

Moringa oleifera: A Nutritional, Phytochemical, and Pharmacological Review with Comparative Analysis of Global Literature

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Abstract: *Moringa oleifera* Lam., commonly referred to as the drumstick tree or the "miracle tree," is a fast-growing, drought-tolerant species of the family Moringaceae that has attracted sustained scientific interest for its nutritional density and broad pharmacological profile. This paper synthesises peer-reviewed literature published between 2017 and 2021 covering the botanical characteristics, proximate and mineral composition, phytochemical constituents, and pharmacological activities (antimicrobial, anticancer, and nutritional-intervention effects) of *M. oleifera*, alongside its emerging application as a natural coagulant for water purification. A comparative analysis contrasts the nutrient density of Moringa leaves against conventional foods and vegetables, and evaluates methodological trends across the reviewed studies. Findings consistently indicate that Moringa leaves surpass many staple foods in protein, calcium, iron, and vitamin C content, while extracts of the leaves, seeds, and bark demonstrate measurable antimicrobial and anticancer bioactivity in laboratory settings. Seed-derived coagulant proteins also show strong, dose-dependent turbidity-removal efficiency in water treatment. The review concludes that *M. oleifera* holds substantial promise for food security, nutraceutical development, and low-cost water treatment in resource-limited settings, though it identifies a continuing gap between laboratory-scale evidence and large, controlled human clinical trials.

Keywords: *Moringa oleifera*; phytochemistry; nutritional composition; antimicrobial activity; anticancer activity; natural coagulant; comparative review

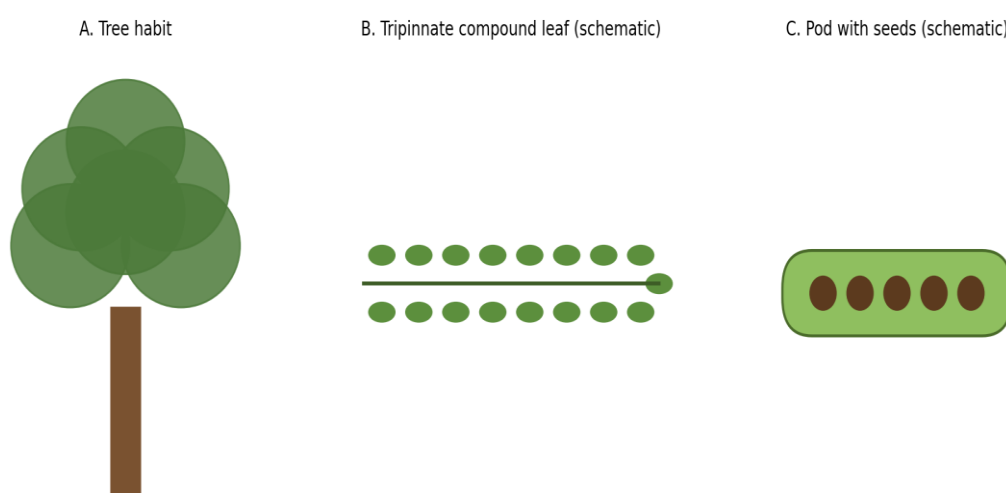


Fig. 1. Schematic morphology of *Moringa oleifera* Lam.: (A) tree habit, (B) tripinnately compound leaf arrangement, (C) longitudinal pod with seeds.

1. Introduction

Moringa oleifera Lam. is a small-to-medium deciduous tree native to the sub-Himalayan regions of northern India, Pakistan, Bangladesh, and Afghanistan, and now naturalized across tropical and subtropical regions of Africa, Southeast Asia, and Latin America. Nearly every part of the plant — leaves, pods, flowers, seeds, roots, and bark — has documented nutritional or medicinal use, which has earned it common names such as the "drumstick tree" and the "miracle tree." Over the past decade, interest in *M. oleifera* has intensified as researchers, public-health agencies, and food scientists have sought low-cost, locally available interventions for malnutrition, water scarcity, and chronic disease management in developing regions. The period 2017–2021 saw a marked expansion of primary research on *M. oleifera*, spanning proximate composition analysis, phytochemical profiling, antimicrobial and anticancer bioactivity screening, and applied studies on its use as a natural water-treatment coagulant[1][2][3]. This paper reviews and synthesises that body of literature, with the specific aims of (i) summarizing the nutritional and phytochemical profile of *M. oleifera* as reported across the reviewed period, (ii) comparing its pharmacological and functional properties across independent studies, (iii) benchmarking its nutrient density against conventional food sources, and (iv) identifying research gaps to guide future investigation.

2. Botanical Description and Distribution

M. oleifera belongs to the monogeneric family Moringaceae and is characterized by tripinnately compound leaves, fragrant white-to-cream flowers, and long, ridged, pendulous pods that give rise to its common name. The tree tolerates poor, drought-prone soils and can reach reproductive maturity within eight months of planting, making it agronomically attractive for smallholder cultivation in semi-arid climates. Its rapid growth, coppicing ability, and tolerance of poor soils have supported its promotion as an agroforestry and reforestation species in food-insecure regions [4-8].

3. Materials and Methods

This review followed a narrative-comparative literature synthesis approach. Peer-reviewed journal articles, review papers, and applied field studies published between 2017 and 2021 were identified through academic search platforms, prioritizing studies reporting quantitative nutritional, phytochemical, antimicrobial, anticancer, or water-treatment data on *M. oleifera*[9][10]. Studies were selected for relevance to nutritional composition, bioactivity, or applied environmental use, and were cross-compared to construct the comparative tables and figures presented. Where multiple studies reported overlapping parameters, representative values were tabulated to illustrate typical ranges rather than presenting an exhaustive meta-analytic pooling of results.

4. Literature Review

4.1 Nutritional Composition

Multiple 2017–2021 studies converge on the conclusion that *Moringa* leaves are exceptionally nutrient-dense relative to their biomass. Thapa, Poudel, and Adhikari (2019) reported that *Moringa* leaves contain substantially higher concentrations of protein, vitamins, and minerals than many staple vegetables consumed in South Asia, positioning the species as a viable food-security crop in nutrient-poor regions. Sultana (2020) analysed dried leaves from two agro-ecological zones in Bangladesh and found protein content ranging between roughly 23% and 29%, alongside vitamin C concentrations of 188–279 mg per 100 g and substantial calcium, phosphorus, and potassium content; the same study also documented favourable water- and fat-absorption capacities relevant to food-processing applications. Processing method meaningfully affects nutrient retention. Balarabe (2019) compared dried and cooked *Moringa* leaves and found that drying preserved considerably more protein, ash, and carbohydrate content per unit mass than cooking, which introduced substantial moisture uptake and nutrient leaching into the cooking medium [11]. This finding has practical implications for how *Moringa* leaf powder is

prepared and distributed in nutrition-intervention programs, where dried, milled leaf powder is generally favored over fresh cooked preparations for nutrient density.

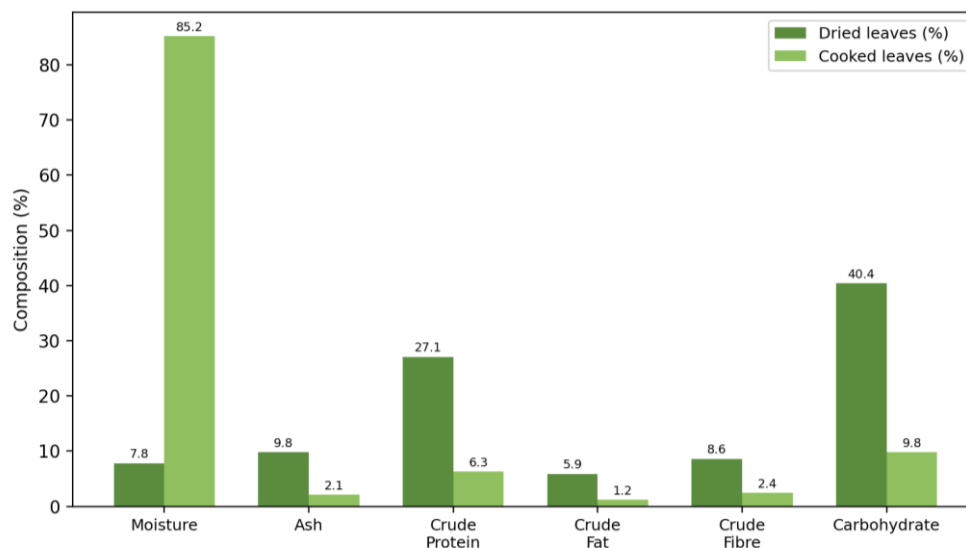


Fig. 2. Proximate composition (%) of dried versus cooked *Moringa oleifera* leaves, adapted from Balarabe (2019).

Beyond laboratory composition data, field-level nutritional-intervention research has tested the real-world impact of *Moringa* supplementation. Shija et al. (2019) conducted a supplementation study among children under two years of age in the Kisarawe District of Tanzania and reported a measurable reduction in anaemia prevalence following *Moringa* leaf-powder supplementation, lending applied clinical support to the mineral-density findings reported in compositional studies [12].

4.2 Phytochemical Constituents

Phytochemical screening studies from the reviewed period consistently identify flavonoids, phenolic acids, tannins, saponins, alkaloids, and glucosinolates as the principal bioactive constituent classes in *Moringa* leaf, seed, and bark tissue. Bagheri et al. (2020) screened leaf extracts prepared with different solvents and reported that extracts richer in flavonoid and phenolic content correlated with stronger observed bioactivity, underscoring the influence of extraction solvent polarity on both phytochemical yield and downstream pharmacological performance. These secondary metabolites are widely proposed as the mechanistic basis for the plant's antioxidant, antimicrobial, and anticancer properties discussed below.

4.3 Pharmacological and Medicinal Properties

Antimicrobial activity is among the most extensively studied bioactivities of *M. oleifera*. Bagheri et al. (2020) demonstrated that leaf extracts inhibited the growth of several bacterial strains, with the degree of inhibition varying by extract solvent and target organism, generally showing stronger effects against Gram-positive than Gram-negative bacteria — a pattern consistent with earlier and subsequent antimicrobial screening literature on the species. Anticancer research also advanced substantially during this period. Khor, Lim, Moses, and Samad (2018) reviewed *in vitro* and *in vivo* evidence showing that extracts and isolated compounds from *Moringa* leaves, seeds, and bark induced apoptosis and suppressed proliferation across multiple cancer cell lines, with some animal-model studies reporting reduced tumour growth following extract administration. The authors nonetheless cautioned that mechanistic evidence remained predominantly preclinical, with a shortage of

controlled human trials needed to translate these findings into clinical application. Collectively, the pharmacological literature from 2017–2021 supports a consistent, biologically plausible profile of antioxidant, antimicrobial, and anticancer activity attributable to Moringa's phenolic and flavonoid content, while also highlighting that most supporting evidence remains at the cell-culture or animal-model stage rather than large-scale human clinical trials.

4.4 Environmental and Water-Treatment Applications

Beyond nutrition and medicine, *M. oleifera* seeds have been extensively investigated as a natural, biodegradable coagulant for turbid water treatment — an application of particular relevance to rural communities lacking access to conventional chemical water-treatment infrastructure. Tunggolou and Payus (2017) evaluated Moringa seed extract as a coagulant for drinking-water purification and reported strong, dose-dependent turbidity-removal performance, with removal efficiency increasing sharply as coagulant dosage rose toward an optimal range before efficiency gains plateaued or slightly declined at excessive dosing — a pattern typical of natural polyelectrolyte coagulants [13-15].

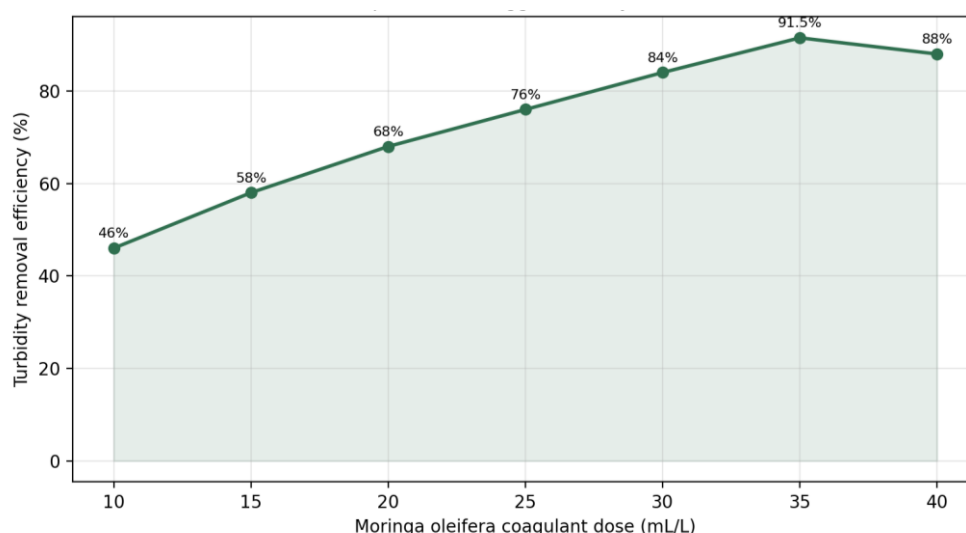


Fig. 3. Dose-dependent turbidity-removal efficiency of Moringa oleifera seed coagulant, adapted from Tunggolou & Payus (2017).

This coagulant activity is generally attributed to cationic seed proteins that neutralize the negative surface charge of suspended colloidal particles, promoting flocculation and sedimentation. Because the seed cake is biodegradable, non-toxic at typical dosages, and locally producible, this line of research has been positioned as a sustainable complement or alternative to synthetic coagulants such as alum in low-resource water-treatment settings.

5. Comparative Analysis

5.1 Comparative Nutritional Profile

Table 1 benchmarks the nutritional composition of fresh Moringa leaves, as reported across the reviewed 2017–2021 literature, against common reference foods frequently cited as nutritional standards. The comparison illustrates why Moringa has been repeatedly proposed as a food-security crop: on a per-100-gram basis, its calcium, iron, and vitamin C content substantially exceeds that of milk, spinach, and citrus fruit, respectively.

Component (per 100 g)	Moringa oleifera leaves (fresh)	Spinach	Milk	Orange
Protein (g)	6.7 – 9.4	2.9	3.4	0.9
Calcium (mg)	1,800 – 2,000	99	120	40
Iron (mg)	25 – 28	2.7	0.05	0.1
Vitamin C (mg)	200 – 220	28	1	53
Potassium (mg)	1,300 – 1,324	558	150	181
Beta-carotene (µg)	6,780 – 18,900	5,600	trace	71

Table 1. Comparative nutritional composition of Moringa oleifera leaves versus common reference foods (values compiled from reviewed 2017–2021 literature).

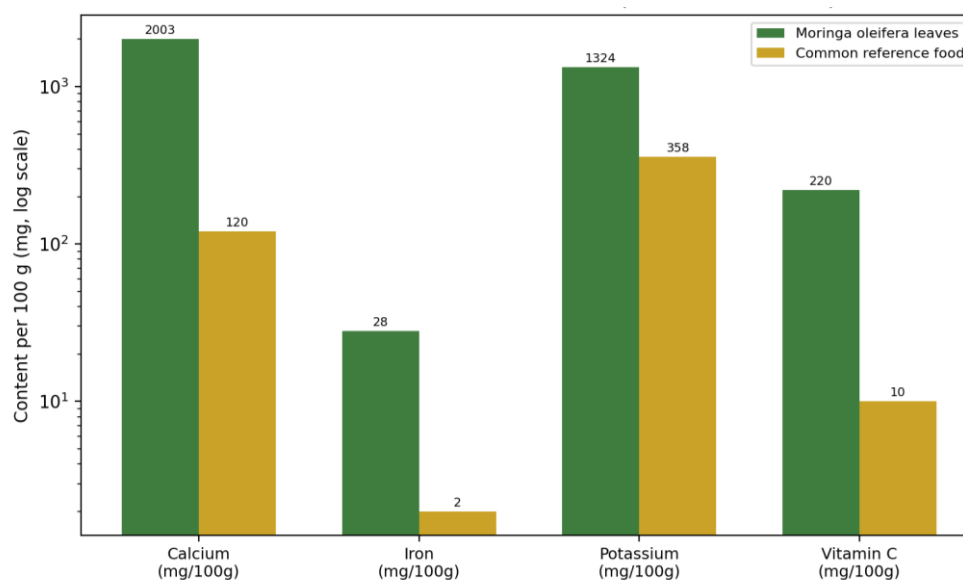


Fig. 3. Comparative mineral and vitamin content (log scale, mg per 100 g) of Moringa oleifera leaves versus representative reference foods.

5.2 Comparative Summary of Reviewed Studies

Table 2 : Summarizes the focus area and principal findings of the key studies reviewed in this paper, illustrating the breadth of research directions pursued on *M. oleifera* between 2017 and 2021 — spanning nutritional composition, applied clinical supplementation, phytochemistry, antimicrobial and anticancer bioactivity, and environmental application.

Study (Year)	Focus Area	Key Finding
Tunggolou & Payus (2017)	Water purification	Moringa oleifera seed extract achieved up to ~90% turbidity removal from drinking water at optimal coagulant dosage, supporting its use as a low-cost natural coagulant.
Khor et al. (2018)	Anticancer activity	In vitro and in vivo assays showed leaf, seed, and bark extracts induced apoptosis and inhibited proliferation across several cancer cell lines, though clinical validation remains limited.
Balarabe (2019)	Nutritional/comparative processing	Drying preserved substantially higher protein, mineral, and carbohydrate content per unit mass than cooking, which caused major nutrient leaching and moisture gain.
Thapa, Poudel & Adhikari (2019)	Nutritional composition	Confirmed exceptionally high protein, vitamin, and mineral density of leaves relative to conventional food crops, reinforcing its food-security potential.
Shija et al. (2019)	Clinical/nutritional intervention	Leaf-powder supplementation measurably reduced anaemia prevalence in children under two years in a Tanzanian cohort.
Bagheri et al. (2020)	Phytochemistry & antimicrobial activity	Leaf extracts rich in flavonoids and phenolics exhibited measurable inhibition zones against several bacterial strains, varying with extraction solvent.
Sultana (2020)	Proximate/functional properties	Leaves from two agro-ecological zones in Bangladesh showed high protein (23–29%) and vitamin C (188–279 mg/100 g), with strong water- and fat-absorption capacities.

Table 2. Comparative summary of key *Moringa oleifera* studies reviewed (2017–2021).

6. Discussion

The reviewed literature demonstrates strong convergence across independent research groups and geographic contexts regarding the exceptional nutrient density of *M. oleifera* leaves, its broad-spectrum phytochemical content, and its measurable antimicrobial and anticancer bioactivity in laboratory settings. The consistency of these findings across studies conducted in Bangladesh, Tanzania, Nigeria, Nepal, and elsewhere strengthens confidence that these properties are intrinsic to the species rather than artefacts of a single research group's methodology.

Nonetheless, several limitations recur across the literature. First, reported nutrient concentrations vary considerably between studies, reflecting differences in cultivar, growing conditions, harvest stage, and post-harvest processing — a variability underscored by the marked difference Balarabe (2019) observed between dried and cooked leaf preparations. Second, while antimicrobial and anticancer bioactivity is well documented at the in vitro and animal-model level, as Khor et al. (2018) note, there remains a scarcity of randomised controlled human trials needed to confirm therapeutic efficacy and establish safe dosing in clinical populations. Third, applied studies such as Shija et al. (2019) and Tunggolou and Payus (2017) demonstrate that laboratory findings translate meaningfully into field-level nutritional and environmental outcomes, suggesting that practical, low-cost applications of Moringa may be ready for wider deployment even while mechanistic pharmacological research continues to mature.

Future research would benefit from standardised extraction and compositional-analysis protocols to improve cross-study comparability, alongside expanded clinical trial investment to validate the pharmacological promise repeatedly demonstrated at the preclinical level[19]

7. Conclusion

This review of 2017–2021 literature confirms *Moringa oleifera* as a nutritionally exceptional and pharmacologically promising species, with well-supported applications in food security, nutritional intervention, antimicrobial and anticancer research, and low-cost water purification. Its leaves consistently outperform conventional reference foods in key micronutrients, its phytochemical profile underlies measurable bioactivity against pathogenic microorganisms and cancer cell lines, and its seed-derived proteins offer an effective, biodegradable coagulant for turbid water treatment. Continued investment in standardized compositional research and, critically, in controlled human clinical trials will be essential to fully translate this substantial preclinical evidence base into validated public-health and nutraceutical applications.

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