

***Moringa oleifera* Lam.: A Comprehensive Review of its Tree Components, Nutritional Profile, and Therapeutic Potential**

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ABSTRACT

Moringa oleifera Lam., commonly called the drumstick tree, is a fast-growing, drought-resistant plant with wide-ranging uses in nutrition, medicine, agriculture, and environmental sustainability. This review highlights the morphological characteristics, phytochemical richness, and diverse applications of its leaves, seeds, pods, flowers, bark, and roots. Rich in essential nutrients, the leaves serve as effective supplements to combat malnutrition, especially in

developing regions. Seeds yield oil with antioxidant and anti-inflammatory properties and find application in biodiesel production and water purification. The bark and roots exhibit medicinal activities such as antidiabetic, analgesic, and antimicrobial effects. Moreover, its ability to thrive in poor soils and sequester carbon makes it a valuable ally in combating climate change and food insecurity. However, challenges including antinutritional compounds, lack of dosage standardization, and regulatory gaps need attention. Consolidating global research, this review emphasizes *M. oleifera* as a sustainable bioresource and calls for deeper clinical and industrial exploration.

Keywords *Moringa oleifera*, Bioactive compounds, Traditional medicine, Antioxidant activity, Sustainable agriculture.

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INTRODUCTION

Moringa oleifera Lam., a species from the Moringaceae family comprising approximately 13 recognized species, is a fast-growing tropical perennial native to the northwestern regions of the Indian subcontinent. Its cultivation has expanded significantly beyond South and Southeast Asia to regions such as North and South America, the Caribbean, sub-Saharan Africa, the Middle East, Sudan, Indonesia, Florida (USA), and the Pacific Islands (Padayachee and Baijnath 2012, Outani *et al.* 2023). Due to its widespread

distribution and diverse cultural uses, *M. oleifera* is known by various vernacular names including “drumstick tree,” “horseradish tree,” “benzolive tree,” “moonga,” “sajna,” “mlonge,” and “Ben oil tree”(Zainab *et al.* 2020).

Moringa oleifera is widely recognized for its drought tolerance and ability to grow in nutrient-poor soils, primarily due to its tuberous root system (Popoola and Obembe 2013). Its various parts including leaves, seeds, and pods are rich in essential bioactive compounds such as polyphenols, flavonoids, vitamins, and minerals, which contribute to both its nutritional and therapeutic potential (Rockwood *et al.* 2013). Moringa seeds, which account for approximately 33-60% of the seed’s dry weight, are particularly rich in proteins, lipids, and carbohydrates (Vats and Gupta 2017). The tree has been traditionally used in the treatment of several diseases, including diabetes, cardiovascular disorders, herpes, and rheumatism and moringa seeds contain high protein content (~52%) with all the essential amino acids and could act as a potential source of functional protein isolate for application in food and biomedical industries (Kumar *et al.* 2022, Satalangka *et al.* 2013). Furthermore, its leaves and flowers exhibit insecticidal activity against disease vectors such as *Anopheles stephensi* and *Aedes aegypti*, suggesting additional applications in vector control strategies (Brilhante *et al.* 2017).

Saa *et al.* (2019) was highlighted the rich nutritional profile of whole *Moringa oleifera* seeds, emphasizing their high content of bioactive compounds. Among these, alkaloids, glucosinolates, isothiocyanates, and thiocarbamates have garnered attention for their notable pharmacological properties and therapeutic benefits (Leone *et al.* 2016). It functions as a natural windbreak, helping to prevent soil erosion, while its wood is valued for its thermal insulation properties, making it suitable for construction and rural housing applications (Dhakar *et al.* 2011, Outani *et al.* 2023). Beyond its nutritional and medicinal value, *M. oleifera* also contributes significantly to environmental sustainability (Sujatha and Patel 2017). (Němec *et al.* 2020, Al-Khalasi *et al.* 2024). The whole parts of a plant contain valuable and essential therapeutic features; it has the richest content

of antiradical components and nutrients. Various secondary components include hexacosane, pentacosane, phytol, carotenes, tocopherols, isothiocyanates, myricetin, quercetin, kaempferol, rutin, chlorogenic acid, ferulic acid, sinalbin, and gallic acid. In addition to seeds, the leaves of *M. oleifera* are widely utilized in combating malnutrition, particularly in low-income regions, due to their dense concentration of essential micronutrients and antioxidants (Bancesi *et al.* 2020, Singh *et al.* 2022). Across many African regions, the tree has been extensively utilized for food, medicine, and agroforestry applications (El Bilali *et al.* 2024, Daba 2016, Manuwa *et al.* 2020, Singh *et al.* 2020, Shah *et al.* 2024).

Parts of the *M. oleifera* and their composition

Moringa oleifera is widely recognized for its multifunctionality, primarily due to the edibility and utility of nearly all its parts, including leaves, seeds, pods, flowers, and roots. What distinguishes *M. oleifera* from many other plant species is its remarkably high nutritional profile, which includes essential vitamins, minerals, proteins, and antioxidants (Anwar *et al.* 2007). Table 1 presents a comparative overview of the morphological features and primary characteristics of different parts of the *M. oleifera* tree.

Uses of the *M. oleifera*

One of the principal applications of *Moringa oleifera* lies in human nutrition, owing to its dense concentration of essential nutrients. It is widely incorporated into culinary practices, serving as a staple component in cooked meals, salads, soups, and sauces. While numerous plants in nature contribute to restoring physiological balance and promoting well-being, *M. oleifera* stands out as one of the most nutritionally valuable tropical perennial vegetables. A growing spectrum of therapeutic characteristics of leaves has been found and used in the remission or treatment of oxidative stress, liver disease, neurological disease, hyperglycemia and cancer (Hassan *et al.* 2021). Its diverse edible parts offer a rich source of proteins, vitamins, and bioactive compounds. Figure 1 illustrates the key nutritional benefits of *M. oleifera*, and the specific uses of each plant part are detailed in the following sections.

Table 1. Parts of the plant and its main characteristic. (Folorunso *et al.* 2012, Oyeyinka and Oyeyinka,2018).

Various parts	Plant images	Morphological features
Leaves		It is characterized by having compound leaves, alternate and non-stypulous, deciduous, odd or bi-tripinates leaves, with opposite and whole leaflets. They are usually between 25-50 cm long
Flowers		It has bisexual flowers arranged in axillary panicles 10 to 25 cm long. The flowers are certain are cream or white, 5 thin spatulated petals, 5 linear lanceolate sepals and 5 yellow stamens. The stamens are inserted at the edge of the disc, with free filaments and unilocular anthers, bent down words, and oblong. The ovary is stipitate and lanceolate
Pods		The fruits are in the capsule, trivalved and some with oilseeds. They are dehiscent and 20 to 40 cm in length contain 12 to 35 seeds per fruit. During vegetative growth they are white and change their color to brown at maturity
Seeds		Seeds are round to triangular, dark brown with a whitish winged edge, 2.5 to 3 mm long enclosed in hard, lightweight pods
Roots		Pivoting with abundant branching reaching 0.4 to 3 m in length

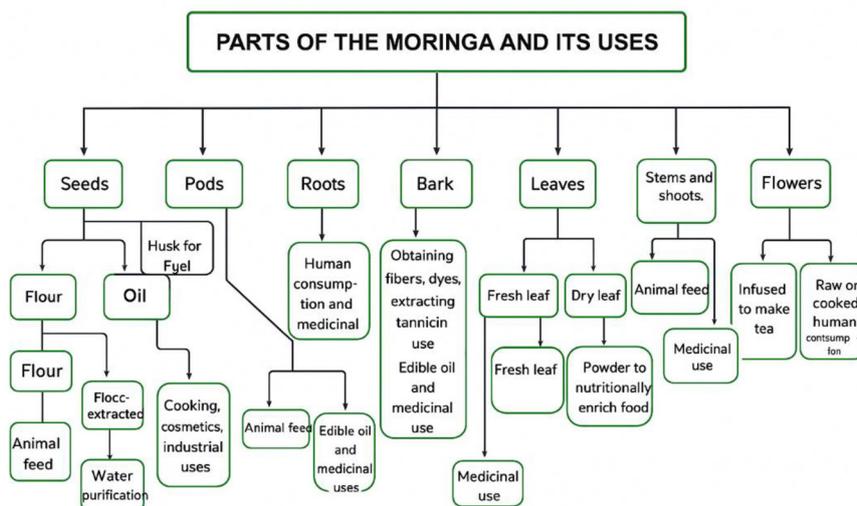


Fig. 1. Parts of the moringa and its uses (Canett-Romero *et al.* 2014).

Leaves

The leaves of *Moringa oleifera* which resemble fern-like foliage possess the highest nutrient density among all parts of the plant. They are particularly rich in protein, comprising approximately 19% to 29% of their dry weight (Cao *et al.* 2023). The leaves are also notable for their abundance of essential vitamins, including vitamin E, and provitamin A (reported to be four times higher than in carrots), as well as vitamin C (up to seven times more than in oranges when fresh), along with several B-complex vitamins. In terms of mineral content, *M. oleifera* leaves contain calcium levels exceeding those found in milk by more than fourfold, and are also rich in iron, making them a valuable dietary component in combating anemia (Oyeyinka and Oyeyinka 2018). Additionally, their potassium content is nearly three times greater than that of bananas, as illustrated in Table 1. Remarkably, except for vitamin C, *M. oleifera* leaf powder retains even higher concentrations of nutrients compared to fresh leaves, rendering it a reliable year-round nutritional supplement, particularly in resource-constrained regions and the high content of phytochemicals, carotenoids, and glucosinolates is responsible for the majority of these activities are reported (Kashyap *et al.* 2022, Price 2007).

The leaves of *Moringa oleifera* offer remarkable culinary versatility and substantial nutritional benefits, making them particularly valuable in regions affected by malnutrition. They can be consumed fresh in salads, vegetable-based dishes, soups, and stews, or used as a seasoning to enhance flavor and nutritional value (Brilhante *et al.* 2017, Srinivasamurthy *et al.* 2017). The resulting powder retains a protein content comparable to soybeans (approximately 22–24%) and is shelf-stable at room temperature, preserving its nutritional integrity over time. This makes *M. oleifera* leaf powder a practical and sustainable solution for addressing protein-energy malnutrition in vulnerable populations (Bancesi *et al.* 2020).

Beyond its extensive use in human nutrition, *Moringa oleifera* leaves have demonstrated significant value in animal feed formulations. Their inclusion in livestock diets has been shown to enhance metabolic efficiency and stimulate beneficial microbial

activity in the gastrointestinal tract (Makanjuola *et al.* 2014, Ariani *et al.* 2023). These benefits have been documented across various species, including goats, sheep, cattle, poultry, and pigs, leading to improved productivity and overall health outcomes (Babiker *et al.* 2017, Mukumbo *et al.* 2014). Observed effects include better feeding behavior and weight gain in sheep and goats, improved milk yield and quality in cows, and increased protein output in pigs (Nurhayati *et al.* 2024). Importantly, the leaves are considered the safest part of the plant when consumed over prolonged periods, with relatively high oral LD₅₀ values 17.8 g/kg body weight for aqueous extracts and 15.9 g/kg for full leaf doses indicating low acute toxicity (Canett-Romero *et al.* 2014, Stohs and Hartman 2015).

Stems, shoots and flowers

The stem pulp of *Moringa oleifera* has found industrial applications, particularly in the production of paper and textiles, due to its fibrous composition (Brilhante *et al.* 2017). In addition to industrial use, the stems and young shoots are also incorporated into animal feed and have been traditionally used for medicinal purposes. The flowers of *M. oleifera* are nutritionally dense, containing essential nutrients such as proteins, calcium, potassium, polyunsaturated fatty acids, and antioxidants like α - and γ -tocopherol. As a result, they are processed into herbal teas, food additives, and dietary supplements (Emmanuel *et al.* 2012). When fried, the flowers reportedly offer a flavor similar to mushrooms, enhancing their culinary appeal.

Moreover, both the pods and seeds of *M. oleifera* have been extensively studied for their nutritional potential. The seeds contain substantial levels of crude protein (9.98–51.80 g), crude fiber (17.26–20.00 g), carbohydrates (3.36–18.00 g), fat (38.67–43.60 g), and ash (3.60–5.00 g) per 100 g highlighting their value as a high-energy, nutrient-rich food source (Falowo *et al.* 2018). The nutritional density of these plant parts supports their utilization in functional foods and animal nutrition.

Moringa oleifera pods are abundant in dietary fiber and contain relatively low levels of lipids, while offering significant amounts of unsaturated and

essential fatty acids most notably oleic acid, which contributes to their cardiovascular health benefits. The dried flowers of *M. oleifera* are widely used in the preparation of herbal teas and have been reported to be excellent sources of essential minerals such as potassium and calcium (Singh *et al.* 2021). In addition to being consumed as infusions, the flowers can be eaten raw or cooked, making them a versatile component of both traditional and functional diets.

Root and bark

Numerous studies have identified the presence of bioactive alkaloids such as moringin and moringinine in *Moringa oleifera* root extracts, which contribute to their reported analgesic effects, including the relief of conditions such as lumbago when administered in appropriate dosages (Mahmood *et al.* 2010). Culinary use of the roots is also common, where they impart a sharp, horseradish-like flavor to sauces and dishes (Kamble *et al.* 2022, Worku and Tolossa 2024). However, caution is warranted, as excessive consumption of various plant parts including roots, seeds, bark, and even leaves can pose health risks (Canett-Romero *et al.* 2014). Specifically, alkaloids like spirochin and benzyl isothiocyanate, found in roots and bark, may become toxic depending on dosage and exposure duration (Paul and Didia 2012). For instance, spirochin has been shown to induce tachycardia at doses as low as 35 mg/kg body weight, and can lead to renal damage when administered periodically at levels exceeding 46 mg/kg. Despite their toxicity potential, these alkaloids possess prophylactic and antiseptic properties, especially effective against gram-positive bacterial pathogens such as *Staphylococcus* and *Streptococcus* (Klimek-Szczykutowicz *et al.* 2024). Additionally, *M. oleifera* bark provides industrially useful compounds like tannins, fibers, and dyes, which are employed in leather tanning and textile processing (Kamble *et al.* 2022).

Pods

Moringa oleifera begins to produce lobed flowers and elongated pods during its second year of growth. The pods are typically harvested while still young, tender, and green, as they offer high nutritional value, including essential amino acids and a range of vitamins and

the nutrient composition, polyphenol content, and antioxidant potential of semolina pasta improved ($p \leq .05$) with increasing pod powder levels (0%–20%) (Kamble *et al.* 2022). These immature pods are consumed both raw and cooked similar to peas or green beans and are often described as having a flavor reminiscent of asparagus. When fully mature, the pods are usually fried and have a taste comparable to peanuts (Xie *et al.* 2024). Mature seeds yield approximately 38–40% edible oil, commonly referred to as Ben Oil, while chemical properties for various applications in food, pharmaceutical and cosmetic industries for development of high value products (Sharma *et al.* 2024). This oil is clear, odorless, mildly sweet, and preserves the natural flavor of food (Liu *et al.* 2018). Rich in monounsaturated fatty acids, particularly oleic acid, Ben Oil mirrors the nutritional profile of olive oil and contains anti-inflammatory compounds beneficial in alleviating symptoms associated with arthritis, rheumatism, and gout (Lakshmi Priya Gopalakrishnan *et al.* 2016).

Historically, *M. oleifera* has been revered for its medicinal value, gaining global interest across the food, pharmaceutical, and cosmetic industries (Gnasegaran *et al.* 2017). Various plant parts leaves, roots, seeds, bark, fruits, flowers, and immature pods exhibit a range of pharmacological activities, including cardiogenic, antitumor, antiulcer, antispasmodic, anti-inflammatory, and antidiabetic effects (Shivanna *et al.* 2024). Notably, the high ascorbic acid content in its tissues has been shown to stimulate insulin secretion, thereby aiding in the regulation of blood glucose levels (Dzuvor *et al.* 2018). A summary of these medicinal properties, categorized by moringa plant part, is presented in the Table 2.

Aqueous extracts from *Moringa oleifera* seeds and fresh leaf juice have demonstrated significant antibacterial activity, particularly against common skin pathogens such as *Staphylococcus aureus* and *Pseudomonas aeruginosa* (Wang *et al.* 2023). The roots and seeds are rich in bioactive compounds, including isothiocyanates and glucomoringin, which are known for their potent antibacterial and antifungal properties (Lakshmidamma *et al.* 2021). Among these, the alkaloid moringin exhibits pharmacological activity similar to ephedrine and

Table 2. Medicinal properties of *M. oleifera* parts.

Part of the plant	Medicinal use	References
Roots	Analgesic, anti-inflammatory, antitumor, antidiabetic, snake bite, antiulcer, antispasmodic, cholesterol-lowering effect, antibacterial, antiurolytic, antifungal, antidiuretic and antihypertensive	(Liu <i>et al.</i> 2018)
Leaves	Anticatarhal, antidiabetic, antiscorb, antihypertensive, antiproliferative, antioxidant, anxiolytic, diuretic, pharyngitis, cholesterol-lowering effect, hemorrhoids, glandular swellings, anti-inflammatory and anti-hyperthyroidism	(Dixit <i>et al.</i> 2016)
Flowers	Anti-inflammatory, antipsychotic and anti-tumor	(Dixit <i>et al.</i> 2016)
Seeds	Antidiuretic, antitumor, genitourinary, antituberculous, anti-asmati antibacterial and hepatoprotective	(Al-Jadabi <i>et al.</i> 2023)

has shown potential in managing bronchial asthma (Adouko *et al.* 2020). The leaves of *M. oleifera* are also rich in various phytochemicals such as sitosterol and phenolic compounds, which are associated with cholesterol-lowering and antioxidant effects (Adouko *et al.* 2020). Additionally, seed infusions have been reported to possess antidiuretic effects, contributing to renal health leaf extracts have further demonstrated anti-proliferative effects against cancer cell lines, suggesting potential chemopreventive properties. Moreover, these extracts have shown regulatory influence on endocrine function and may be beneficial in treating hyperthyroidism. Studies also indicate that aqueous and alcoholic extracts of *M. oleifera* roots possess antiurolytic properties, reducing urinary oxalate, calcium, and phosphate levels, which may offer therapeutic potential for urinary tract conditions (Liu *et al.* 2018).

Seeds

The seeds of *Moringa oleifera* exhibit remarkable versatility, offering valuable applications across multiple industries. The oil extracted from the seeds is particularly esteemed in culinary, cosmetic, and medicinal sectors due to its high oxidative stability and mild aroma (Núñez-Gastélum *et al.* 2023). In the fragrance industry, the oil is especially prized for its ability to absorb and retain scents, making it a key component in deodorants and perfumes (Das *et al.* 2024). Furthermore, specific protein fractions and peptides present in the seed oil contribute to skincare and haircare formulations by providing antioxidant protection against environmental stressors and mit-

igating signs of premature aging (Das *et al.* 2024). Globally, seed extracts are also used in hair care products for their nourishing and restorative properties.

Beyond personal care, *M. oleifera* seed cake obtained after oil extraction has gained prominence as a natural coagulant in water purification processes (Fatima *et al.* 2023). Its protein content facilitates the flocculation of impurities, thus offering a low-cost solution to combat waterborne diseases in developing regions (Srivastava *et al.* 2023). Despite efforts to incorporate *M. oleifera* seeds into food products like fortified cookies and weaning flours, widespread human consumption is limited by challenges such as inherent bitterness and the presence of antinutritional factors like lectins (Saa *et al.* 2019). Nonetheless, the seeds comprising up to 40% oil content are considered a promising raw material for biodiesel production, offering an eco-friendly alternative energy source (Raman *et al.* 2018). Overall, *M. oleifera* seeds stand out for their broad-spectrum utility in personal care, environmental sustainability, and renewable energy sectors (Fernandes *et al.* 2015).

Challenges and future perspectives

Despite its diverse applications, several challenges must be addressed before *Moringa oleifera* can be fully integrated into mainstream nutrition and healthcare systems.

Presence of antinutritional compounds

Various parts of *M. oleifera*, especially seeds and

roots, contain antinutritional factors such as phytates, tannins, saponins, and lectins. These compounds can interfere with mineral absorption, reduce protein digestibility, and pose toxicity risks when consumed in excessive amounts. For instance, spirochin (in roots) and benzyl isothiocyanate may cause neurological and renal complications at higher doses (León López *et al.* 2020).

Lack of dosage standardization

Although many studies highlight its pharmacological potential, there is no consensus on safe therapeutic dosages for human consumption. Variations in plant part, cultivation region, and processing methods result in inconsistent phytochemical profiles, making it difficult to establish universally accepted dosage guidelines. Controlled clinical trials are urgently required to define dose-response relationships and establish standardized recommendations (Azlan *et al.* 2022).

Regulatory gaps

Currently, Moringa-based products are marketed largely as dietary supplements with minimal regulatory oversight. This can lead to issues such as adulteration, mis-labelling, and unverified health claims. Establishing robust quality-control protocols, certification standards, and global regulatory frameworks will be essential to ensure consumer safety and promote sustainable commercialization (Azlan *et al.* 2022).

Research and Policy Recommendations

Future research should focus on developing detoxification techniques to reduce antinutritional compounds, standardizing extraction processes, and conducting multicentric clinical studies. Policymakers should consider including Moringa-based interventions in public nutrition programs, supported by guidelines on dosage, safety, and product quality control (Zhang *et al.* 2024).

CONCLUSION

Moringa oleifera, commonly referred to as the drumstick tree, is a multifaceted botanical resource offering

exceptional value across nutritional, medicinal, environmental, and industrial domains. Each component of the tree leaves, seeds, pods, flowers, bark, and roots exhibits a unique spectrum of bioactive compounds including vitamins, minerals, phenolics, flavonoids, and alkaloids. These confer significant antioxidant, anti-inflammatory, antimicrobial, antidiabetic, and cardioprotective properties, positioning Moringa as a promising natural remedy in traditional and modern therapeutic systems. Nutritionally, its leaves and seeds serve as potent supplements against protein-energy malnutrition, particularly in low-income regions. Industrially, Moringa seed oil finds application in biodiesel, cosmetics, and water purification, while the defatted seed cake contributes to environmental remediation. Despite these benefits, constraints such as the presence of antinutritional factors, variability in phytochemical composition, and limited clinical validations pose challenges for mainstream adoption. Furthermore, its role in climate-resilient agriculture and carbon sequestration highlights its relevance to sustainable development goals. To unlock its full potential, interdisciplinary research focusing on toxicology, standardized extraction, clinical trials, and global regulatory frameworks is essential. Overall, *Moringa oleifera* emerges as a strategic multipurpose plant capable of addressing public health, nutritional security, and environmental sustainability in an integrated manner.

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