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Exploring *Moringa oleifera* as Functional Food and Future Neutraceutical: An update on its Therapeutic Potential

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Abstract

Moringa oleifera (*M. oleifera*) is associated to the Moringaceae family, is commercially grown for its nutritive importance and amazing pharmacological activities in Himalayan range but is commonly planted throughout the equator. Moringa seeds, roots, stems, leaves, flowers, fruits are marvelously treasury of phytonutrients, polysaccharides, oil, protein, vitamins, minerals, amino acids. This review artefact firstly portrayed the nutritional and non-nutritional configuration of *M. oleifera* which encompasses carbohydrates, proteins, amino acids, carotenoids, minerals, vitamins, fibers, fatty acids, lipids, polyphenols, alkaloids, glucosinolates, saponins, oxalates, and phytates. The review also unfolds bioactivities (antimicrobial, wound healing, analgesic, antipyretic and anti-inflammatory, anticancer, antifertility, hepatoprotective, anti-hypertensive, cardiovascular, and cholesterol-lowering, anti-ulcer, anti-diabetic, CNS, anti-allergic and anti-asthmatic, anti-obesity) of the *M. oleifera* along with its application in nutraceuticals. In addition, the analysis highlights the quantitative chemical analysis methods used for separation, ablution, and depiction of organic molecules from *M. oleifera*, processing and commercial application of *M. oleifera*. This complete review also provides acumen into food fortification and toxicity profile along with pre-clinical and clinical studies of *M. oleifera* for the first time. *oleifera* is a premium provenance of vitamins, nutrition, and minerals for implementation in foods. The actinic effects recommend the use of bioactive constituents in the evolution of ingenious food, feed, biotechnology, cosmetics, agriculture, and drug compounds. To conclude, *Moringa oleifera* illustrates the potential of nutritionally domain, biotech-enhanced herbs in building resilient and health-focused food systems for the future.

Key words: *Moringa oleifera*, Phytochemical, Bioactivities, Analytical, Food fortification, Bionutrition.

Introduction

Moringa oleifera (*M.oleifera*) or Drumstick, one of the most significant fruit crops, characterize to the Moringaceae family that grows in the Himalayan range but is widely farmed across the equators(1). Presently, *M.oleifera* is widely appreciated and consumed across the globe because it is capable of providing nutrients and bioactive compounds(2). The worldwide market for Moringa products, which is reckoned to be opulenced over $4.6 billion, is mostly reliant on India. India is the world's greatest producer of the drumstick, accounting for 41% of worldwide output, followed by other tropical regions such as Western Africa (33%), Malaysia and the Philippines (12%), China (8%), and Venezuela (6%)(3). Moringa is high in vitamins, minerals, fibers, and proteins and they pack a nutritional punch(4). Researchers have found that the seeds, leaves, stem bark, flowers, and fruits of the *M. oleifera* plant contain a wide range of nutrients, such as sugars, proteins, amino acids, minerals, vitamins, fibres, and polyphenols; each has its own set of bioactivities. Researchers extracted alkaloids, flavonoids, glycosides, saponins, and tannins as the main active ingredients from *M. oleifera* (5). Researchers have found that *M.oleifera* has a lot of useful health benefits, including helping with asthma, diabetes, hepatoprotection, inflammation, infertility, cancer, infections, antioxidants, the heart, ulcers, the central nervous system, allergies, wound healing, and pain.(5).

It is possible to separate, wash, and show organic molecules from *M. oleifera* using a lot of different analytical methods, Gas chromatography, gas chromatography-mass spectrometry, gel electrophoresis, atomic absorption spectroscopy, flame photometry, ultra-violet spectrophotometry, soxhlet extraction, flame ionization, gas chromatography-mass spectrometry, supercritical CO2, Fourier transform infrared spectroscopy, high-performance liquid chromatography-electrospray ionization-quadrupole time-of-flight-mass spectrometry, and gas chromatography. The part of the Moringa most used for human consumption is the leaves and seed. Leaves of Moringa are high in critical nutrients that help so it is expected to avoid disease. Leaves can be devoured raw, roasted, or dried powdered and kept for months without losing nutritious content and these leaves are a powerhouse of antioxidants Quercetin and Chlorogenic acid(6). The fresh leaves are eatable and can be prepared and comestible like spinach or used in bisque and salads. Vitamin A, B, and C, minerals, and sulfur are all abundant in them(7). *M. oleifera* leaves provide an alternative for vegetarians and vegans who don't consume meat. Dried leaves have a higher micronutrient concentration as compared to the content of vitamin A of carrots, the calcium of milk, potassium of bananas, and iron of spinach(8).

Moringa-based products such as capsules and pills, leaf powder, health tonic, dehydrated drumstick powder, and other traditional remedies are among the health items available in the market(9). Besides, different industries including cosmetics, pharma, nutraceuticals, herbal industry, and FMCG are using Moringa as a raw material for diverse product development(10).The demand has started now for high-quality healthful foods and innovative food products of Moringa. Hence, Food fortification is now started with the leaves of Moringa. A spoonful of the powder is appended to baby food, soups, and vegetables to boost nutrients without altering the flavor(11). Moringa leaf is processed into a variety of forms and is widely appreciated and consumed all over the world due to its capability of providing nutrients and the presence of diverse bioactive compounds.

In this review study, various parts of *M. oleifera* have been looked at and evaluated for their nutritional value, how they are processed, how they can be enhanced, their phytochemicals, their medical effects, research studies before and after clinical trials, and products available for sale. Besides, this review highlights the fortification and processing of Moringa and various sophisticated analytical techniques for the recognition of metabolites present in *M. oleifera*. So, a search of the literature was done using PubMed, Scopus, ACS, Web of Science, ScienceDirect, CNKI (China Knowledge Resource Integrated Database), Google Scholar, and SciFinder. With the information we have now, it might be possible to connect the way it works with the main chemical of *M. oleifera*, especially in functional foods. So, this review could be very helpful for people who want to know more about how *M. oleifera* could be used in useful foods and health. The graphic abstract provides a summary of *M. oleifera*, highlighting its chemical makeup, its health benefits, how it's processed, its use in health foods, ways to enhance food with it, research studies, and the products mentioned in the review.

Phytochemical profile of *M. oleifera*

Phytochemicals are considered as specialized product present in the plants, which gathered in dense flocks but perform a minor or non-existent role in plant growth and improvement(12). Based on their chemical composition, plant-based phytochemicals are splitted into five divisions namely polyphenols, carotenoids, alkaloids, terpenoids, and sulfur-containing compounds(13). The Moringa tree contains a high proportion of these compounds as well and it is expected that the pharmacological properties of *M.oleifera* could be closely associated with the existence of potential phytochemicals illustrated in Table 1. Moreover, supplementary Fig. S1 shows the nutritional profile reported in *Moringa oleifera* seeds, leaves, stem, flower, and fruit pods. The below section covers the chemical variety of *M.oleifera* as source of functional food and human benefits.

Carbohydrates

Carbohydrates are generated from plants in their natural state. Plants need carbs like starch, resistant starch, sucrose, raffinose, stachyose, pectin, cellulose, and more (14). Because of their functional qualities as a stabilizer, sweetener, thickening, emulsifying agent, and gelling agent, these carbohydrates are extracted and added to foods. The overall carbohydrate content of the *M. oleifera* seed is 9-16%(15) or 14.4g/100g(16), whereas in the seed hull the level of carbohydrate is 55.2±0.62%(17). Tope, O.D., et al., reveal that *M. oleifera* constitutes 88.28% in stem bark and 88.97% in fruit pod(18). Raymond., et al stated the carbohydrate amount in leaves is 32.16±0.03%(19).In accordance with modern research in *M. oleifera* flowers, the quantitative proximate carbohydrate composition is 36.04g/100 g of the sample(20).

Proteins

M. oleifera isa good source of proteins depending on their location. The outcome of the proximate analysis manifest that *M. oleifera* contains 40.34±0.45% protein in seeds(21) and 5.25±0.011% in seed hull. Setiaboma et al. found that the protein content (% db) in the stem of *M. oleifera* is 8.31±0.08, 8.04±0.09, and 7.56±0.10 using three different drying methods: drying in the sun, drying in the shade, and drying in a room (22). Fejér, J., et al., said that the protein level of *M. oleifera* leaves is 20.54±0.85% (23).

Amino acids

Amino acids are necessary for the survival of all living things. They are proteins' monomeric units. Because the creation of that particular protein would be complete, the lack of a certain amino acid might result in medical health issues. The abundant amino acids found in *M. oleifera* include arginine, glutamic acid, aspartic acid, leucine, isoleucine, and methionine. A recent study by Liang, L., et al. revealed that glutamate and arginine are the most abundant amino acids in *M. oleifera* seeds. (21). Gu, X., Y. Yang, and Z. Wang in their research disclose that it also exhibits leucine and phenylalanine in the seed protein(24). Leaves of *M. oleifera* contain phenylalanine and threonine in an equal amount(25). Innocent, I.O. and I. Igwilo stated that the amount of glutamate is found highest in the stem of *M. oleifera*(26) followed by flower according to Amaechi, N., Q. Onwuka, and L. Ihechere. The fruit of *M. oleifera* has 30% of total amino acids(27). The whole plant contains glutamate, aspartic acid, and leucine in the towering amount and cysteine and methionine in the least amount. It's important to know that each amino acid serves a specific purpose in an animal's body, besides being needed to make protein, which could include enzymes (28). Amino acids are essential not only for the production of red blood cells but also for the synthesis of enzymes, immunoglobulins, hormones, and for the growth and repair of body tissues (29).

Minerals

Two-thirds of people in the world don't get enough of at least one important ingredient. A noticeable amount of necessary minerals in *M. oleifera* are generally essential for both human and animal diets. *M. oleifera* is considered an important part of the human diet due to its abundance of beneficial nutrients. Minerals like calcium, potassium, magnesium, sodium, zinc, and iron are very important for many important reasons. We looked at how much of these minerals were in different parts of *M. oleifera* and found that the seed (16) has the most phosphorus and the seed hull has the most sodium. In yet another study, Setiaboma et al. , (22)revealed that when the stem bark and leaves of *M. oleifera* are dried by three procedures viz. sun drying, shade drying, and cabinet drying, the composition of minerals changed. Raymond and his associates also look into the elemental organization and set up that the flower extract of *M. oleifera* possesses magnesium in the dominant amount(19). Tope, O.D., et al., stated that the whole plant of *M. oleifera* possesses calcium in the highest amount(18).

Vitamins

Vitamins are vital for the progress and preservation of life, and they are required in man's and other animals' diets because most of them are not created by the body. Some behave as anti-oxidants, others carry out peculiar activities. For example, ruminants need vitamin A for many things, like seeing, building bones, keeping their immune systems strong, and keeping epithelium tissue healthy (28). Other vitamins, like water-soluble vitamins and fat-soluble vitamins are essential for the body to work properly. The plant species associated to the Moringaceae family are a good source of Ascorbic acid, Tocopherol, Riboflavin, Nicotinamide, β-Carotene, Retinol, and Carotenoids. Many researchers communicated that the amount of Ascorbic acid, β-Carotene, and Carotenoids in *M. oleifera* is 84.5mg/100 g, 0.6mg/100g, and 28.9mg/100g respectively(16)while the amount of β-carotene, vitamin-C and vitamin-E in seed hull is 2.749mg/100g, 0.698mg/100g and 46.189mg/100g respectively(17). Fejér, J., et al. said that the amount of vitamin-E in *M. oleifera* seed and leaves is 220.61±1.80 mg/kg and178.10 ± 1.55 mg/kg respectively (30).

Fibers

Dietary fiber, widely termed to as feedstuffs or mass, refers to the components of plants that your body cannot digest or absorb, and Raymond; et.al revealed that the proximate composition of crude fibers in *M. oleifera* seed is 8.59 ± 0.11%, leaves is 11.21 ± 0.02% and flower is 14.12 ± 0.01%(19). In research, it is concluded that the stem bark of *M. oleifera* constitutes4.87% fibers and the fruit pod possesses 3.25% fibers(18).

Fatty acids

M. oleifera has been utilized for food production in contrasting wedge of the world. Several authors reported the fatty acid profile of *M. oleifera* and reported that most abundant were oleic acid (66.22-65.78%) followed by 2,3-dioleyl-1-palmitoylglycerol (15.64%) in seeds and Oleic acid(25.01±0.13%) followed by Palmitic acid (24.84±0.10%) is found in the highest amount in leaves(23). The proximate composition of fats in *M. oleifera* stem bark is 0.75%(18). The fat content in the *M. oleifera* flower was found to be 2.9 g/100g dry weight(31) and of the fruitpod is 0.67%(18).The high amount of saturated fatty acid was found with monounsaturated fatty acid (MUFA) content ranging from 19.00±0.29%-80.25±0.26% and polyunsaturated fatty acid (PUFA) content ranged is 0.75±0.055% in *M. oleifera* seeds while their respective amount in leaves ranges from Saturated fats (38.97±0.40%), Monounsaturated fats (27.52±0.20%) to polyunsaturated fats (33.51±0.33%)(23).

Lipids

Fats, waxes, oils, hormones, and certain membrane constituents are examples of organic mixtures known as lipids, which are insoluble in water and serve as chemical messengers and energy-storing molecules. According to studies, *M. oleifera* seeds contain 31.85±1.54% lipid (23). According to Dhakad, A.K., et al., the lipid content of *M. oleifera* leaves is 12.48 ± 0.62%, whereas the lipid content of the stem and fruit pod is 12.2 g/100 g and 0.10 0.10g/100g, respectively (23).

Polyphenols

This is a big group of phytochemicals called polyphenols. Chemically, they have either one phenol ring (phenolic acids) or more than one phenol ring (flavonoids). Flavonoids, phenolic acids, and tannins are some of the polyphenols that are found in moringa. The Folin-Ciocalteau test is usually used to find out how much total phenolic acid is in Moringa. We use gallic acid to determine the total phenolic acid and tannin content (33, 34). A study by Sulaiman Mohammed et al. found that the seeds' extract has a total phenolic level of 10.179 mg GAE/g dry matter, giving them a B grade. This value is based on the seed's total antioxidant content (35). It's 71.9 mg/100g in the stem (36). According to Alhakmani et al., the total amount of phenolics in flower extract is 19.31 mg of GAE per gram (37). The study found that the total flavonoid content in *M. oleifera* seeds is 99.72 mg of quercetin equivalents per gramme of extract after extracting for 5 hours using a 1:10 ratio of seeds to solvent (38). Researchers found that the stem bark of *M. oleifera* has 1.55±0.15% of the plant's total flavonoids. The leaves have 7.86±0.33% TFC (39), the flowers have 14.27±0.62 mg QAE/g (40), and the fruit pod has 5.2 ± 0.003% TFC (41). According to Prabakaran, M. et al., the water extract had the most flavonoids (69.3 mg/g), which is the highest amount (42).

Alkaloids

Plants make alkaloids, which are nitrogen-containing chemical substances that come from breaking down amino acids. Research has proven that Moringa contains a number of these alkaloids, despite their rarity. Besides these, the amount of alkaloids varies in different parts of *M. oleifera* like in seed(1.51±0.49%), leaves (6.68±2.35 %), stem bark (0.53±0.25%)(39), flower extract (0.25 ± 0.00 mg/100g) (19), fruit pod (3.1 ± 0.004%)(41). The most commonly extracted indole alkaloid from Moringa leaves is N,-L-rhamnopyranosyl vincosamide (43). The leaves also contain some rare pyrrole alkaloid glycosides called marumosides A and B, according to the researchers. These are 4"-O-α-L-rhamnopyranoside, 4'-hydroxyphenylethanamide, and pyrrolemarumine (44)**.**

Glucosinolates

M. oleifera has a lot of glucosinolates, which are a group of different glycosidic molecules that contain sulphur and nitrogen. Compounds called glucosinolates have been found in different parts of Moringa plants, like the seed, leaves, stem, flower, and fruit pods. The main glucosinolate (45) found in Moringa is glucomoringin. The seeds have the most of it (202 mg/g dry weight), followed by the leaves (33.9–59.4 mg/g) and the stem (16.3 mg/g) (46). Amaglo, N.K., et al. (47) described the amount of glucosinolates found in flowers (18.32 mg/g) and fruit pods (8.52–25.56 mg/g). The amounts of glucosinolate in Moringa trees from different parts of the world have been found to vary a lot (48). The enzyme myrosinase breaks down glucosinolates in plants, making glucose, isothiocyanates, nitriles, and thiocarbamates. These chemicals are also found in moringa (49)**.**

Saponins

All of a legume plant's cells naturally contain saponins. They create stable, soap-like foams in water and are part of a complex and chemically diverse group of compounds.The saponins content in *M. oleifera* seed is 27.18±0.95%, stem bark is 14.3±0.33%, leaves is 35.66±0.78%(39).In an analysis of Fahal, M., et al., the saponin content of *M. oleifera* fruit pods was discovered to be 6.5±0.1%(41).

Oxalates and Phytates

Oxalates, which are also called oxalic acid, are naturally occurring compounds in plants. Phytates, on the other hand, are antioxidant compounds that can be found in whole grains, beans, nuts, and seeds. We get these plant-based oxalates from the food we eat, and our bodies make them as waste. Leafy greens and beans are two examples of foods that are high in oxalates and also high in nutrients that are good for your health. Oxalates can increase the risk of kidney stones by binding to calcium as they exit the body. The main problem with phytates is that they can link to iron, zinc, manganese, and, to a lesser extent, calcium in food and make it take longer for the body to absorb them. The amount of Oxalates and Phytates in *M. oleifera* seed extract are 0.82±0.02 mg/100g DW and 9.60±0.70 mg/100g DW(19) and their respective amount in stem bark is 17.172±0.51 and 0.62±0.04 mg/100g respectively. Moreover in leaves extract the amount of oxalates and Phytates is 0.40 ± 0.01 mg/100g DW and 5.30 ± 0.03mg/100 g DW respectively(39).Athira, K., et al., observed that in the fruit pod of *M. oleifera* the amount of oxalates and phytates is 15.7 mg/100g and 18.7 mg/100g respectively(50).

Carotenoids

A group of phytomolecules called carotenoids give fruits and vegetables their red, yellow, and orange colours. 6.6–17.4 mg/100g of fresh moringa leaves contain β-carotene, which is a form of vitamin A. This is a lot more than you'll find in carrots, apples, and apricots (51). β-carotene levels in dried leaves are much higher, ranging from 23.31 mg/100g to 39.6 mg/100g (52). Many different types of carotenoids have been found in the leaves, flowers, and young pods of Indian cultivars that are grown in a business way. (13). E-lutein, primarily present in leaves and meals, accounted for more than half of all carotenoids. Supplementary Fig. S2 highlight the essential nutrients profile reported in *M. oleifera* seeds, leaves, stem, flowers, and fruit pods.

Techniques used in analytical chemistry for *Moringa oleifera*

Isolation is the first and most important step in getting back the living molecules. We use gas-liquid chromatography and high-performance liquid chromatography (HPLC) to identify the sugars in *M. oleifera* (53). We used flame photometry to find out how much sodium, potassium, and calcium was in the sample. Atomic absorption spectroscopy was used to find out how much magnesium, iron, copper, manganese, zinc, and selenium was in the sample (54). For phosphorus, a standard colorimetric approach was used(55). The Folin-Ciocalteu spectrophotometric method was used to find out how many total phenolics were in Moringa powder (56). We use a UV spectrophotometer to determine the total carotenoids in an object (57). Two-flame ionization detectors and the Soxhlet method are used in gas-liquid chromatography to find fatty acids in Moringa (58), (59), (60), GC and GCMS were both used together to look at the fixed oil from *M. oleifera* seed oil. Three different extraction methods—supercritical CO_2, soxhlet, and liquid methods—were used to find out the yield, efficiency, physicochemical properties, nutritional and antinutritional makeup, antimicrobial, and antioxidant activities of oil from moringa seed kernels (62). There is a useful way to identify many different kinds of natural chemicals in Moringa plants using liquid chromatography with mass spectrometry (LC-MS). These chemicals include alcohols, nucleosides, phenolics, organic acids, and amino acids (63). It was possible to identify 50 beneficial compounds from *M. oleifera* using HPLC–ESI–QTOF–MS. These compounds included organic acids, nucleosides, glucosinolates, and phenolic compounds (64). Usually, HPLC, Bradford and Lowry tests, Kjeldahl digestion, and polyacrylamide gel electrophoresis are used to find out how much protein is in Moringa leaves (66). Fig. 1 shows the structures of several metabolites detected by various analytical techniques.

Pharmacological activities of *Moringa oleifera*

Due its major nutraceutical qualities and phytochemical makeup, *M. oleifera* has become a popular ingredient for the production of functional meals. New foods that contain active ingredients from *M. oleifera* have unique biological and medicinal properties. Researchers have looked at how these parts of *M. oleifera* can fight free radicals, tumors, germs, viruses, high blood sugar, and more. Fig. 2 depicted the diverse therapeutic action of *M. oleifera* in different organs of human body. *M. oleifera* can protect the liver and make the immune system stronger. The following sections discuss the main therapeutic application of *M. oleifera* in illustrate in Fig. 3.

Antimicrobial activity

Researchers found that *M. oleifera* was highly effective at killing microbes and had a good amount of polyphenols. Many studies have shown that myricetin and quercetin are the most common polyphenols in *M. oleifera* and are what make the plant antibacterial. The minimum inhibitory concentrations (MICs) showed that the ethyl acetate root extracts stopped bacterial growth by 86.1%, and the ethanolic leaf extracts stopped it by 79.3%. Additionally, flavonoids, myricetin, and quercetin were discovered to make it harder for bacteria to make nucleic acids. Oladeji et al. found that the useful compounds in the chloroform, ethyl acetate, and ethanol leaf extracts of *M. oleifera* included saponins, tannins, flavonoids, terpenoids, and phlobatannins. The ethanolic leaf extract worked better than the chloroform and ethyl acetate extracts against nystatin, streptomycin, and gentamicin, which are common antibiotics. (68). We checked i the leaves, stems, as well as seeds of *M. oleifera* (both water-based and alcohol-based) could kill drug-resistant Staphylococcus aureus strains found in raw milk. Penicillin was used as a positive control (69). This test was done in addition to the disc-diffusion agar method. Biosynthesized nanoparticle products made from *M. oleifera* leaf extracts show potential broad-spectrum antibacterial activity, according to Moodley, J.S., et al.(70).

Wound healing, analgesic, antipyretic and anti-inflammatory activity

Studies have shown that extracts from *M. oleifera* leaves that are standardized in water have the best qualities for attracting and resettling human skin fibroblast and human keratinocyte cells, which helps wounds heal faster (71). Another study looked at an excision wound and found that hydrogels containing the hydroalcoholic extract of *M. oleifera* seeds helped the wound heal significantly compared to both controls ($p<0.001$) and standard treatment ($p<0.001$). Putting the prepared hydrogel on the wound increased its breaking strength. (72). Using an ethanolic solution of moringa leaves can help wounds heal faster by raising collagen production and deposition at the wound site. This raises the amount of collagen per unit area, which also makes the tissue stronger (73). *M. oleifera* extracts from leaves, both non-polar and polar, have strong pain-relieving effects, likely working in both the brain and the body's nerves (74). According to a study, *M. oleifera* plays a significant role in the plant mixture (JU-RU-01), which lowers fever and reduces inflammation (75). We gave rats 50 mg/kg, 100 mg/kg, or 200 mg/kg of an ethanolic extract of M. oleifera. This dosage made the reaction times much faster in Eddy's hot plate method and the tail immersion method compared to the control group (76). The rats felt less pain in the middle area after this. This time, acetic acid made the mice move around a lot. The methanolic extract of *M. oleifera* might have helped them feel less pain than diclofenac sodium, which is a popular drug (77). We also extracted the stem bark, leaf, and pod of *M. oleifera* with ethanol and water and fed it to albino rats. The carrageenan made the rats' paws bigger. It is the job of this chemical to stop the inflammatory reaction.

Anticancer activity

More than one study has found that *M. oleifera* can help fight cancer. Moringa oleifera has quinic acid, octadecanoic acid, hexadecanoic acid, palmitic acid, tocopherol (Vitamin E), and sitosterol, among other things, according to a GC-MS test. Its water-based extract may be able to slow tumour growth without affecting the body's normal functions and physiology. (80). MCF7 cell growth is slowed down when more crude water extract, hexane, and dichloromethane fractions from *M. oleifera* seeds are used, with IC50 values of 280 g/ml, 130 g/ml, and 26 g/ml, respectively. The results showed that the substances from *M. oleifera* leaves, extracted using the Soxhlet method, were very effective at killing the MCF-7 human breast cancer cells, with an IC50 value of 81.77 ± 6.051 g/mL. This activity increased with concentration. (82). In another lab study, *M. oleifera* stem extract (MSE) at a concentration of 100–400 g/mL helped protect cells from damage caused by oxidative stress. Additionally, using a 6% MSE cream on a mouse's skin stopped damage from UVB exposure. Also, applying 6% MSE cream to the skin of a mouse prevented UVB-induced oxidative stress damage (83). Furthermore, *M. oleifera* flower extract slows the growth of prostate cancer in PC-3 cells by blocking the AKT pathway (84). Another study showed that *M. oleifera* extract is very good at killing Ehrlich ascites cancer (EAC) cells in Swiss white mice (85).

Anti-fertility activity

There was a study not long ago that showed an ethanol extract from *M. oleifera* leaves could help female Wistar rats get pregnant by stopping the process at 250 and 500 mg/kg (86). If you give cold or hot water extracts of *M. oleifera* leaves (MOL) to a test tube, the uterus will contract more or less strongly ($p < 0.05$). The muscle contracted more with the cold MOL (89.7%) than with the hot MOL (50.6%). MOL cold water extracts given before and after mating stopped conception 100% of the time before mating and 80% of the time after mating. When MOL was mixed with hot water, it stopped conception 96.6% of the time and 58% of the time (87). The methanol part of moringa seeds greatly decreased testosterone, luteinizing hormones, sperm movement, and sperm count in rats that were treated compared to rats that were not treated.(88).

Hepatoprotective activity

Several studies have indicated that moringa can protect the liver. For instance, giving *M. oleifera* (500 mg/kg) to mice every day as a supplement for 28 days kept them from getting liver damage from cadmium (89). In a different study, it was found that an ethanolic extract of plant seeds treat the liver by ethanol-induced hepatotoxicity and act as an antioxidant. This may be because it contains glucosinolates, isothiocyanates, thiocarbamates, flavonoids. (90). Additionally, in a lab setting, the digestion of *M. oleifera* leaves produces peptides that could potentially serve as a source of anti-inflammatory substances (91). However, the *M. oleifera* plant extract is very good at stopping heat from breaking down proteins, with IC50 values of 271.25±2.74% for acetone extracts and 304.25±2.33% for ethanol extracts (92). Another study found that *M. oleifera* leaf and seed extracts (11.1–100 g/mL) can reduce inflammation by stopping the production of NO. (93).

Anti-hypertensive, cardiovascular, and cholesterol-lowering activity

There is growing evidence that *M. oleifera* extracts reduce systolic blood pressure by blocking two important pathways associated with ACE inhibition and NO generation. The fresh leaf extract of *M. oleifera* produced new compounds called Niazicin-A, Niazimin-A, and Niaziminin-B that help lower blood pressure. These glycosides bind to ACE with great affinity, partly block the enzyme's active sites, and lower blood pressure (94). According to reports, *M. oleifera* methanolic extract has a therapeutic effect at dosages ranging from 1 to 4 mg without producing cardiac arrest and has a beneficial cardiac tonic effect. (95). In a different study, the methanolic extract of *M. oleifera* leaves helped resolve problems with serum biochemical markers, kept antioxidant levels normal, fixed the heart's normal histological structure, and was used as an extra treatment to stop Al Phosphide from damaging the heart (96). Furthermore, the leaves of *M. oleifera* can lower blood pressure in people by lowering electrolytes (97). A study by Jain, P.G., and others found that *M. oleifera* reduces blood cholesterol, triacylglyceride, the atherogenic index compared to people who followed a high-fat cholesterol diet (98). A different study found that a polyphenol preparation from *M. oleifera* leaves lowers cholesterol levels by a large amount (99). It does this by lowering HMG CoA reductase activity and faecal bile acid binding. In a lab experiment, diabetic rats were given a methanolic extract of *M. oleifera* (250 mg/kg) by mouth for 42 days. It was found that the blood levels of liver enzyme indicators and normalised lipid profile values were much lower than in the normal control group.(100).

Anti-ulcer activity

There is more and more proof that the flower and leaf extracts of *M. oleifera* in petroleum ether, acetone, and methanolic form can help heal acetic acid wounds and make the tissue that has been damaged have more collagen (101). Another lab study that the liquid seed extract of sample lowers the number of ulcers and contractions caused by histamine in the ileum of guinea pigs when given at a dose of 500 mg/kg (102). A recent study discovered that the extract from *M. oleifera* leaves may contain active substances that protect the stomach and make mucus. These substances could serve as a model for developing safe and effective ulcer treatment agents.(101).

Anti-diabetic activity

It ranks third in the world's list of causes of death, only behind heart disease and cancer. In a recent in vitro study, diabetic rats' hearts were treated with 300 mg/kg of *M. oleifera* methanolic extract. The medicine lowered both hyperglycemia and the associated reactive stress (103). Dong, Z., et al. said that different substances found in M. oleifera, such as anthraquinone, 2-phenylchromenylium, hemlock tannin, sitogluside, and A-phenolic steroid, have been looked at as possible diabetes mellitus medicines. (104). The findings suggested that the leaves of *M. oleifera* are excellent at fighting diabetes because they raise antioxidant levels and stop chemicals that cause inflammation (105). Not only that, but the ethanol and butanol extract worked the best and lowered the blood sugar of diabetic rats (106).

CNS activity

M. oleifera has strong effects on the central nervous system (CNS), and the plant's water-based extract may have a dose-dependent effect on the CNS (107). Furthermore, methanol and n-hexane extracts of *M. oleifera* leaves can help treat anxiety conditions because they calm people down (108). Furthermore, high amounts of the methanolic and hydroalcoholic extract of *M. oleifera* have been shown to have a big impact on memory and learning, which suggests that they might be useful in treating Alzheimer's disease (109). However, the GABA-ergic systems are activated by *M. oleifera* oil, which alters sleep structures(110).

Anti-allergic and anti-asthmatic activity

M. oleifera can help allergic people because it stops the early and late stages of allergic responses. It also prevents mast cells from releasing histamine and beta-hexosaminidase, along with different levels of IL-4 and TNF. (111-112) In allergic mice, a liquid solution of *M. oleifera* leaves lowers allergy symptoms by stopping mast cells from activating and balancing the Th1/Th2 balance so that Th1 is more dominant. (113). When mixed with the methanolic extract of *M. oleifera* leaves, it can help people with asthma breathe better (114). An experiment done in a lab showed that the ethanolic seed extract of *M. oleifera* can stop the immune system's inflammation reactions that make Wistar rats get asthma. It also lowers the amounts of TNF-alpha, IL-4, and IL-6 in the blood and fluid in the bronchi (115).

Anti-obesity activity

A lot of people around the world are overweight or obese, and being overweight or obese is linked to a number of other health problems. A recent study found that *M. oleifera* extracts reduced the levels of leptin and resist in mRNA and increased the levels of the adiponectin gene in obese rats compared to untreated obese rats.(116) Also, it has a big impact on the mRNA translation of key enzymes linked to obesity, like fatty acid synthase and HMG-CoA reductase, as well as MC4R and PPAR. This results in a decrease in fat storage and an increase in fat burning. People could lower their BMI, TG, and LDL by getting liver tests back to normal (117). The results of another lab experiment indicated that when mice were given an HFD with MOE for nine weeks, their body weight, TG levels, lipid markers, and the weights of different organs all went down by a lot (118). Studies on *M. oleifera's* bioaccessibility and absorption come up with (Supplementary Table S1) reported by various researchers.

Processing of *Moringa oleifera*

Healthy food for people of all ages can be found in *M. oleifera* and moringa leaf powder can be made into many different types of products, such as pills, capsules, and cereals. Reports say that *M. oleifera* leaves can be eaten raw, roasted, or dried and crushed, and they can be kept for months without losing any of their nutritional value(120). When the nutritional content of raw, germinated, and fermented moringa seed When different types of flour were compared, it was found that fermented and sprouted seed flour had the most amino acids and raw seed flour had more antioxidants. In the process of sprouting and fermentation, biochemical and microbial activity may have caused this (121). Still, a study looked at what happened to the nutrients in moringa leaves when they were boiled, simmered, and blanched to see if they were retained. It was surprising that heating worked the best of the three methods; it greatly decreased the amounts of oxalate, and phytate. To get the most out of the seeds and leaves, they need to be cleaned because phytate and other anti-minerals can make some nutrients less bioavailable. (122),(123). In a different study, the author looked at what happened to the nutritional value of a leaf when it was dried at different temperatures (75°C, 85°C, and 95°C) for different amounts of time (5, 7.5, and 10 minutes). They saw that the levels of saponin, protein, and vitamin C dropped a lot, but the levels of vitamin A went up. The suggestion was to dry the food at 85°C for 7.5 minutes to enhance its nutritional value (124). Microwave, freeze-drying, shade, and sun-drying all had almost no caloric loss. Oven drying at 50°C came in second (125). Dollah et al. said that adding *M. oleifera* seed oil to the other vegetable oils (palm oil, palm kernel oil, pure coconut oil, and palm stearin) would make them healthier, better for keeping, and more nutritious (126), (127). Moringa seed is a natural way to make blood clot, and it is also very good for you you (128). Pontual et al. studied how the Moringa flower protein can break down azo-casein, α-casein, and β-casein using these proteins as substrates.(129) Distinct method of processing of different parts of *M. oleifera* is illustrated in Table 2.

Commercial application of *Moringa oleifera*

M. oleifera is used in business in several different ways. For example, moringa seeds are used to make ben oil, which can be used instead of olive oil in cooking and for making perfumes and lubricants. Additionally, moringa seeds are good at coagulating, which means they can separate organic and mineral bits from a solution. They can also soak up pollutants and insecticides (130). According to Suhartini et al., they used coconut fiber, sand, and dried *M. oleifera* to make a two-stage clarifier for treating tapioca starch wastewater. This procedure improved the water's physical and chemical properties and kept the pH stable (131). Surface water treatment with *M. oleifera* modified with magnetic nanoparticles like iron oxide, on the other hand, was found to be helpful because it cut down on the time it took for the water to settle. (132) You can also turn moringa seeds into biodiesel (134) and use them in cosmetics (133). On the other hand, you can use seedcakes as fertilizer or green soil (135). People use Moringa flowers to make a tea that can lower cholesterol (136), and they claim that fried Moringa flowers taste like mushrooms (137). However, you can add *M. oleifera* leaves to the food that hens and layers consume to enhance its nutritional value. Because they are a good source of protein, they can replace more expensive foods like soybean meal and crushed nut cake (138). Table 3 shows commercial application of different parts of *M. oleifera*.

Use of Moringa as functional food

From the last decades, *M. oleifera* has become more popular as a useful food ingredient and Moringa leaves can be used alone or in combination with spinach, melon, and other vegetables in soups, according to studies(139).On the other hand *M. oleifera* flower and leaf powder are used in starting diets, and they have been shown to have a higher nutritional content(137). Although paneer with varied quantities of *M. oleifera* leaf extract has better nutritional content than ordinary paneer(140).Furthermore, herbal biscuits containing 5% *M. oleifera* leaf powder have been demonstrated to increase protein content by 14%(142).Rabiul Alam Roni.et.al found that cake augmented with 1.5% *M. oleifera* leaf powder and 2% ripened banana flour provided enhanced nutritional quality and may have contributed to improved food and nutritional security for vulnerable groups(143).*M. oleifera* leaves were utilized to strengthen yogurt by Hekmat et al and in terms of sensory metrics, the product fell short of the control, but it did not stop Lactobacillus rhamnosus GR-1 from growing in yogurt(144**).** Emilike et al. investigated the effect of several drying procedures (sun-dried, oven-dried, shadow dried) on Moringa chin-chin. When compared to the control, they discovered that oven-dried samples had lower fat and moisture levels. Elemental analysis found that the oven-dried sample had the highest calcium content (190.5 mg/100 g), the sun-dried sample had the maximum zinc level (7.1 mg/100 g), and the shade dried sample had the greatest iron content (51.3 mg/100 g)(145). Further study revealed that *M. oleifera* dried powder has also been used in muffin production, with up to 12% concentration (per 55gms of flour used) of dried leaves powder(146). Besides, dried Moringa leaves were mixed into khakhras in proportions of 0, 2, 4, 6, 8, 10%, and the moisture, fat, ash, protein, carbohydrate, and antioxidant activity of the khakhras were all improved by incorporating such processed leaves(147). Also, different amounts of moringa leaf (2g, 4g, 6g, 8g, and 10g) were mixed with whole wheat flour to make cakes. As the Moringa concentration rose, the amounts of moisture, crude protein, crude fiber, and total ash increased, while the amounts of total fat and carbohydrates decreased (148).

Food fortification with *Moringa oleifera*

Adding important nutrients like vitamins and minerals to everyday foods to make them healthier is called food fortification. Usually, fortification can cause sharp and minor changes in a population's micronutrients. *M. oleifera* leaf powder (MOLP) was supposedly used in the fortification of yam flour amala in concentrations of 2.5%, 5%, 7.5%, and 10%(149). Along with cereal, gruel is a food for babies and an early morning cereal for people. It is made from maize and sorghum, and adding MOLP or *M. oleifera* flower powder (MOFP) to maize or millet gruel made it much healthier (137). Some people also think that adding *M. oleifera* leaf, flower, and seed powder to bread dough made from wheat flour alone or with other flours could make the dough healthier (150). You can also add a small amount of MOLP to baby food, soups, and veggies to enhance their health without altering their taste or smell. You can also use it instead of fresh leaves in spur sauces, or you can mix a few large tablespoons into other sauces right before adding the meat.(151) Supplementary Table S2 limned the different marketed formulation of *M. oleifera* with their specific use and dosage form.

Toxicity

Asare et al. did a study where rats were given 1,000 mg/kg as well as 3,000 mg/kg of a liquid leaf extract of plant sample and then watched for up to 14 days. The results showed how dangerous the extract was in different work settings. The extract from plant leaves was still genotoxic at a level of 3000 mg/kg, which is a lot higher than what is normally used. While 3000 mg/kg was higher than usual, a 1000 mg/kg Ambi et al. reported that there was a significant increase ($p<0.05$) in blood total protein and globulin levels with dose, and there was a substantial ($p<0.05$) rise in serum ALT, AST, BUN, and creatinine levels in rats that were given a methanolic extract of *M. oleifera* (MEMO) at 200 and 400 mg/kg b.w., which suggests the liver and kidneys were not working properly. MEMO raised the body weight of all the test animals significantly ($p<0.05$) and in a way that depended on the dose (153). Awodele et al. looked into how dangerous a water extract of leaves was for mice. In an acute trial, mice were given up to 6400 mg/kg orally and 1500 mg/kg intraperitoneally. In a sub chronic trial, mice were given 250, 500, and 1500 mg/kg orally for 60 days. Hematological or biochemical tests, as well as sperm quality, did not show any major effects (154). In a different study, Oyagbemi et al. looked at what happened to 30 rats when they were given 50, 100, 200, or 400 mg/kg of a methanol extract of *M. oleifera* every day for 8 weeks. It was 30:1 in terms of percentage. In contrast to what happens with an aqueous extract, all animals that were given *M. oleifera* gained a lot of weight that depended on the dose. Serum levels of alanine aminotransferase, aspartate aminotransferase, blood urea nitrogen, and creatinine also rose significantly in rats that were given 200 and 400 mg/kg of M. oleifera. It is important to note that methanol, not water, was used to make the extract. At a dose of 400 mg/kg, the 30:1 concentration of the methanol extract would be the same as 12 g of leaves per kilogram, which is a very unlikely amount. (153) Adedapo et al. studied the safety of giving mice 400, 800, 1600, and 2000 mg/kg body weight a liquid leaf extract by mouth. It was either a single high dose or given every day for 21 days, except for the largest amount. The results showed that *M. oleifera* leaves were safe to eat at levels up to 2000 mg/kg. During the test, the rats' body weights went down in a way that depended on the amount. (155)

A study by Asiedu-Gyekye et al. looked into the possible harmful effects of giving mice a single oral dose of 5000 mg/kg of a liquid *M. oleifera* extract and oral doses of up to 1000 mg/kg of the same extract over the course of 14 days. There were no obvious side effects or tissue changes at these amounts. Several liver tests went up to levels that were statistically significant, although the changes were small. A 1000 mg/kg dose in a rat is more than 30 times the average dose of 400 mg of water extract in a person who weighs 80 kg. The weights of the testicles and epididymis went up in a dose-dependent way, as did the width of the seminiferous tubules and the thickness of the epididymal epithelial layer. These changes were linked to an increase in spermatogenesis. (156) Also, three different tests were used to see if an extract from *M. oleifera* seeds in water could cause mutations. These tests included the Ames assay by Rolim et al. They discovered that the seed extract at a concentration of 0.2 g/L was not genotoxic, did not pose any health risks to humans, and could be used to treat human water. More than 0.4 g/L of water-soluble *M. oleifera* lectin, taken from the extract, was shown not to cause mutations. (157) Ajibade et al. looked for chemical parts in a methanol solution of *M. oleifera* seeds and used it in tests to see how harmful it was to rats in both short-term and long-term ways. Researchers looked for saponins, tannins, terpenes, alkaloids, flavonoids, carbs, and heart glycosides in plants. But they didn't find any anthraquinones.

Acute poisoning was seen at a dose of 4000 mg/kg, and death was seen at a dose of 5000 mg/kg. When the dose was less than 3000 mg/kg, there were no bad effects. According to the researchers, methanol extracts of *M. oleifera* seeds can be used for food. (158) Furthermore, Paul and Didia looked into what happened to the liver and kidneys of 24 guinea pigs when they put a methanol extract of *M. oleifera* root on them. The guinea pigs received daily injections of the root extract into their abdomens at doses of 3.6, 4.6, and 7.0 mg/kg, or a control. The therapy went on for three weeks. In histology sections, all of the treatment groups had liver damage that was worse than usual. The results showed that hepatotoxicity was time-dependent rather than dose-dependent. There was some damage to the tubules and inflammation in the interstitial space in the 4.6 mg/kg group, but in the 7.0 mg/kg group, inflammatory cells and undefined eosinophilic materials were found in the interstitial space. There was no information about what the extract was made of or how much was in it, and the study used a root methanol extract that was injected into the abdomen instead of being taken by mouth (159). Table S3 shows a number of clinical studies that were done on *M. oleifera*. In table 4 highlight the in vitro studies of *M. oleifera.*

Conclusion

M. oleifera is extensively planted and devoured in many nations, as well as exported to other areas of the world because of its nutritional profile and several therapeutic biological activities in the human body. It has been shown in the review that the seeds, leaves, stem, flower, and fruit pods of *M. oleifera* also have a remarkable makeup of functional carbohydrates, proteins, amino acids, vitamins, minerals, and polyphenols. The animal in-vitro studies and clinical trials on humans have proved its beneficial effects as a strong anticancer, anti-diabetes, antioxidant, anti-microbial, anti-obesity, wound-healing, analgesic, anti-inflammatory, anti-hypertensive, hepatoprotective, anti-fertility, anti-allergic, anti-asthmatic, lactation enhancer, and CNS agent. This review also underscored the application of *M. oleifera* in feed, fuel, cosmetics, pharma, agriculture, livestock, medicine, and as a primary ingredient in specialized foods for diabetic, hypertensive, cancer, breast-feeding mother, and malnutrition patients based on nutritional and desirable bioactivities. Various clinical investigations have been done to guarantee the safety of *M. oleifera* ingestion; nevertheless, knowledge of human metabolism and mechanism of action is limited, and some results are pending while others reveal positive outcomes.

Comprehensive research has aided the utilization of *M. oleifera* as a healthy ingredient in the food sector. However, significant research into the biological mechanisms of *M. oleifera* root, seed, leaves, stem, bark, flower, and fruit extract bioactivities is required. More research on the therapeutic potential and toxicity of certain Moringa extract molecules for culinary and pharmaceutical applications is required. Furthermore, there is a lack of information on the many phytochemicals or active components found in various portions of *M. oleifera* and their effects on the human system. Furthermore, nutrients derived from *M. oleifera* must be assessed for use in the food sector. Clinical trials of Moringa accessible products on people, taking into account all safety concerns, will increase the *Moringa oleifera's* value in the food, pharmaceutical, and cosmeceutical industries.

M. oleifera (M. oleifera), Fast moving consumer goods(FMCG),China Knowledge Resource Integrated Database (CNKI), Monounsaturated fatty acid (MUFA), Polyunsaturated fatty acids (PUFA), Gallic acid equivalent (GAE), Total flavonoids content (TFC), Quercetin acid equivalent (QAE), dry weight (DW), High performance thin layer chromatography (HPLC), Gas Chromatography Mass Spectrometry (GCMS), Gas chromatography (GC), Fourier Transform Infrared Spectroscopy (FTIR), Liquid Chromatography Mass Spectrometry (LCMS), High-performance liquid chromatography coupled to electrospray ionisation and quadrupole time-of-flight mass spectrometry (HPLC-ESI-QTOF-MS), Minimum inhibitory concentration (MIC), *M. oleifera* stem extract (MSE), Ak strain transforming (AKT), Ehrlich ascites carcinoma (EAC), *M. oleifera* leaves (MOL), Nitrous oxide (NO), Angiotensin converting enzyme (ACE), Aluminium (Al), Very low density lipoprotein (VLDL), Low density lipoprotein (LDL), β-Hydroxy β-methylglutaryl-CoA (HMG-CoA), *M. oleifera* flower powder (MOFP), Central nervous system (CNS), Gamma-Aminobutyric acid (GABA), Interleukin-4 (IL-4), Interleukin-6 (IL-6), Tumour necrosis factor (TNF), T Helper Cell Type 1 (Th1), T helper cell Type 2 (Th2), Messenger Ribonucleic acid (m-RNA), Melanocortin 4 receptor (MC4R), Peroxisome proliferator-activated receptors (PPARs), *M. oleifera* (MO), Body mass index (BMI), Total triglycerides (TG), High fat density (HFD), *M. oleifera* extract (MOE), Sunflower oil (SFO), Soyabean oil (SBO), *M. oleifera* leaf powder (MOLP), Alanine transaminase (ALT), Aspartate aminotransferase (AST), Blood urea nitrogen (BUN), Methanolic extract of *M. oleifera* (MEMO), Lethal dose 50 (LD50), Prostate cancer cells (PC-3 cells), Ultraviolet-B (UV-B).

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