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REVIEW

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Phytochemistry, nutritional composition and pharmacological potential of *Moringa oleifera*: A comprehensive review

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ABSTRACT

Moringa oleifera is a medicinally important plant of the family Moringaceae, which is highly valued because of its enormous nutritional and therapeutic potential. Each part of *M. oleifera* is said to contain medicinal properties, which contributes to its diversity and value as a medicinal herb. Literature has revealed that the plant possesses anticancer, antimicrobial, anti-inflammatory, antidiabetic, antifertility, hepatoprotective, cardiovascular, and other important pharmacological attributes. Most of these biological activities of the plant are due to its high content of phytochemicals, including flavonoids, alkaloids, saponins, terpenes, glucosides, glucosinolates, anthocyanins, and steroids. Aside from the plant's exceptional phytochemicals and therapeutic potentials, it is also rich in essential nutrients such as vitamins, minerals, proteins, beta-carotene, fiber, and fatty acids. This systematic review aims at providing updated and categorized scientific data on phytochemicals, nutritional composition, and pharmacological potentials of *M. oleifera*. The information compiled in this present review would be crucial for developing novel therapeutic medicines and pharmaceutical formulations, which are more effective with great curative actions.

1. Introduction

Plants with medicinal properties have been utilized to cure human ailments since the genesis of humanity. The upsurge of interest in natural pharmaceuticals began around a decade ago, owing to the belief that natural medicine is safer than synthetic medicine (Kenwat et al., 2013). Due to the growing interest in the use of medical plants around the world, which is growing at a pace of 7 to 15% yearly, there has been a significant increase in medicinal plant-based industries (Kumar, 2013). Medicinal plants are used by roughly 70-80 percent of the world's people, mainly in developing nations, to combat their health regiments (Ekor, 2014), and about 25% of synthesized pharmaceuticals are made from medicinal plants (Pan et al., 2013).

Herbal medications and their constituents are essential in several therapeutic systems such as Unani, Siddha, yoga, homeopathy, naturopathy, and Ayurveda (Paikra and Gidwani, 2017). Among the diverse medicinal plants, *Moringa oleifera* is largely utilized in many traditional systems of medicine and folklore for many diseases. What is fascinating about *M. oleifera* is that a separate part of the plant is used as medicine.

M. oleifera is generally known as the "wonder plant" or the "tree of life" (Mishra et al., 2020). This name is derived from the plant's numerous uses, particularly concerning medicine and nutrition. It is already an important crop grown for commercial purposes in locations such as India, Ethiopia, the Philippines, Sudan, the West, East, South Africa, and Asia (Mbikay, 2012). The immature seed pods are consumed in some regions, but the fresh leaves are

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generally utilized as a staple food due to their high nutritional content (Thurber and Fahey, 2009). *Moringa* is frequently regarded as an important famine food due to its high resistance to arid conditions owed to its tuberous roots (Berushka and Himansu, 2012). Virtually every part of *M. oleifera*, including leaves, flowers, bark, green pods, roots, and seeds, is beneficial for medicine, functional food preparations, nutraceuticals, water filtration, and biodiesel generation (Saini, 2013).

Many reports have appeared in mainstream scientific journals over the last two decades describing the nutritive and medicinal properties of *M. oleifera*. According to Popoola and Obembe (2013), *M. oleifera* is nutritious and beneficial to people by providing daily nutritional supplements and boosting their immune systems. Mahmood et al. (2010) reported that *Moringa* leaves are high in vitamin C, A, and essential amino acids. Abd Rani et al. (2018) and Mishra et al. (2020) also added that *Moringa* leaves contain more vitamin A than carrots, more calcium than milk, more iron than spinach, more vitamin C than oranges, and more potassium than bananas, and their protein quality rivals that of milk and eggs. The immature pods, flowers, and leaves of the *Moringa* tree are also utilized in cooking in several regions of the world (Stevens et al., 2013). Because of the high level of monounsaturated fatty acids (in the form of oleic acid) in moringa seed oil, it is used in biodiesel production (Azam et al., 2005).

Studies on *M. oleifera* have revealed some phytochemical substances that offer health benefits beyond the plant's basic nutritional value. Phytochemicals such as alkaloids, tannins, terpenoids, steroidal aglycones, and reducing sugars are abundant in the leaves, flowers, seeds, bark, roots, and immature pods (Paikra and Gidwani, 2017). Leone et al. (2015) stated that phenolic acids, flavonoids, polyphenols, alkaloids, glucosinolates, isothiocyanates, tannins, and saponins are all present in the leaves, which is the most often used component of the plant. *M. oleifera* leaves have also been discovered to be a significant source of phenolics and glucosinolates (Amaglo et al., 2010). The presence of a high concentration of bioactive compounds in the leaves of *M. oleifera* may explain its pharmacological properties. According to Sivasankari et al. (2014), the leaves of *M. oleifera* are used to treat a variety of diseases ranging from malaria and typhoid fever to hypertension and diabetes. The *M. oleifera* foliage also guards against inflammation, oxidative stress, hepatic fibrosis, liver damage, hypercholesterolemia, bacterial activity, and cancer (Okwari et al., 2013; Halaby et al., 2013; Efiong et al., 2013). Other plant parts, such as the roots, bark, gum, fruit (pods), flowers, and seeds, have also been shown to have biological activities such as protection against gastric ulcers, antidiabetic, hypotensive, and anti-inflammatory properties (Oyedepo et al., 2013; Vergara-Jimenez et al., 2017).

Several works have been conducted to explore the potential of *M. oleifera* in traditional systems of medicine and nutrition. However, little or no updated and a well-organized comprehensive review exists on the phytochemicals, nutritive values, and pharmacological properties of *M. oleifera*. Hence, this present review is focused on compiling the phytochemical compounds, nutritional composition, and pharmacological potentials of the various parts of *M. oleifera*. Additionally, the prospects of this important medicinal plant will be evaluated. This review work would encourage new research on *M. oleifera* by serving as valuable background for future studies.

2. Methodology

An extensive search for important literature was performed through several scientific databases, including Google Scholar, Scopus, PubMed, and ScienceDirect, for journal articles published from 2000 to 2022. This was done using the keywords of *Moringa oleifera*, phytochemistry, nutrition, and pharmacognosy. Only data from books, original research papers, and review articles from peer-reviewed journals linked to the keywords mentioned above were incorporated in the present review. The various citations were combined using the EndNote X9 citation tool (Thomson Reuters, Toronto, Canada). The PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analysis) framework for collecting data for this review is displayed in Figure 1.

3. Geographical source

M. oleifera is a rapidly growing tree widely cultivated throughout India's plains and has naturalized in tropical areas. Sri Lanka, Northern Pakistan, Bangladesh, the Arabian Peninsula, Asia, West and East Africa, southern Florida, South America: Mexico, Peru, Brazil, and Paraguay are where the *Moringa* plant is grown. It thrives in all soil types and is cultivated in hedges and gardens (Gupta, 2010; Bhattacharjee, 2005).

4. Taxonomical classification

M. oleifera has the following taxonomical hierarchy from kingdom to species:
Kingdom - Plantae
Sub-kingdom - Tracheobionta
Super division - Spermatophyta
Division - Magnoliophyta
Class - Magnoliopsida
Sub-class - Dilleniidae
Order - Capparales
Family - Moringaceae
Genus - *Moringa*
Species - *oleifera* (Fahey, 2005).

5. Common name

The *M. oleifera* plant is known by several names in different languages throughout the world, as presented in Table 1.

6. Botany/Morphology

M. oleifera is a rapidly growing herbaceous tree with a trunk diameter of 20-60 cm and a height of 7-12 m. It has spreading, delicate branches, feathery foliage with tripinnate leaves, and whitish-gray bark (Bashir et al., 2016). Major plant parts encompass the leaves, stem, flowers, fruits, seeds, roots, and bark.

Leaves: The leaves are bipinnate or tripinnate and can grow to be 45 cm long. These are compound leaves with 1-2 cm long leaflets. The upper surface of the leaflets is hairy and green (Paikra and Gidwani, 2017).

Stem: The stem is fragile, with a corky, whitish-gray bark, drooping branches, pale green leaves (30-60 cm long) with opposing, elliptical leaflets, and bipinnate or tripinnate leaves (Pandey et al., 2011).

Flowers: The bisexual fragrance flowers are yellowish-white and borne on long stalks of axillary panicles that spread or droop (10-25 cm long). Individual flowers are 2 cm wide and 0.7 to 1 cm long with five unequal yellowish-white, spathulate petals with thin veins, five stamens with five smaller sterile filaments, and a pistil with a 1-celled ovary and slender style (Bashir et al., 2016).

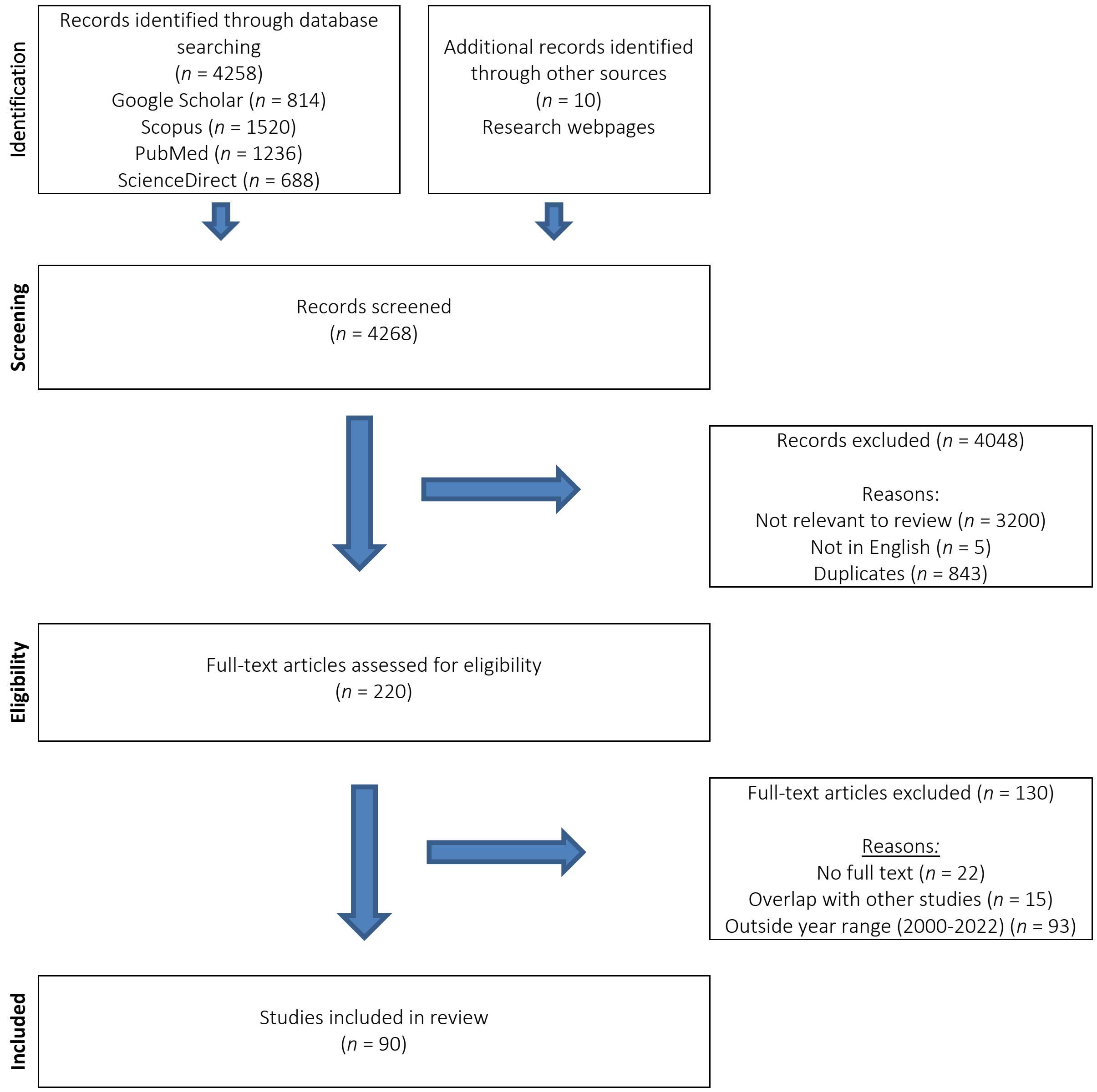


Figure 1. PRISMA flowchart for the review methodology

Table 1. Common names for *M. oleifera* in different languages (Paikra and Gidwani, 2017; Abdull Razis et al., 2014)

Language	Name
English	Drumstick tree, Horseradish tree
French	Benzolive, Bèn ailé
Spanish	Morango, Ben, Moringa
Portuguese	Morungo, Moringuiero
German	Behenbaum, Bennussbaum
Italian	Sandalo ceruleo
Latin	*Moringa oleifera*
Chinese	La ken
Arabian	Rawag
Hindi	Suguna, Sainjna
Malayalam	Murinna, Sigru

Fruits: Fruits are tri-lobed capsules that are commonly known as pods. It is pendulous, brown triangular, and divides into three lengthwise halves when dried. During the development stage of the fruit, it contains approximately 26 seeds. Unripe pods are green and turn brown as they mature (Paikra and Gidwani, 2017).

Seeds: Seeds are 1 cm in diameter, round, with a brownish semi-permeable seed hull and three papery wings. Seed hulls are brown to black but can be white if the kernels are not viable. Within two weeks, viable seeds germinate. Each tree can produce 15.000 to

25.000 seeds per year. The average seed weight is 0.3 grams (Paikra and Gidwani, 2017).

Bark and wood: The bark is whitish gray, thick and soft, fissured and warty or corky, and becomes rough as it ages (Mishra et al., 2020).

Roots: Seedlings have a swollen, tuberous, white taproot with a distinctive pungent odor and very few lateral roots (Mishra et al., 2020). Plates of the various parts of the *M. oleifera* are shown in Figure 2.

7. Phytochemistry

Phytochemicals are chemical elements derived from plants. They are non-nutritive plant chemicals with protective or disease preventive properties (Abd Rani et al., 2018). These chemicals are established to impact human health and contribute to the flavor, texture, smell, and color of plants (Anwar and Bhanger, 2003). *M. oleifera* is rich in a combination of phytochemicals such as terpenes, quercetin, β-sitosterol, caffeoylquinic acid, kaempferol, kaempferitrin, isoquercitrin, rhamnetin, rhamnose, and a fairly unique group of compounds called the glucosinolates and isothiocyanates (Fahey, 2005; Amaglo et al., 2010). Different parts of the *M. oleifera* contain numerous phytochemical compounds. Coppin et al. (2013) reported that the stem bark contains two alkaloids, moringine, and moringinine, with vanillin, β-sitosterol, 4-hydroxymellin, and octacosanoic acid identified in the stem of the plant (Anwar and Bhanger, 2003). The flowers of *M. oleifera* have also been established to contain quercetin and kaempferol (Siddhuraju and Becker, 2003). Studies have also shown the presence of polyphenols, niazimicin, benzyl isothiocyanate, 3-caffeoylquinic, and 5-caffeoylquinic acid in the leaves of *M. oleifera* (Muhammad et al., 2016). A study by Kasolo et al. (2010) identified the presence of protective phytochemicals, including gallic tannins, catechol tannins, steroids and triterpenoids, saponins, anthraquinones, alkaloids, and reducing sugars in ether, ethanol, and aqueous extracts of the roots. The diversity of these phytochemicals in the various parts of the *Moringa* tree contributes to its numerous pharmacological uses (Abd Rani et al., 2018). The chemical structures of selected phytochemical compounds in the *M. oleifera* are shown in Figure 3, with their therapeutic properties presented in Table 2.

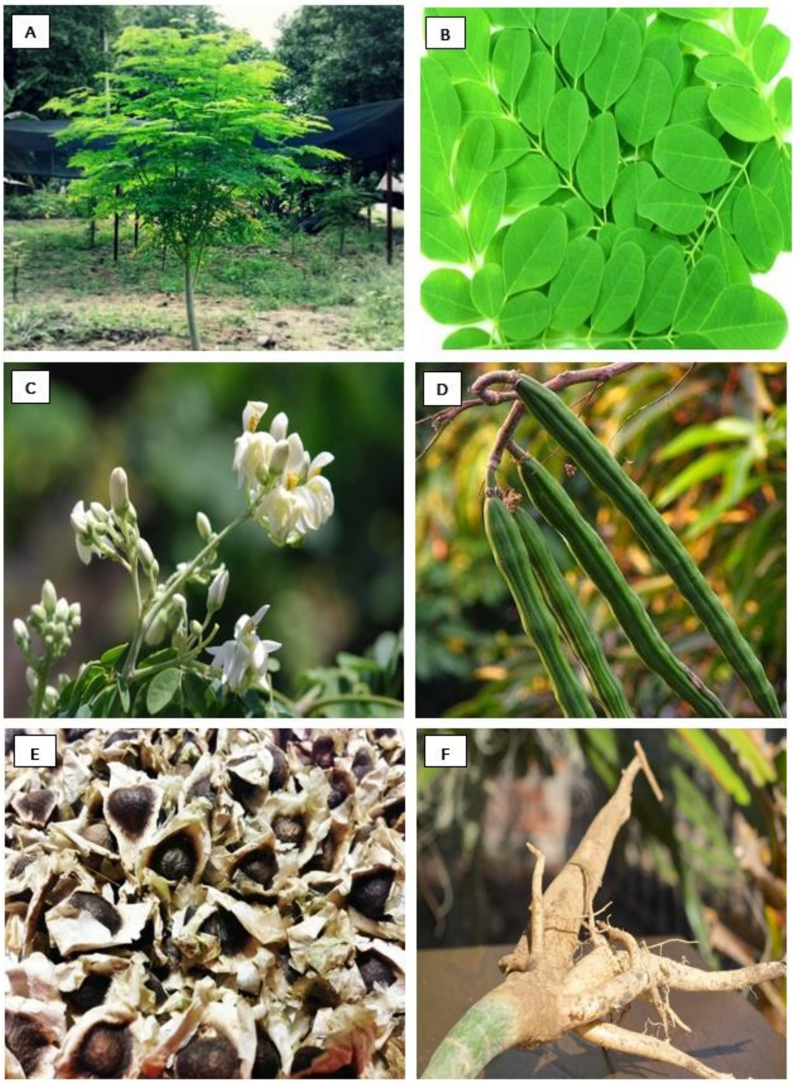
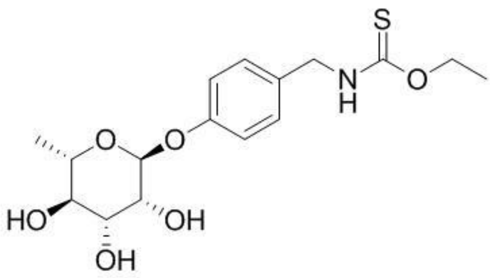


Figure 2. Parts of *M. oleifera* tree
Field grew whole tree (A); Leaves (B); Flowers (C); Fruits (D); Seeds (E); Roots (F)

8. Nutritional composition

There is a wealth of scientific evidence on the nutritional content of *M. oleifera*, which can be linked to its nutritive and medicinal benefits. According to Al-Kharusi et al. (2009) and Abdull Razis et al. (2014), the nutritional value of a plant plays a vital role in its medicinal and therapeutic properties. *M. oleifera* has been found to contain many essential nutrients, including vitamins, minerals, amino acids, beta-carotene, fiber, antioxidants, omega 3 and 6 fatty acids (Kasolo et al., 2010; Fahey, 2005). Fahey (2005) reported that *Moringa* leaves have a higher vitamin C content than oranges, a higher vitamin A content than carrots, a higher calcium content than milk, a higher iron content than spinach, and higher potassium content than bananas and that the protein quality of the leaves is comparable to that of milk and eggs. *M. oleifera* immature pods also contain approximately 46.78 percent fiber, 20.66 percent protein, and 30 percent of amino acid (Mishra et al., 2020). Many parts of the plant serve as a repository for these vital nutrients. As a result, it is unusual for a single plant to contain several essential nutrients in such high concentrations as *M. oleifera*.



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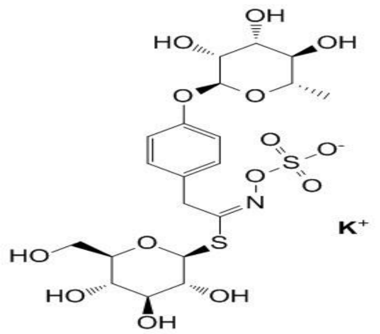

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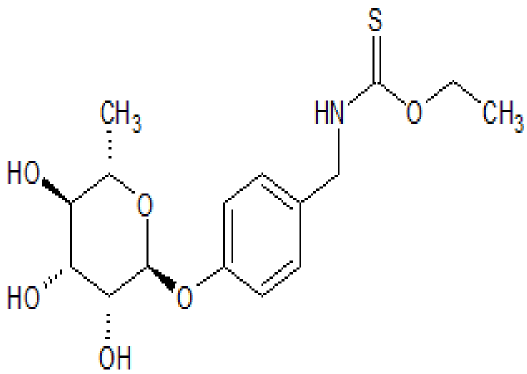

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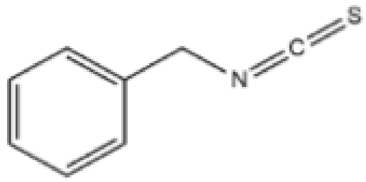

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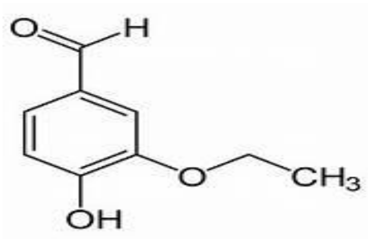

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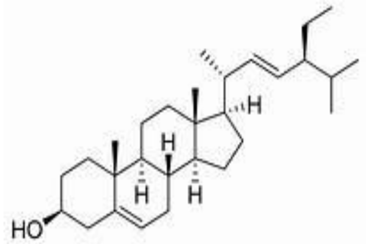

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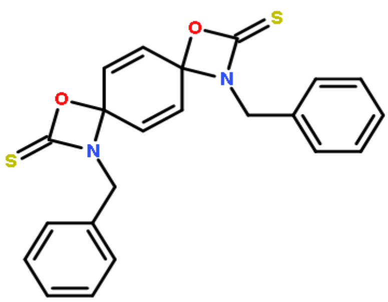

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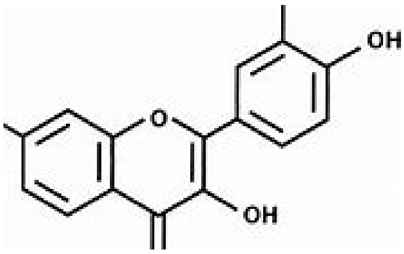

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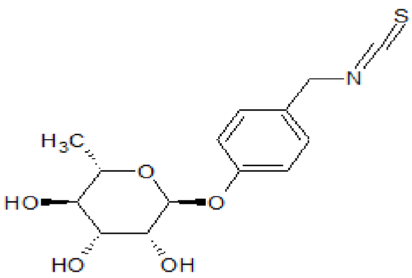

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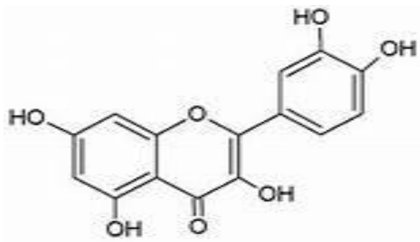

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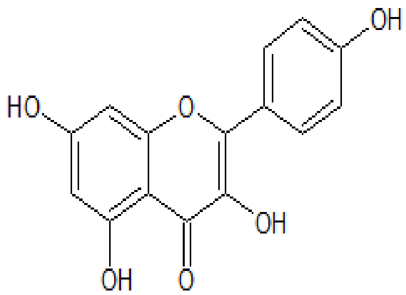

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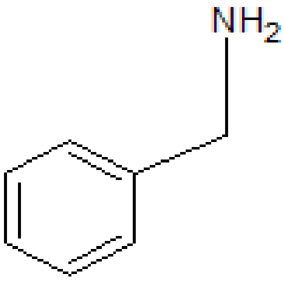

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Figure 3. Structures of selected phytochemicals isolated from *M. oleifera*

Glucosinolate (1), Glucomoringin (2), Niazimicin (3), Benzyl isothiocyanate (4), Vanillin (5), β-sitosterone (6), Pterygospermin (7), Terpenoid (8) 4-(α-L-rhamnosyloxy) benzyl isothiocyanate (9), Quercetin (10), Kaempferol (11), Moriginine (12)

Vitamins are one of the abundant nutrients, particularly in the leaves of *M. oleifera*. Dillard and German (2000), as well as Toma and Deyno (2014) stated that *M. oleifera* leaves are rich in vitamin C, β-carotene, protein, calcium, and potassium and are excellent sources of natural antioxidants. Mishra et al. (2020) also reported that *M. oleifera* leaves contain vitamins including vitamin B such as folic acid, beta-carotene of vitamin A, vitamin C, D, and E, pyridoxine, and nicotinic acid. Fresh leaves have also been proven to have higher levels of vitamin C than typical sources like oranges (Leone et al., 2015). A high content like this is significant due to vitamin C's role in facilitating the conversion of cholesterol into bile acids, thereby lowering blood cholesterol levels (Leone et al., 2015). Vitamin E, particularly α-tocopherol, is also established in the leaves of *M. oleifera* in amounts comparable to those found in the nuts (Sánchez-Machado et al., 2006).

Table 2. List of selected phytochemicals in *M. oleifera* and their biological properties

No	Phytochemical	Plant part	Biological property	Reference
1	Glucosinolate	Leaves	Chemopreventive activity by activating apoptosis	Waterman et al., 2014
2	Glucomoringin	Leaves	Anti-colon, carcinogenic activity	Fahey et al., 2018
3	Niazimicin	Leaves	Anti-cancer activity	Adejumo et al., 2012
4	Benzyl isothiocyanate	Leaves	Anti-inflammatory and anti-cancer activity	Waterman et al., 2014
5	Vanillin	Stem	Anti-cancer, neuroprotective activity	Bennett et al., 2003
6	β-sitosterone	Stem	Antioxidant, hypolipidemic activity	Rajanandh and Kavitha, 2010
7	Pterygospermin	Seeds	Anti-herpes, cramps, rheumatism, epilepsy	Biswas et al., 2020
8	Terpenoid	Seeds	Anti-cancer, anti-hyperglycemic, and antibacterial activity	Mehra et al., 2017; Huang et al., 2012
9	4-(α-L-rhamnosyloxy) benzyl isothiocyanate	Seeds	Antimicrobial, antitumor enhancer	Popoola et al., 2020
10	Quercetin	Flowers	Inhibit mutations, prevent carcinogenesis	Imran et al., 2019; Leone et al., 2015
11	Kaempferol	Flowers	Antioxidant, inhibit mutations	Imran et al., 2019; El-Alfy et al., 2011
12	Moriginine	Bark, stem	Anti-inflammatory and anti-ulcer activity	Rajbhar et al., 2018

Vitamin E acts principally as an antioxidant agent, but it is also involved in gene expression regulation, inhibition of cell proliferation, platelet aggregation, monocyte adhesion, and bone mass regulation (Sánchez-Machado et al., 2006). A few B vitamins, comprising riboflavin, thiamine, and niacin, have also been found in the leaves of *M. oleifera* (Leone et al., 2015). These vitamins primarily function as co-factors for numerous enzymes involved in nutrient metabolism and energy production (Leone et al., 2015).

Moringa contains a diversity of minerals necessary for healthy growth and development. The most abundant minerals in the tissues of *M. oleifera* are calcium (Ca), potassium (K), and magnesium (Mg) (Amaglo et al., 2010). The immature pods and vegetative parts have the maximum K, whereas the seeds and leaves contain more Mg and Ca (Amaglo et al., 2010). *M. oleifera*'s leaves are also a superb source of iron, zinc, and copper (Saini et al., 2016; Mishra et al., 2020). *M. oleifera* leaves contain approximately 25.5 to 31.03 mg/kg of zinc, the daily zinc requirement in diet (Gopalakrishnan et al., 2016). Zinc is required for the normal proliferation of sperm cells as well as the synthesis of DNA and RNA (Gopalakrishnan et al., 2016). Regarding iron, Fuglie (2005) reported that *Moringa* contains more iron than spinach. He also added that moringa leaves contain more iron than beef. Thus, beef contains only 2 mg of iron, whereas *Moringa* leaf powder contains 28 mg of iron. Hence, *Moringa* powder can be used as a substitute for iron tablets to treat anemia.

Fatty acids have also been found in some parts of the *Moringa* tree. Saini et al. (2016) stated that the *Moringa* leaves contain omega-3 and omega-6 polyunsaturated fatty acids (PUFAs) in the form of linolenic acid and linoleic acid. When equated to the leaves, unripe pods and flowers have a higher concentration of total monounsaturated fatty acids (MUFAs, 16-30%) and a minor content of polyunsaturated fatty acids (PUFAs, 34-47%) (Saini et al., 2016).

Moreover, palmitic acid has also been identified as the most copious saturated fatty acid in *Moringa* leaves, accounting for 16-18% of the overall fatty acids (Saini et al., 2016). Studies have as well shown that the seed oil of *Moringa* contains approximately 76 percent PUFA, making it an excellent olive oil substitute (Lalas and Tsaknis, 2002). These PUFAs can lower cholesterol (Lalas and Tsaknis, 2002). The *Moringa* seeds and seed oil also contain substantial amounts of oleic, stearic, arachidic acid, linoleic, and linolenic acids (Amaglo et al., 2010).

9. Pharmacological studies

Some scientific investigations have reported that specific components of *M. oleifera* preparations possess many pharmacological actions, including antimicrobial, anti-inflammatory, anticancer and antitumor, antidiabetic, antifertility, antioxidant, anti-asthmatic, hepatoprotective, cardiovascular, and immunomodulatory activities. Key reports and findings on these important pharmacological properties ascribed to *M. oleifera* are compiled below.

9.1. Antibacterial and antifungal

Phytochemicals and plant extracts with antimicrobial properties are important in therapeutics (Moyo et al., 2012). Due to antimicrobial resistance, there has been a surge in interest in medicinal plants possessing such capabilities. *M. oleifera* is an effective antibacterial agent, as evidenced by studies showing a significant reduction in the growth of test bacteria. In a study using erythromycin as a positive control, Gopalakrishnan et al. (2016) discovered that *M. oleifera* had potential antibacterial activity against four key bacterial strains tested: *Staphylococcus aureus*, *Bacillus megaterium*, *Citrobacter freundii*, and *Pseudomonas fluorescens*. Vinoth et al. (2012) also conducted a study on *M. oleifera* where the aqueous and ethanolic leaf extracts demonstrated antibacterial activity against *Salmonella* spp., while acetone leaf extracts at a concentration of 5 mg/mL also displayed antibacterial activity against *S. aureus*, *Escherichia coli*, *Enterobacter cloacae*, *Proteus vulgaris*, and *Micrococcus kristinae*. The bark extract of the *Moringa* tree has also been demonstrated to possess antifungal properties (Toma and Deyno, 2014). Ringworms are mostly treated with *M. oleifera* seed oil, according to Shikwambana and Mahlo (2020). Isitua et al. (2016) stated that *M. oleifera* leaves extract could potentially be used to treat aspergillosis in humans, based on their findings, which showed high antifungal activity against *Aspergillus flavus*, a fungus that causes aspergillosis in humans. Kou et al. (2018) also found that the aglycone of deoxy-niazimicin extracted from the chloroform portion of ethanol extract was accountable for the antifungal and antibacterial activity in the root bark of *M. oleifera*. These findings and reports prove the ability of *M. oleifera* extracts to inhibit the growth of some strains of bacteria and fungi, indicating their potential to either block or outwit resistance mechanisms by these pathogenic microorganisms.

9.2. Anti-inflammatory activity

Inflammation is a frequent symptom of a diverse array of chronic infections. Anti-inflammatory mediators are in charge of alleviating pain and reducing inflammation, thereby promoting health. Because of their safety and effectiveness, medicinal plants as anti-inflammatory agents are considered viable and logical options (Alhakmani et al., 2013). Several studies have been conducted to investigate *M. oleifera*'s anti-inflammatory properties. Ndiaye et al. (2002) reported that the aqueous extract of the root of *M. oleifera* (750 mg/kg) displays anti-inflammatory activity by obstructing carrageenan-induced edema in rats to the same level as the effective anti-inflammatory drug indomethacin. A study by Fidrianny et al. (2021) also inferred that the anti-inflammatory properties of silver nanoparticles (AgNps) synthesized from *M. oleifera* flowers exhibited a significant and higher inhibition percentage by albumin denaturation activity. *Moringa* seed extract's hepatoprotective properties, discovered in an anti-fibrotic study by Hamza (2010), indicated that *Moringa* possesses anti-inflammatory properties against CCL_4-induced liver damage and fibrosis.

9.3. Anticancer and antitumor activity

On a global scale, cancer is responsible for around 1 in every 6 mortalities (Singh et al., 2020). Plants are frequently used to produce clinically relevant antitumor chemicals that can be turned into anticancer drugs (Kamuhabwa et al., 2000). One of the numerous benefits of employing dietary or natural chemicals as a cancer adjuvant is that they are low in toxicity and have few negative side effects (Nair and Varalakshmi, 2011). *M. oleifera* has been shown to have anticancer effects in several investigations. In chemical carcinogenesis, niazimicin, a chemical molecule found in *M. oleifera*, has been postulated as a strong chemopreventive agent (Toma and Deyno, 2014). Hagoel et al. (2019) reported in a study that the aqueous leaf extract of *M. oleifera* lessens pancreatic cancer cell existence, tumor growth, and metastatic actions. Anticancer drugs typically target ROS induction. However, *Moringa* leaf extracts were discovered to have the ability to attack ROS induction (Gopalakrishnan et al., 2016). Earlier research has demonstrated that intake of *M. oleifera* seedpod extracts can prevent skin tumors, including a significant reduction in skin papillomas in a mouse model (Bharali et al., 2003). Toma and Deyno (2014) also found that niaziminin, a thiocarbamate derived from the leaves of *M. oleifera*, inhibits tumor-promoter-induced Epstein–Barr virus activation.

9.4. Antioxidant activity

Antioxidants are chemicals that provide free atoms to the human body while suppressing free radicals, which cause cell damage and oxidative stress. Natural antioxidants are abundant in medicinal plants. *Moringa* leaves have been established to be high in natural antioxidants such as flavonoids, quercetin, β-sitosterol, and zeatin (Fahey, 2005; Amaglo et al., 2010). Tender and mature leaf extracts were found to have great scavenging properties on free radicals, nitric oxide radicals, and superoxides (Sreelatha and Padma, 2009). Ethanol, methanol, and water extracts of freeze-dried *Moringa* leaves were also found to have antioxidant and free radical scavenging properties, with all leaf extracts capable of scavenging superoxyl and peroxyl radicals, according to Siddhuraju and Becker (2003). *M. oleifera* also showed excellent antioxidant activity from the most isolated compounds in different *in vitro* bioassays compared to typical antioxidant compounds in a study that employed the 2,2'-diphenyl-1-picrylhydrazyl (DPPH) radical technique (Hamed et al., 2017). Furthermore, an *in vivo* study conducted by Jaja-Chimedza et al. (2018) on normal and obese male mice demonstrated that *Moringa* seed extract could increase metabolic health through its intracellular antioxidant and anti-inflammatory actions.

9.5. Antidiabetic activity

Diabetes is one of the most common metabolic illnesses in the world, and it is a huge public health issue. Hyperglycemia is usually treated with synthetic oral medications and insulin remedies. However, many of these medications have negative side effects and are too expensive for disadvantaged people, particularly in emerging nations. As a result, the demand for cost-effective and efficient hypoglycemic medicines with fewer side effects will always exist. *Moringa* has been demonstrated to have anti-diabetic properties in several investigations. Muhammad et al. (2016) investigated the anti-diabetic effect of *M. oleifera* seeds, roots, and stem bark extracts in diabetic mice and reported that the aqueous, ethanolic, and methanolic extracts of these plant parts provided good glycemic control in the diabetic animals. Another study by Irfan et al. (2017) established that the anti-hyperglycemic activity in diabetic rats was due to the kaempferol-3-*O*-glucoside, quercetin-3-D-glucoside, and crypto chlorogenic acid in the leaf extract of *M. oleifera*. In streptozotocin (STZ)-induced diabetic albino rats, Gupta et al. (2012) found that the methanolic pods extract of *M. oleifera* has anti-diabetic properties. *Moringa* seed powder effectively lowered fasting blood sugar in STZ-induced diabetic rats in a similar study by Owens et al. (2020).

9.6. Anti-asthmatic activity

Asthma is a long-lasting respiratory disease that affects a considerable part of the world's population, accounting for about 90% of cases in most global surveys (Mahajan et al., 2009). For hundreds of years, complementary and alternative medicine has been utilized to treat asthma. *M. oleifera*, in particular, is effective in treating asthma, with literature describing the plant's anti-asthmatic properties. In guinea pigs, Mahajan et al. (2009) tested the efficiency of *n*-butanol extracts of *M. oleifera* seeds against ovalbumin-induced airway inflammation. The study found that the seeds extract of *M. oleifera* seed extracts protect against acetylcholine-induced bronchoconstriction and airway inflammation by increasing tidal volume and respiration rate, as well as differential and total cell counts in blood and bronchoalveolar lavage fluid. They concluded that the anti-asthmatic properties of *M. oleifera* seed extracts were due to the regulation of Th1/Th2 cytokine imbalances. In another study by Singh and Navneet (2018), *M. oleifera* seed kernels used in bronchial asthma demonstrated a simultaneous improvement in respiratory functions and a significant reduction in the severity of asthma symptoms. Agrawal and Mehta (2008) also conducted a clinical trial to evaluate if *M. oleifera* seed kernels effectively treat bronchial asthma. The dried seed kernels were given to 20 patients with mild to moderate asthma at a dose of 3 kg for three weeks. The results showed that treatment with *M. oleifera* extracts resulted in a significant reduction in the intensity of asthma symptoms as well as an improvement in lung function metrics.

9.7. Antifertility activity

Women have traditionally utilized medicinal plants to aid childbirth, promote menstrual flow, and limit fertility (Agrawal et al., 2018). *M. oleifera* is well-known for its therapeutic benefits. However, its antifertility properties have also been studied. In female albino rats, Zade and Dabhadkar (2015) found that alcoholic extracts of *M. oleifera* leaves had an antifertility effect. In that study, *M. oleifera* leaf extract was found to prevent 100% of implantation in seven rats. Mishra et al. (2011) also studied the antifertility properties of *M. oleifera* aqueous and ethanolic (90%) extracts in rats orally dosed for 10 days after insemination, with emphasis on fetal development. *M. oleifera* leaf extracts were completely (100%) abortive at dosages of 175 mg/kg of initial dry material. *M. oleifera*'s antifertility properties and prospects could make it a valuable option for modern contraception and antifertility issues for women, especially in rural populations in underdeveloped nations with limited financial resources and access to healthcare.

9.8. Hepatoprotective activity

The liver is an important organ that conducts various activities, including detoxification and protein synthesis. The effects can be fatal when the liver's activities are harmed by the many substances to which humans are exposed. Many medications used to treat liver problems are insufficient and may pose dangerous side effects. The search for efficient hepatoprotective medications frequently focuses on medicinal plants used to treat some liver diseases (Buraimoh et al., 2011). Tejas et al. (2012) reported that the methanolic leaf extract of *M. oleifera* has a hepatoprotective effect, which could be attributed to the presence of quercetin in the leaves. Buraimoh et al. (2011) also investigated the hepatoprotective effects of *M. oleifera* ethanolic leaf extract on paracetamol-induced liver damage histopathology. Compared to the negative control group, which had deformed hepatic cords, necrotic cells, and obliterated sinusoids, Wistar rats given extracts (500 mg/kg) had less necrotic cell damage and broader sinusoidal gaps. *M. oleifera* leaves have also been demonstrated to lower plasma aspartate aminotransferase (AST), alkaline phosphatase (ALP), alanine aminotransferase (ALT), and creatinine (Sharifudin et al., 2013), as well as alleviate hepatic and renal damage caused by medications (Ouédraogo et al., 2013). *Moringa* flower extracts, both aqueous and alcoholic, have also been demonstrated to possess strong hepatoprotective properties (Toma and Deyno, 2014).

9.9. Cardiovascular activity

A multitude of ailments that affect the circulatory system (heart and blood vessels) is cardiovascular disease. For millennia, medicinal plants have been utilized to treat cardiovascular disorders. This is due to their antioxidant, vasodilator, adrenoceptor, and platelet-activating factor (PAF) antagonist properties (Chumark et al., 2008). The cardiovascular effects of *M. oleifera* have been investigated using animal and human models. Randriamboavonjy et al. (2016) studied the heart effects of *M. oleifera* seed powder given orally to spontaneously hypertensive rats (SHR). SHR was given either *Moringa* powdered food (750 mg/day for 8 weeks) or regular food. After that, hemodynamic parameters were measured *in vivo*. According to the findings, *M. oleifera* treatments did not change blood pressure in SHR but did lower nocturnal heart rate and improved diastolic cardiac function. Nandave et al. (2009) investigated the cardioprotective efficacy of lyophilized hydroalcoholic extract of *M. oleifera* in a male Wistar albino rat model of myocardial infarction induced by isoproterenol (ISP). Compared to the ISP control group, chronic *Moringa* therapy resulted in a significant increase in the positive regulation of biological enzymes (catalase, superoxide dismutase, lactate dehydrogenase, creatine kinase, and glutathione peroxidase), but no significant change in reduced glutathione. *Moringa* treatment significantly reduced lipid peroxidation in heart tissue. According to Chhikara et al. (2020), oxidative stress-induced chronic diseases such as cardiovascular issues could be reduced due to flavonoids in *M. oleifera*.

9.10. Immunomodulatory activity

Plant-based immunomodulation is a hot topic in scientific circles since it offers a viable alternative to traditional chemotherapy for various disorders. It is based on plants' ability to control immunological activities efficiently, promoting positive health and maintaining the body's resistance to illness. Sudha et al. (2010) investigated the immunomodulatory effects of a methanolic extract of *M. oleifera* leaves in a mouse cellular and humoral immunity model. The extracts were given at two doses (250 and 750 mg/kg) to mice, which significantly boosted serum immunoglobulin levels and avoided mortality caused by bovine *Pasteurella multocida*. Alkaloids are abundant phytochemicals in *M. oleifera* and have immunomodulatory properties, according to Obi et al. (2018). Certain bitter alkaloids, such as tropane alkaloids, are converted into dimethylxanthine in the liver and then to methyl uric via CYP450 oxygenase systems (Obi et al., 2018). Gupta (2010) also found that ethanolic leaf extracts of *M. oleifera* have an immunomodulatory effect in mice, leading cyclophosphamide-induced immunosuppression to be significantly reduced. After prolonged administration of the extracts, normal mice showed a considerable rise in white blood cell (WBC) count, phagocytic index, percent neutrophils, and thymus and spleen weight.

10. Future prospects

M. oleifera, with its rich source of nutrients, abundant phytochemicals, and numerous pharmacological actions, has the potency to help combat malnutrition and improve medicine. The diverse nutritional elements of the plant, particularly in the leaves, have a promising role in producing healthy food products and nutraceuticals. The abundant phytochemical compounds in distinct parts of the plant have the potential to be used in the manufacturing of pharmaceutical products and offer therapies for a wide range of diseases. Industrially, the plant also has a fascinating prospect of being used in the production of biodiesel (the seeds), cosmetics, and water purification systems. Hence, *M. oleifera* deserves extensive investigations to isolate and better elucidate the mechanism of actions of the various active compounds responsible for its nutritional and medicinal efficacies.

11. Conclusions

M. oleifera, with its unique nutritive and medicinal properties, has a remarkable potential to provide an inexpensive and credible auxiliary to conventional medicine. The present review documented the phytochemical compounds, nutritional composition, and pharmacological potential of *M. oleifera*. Numerous scientific investigations revealed that individual parts of the plant possess anticancer, antimicrobial, anti-inflammatory, antidiabetic, antifertility, hepatoprotective, cardiovascular, and immunomodulatory actions. Many essential nutrients, including vitamins, minerals, proteins, beta-carotene, fiber, and fatty acids, were also present in *M. oleifera*, justifying the plant's usage for decades to combat malnutrition.

Moreover, medicinally important phytochemicals such as alkaloids, flavonoids, terpenes, sterols, flavonoids, glycosides, and anthocyanins were established to be present adequately in *M. oleifera*; and this makes the plant therapeutically imperative and/or nutritionally valuable. The present review recommends in-depth investigations into the isolation and purification of novel pharmacologically active and industrially important phytochemical compounds in *M. oleifera*, as much work has not been conducted in this field. Additionally, more rigorous research on the toxicity of *M. oleifera* is required, including clinical trials in humans, to ascertain its safety and achieve a level of proof required for full biomedical endorsement of the plant for therapeutics.

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Conflict of interest

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Supplementary File

None.

References

Abd Rani, N.Z., Husain, K., Kumolosasi, E., 2018. *Moringa* genus: a review of phytochemistry and pharmacology. *Frontiers in Pharmacology*, 9, 108.
Abdull Razis, A.F., Ibrahim, M.D., Kntayya, S.B., 2014. Health benefits of *Moringa oleifera*. *Asian Pacific Journal of Cancer Prevention*, 15(20), 8571-8576.
Adejumo, O.E., Kolapo, A.L., Folarin, A.O., 2012. *Moringa oleifera* Lam.(Moringaceae) grown in Nigeria: *In vitro* antisickling activity on deoxygenated erythrocyte cells. *Journal of Pharmacy & Bioallied Sciences*, 4(2), 118-122.
Agrawal, B., Mehta, A., 2008. Antiasthmatic activity of *Moringa oleifera* Lam: A clinical study. *Indian Journal of Pharmacology*, 40(1), 28-31.
Agrawal, S.S., Vishal, D., Sumeet, G., Shekhar, C., Ashish, N., Parul, D., Varun, S., 2018. Antifertility activity of ethanol leaf extract of *Moringa oleifera* Lam in female wistar rats. *Indian Journal of Pharmaceutical Sciences*, 80(3), 565-570.
Alhakmani, F., Kumar, S., Khan, S.A., 2013. Estimation of total phenolic content, *in–vitro* antioxidant and anti–inflammatory activity of flowers of *Moringa oleifera*. *Asian Pacific Journal of Tropical Biomedicine*, 3(8), 623-627.
Al-Kharusi, L.M., Elmardi, M.O., Ali, A., Al-Said, F.A.J., Abdelbasit, K.M., Al-Rawahi, S., 2009. Effect of mineral and organic fertilizers on the chemical characteristics and quality of date fruits. *International Journal of Agriculture and Biology*, 11(3), 290-296.
Amaglo, N.K., Bennett, R.N., Curto, R.B.L., Rosa, E.A., Turco, V.L., Giuffrida, A., Timpo, G.M., 2010. Profiling selected phytochemicals and nutrients in different tissues of the multipurpose tree *Moringa oleifera* L., grown in Ghana. *Food Chemistry*, 122(4), 1047-1054.
Anwar, F., Bhanger, M.I., 2003. Analytical characterization of *Moringa oleifera* seed oil grown in temperate regions of Pakistan. *Journal of Agricultural and Food Chemistry*, 51(22), 6558-6563.
Azam, M.M., Waris, A., Nahar, N.M., 2005. Prospects and potential of fatty acid methyl esters of some non-traditional seed oils for use as biodiesel in India. *Biomass and Bioenergy*, 29(4), 293-302.
Bashir, K.A., Waziri, A.F., Musa, D.D., 2016. *Moringa oleifera*, a potential miracle tree; a review. *IOSR Journal of Pharmacy and Biological Sciences*, 11, 25-30.
Bennett, R.N., Mellon, F.A., Foidl, N., Pratt, J.H., Dupont, M.S., Perkins, L., Kroon, P.A., 2003. Profiling glucosinolates and phenolics in vegetative and reproductive tissues of the multi-purpose trees *Moringa oleifera* L.(horseradish tree) and *Moringa stenopetala* L. *Journal of Agricultural and Food Chemistry*, 51(12), 3546-3553.
Berushka, P., Himansu, B., 2012. An overview of the medicinal importance of Moringaceae. *Journal of Medicinal Plants Research*, 6(48), 5831-5839.
Bharali, R., Tabassum, J., Azad, M.R.H., 2003. Chemomodulatory effect of *Moringa oleifera*, Lam, on hepatic carcinogen metabolising enzymes, antioxidant parameters and skin papillomagenesis in mice. *Asian Pacific Journal of Cancer Prevention*, 4(2), 131-140.
Bhattacharjee, K.S.,2005. Hand Book of Aromatic Plants. 2nd Revised and Enlarged Edition. Pointer Publishers, India, 298.

Biswas, D., Nandy, S., Mukherjee, A., Pandey, D.K., Dey, A., 2020. *Moringa oleifera* Lam. and derived phytochemicals as promising antiviral agents: A review. *South African Journal of Botany*, 129, 272-282.

Buraimoh, A.A., Bako, I.G., Ibrahim, F.B., 2011. Hepatoprotective effect of ethanolic leave extract of *Moringa oleifera* on the histology of paracetamol induced liver damage in Wistar rats. *International Journal of Animal and Veterinary Advances*, 3(1), 10-13.

Chhikara, N., Kaur, A., Mann, S., Garg, M.K., Sofi, S.A., Panghal, A., 2020. Bioactive compounds, associated health benefits and safety considerations of *Moringa oleifera* L.: An updated review. *Nutrition & Food Science*, 51(2), 255-277.

Chumark, P., Khunawat, P., Sanvarinda, Y., Phornchirasilp, S., Morales, N.P., Phivthong-Ngam, L., Klai-upsorn, S.P., 2008. The *in vitro* and *ex vivo* antioxidant properties, hypolipidaemic and antiatherosclerotic activities of water extract of *Moringa oleifera* Lam. leaves. *Journal of Ethnopharmacology*, 116(3), 439-446.

Coppin, J.P., Xu, Y., Chen, H., Pan, M.H., Ho, C.T., Juliani, R., Wu, Q., 2013. Determination of flavonoids by LC/MS and anti-inflammatory activity in *Moringa oleifera*. *Journal of Functional Foods*, 5(4), 1892-1899.

Dillard, C.J., German, J.B., 2000. Phytochemicals: nutraceuticals and human health. *Journal of the Science of Food and Agriculture*, 80(12), 1744-1756.

Efiong, E.E., Igile, G.O., Mgbeje, B.I.A., Otu, E.A., Ebong, P.E., 2013. Hepatoprotective and anti-diabetic effect of combined extracts of *Moringa oleifera* and *Vernonia amygdalina* in streptozotocin-induced diabetic albino Wistar rats. *Journal of Diabetes and Endocrinology*, 4(4), 45-50.

Ekor, M., 2014. The growing use of herbal medicines: issues relating to adverse reactions and challenges in monitoring safety. *Frontiers in Pharmacology*, 4, 177.

El-Alfy, T.S., Ezzat, S.M., Hegazy, A.K., Amer, A.M., Kamel, G.M., 2011. Isolation of biologically active constituents from *Moringa peregrina* (Forssk.) Fiori.(family: Moringaceae) growing in Egypt. *Pharmacognosy Magazine*, 7(26), 109-115.

Fahey, J.W., 2005. *Moringa oleifera*: a review of the medical evidence for its nutritional, therapeutic, and prophylactic properties. Part 1. *Trees for Life Journal*, 1(5), 1-15.

Fahey, J.W., Olson, M.E., Stephenson, K.K., Wade, K.L., Chodur, G.M., Odee, D., Hubbard, W.C., 2018. The diversity of chemoprotective glucosinolates in Moringaceae (*Moringa* spp.). *Scientific Reports*, 8(1), 1-14.

Fidrianny, I., Kanapa, I., Singgih, M., 2021. Phytochemistry and pharmacology of moringa tree: an overview. *Biointerface Research in Applied Chemistry*, 11(3), 10776-10789.

Fuglie, L.J., 2005. The *Moringa* Tree. A local solution to malnutrition, http://www.moringa news.org/documents/Nutrition, (Accessed:15 March, 2022).

Gopalakrishnan, L., Doriya, K., Kumar, D.S., 2016. *Moringa oleifera*: A review on nutritive importance and its medicinal application. *Food Science and Human Wellness*, 5(2), 49-56.

Gupta, R., Mathur, M., Bajaj, V.K., Katariya, P., Yadav, S., Kamal, R., Gupta, R.S., 2012. Evaluation of antidiabetic and antioxidant activity of *Moringa oleifera* in experimental diabetes. *Journal of Diabetes*, 4(2), 164-171.

Gupta, R.K., 2010. Medicinal and aromatic plants. CBS publishers and distributors, 234, 499.

Hagoel, L., Vexler, A., Kalich-Philosoph, L., Earon, G., Ron, I., Shtabsky, A., Lev-Ari, S., 2019. Combined effect of *Moringa oleifera* and ionizing radiation on survival and metastatic activity of pancreatic cancer cells. *Integrative Cancer Therapies*, 18, 1534735419828829.

Halaby, M.S., Metwally, E.M., Omar, A.A., 2013. Effect of *Moringa oleifera* on serum lipids and kidney function of hyperlipidemic rats. *Journal of Applied Sciences Research*, 9, 5189-5198.

Hamed, M.M., Mohamed, M.A.M., Ahmed, W.S., 2017. Chemical constituents, *in vitro* antioxidant activity, oral acute toxicity and LD_{50} determination of *Moringa oleifera* leaves. *International Journal of Pharmacy and Pharmaceutical Sciences*, 9(5), 240-247.

Hamza, A.A., 2010. Ameliorative effects of *Moringa oleifera* Lam seed extract on liver fibrosis in rats. *Food and Chemical Toxicology*, 48(1), 345-355.

Huang, M., Lu, J.J., Huang, M.Q., Bao, J.L., Chen, X.P., Wang, Y.T., 2012. Terpenoids: natural products for cancer therapy. *Expert Opinion on Investigational Drugs*, 21(12), 1801-1818.

Imran, M., Salehi, B., Sharifi-Rad, J., Aslam Gondal, T., Saeed, F., Imran, A., Estevinho, L.M., 2019. Kaempferol: A key emphasis to its anticancer potential. *Molecules*, 24(12), 2277.

Irfan, H.M., Asmawi, M.Z., Khan, N.A.K., Sadikun, A., Mordi, M.N., 2017. Anti-diabetic activity-guided screening of aqueous-ethanol *Moringa oleifera* extracts and fractions: Identification of marker compounds. *Tropical Journal of Pharmaceutical Research*, 16(3), 543-552.

Isitua, C.C., Ibeh, I.N., Olayinka, J.N., 2016. *In vitro* Antifungal Activity of *Moringa oleifera* Lam Leaf on some selected clinical fungal strains. *Indian Journal of Applied Research*, 6(8), 548-552.

Jaja-Chimedza, A., Zhang, L., Wolff, K., Graf, B.L., Kuhn, P., Moskal, K., Raskin, I., 2018. A dietary isothiocyanate-enriched moringa (*Moringa oleifera*) seed extract improves glucose tolerance in a high-fat-diet mouse model and modulates the gut microbiome. *Journal of Functional Foods*, 47, 376-385.

Kamuhabwa, A., Nshimo, C., de Witte, P., 2000. Cytotoxicity of some medicinal plant extracts used in Tanzanian traditional medicine. *Journal of Ethnopharmacology*, 70(2), 143-149.

Kasolo, J.N., Bimenya, G.S., Ojok, L., Ochieng, J., Ogwal-Okeng, J.W., 2010. Phytochemicals and uses of *Moringa oleifera* leaves in Ugandan rural communities. *Journal of Medicinal Plants Research*, 4(9), 753-757.

Kenwat, R., Prasad, P., Satapathy, T., Roy, A., 2013. *Martynia annua*: an overview. *Pharmaceutical and Biosciences Journal*, 1(1), 7-10.

Kou, X., Li, B., Olayanju, J.B., Drake, J.M., Chen, N., 2018. Nutraceutical or pharmacological potential of *Moringa oleifera* Lam. *Nutrients*, 10(3), 343.

Kumar, S., 2013. Systematic pharmacognostical, phytochemical and pharmacological review on an ethno medicinal plant, *Basella alba* L. *Journal of Pharmacognosy and Phytotherapy*, 5(4), 53-58.

Lalas, S., Tsaknis, J., 2002. Characterization of *Moringa oleifera* seed oil variety "Periyakulam 1". *Journal of Food Composition and Analysis*, 15(1), 65-77.

Leone, A., Spada, A., Battezzati, A., Schiraldi, A., Aristil, J., Bertoli, S., 2015. Cultivation, genetic, ethnopharmacology, phytochemistry and pharmacology of *Moringa oleifera* leaves: An overview. *International Journal of Molecular Sciences*, 16(6), 12791-12835.

Mahajan, S.G., Banerjee, A., Chauhan, B.F., Padh, H., Nivsarkar, M., Mehta, A.A., 2009. Inhibitory effect of n-butanol fraction of *Moringa oleifera* Lam. seeds on ovalbumin-induced airway inflammation in a guinea pig model of asthma. International Journal of Toxicology, 28(6), 519-527.

Mahmood, K.T., Mugal, T., Haq, I.U., 2010. *Moringa oleifera*: a natural gift-A review. *Journal of Pharmaceutical Sciences and Research*, 2(11), 775.

Mbikay, M., 2012. Therapeutic potential of *Moringa oleifera* leaves in chronic hyperglycemia and dyslipidemia: a review. *Frontiers in Pharmacology*, 3, 24.

Mehra, M., Jakhar, N., Joshi, S., Meghwal, M., 2017. Phytotherapaeutic functionality of *Moringa oleifera* Lam for health. *International Journal of Cell Science & Molecular Biology*, 3(2), 42-45.

Mishra, G., Singh, P., Verma, R., Kumar, S., Srivastav, S., Jha, K.K., Khosa, R.L., 2011. Traditional uses, phytochemistry and pharmacological properties of *Moringa oleifera* plant: An overview. *Der Pharmacia Lettre*, 3(2), 141-164.

Mishra, S., Lakhawat, S., Pandey, H., 2020. *Moringa oleifera*: A Miracle Plant. *Popular Kheti*, 8(2), 29-30.

Moyo, B., Masika, P.J., Muchenje, V., 2012. Antimicrobial activities of *Moringa oleifera* Lam leaf extracts. *African Journal of Biotechnology*, 11(11), 2797-2802.

Muhammad, H.I., Asmawi, M.Z., Khan, N.A.K., 2016. A review on promising phytochemical, nutritional and glycemic control studies on *Moringa oleifera* Lam. in tropical and sub-tropical regions. *Asian Pacific Journal of Tropical Biomedicine*, 6(10), 896-902.

Nair, S., Varalakshmi, K.N., 2011. Anticancer, cytotoxic potential of *Moringa oleifera* extracts on HeLa cell line. *Journal Natural Pharmaceuticals*, 2(3), 138-142.

Nandave, M., Ojha, S.K., Joshi, S., Kumari, S., Arya, D.S., 2009. *Moringa oleifera* leaf extract prevents isoproterenol-induced myocardial damage in rats: evidence for an antioxidant, antiperoxidative, and cardioprotective intervention. *Journal of Medicinal Food*, 12(1), 47-55.

Ndiaye, M., Dieye, A.M., Mariko, F., Tall, A., Faye, B., 2002. Contribution to the study of the anti-inflammatory activity of *Moringa oleifera* (Moringaceae). *Dakar Medical*, 47(2), 210-212.

Obi, A., Egwurugwu, J.N., Ojefa, S.O., Ohamaeme, M.C., Ekweogu, C.N., Ogunnaya, F.U., 2018. Immunomodulatory effects of hydromethanolic extract of *Moringa oleifera* leaf on male wistar rats. *Nigerian Journal of Experimental and Clinical Biosciences*, 6(1), 26-32.

Okwari, O., Dasofunjo, K., Asuk, A., Alagwu, E., Mokwe, C., 2013. Anti-hypercholesterolemic and hepatoprotective effect of aqueous leaf extract of *Moringa oleifera* in rats fed with thermoxidized palm oil diet. *Journal of Pharmaceutical and Biological Sciences*, 8, 57-62.

Ouédraogo, M., Lamien-Sanou, A., Ramdé, N., Ouédraogo, A.S., Ouédraogo, M., Zongo, S.P., Guissou, P.I., 2013. Protective effect of *Moringa oleifera* leaves against gentamicin-induced nephrotoxicity in rabbits. *Experimental and Toxicologic Pathology*, 65(3), 335-339.

Owens, F.S., Dada, O., Cyrus, J.W., Adedoyin, O.O., Adunlin, G., 2020. The effects of *Moringa oleifera* on blood glucose levels: a scoping review of the literature. *Complementary Therapies in Medicine*, 50, 102362.

Oyedepo, T.A., Babarinde, S.O., Ajayeoba, T.A., 2013. Evaluation of anti-hyperlipidemic effect of aqueous leaves extract of *Moringa oleifera* in alloxan induced diabetic rats. *International Journal of Biochemistry Research & Review*, 3(3), 162-170.

Paikra, B.K., Gidwani, B., 2017. Phytochemistry and pharmacology of *Moringa oleifera* Lam. *Journal of Pharmacopuncture*, 20(3), 194-200.

Pan, S.Y., Zhou, S.F., Gao, S.H., Yu, Z.L., Zhang, S.F., Tang, M.K., Ko, K.M., 2013. New perspectives on how to discover drugs from herbal medicines: CAM's outstanding contribution to modern therapeutics. *Evidence-Based Complementary and Alternative Medicine*, 2013, 627375.

Pandey, A., Pradheep, K., Gupta, R., Nayar, E.R., Bhandari, D.C., 2011. 'Drumstick tree'(*Moringa oleifera* Lam.): a multipurpose potential species in India. *Genetic Resources and Crop Evolution*, 58(3), 453-460.

Popoola, J.O., Aworunse, O.S., Oyesola, O.L., Akinnola, O.O., Obembe, O.O., 2020. A systematic review of pharmacological activities and safety of *Moringa oleifera*. *Journal of Herbmed Pharmacology*, 9(3), 174-190.

Popoola, J.O., Obembe, O.O., 2013. Local knowledge, use pattern and geographical distribution of *Moringa oleifera* Lam. (Moringaceae) in Nigeria. *Journal of Ethnopharmacology*, 150(2), 682-691.

Rajanandh, M.G., Kavitha, J., 2010. Quantitative estimation of β-sitosterol, total phenolic and flavonoid compounds in the leaves of *Moringa oleifera*. *International Journal of PharmTech Research*, 2(2), 1409-1414.

Rajbhar, Y.P., Rajbhar, G., Rawat, P.L., Shardulya, S., Kumar, M., 2018. Grow *Moringa* (*Moringa oleifera*), the miracle tree on the earth. *Horticulture International Journal*, 2(4), 166-172.

Randriamboavonjy, J.I., Loirand, G., Vaillant, N., Lauzier, B., Derbré, S., Michalet, S., Tesse, A., 2016. Cardiac protective effects of *Moringa oleifera* seeds in spontaneous hypertensive rats. *American Journal of Hypertension*, 29(7), 873-881.

Saini, R.K., 2013. "Studies on enhancement of carotenoids, folic acid, iron and their bioavailability in *Moringa oleifera* and *in vitro* propagation (Doctoral dissertation, University of Mysore).

Saini, R.K., Sivanesan, I., Keum, Y.S., 2016. Phytochemicals of *Moringa oleifera*: a review of their nutritional, therapeutic and industrial significance. *3 Biotech*, 6(2), 1-14.

Sánchez-Machado, D.I., Lopez-Cervantes, J., Vázquez, N.R., 2006. High-performance liquid chromatography method to measure α-and γ-tocopherol in leaves, flowers and fresh beans from *Moringa oleifera*. *Journal of Chromatography A*, 1105(1-2), 111-114.

Sharifudin, S.A., Fakurazi, S., Hidayat, M.T., Hairuszah, I., Aris Mohd Moklas, M., Arulselvan, P., 2013. Therapeutic potential of *Moringa oleifera* extracts against acetaminophen-induced hepatotoxicity in rats. *Pharmaceutical Biology*, 51(3), 279-288.

Shikwambana, N., Mahlo, S.M., 2020. A survey of antifungal activity of selected south African plant species used for the treatment of skin infections. *Natural Product Communications*, 15(5), 1934578X20923181.

Siddhuraju, P., Becker, K., 2003. Antioxidant properties of various solvent extracts of total phenolic constituents from three different agroclimatic origins of drumstick tree (*Moringa oleifera* Lam.) leaves. *Journal of Agricultural and Food Chemistry*, 51(8), 2144-2155.

Singh, A., Navneet, X., 2018. Ethnomedicinal, pharmacological and antimicrobial aspects of *Moringa oleifera* Lam. A review. *The Journal of Phytopharmacology*, 7(1), 45-50.

Singh, A.K., Rana, H.K., Tshabalala, T., Kumar, R., Gupta, A., Ndhlala, A.R., Pandey, A.K., 2020. Phytochemical, nutraceutical and pharmacological attributes of a functional crop *Moringa oleifera* Lam: An overview. *South African Journal of Botany*, 129, 209-220.

Sivasankari, B., Anandharaj, M., Gunasekaran, P., 2014. An ethnobotanical study of indigenous knowledge on medicinal plants used by the village peoples of Thoppampatti, Dindigul district, Tamilnadu, India. *Journal of Ethnopharmacology*, 153(2), 408-423.

Sreelatha, S., Padma, P.R., 2009. Antioxidant activity and total phenolic content of *Moringa oleifera* leaves in two stages of maturity. *Plant Foods for Human Nutrition*, 64(4), 303-311.

Stevens, G.C., Baiyeri, K.P., Akinnnagbe, O., 2013. Ethno-medicinal and culinary uses of *Moringa oleifera* Lam. in Nigeria. *Journal of Medicinal Plants Research*, 7(13), 799-804.

Sudha, P., Asdaq, S.M., Dhamingi, S.S., Chandrakala, G.K., 2010. Immunomodulatory activity of methanolic leaf extract of *Moringa oleifera* in animals. *Indian Journal of Physiology and Pharmacology*, 54(2), 133-140.

Tejas, G.H., Umang, J.H., Payal, B.N., Tusharbinu, D.R., Pravin, T.R., 2012. A panoramic view on pharmacognostic, pharmacological, nutritional, therapeutic and prophylactic values of *Moringa olifera* Lam. *International Research Journal of Pharmaceuticals*, 3, 1-7.

Thurber, M.D., Fahey, J.W., 2009. Adoption of *Moringa oleifera* to combat under-nutrition viewed through the lens of the "Diffusion of Innovations" theory. *Ecology of Food and Nutrition*, 48(3), 212-225.

Toma, A., Deyno, S., 2014. Phytochemistry and pharmacological activities of *Moringa oleifera*. *International Journal of Pharmacognosy*, 1(4), 222-231.

Vergara-Jimenez, M., Almatrafi, M.M., Fernandez, M.L., 2017. Bioactive components in *Moringa oleifera* leaves protect against chronic disease. *Antioxidants*, 6(4), 91.

Vinoth, B., Manivasagaperumal, R., Balamurugan, S., 2012. Phytochemical analysis and antibacterial activity of *Moringa oleifera* Lam. *International Journal of Research in Biological Science*, 2(3), 98-102.

Waterman, C., Cheng, D.M., Rojas-Silva, P., Poulev, A., Dreifus, J., Lila, M.A., Raskin, I., 2014. Stable, water extractable isothiocyanates from *Moringa oleifera* leaves attenuate inflammation *in vitro*. *Phytochemistry*, 103, 114-122.

Zade, V., Dabhadkar, D., 2015. Antifertility effect of alcoholic extract of *Moringa oleifera* stem bark on estrous cycle and estrogenic activity of female albino rat. *American Journal of Advanced Drug Delivery*, 3(3), 223-235.

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