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A Systematic Review Using the PRISMA Methodology on Nutrients and Antioxidant Capacity in Moringa (*Moringa oleifera* Lam.) and Its Applications in the Food Industry

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ABSTRACT

Moringa oleifera Lam. is gaining popularity due to its versatility in growing in various environments and its nutritional and medicinal properties. This systematic review, conducted using the PRISMA methodology, synthesizes literature from PubMed and Web of Science to address the growing interest in *M. oleifera* within the food industry. The edible parts of *M. oleifera* are rich in protein, minerals, and vitamins, making it an excellent food supplement to meet nutritional needs and balance the diet. This plant also contains a significant amount of functional bioactive compounds, such as polyphenols and flavonoids. Given its high nutrient content, combined with its low-cost and easy cultivation, *M. oleifera* holds a promising potential for the Australian food industry. Many parts of *M. oleifera* have significant utility across culinary, nutritional, pharmacological, and phytochemical domains. For example, Moringa leaves and seeds can be used as a nutritional enhancer in wheat-based products or snacks and as ingredients in medicinal formulations. Overall, this systematic review highlights the significant antioxidant potential of *M. oleifera* and its implications for improving nutritional strategies and health outcomes within the food industry. The findings support further exploration of the multifaceted benefits of *M. oleifera* and its integration into dietary and medicinal applications.

KEYWORDS
Fortification; Moringa; phenolic compounds; phytochemicals; polyphenol

Introduction

Moringa (*Moringa oleifera* Lam.) is a multipurpose tree that grows extensively in tropical and subtropical regions across the world. The plant is indigenous to the western and southern parts of the Himalayas, along with India, Asia Minor, Africa, Arabia, and Pakistan. Nowadays, it is extensively cultivated in several regions, such as Central, South, and North America, Cambodia, the Philippines, and the Caribbean Islands.[1]

Moringa has been extensively studied for its potential to provide ecologically sustainable and economically viable nutritious food around the world, especially in malnourished populations.[2] Moringa is rich in protein, dietary fibre, vitamins, and minerals, making it an ideal source as a functional food ingredient. In addition, an abundance of bioactive compounds such as flavonoids, phenolic acids, and tannins, contributes to the potent antioxidant properties of Moringa.[3] Pharmacological studies have demonstrated that extracts

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from different parts of Moringa have antioxidant,[4] antidiabetic, antibacterial,[5] and anticancer properties.[6] Numerous studies have shown that all parts of Moringa plant, including leaves, seeds, pods, and flowers contain phytochemical compounds with nutritional and functional properties.[7] Therefore, the use of Moringa as a functional food source with therapeutic benefits has been gaining attention in recent years. Although there has been much research on the composition of Moringa, further research is needed on its nutritional and functional components, their specific applications in the food industry, and their efficacy when consumed. This systematic review aims to address this knowledge gap by compiling and analysing existing studies on the composition and application of Moringa within the food industry, following the guidelines of Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA).

Botany: morphology and cultivation

Moringa is a genus in the Moringaceae family, consisting of 13 species found worldwide. *Moringa oleifera*, *Moringa stenopetala*, and *Moringa peregrina* are among the commonly cultivated species.[1] It is a perennial and deciduous plant, surviving in cold conditions but cannot tolerate severe cold. This plant produces flowers and pods one to three times per year, depending on the variety.[8] The number of secondary rachises on the main rachis significantly influences the biomass production. The flowers are zygomorphic and range in colour from white to cream. Each flower contains five sepals, ten petals, and ten stamens of which five with anthers and five without anthers.[9] The petals are longer and unequal. Pods can grow up to 30 cm (12 inches) in length and contain numerous seeds. The pods are initially green and turn brown as they mature.

Moringa is typically grown under tropical and subtropical climatic regions, where it thrives best at temperatures ranging from 25 to 35°C.[10] For ideal growth, the soil should have a sandy or loamy texture and a pH level that ranges from slightly acidic to slightly alkaline. Additionally, the favourable rainfall range for optimal growth is between 250 to 3000 mm. In general, Moringa is highly adaptable and can grow in various environmental conditions and soil types, making it conducive to cultivation in many parts of the world.[11] Due to its ability to thrive under diverse circumstances, it can be grown on a small to large scale, presenting the potential for smallholder farming sectors to substantial commercial benefits.[12]

Methodology

This systematic review employed the PRISMA guidelines in order to ensure methodological rigor and transparency. The PRISMA serves as a standard approach in systematic review methodology that provides a standardized framework ensuring the highest standards of transparency, reproducibility, and scientific rigor. By carefully following the PRISMA checklist and documenting the entire process, including through a PRISMA flow diagram, we aimed to minimize bias and increase the credibility of the findings of researchers.[13,14]

Literature search

The systematic review followed a structured approach: (1) formulating research questions, (2) identifying pertinent literature, (3) selecting studies, and (4) extracting data adhering to the PRISMA flow diagram. Searches were conducted in PubMed and Web of Science databases using specific subject headings and English language criteria. Search terms included keywords related to Moringa, its nutritional components (such as nutrients, antioxidants, polyphenols, bioactive compounds), and its application in the food industry. Citation management and duplicate removal were facilitated using EndNote 21 software.

Selection criteria

As shown in Fig. 1, initial screening involved evaluating titles and abstracts. Articles were excluded if they were: (1) general reviews; (2) non-English; (3) published before 2000; (4) not peer-reviewed; (5) unrelated to the topic or (6) not directly relevant to the scope of this review. Studies were included if they focused on: (1) the nutritional and antioxidant properties of Moringa; or (2) specific applications of Moringa in the food industry. Full-text articles underwent further review and were excluded if: (1) nutrient or antioxidant data were unclear; (2) bioactive compounds were unspecified; (3) specific data were missing; (4) full text was inaccessible; or (5) the study lacked direct relevance to food industry applications.

Risk of bias assessment

Bias assessment in this review utilized criteria tailored for nutritional and food science studies, adapted from The Methods Guide for Comparative Effectiveness Reviews.[15] The evaluation was conducted

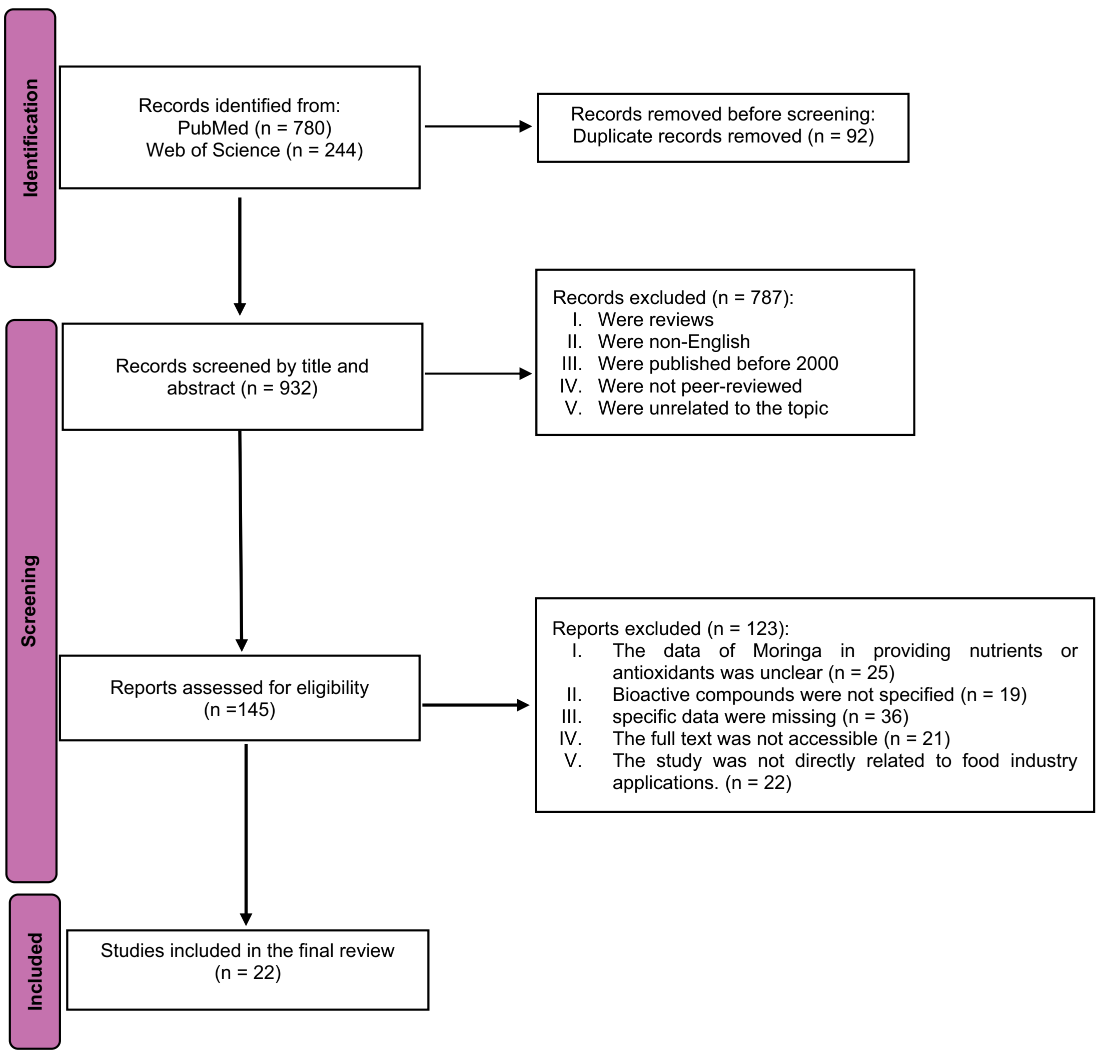

Figure 1. PRISMA flow diagram of literature search and screening of *M. oleifera*.

using the specific form detailed in Table 1. Each bias-related question score is 0–2, where 0 indicates not reported/unclear, 1 indicates not adequately assessed, and 2 indicates adequately assessed, as described by Andreo-Martinez et al.[38] as follows:

(1) Scored based on aim clarity: 0 for unclear alignment with Moringa research, 1 for ambiguous aims, and 2 for clearly stated aims.
(2) Scored based on experimental design clarity: 0 for unreported design, 1 for unclearly reported design, and 2 for accurately reported design, focusing on methods for assessing Moringa's nutritional and antioxidant properties.
(3) Scored based on sample identification and evaluation: 0 for no reported Moringa properties, 1 for partial reporting (e.g., nutrients or antioxidants), and 2 for comprehensive profiles including polyphenols, vitamins, and bioactive compounds.
(4) Scored based on comparability or reproducibility: 0 for requiring sophisticated instruments and low reproducibility, 1 for moderate reproducibility with less sophisticated equipment, and 2 for easy reproducibility in standard food science labs.
(5) Scored based on clarity of bias assessment: 0 for poorly described abstract, methods, and conclusions, 1 for brief descriptions, and 2 for clear and comprehensive descriptions.

Table 1. Summary of bias scoring for the selected articles*.

Items	1. Clear aim statement	2. Accurate experimental design	3. Identification and evaluation of sample	4. Comparability or reproducibility	5. Other biases	6. Adequate statistical analysis	Total score	Overall bias risk level
Sánchez-Machado et al.[16]	2	2	2	1	2	1	10	L
Qadir et al.[17]	2	2	2	2	2	2	12	L
Shih et al.[18]	2	2	2	1	2	1	10	L
Adisakwattana and Chanathong[19]	1	2	2	2	2	1	10	L
El-Shehawi et al.[20]	2	2	2	1	2	0	9	M
Xu et al.[21]	2	2	2	2	2	1	11	L
Teixeira et al.[22] du Toit et al.[23]	1	2	2	2	2	2	11	L
Jahan et al.[24]	2	1	2	1	2	2	10	L
Park et al.[25]	2	2	2	2	2	0	10	L
Hussin et al.[26]	2	2	2	1	2	1	10	L
Bolarinwa et al.[27]	1	2	2	2	1	1	9	M
Katmawanti et al.[28]	2	2	2	2	2	0	10	L
Roni et al.[29]	2	2	2	2	2	1	11	L
Agba et al.[30]	2	2	2	2	2	1	11	L
Zhang et al.[31]	2	2	2	2	2	1	11	L
Jideani et al.[32]	1	1	2	2	2	1	9	M
Vanajakshi et al.[33]	1	2	2	2	2	1	10	L
Gomes et al.[34]	2	1	1	1	2	1	8	M
Ademosun[35]	2	2	2	1	1	0	8	M
Madane et al.[36]	2	2	2	2	2	2	12	L
González-Burgos et al.[37]	2	2	1	2	2	1	10	L

*The bias assessment involved two reviewers to maintain objectivity and consistency. Scorings ranged from 0 (not reported/unclear) to 1 (not adequately assessed) and 2 (adequately assessed). The overall risk of bias was categorized into three levels based on total scores: H (high, 6–0), M (moderate, 7–9), and L (low, 10–12)

(6) Scored based on the adequacy of statistical analyses: 0 for no statistical analysis, 1 for incomplete analysis, and 2 for detailed analysis including means, standard deviations, and appropriate statistical tests.

Data extraction and management

Extracted data included the specific parts of Moringa used, the extraction methods or states of the samples, detailed nutrient and antioxidant profiles of Moringa, and the common applications in the food industry.

Nutritional composition

Numerous studies have shown various nutritional content across different parts of *Moringa oleifera*, making it a valuable source of food, fibre and medicine. Moringa is low in carbohydrates and fat, but rich in protein, essential amino acids, vitamins, minerals, antioxidants, and bioactives. The nutrients and phytochemicals in the leaves and seeds of Moringa are detailed in Fig. 2. Some studies have demonstrated that the nutritional profile in Moringa can be attributed to factors such as genetic diversity, soil composition, fertiliser application, water availability, plant age, and harvesting stages. The differences in processing methods, such as drying and extraction techniques, can further influence the nutritional profile of Moringa.[39] For example, several researchers have analysed the protein content in leaves and pods of different Moringa cultivars, indicating that the average protein content in leaves ranges from 29–33 g/100 g, while in pods ranges from 2.5–13.8 g/100 g (Table 2). Similarly, it has also been found that the fat content varies in different parts of the Moringa plant: 5.0–30.6 g/100 g in fresh leaves, 0.1–0.5 g/100 g in fresh pods, and 38.2–40.3 g/100 g in fresh seeds. Moringa is a plant that is rich in polyunsaturated fatty acids, such as omega-3 and omega-6. These fatty acids have the potential to improve cardiovascular health, mood stimulation, and overall well-being. Moringa possesses minimal amounts of saturated fatty acids with high levels of monounsaturated fatty acids. In addition, Ma et al.[40] reported that Moringa pods contain up to 47% fibre, which is comparable to the levels found in high-fibre sources like edible seaweeds (around 53.9–76.9 g/100 g dry weight).[41]

Numerous studies have demonstrated that Moringa is abundant in trace elements and minerals, comprising six macro minerals (calcium, magnesium, phosphorus, potassium, sodium, and sulphur) and five trace elements (zinc, copper, iron, manganese, and selenium).[42] Due to its rich content of macro and trace elements, Moringa leaf powder has garnered significant interest for nutrient fortification, particularly in improving nutrition for children and women. Incorporating Moringa leaf powder into foods, such as bread, has been shown to enhance nutrient content, including calcium, magnesium, and beta-carotene.[43] In addition, zinc contained in Moringa is essential for DNA and RNA synthesis, helping humans meet their daily dietary zinc intake requirements.[44] Moringa also contains a variety of vitamins, such as vitamins A, B, C, D, and E.[6,45] Research shows that fresh leaves contain seven times more vitamin C compared to oranges, twenty-five times more iron than spinach, four times more proteins than egg, ten times more vitamin A than carrot, seventeen times more calcium than milk, fifteen times more potassium than banana.[46] Beyond its high nutritional quality, Moringa emerges as a sustainable and economically viable nutrient supplement, particularly beneficial for addressing malnutrition or deficiencies in developing countries.[2] Because of its favourable nutritional and cultivation properties, Moringa can promote food security within rural development initiatives and support sustainable land use due to its fast establishment, resilience under hot and dry conditions as well as fixing nitrogen in the soil as it belongs to the Leguminosae family.

Bioactive compounds

Moringa is widely known for its high-value potential with a wide range of bioactive compounds, classified as secondary metabolites or phytochemicals. These compounds include alkaloids, saponins,

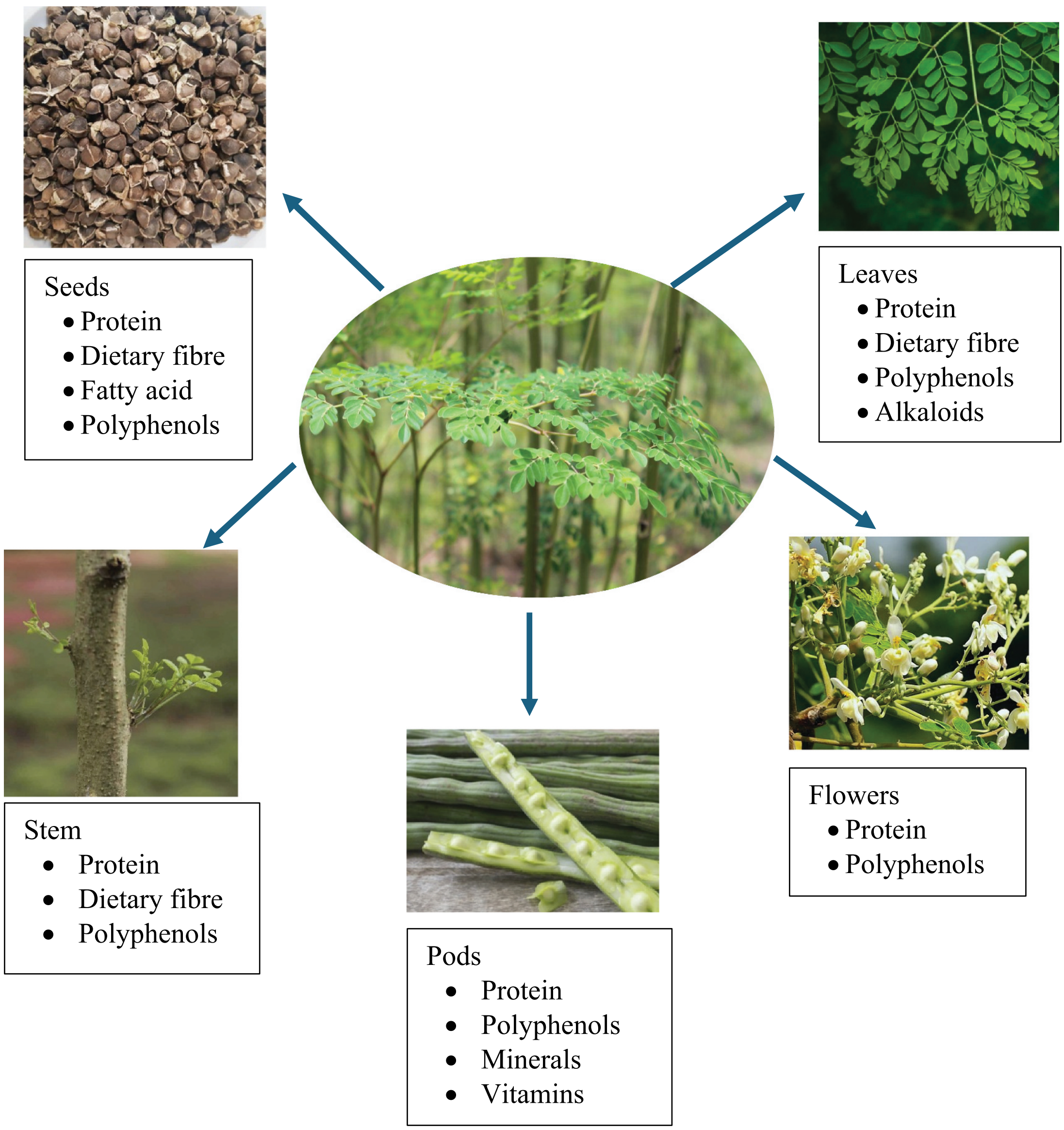

Figure 2. Main compositions in the various vegetative parts of *M. oleifera* plant.

steroids, tannins, phenolic acids, flavonoids, anthocyanins, and glucosinolates. Although phenolic acids and flavonoids are primarily recognized for their antioxidant potential, other compounds such as alkaloids and saponins exhibit antimicrobial and anti-inflammatory properties.[47] Paikra et al.[48] reported that Moringa extract exhibited potent antioxidant and free radical scavenging activity *in vitro*, indicating its potential use as a source of antioxidant compounds that may protect against oxidative stress-induced diseases. The comprehensive profile of phytochemicals in Moringa presents opportunities for its application in pharmaceuticals, supporting ongoing research into its health benefits and applications.

Table 2. Nutritional composition of *M. oleifera* leaves, seeds and pods.

	Moringa component		
Nutritional profile	Leaves	Seeds	Pods
Chemical composition (g/100 g)			
Carbohydrates	8.0–49.3	8.9–12.9	3.7–66.1
Protein	22.4–27.1	38.2–40.3	2.5–19.3
Fibre	7.1–35.0	2.6–2.9	4.8–46.8
Fat	5.0–30.6	38.2–39.1	0.1–1.3
Ash	7.6–14.6	3.5–3.7	6.9
Vitamins (mg/100 g)			
A	6.8–91.8	NA	67
B	423	NA	0.32
C	4.5–220	4.5	120–793
E	9.0–122.2	751.7	40
Minerals (mg/100 g)			
Calcium	147.4–7,230	12.1	30–188
Potassium	1317–2,025	235.7	259–2,847
Phosphorous	300–5,300		110–288
Magnesium	5.6–13.8	97.2	24–317
Copper	0.6–2.1	0.32	3.1
Iron	21.9–51.7	3.6	5.3–8.0
Zinc	0.05–3.1	0.84	NA

Source: Sánchez-Machado et al.,[75] Qadir et al.,[76] Shih et al.,[77] González-Burgos et al.[37]
NA = not available.

Polyphenols

Phenolics are chemical compounds characterized by hydroxyl groups directly bonded to aromatic rings, playing crucial roles in safeguarding plants against physical damage, oxidative stress, and ultraviolet radiation. Moringa is a rich source of polyphenol compounds such as flavonoids, phenolic acids, glycosides, alkaloids, saponins, isothiocyanate, glucosinolate, xanthones, quinones, coumarins, and tannins.[49] Main polyphenol compounds in Moringa leaves include at least 5 lignans (i.e., medioresinol, secoisolariciresinol, isolariciresinol, and epipinoresinol glycosides), 26 flavonoids (i.e., quercetin, apigenin, kaempferol, myricetin glycosides, and luteolin) and 11 phenolic acids and their derivatives (*i.e*., feruloylquinic, caffeoylquinic, and coumaroylquinic acids and their isomers).[50,51]

The polyphenol composition and concentration in Moringa leaves and seeds are given in Table 3. The total phenolic content in Moringa leaves ranges from 45.2 to 380.3 mg GAE/g, and 30.8 to 90.8 mg GAE/g in seeds. Studies have shown that these polyphenol compounds in Moringa have various biological activities contributing to their antibacterial, antifungal, and antioxidant properties.[52,53]

Flavonoids

Flavonoids, a class of polyphenolic compounds abundant in plants, feature a molecular structure comprising two benzene rings. Flavonoids are secondary metabolites playing important metabolic roles and represent the predominant polyphenol group found in Moringa leaves.[54,55] Moringa plants contain a variety of flavonoids, including quercetin, kaempferol, and apigenin, which are

Table 3. Polyphenols content and concentration in *M. oleifera* leaves and seeds (dry weight basis).

Constituents	Sources	Amount	References
Phenolic acids	Leaves	45.2–380.3 mg GAE/g	Adisakwattana and Chanathong,[78] El-Shehawi et al.[20]
	Seeds	30.8–90.8 mg GAE/g	Jahan et al.[24]
Flavonoids	Leaves	15.44 mg catechin/g 192.4 mg RE/g	Xu et al.,[38] Adisakwattana and Chanathong[19]
	Seeds	9.6–10.6 mg/g	Park et al.[25]
Tannins	Leaves	12–38 mg/g	Teixeira et al.[22] du Toit et al.[23]
	Seeds	21.7–97.1 mg GAE/g	Jahan et al.[24]

RE: rutin equivalent; GAE: gallic acid equivalent; QE: quercetin equivalent.

predominantly present in the form of glycosides.[56,57] Lin et al.[58] have identified up to 36 different flavonoids in various parts of the Moringa plant. Nouman et al.[59] and Rodríguez-Pérez et al.[51] also reported that kaempferol, quercetin, and apigenin constituted the predominant polyphenol compounds in Moringa. According to Xu et al.[21] Moringa leaves have a high concentration of flavonoids, potentially reaching up to 192.4 mg rutin equivalents/g of total flavonoids.

Phenolic acids

Phenolic acids are a subclass of polyphenol compounds, characterized by the presence of a carboxylic acid group attached to an aromatic ring. They are mainly classified into two primary subclasses: hydroxycinnamic and hydroxybenzoic acid. Within plant tissues, these acids are often found in bound forms, such as esters, amides, or glycosides, and less frequently exist in their free form.[60,61]

Phenolic acids are the essential components of the human diet and are associated with numerous health benefits. Past studies suggest that a diet rich in phenolic acids, commonly available in fruits and vegetables, can significantly reduce the risk of diseases linked to oxidative stress.[42] Previous research has demonstrated that Moringa leaves are rich in phenolic acids. The total content of phenolic acids in Moringa leaves ranged from 45.2 to 380.3 mg GAE/g dry weight (Table 3). The most common phenolic acids identified in Moringa include chlorogenic acid, ferulic acid, gallic acid, vanillic acid, ellagic acid, caffeoylquinic acid, and coumaroylquinic acid.[62,63] However, the concentration of these phenolic acids can vary depending on different factors such as the extraction technique, geographical location, plant variety, climate, and soil composition.[50,64]

Tannins

Tannins constitute a subclass of polyphenols widely distributed in various plant foods.[65] It has been demonstrated that tannins contribute to antioxidant, anti-inflammatory, and scavenge reactive oxygen species. Tannins have also been shown to inhibit lipid peroxidation and possess anti-apoptotic activities, which help protect against liver damage and other oxidative stress-related conditions.[66–68] However, some studies suggest that although tannins provide some health benefits, their excessive consumption may cause adverse effects such as nausea, vomiting, abdominal pain, constipation, and even liver damage. It is thus important to recognize that a higher tannin content in food does not necessarily indicate superior quality or better nutritional value.[69] Moringa has a moderate concentration of tannin ranging from 12–38 mg/g in leaves and 21.7–97.1 mg GAE/g in seed.[22–24] This moderate tannin content makes Moringa a suitable candidate for the development of functional foods.[70]

Antioxidant properties

Food antioxidants play an important role in human health by mitigating oxidative damage to proteins, lipids, and nucleic acids.[71] Moringa is particularly recognized for its strong antioxidant properties, attributed to the abundance of bioactive compounds across various plant parts, including leaves, flowers, pods, seeds, stems, bark, and roots.[72] These bioactive compounds, such as vitamins, carotenoids, polyphenols, and tocopherols, contribute to antioxidant activity through various mechanisms.[73] There are three main mechanisms that polyphenolic compounds, including flavonoids and phenolic acids, contribute to antioxidant activity: (1) neutralization of free radicals, such as reactive oxygen species (ROS) and reactive nitrogen species (RNS), by donating hydrogen atoms or electrons to reduce oxidative stress; (2) inhibition of enzymes involved in radical production or chelation of trace metals that catalyse radical generation; and (3) regulation or enhancement of endogenous antioxidant defence systems.[74]

The antioxidant properties of Moringa show significant potential for both human health and industrial applications. The use of natural antioxidants from Moringa in food products can help prevent lipid oxidation, thus maintaining food quality, taste, and shelf life.[75] For example, research has demonstrated that polyphenol extracts from Moringa pods and leaves can significantly reduce lipid oxidation in food matrices such as mayonnaise and sunflower oil, suggesting their utility as natural food preservatives. Bholah et al.[76] also demonstrated the efficacy of polyphenol extracts derived from Moringa pods and leaves in inhibiting lipid oxidation in both mayonnaise and bulk sunflower oil. As a highly effective and natural antioxidant, Moringa aligns with global trends toward sustainable and natural solutions in health and food industries. Its rich nutritional and bioactive profiles across different parts, coupled with its adaptability to diverse climates and soil conditions, further highlight its potential as a reliable and scalable source of natural antioxidants for sustainable development.

Application of Moringa in the food industry

Moringa offers a wide range of benefits, including significant potential in addressing nutritional challenges within the food industry. Moringa can help combat imbalanced eating patterns by providing a concentrated source of essential nutrients. In regions with developing economies, where diets often rely heavily on carbohydrates like rice, nutritional deficiencies are common. Moringa, rich in dietary fibre, protein, minerals, and vitamins, can effectively supplement these diets, helping to overcome nutrient gaps and improve overall nutritional balance. It has been reported that incorporating Moringa into the diet, such as through fortified snacks, can significantly increase the intake of essential nutrients like vitamin A and folic acid, leading to improvements in health outcomes, such as reduced anaemia.[77] With increasing awareness of health and a growing preference for natural, plant-based diets, Moringa aligns perfectly with consumer demands. As a natural plant source, Moringa not only provides essential nutrients but also offers a range of bioactive compounds that may contribute to overall health and well-being.

Moringa serves to restore essential nutrients and exerts functional ramifications such as augmenting protein and dietary fibre consumption, facilitating lipid metabolism, enhancing antioxidant capacity, and promoting digestion as a superfood.[78] Moreover, extensive research has demonstrated the safety of incorporating this plant into the diet, thus establishing it as a highly suitable dietary constituent.[79–81]

The incorporation of Moringa into various food products offers several nutritional and preservative benefits (Table 4). As outlined in Table 4, Moringa leaves and seeds can significantly enhance the nutritional profile of foods like noodles, porridge, bread, and cakes by increasing their protein, mineral, and vitamin content. The key findings of Moringa supplementation in the food industry are presented below.

Nutritional Enhancement: Adding Moringa leaves to staple foods such as noodles and porridge can boost their nutritional value by increasing protein, vitamins, and minerals.[42] Moringa's high nutrient density makes it an effective way to enhance the overall nutritional profile of common foods.

Baked Goods: Incorporating Moringa into baked goods like bread and cakes can modify their nutritional content. For instance, A study by Bolarinwa et al.[27] reported that incorporating Moringa seed powder into wheat-based bread significantly increased protein content from 8.5 to 13.5 g/100 g and fiber from 0.08 to 0.62 g/100 g (dry weight) when using 0% to 20% Moringa seed powder. Similarly, Chinma et al.[83] reported that replacing up to 40% of wheat flour with Moringa seed flour in cakes improved protein, crude fibre, and mineral content, although some mineral concentrations (calcium and zinc) were affected. In addition, adding 12% Moringa dried leaf powder to muffins enhanced protein, fat, beta-carotene, vitamin C, and mineral content, making them more nutrient-dense.[84]

Beverages: Moringa has been included in various beverages such as tea. Several studies have identified that co-fermenting Moringa with tea leaves significantly increases the levels of alkaloids,

Table 4. Applications of *M. oleifera* in the food industry and their potential benefits.

Food categories	Items	Moringa part	Inclusion level	Benefits	References
Cooking	Instant porridge	Leaves	From 0 to 7.61% w/w to common commercial baby instant porridge	• Increased protein (from 10 to 17.8%) • Increased mineral content (potassium 250 mg to 867 mg/100 g)	Katmawanti et al.[28]
	Noodles	Leaves	From 0 to 6% w/w	• Increased protein (from 6.26% to 6.64%) • Increased fibre (from 0.31% to 0.80%) • Mineral content (Ca, Mg, P, K, Na, S) • Decreased fat (from 3.40% to 2.47%) • Higher essential amino acids	Hussin et al.[26]
Bakery	Cake	Leaves	From 0 to 2% w/w to common wheat flour	• Increased protein (from 5.79% to 8.90%) • Increased fibre (from 2.70% to 6.98%) • Increased mineral content (Fe K P Zn) • Decreased fat (from 20.2% to 13.1%)	Roni et al.[29]
	Bread	Leaves	From 0 to 20% w/w to common wheat flour	• Increased nutritional composition, including protein (from 8.5 to 13.5 g/100 g dry weight) • Increased fibre (from 0.1 to 10.6 g/100 g dry weight) • Increased mineral content (Ca, Fe, K, and P)	Bolarinwa et al.[27]
	Cookies	Leaves	From 2 to 7.5%w/w to common wheat flour	• Increased protein (from 8.4% to 9.6%) • Decreased fat content (from 12.9% to 12.5%) • Increased Total phenolic content (from 1.21% to 4.9%) • Increased phenolic acids such as chlorogenic, ferulic, and fumaric acids • Increased in vitro protein digestibility	Agba et al.[30]
Beverage	Tea	Leaves	Supplementing 15% moringa tea with dark tea	• Increased caffeine, theophylline, and gallic acid	Zhang et al.[31]
	Fermented beverage	Leaves	From 0 to 4% w/w to common wheat flour	• Improved nutritional composition • Increased protein (from 1.62% to 2.17%) • Decreased fat (from 0.02% to 0.65%) • Increased lactic acid bacteria • Improved anti-inflammatory and anti-pathogenic properties	Jideani et al.[32]
	Probiotic beverage	Leaves	2/3 of total volume	• Antibacterial activity against some of the foodborne pathogens • More minerals like calcium and iron	Vanajakshi et al.[33]
Dairy	Yoghurt	Leaves	2.9 g/L in yogurt	• Higher antioxidant property	Gomes et al.[34]
	Ice cream	Leaves	1 g in 300 g ice cream	• Increased total phenolic content and flavonoid contents (from 4.13 GAE/g to 30.25 GAE/g) • Improved antioxidant properties • Decreased glycemic index (from 61.2% to 27.1%)	Ademosun[35]
Meat	Chicken nuggets	Flower	2% level added to chicken meat	• Improved nutritional composition • Increased protein (about 2%) and fibre (about 12%) • Increased total phenolics (0.059 to 1.121 GAE/g)	Madane et al.[36]
Snack	Ready-to-eat snack	Leaves	From 0 to 20% w/w to common wheat flour	• Increased protein (21.6 g/100 g) and dietary fibre (14.8 g/100 g) • Decreased fat content (3.7 g/100 g)	Adewumi et al.[82]

Figure 3. Applications of *M. oleifera* within the food industry.

lipids, amino acids, organic acids, minerals, vitamin C, vitamin A, and antioxidants in the final tea product.[31,85,86]

Dairy: Yogurt enriched with Moringa leaf powder has exhibited enhanced antioxidant properties.[35] Also, Moringa-infused ice cream has been shown to contain higher concentrations of total phenolic acids and flavonoids, resulting in increased antioxidant activity and a lower glycemic index.[35]

Snacks: Moringa has been frequently incorporated into snack products to enhance their nutritional value. This addition increases nutritional quality, amino acid profile, and sensory attributes as a healthier snack option.[82]

Meat Products: Research on the addition of 2% Moringa flower powder to chicken nuggets demonstrated an increase in protein and dietary fibre content. Further, the inclusion of Moringa significantly increased the total phenolic content, enhancing the antioxidant potential of the final product.[36]

Shelf-Life Extension: Moringa leaf powder has been shown to reduce bacterial, yeast, and mould contamination in foods, potentially extending the shelf life of food products.[87] The rich content of bioactive compounds in Moringa, including phenolic acids, flavonoids, and alkaloids, may contribute to these antimicrobial effects that can inhibit the growth of spoilage organisms. For example, incorporating 5% Moringa leaf extract into mutton patties increased protein content to 21.75% and total phenolic content to 41.96 mg GAE/g while significantly reducing lipid oxidation.[88] The natural preservation properties of Moringa make it a safe and healthy preservatives, helping to maintain the nutritional value and quality of food products.

These examples demonstrate the significant potential of Moringa within the food industry (Fig. 3). Its low establishment cost and high nutrient content make Moringa a valuable resource. When used in appropriate quantities, Moringa does not negatively impact the taste or consumer acceptance of food products, making it an excellent option for enhancing the nutritional value and health benefits of various food items.

Conclusions and future directions

This systematic review demonstrates the significant potential of Moringa as a versatile and sustainable resource for various food applications. The adaptability of Moringa to different climates and soil types, combined with the high utilization potential of its various parts, including leaves, seeds, pods, and stems, highlight its role as a sustainable and promising agricultural resource.

Moringa demonstrates remarkable versatility across different food categories, including baked goods, meat products, dairy and snacks. Beyond enhancing nutritional value by enriching these foods with high-quality proteins, dietary fibre, vitamins, and minerals, Moringa offers several functional benefits within the food industry. These include extended shelf life, enhanced antioxidant activity, and reduced oxidative degradation in food matrices. As a rich source of essential nutrients and bioactive compounds, Moringa has strong potential as both a dietary supplement and a functional food ingredient. Its incorporation into food systems can contribute to addressing malnutrition and supporting global health initiatives. Importantly, the safety of Moringa for human consumption has been well-established, further solidifying its suitability for widespread use as a food supplement.

The potent antioxidant, anti-inflammatory, and antimicrobial activities in Moringa are attributed to its rich polyphenol content, including flavonoids, phenolic acids, and tannins. These bioactive properties not only promote human health but also meet the growing demand within the food industry for sustainable and natural ingredients that enhance both nutritional value and functionality.

Current research has extensively documented the commercial and medical significance of Moringa leaves and seeds. However, other plant parts such as pods and stems remain underexplored despite their considerable potential. For example, Moringa pods have emerged as increasingly sought-after ingredients in the food industry, with growing demand in both local and international markets, particularly in Australia and Europe. Their increasing market value, with prices reaching AUD $18–26/kg, reflects the growing consumer demand for their nutritional and functional benefits. Expanding the utilization of underutilized parts like pods could significantly enhance Moringa's agricultural efficiency and overall economic value. Therefore, further exploration is imperative, focusing on elucidating the antioxidant mechanisms and specific bioactivities of polyphenols from understudied plant parts within food and pharmaceutical applications. Optimizing processing methods, particularly extraction techniques, is important to maximize bioactive content. Also, it is essential to investigate the influence of growing conditions on the variation of bioactive compounds. By integrating Moringa into the food systems, the industry can drive innovation, promote healthier options, and contribute to a more sustainable future.

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Disclosure statement

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Ethical Statements

This study does not involve any human or animal testing.

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