC) induces intracellular ROS, which subsequently leads to cell death. This could be one of the reasons why Moringa is considered an effective anticancer agent. [21]

Moringa leaf, bark, and seed extracts were evaluated for their anticancer properties against human breast (MDA-MB-231) and colorectal (HCT-8) cancer cell lines. Treatment with Moringa leaf and bark extracts decreased colony formation, reduced cell motility, and resulted in low cell survival, high apoptosis, and G2/M phase enrichment in these cells. In a separate study, the aqueous extract of Moringa leaves was found to inhibit the proliferation and progression of cancer in human lung cancer cells (A549) by inducing apoptosis, promoting DNA fragmentation, and enhancing oxidative stress. Treatment with the aqueous extract of Moringa leaves inhibited tumor cell growth, induced apoptosis, and reduced reactive oxygen species (ROS) levels in lung cancer cells as well as other cancer cell types. These findings suggest that Moringa leaves have the potential to reduce cancer cell proliferation and invasion. (26 Z.F. Ma) O-Ethyl-4-[α-L-rhamnosyloxy] benzyl carbamate, along with 4-[α-L-rhamnosyloxy]-benzyl isothiocyanate, niazimicin, and 3-O-[6′-O-oleoyl-α-D-glucopyranosyl]-β-sitosterol, were tested for their potential antitumor-promoting activity using an in vitro assay. The results showed significant inhibitory effects on Epstein–Barr virus early antigen. A seed ointment exhibited effects similar to neomycin in treating Staphylococcus aureus pyoderma in mice. It has been found that niazimicin, a thiocarbamate derived from the leaves of *Moringa oleifera*, inhibits tumor promoter-induced activation of the Epstein–Barr virus. [20]

8. Anti-asthma -:

The Moringin alkaloid found in the M. oleifera plant exhibits activity similar to that of ephedrine. As a result, M. oleifera seeds have demonstrated potential in the treatment of bronchial asthma. [22] The alkaloid-like moringine has the ability to relax the bronchioles, which are the small air passages within the lungs. Additionally, a study conducted to evaluate the effectiveness and safety of Moringa oleifera seed kernels in managing asthma in patients yielded promising results. The research showed a notable reduction in the severity of asthma symptoms and an improvement in respiratory function. [27] The ethanol extract of Moringa oleifera seeds, tested against ovalbumin-induced airway inflammation in guinea pigs, resulted in a significant improvement in respiratory parameters and a reduction in interleukins in bronchoalveolar lavage fluid. [6]

9. Effect on milk production-:

Moringa leaves contain a wide range of both micro and macronutrients. Moringa leaves are rich in complete protein (including all nine essential amino acids), as well as calcium, iron, potassium, magnesium, zinc, and vitamins A, C, E, and B, all of which play a vital role in supporting the immune system. [28] Moringa leaves offer significant benefits in addressing various health issues caused by vitamin and mineral deficiencies. These include vitamin A deficiency (leading to visual impairment), choline deficiency (which can cause fat accumulation in the liver), vitamin B1 deficiency (resulting in beri-beri), vitamin B2 deficiency (causing dry skin and chapping), vitamin B3 deficiency (leading to

dermatitis), vitamin C deficiency (which can cause bleeding gums), calcium deficiency (linked to osteoporosis), iron deficiency (resulting in anemia), and protein deficiency (which can lead to chapped hair and growth disorders in children). The phytosterol compounds in Moringa leaves have lactogenic effects, including sterols, which can help stimulate milk production. Lactagogues have the potential to stimulate the hormones oxytocin and prolactin, both of which play a crucial role in enhancing breast milk production. When a baby sucks during breastfeeding, the stimulation is transmitted to the hypothalamus, which triggers the release of oxytocin. This hormone then causes the smooth muscles around the alveoli to contract, leading to the secretion of milk. When a baby breastfeeds, sensory stimulation from the nipple is sent to the brain, prompting the release of prolactin. This hormone travels through the bloodstream to the breasts, where it stimulates milk-producing cells to increase milk production. [(29)] A study on mice demonstrated a significant increase in breast milk production in these animals. The study suggested that mothers who consumed Moringa oleifera had babies that were heavier compared to those whose mothers did not consume Moringa oleifera. This implies that Moringa oleifera extract may enhance breast milk production, as indicated by the increased weight gain in the babies. [(28)]

IV. CONCLUSIONS

Moringa oleifera stands as a remarkable plant due to its broad-spectrum medicinal and nutritional benefits. Its rich phytochemical profile and wide range of pharmacological activities highlight its potential as a functional food and therapeutic agent. Its applications in improving human health, livestock nutrition, and water purification underscore its importance in sustainable development. Further research and integration into healthcare systems and agricultural practices could help maximize its benefits globally.

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