



***Moringa oleifera* leaves: Processing, nutritional benefits, medicinal value and utilization in food—A review**

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Abstract

Moringa oleifera Lam., commonly known as moringa or drumstick tree, is a multipurpose plant belonging to the family Moringaceae and is widely cultivated in tropical and subtropical regions. Among the different parts of the plant, the leaves have attracted considerable attention because of their high nutritional density, diverse phytochemical composition, functional properties and potential applications in food and nutraceutical products. Moringa leaves provide proteins, dietary fibre, minerals, vitamins, carotenoids and several biologically active compounds, including phenolic acids, flavonoids, glucosinolates and isothiocyanates. However, their nutritional and functional characteristics are strongly influenced by harvesting stage, storage and processing conditions. Conventional processing operations such as blanching, boiling, drying and fermentation can improve shelf life and handling characteristics, although inappropriate thermal treatment may reduce heat-sensitive nutrients and phytochemicals. Drying is particularly important because it enables conversion of fresh leaves into a stable powder that can be incorporated into different food products.

Recent studies indicate that freeze-drying generally provides better retention of several phytochemicals and antioxidant properties than conventional drying, although its higher cost limits large-scale application. Moringa leaf powder has been investigated as a functional ingredient in bakery products, pasta, noodles, beverages, soups, dairy products and other food formulations. Incorporation at moderate levels can improve protein, fibre, mineral and antioxidant content, whereas excessive incorporation may adversely affect colour, flavour, texture and consumer acceptability. Experimental and clinical research also indicates antioxidant, anti-inflammatory, antihyperglycemic, antimicrobial and lipid-modulating activities associated with moringa leaves. Nevertheless, much of the medicinal evidence remains based on laboratory and animal studies, and larger, well-controlled human clinical trials are required before therapeutic claims can be established. This review discusses the processing methods, nutritional composition, bioactive constituents, medicinal potential, safety considerations and food applications of moringa leaves, with emphasis on their potential as a sustainable functional food ingredient.

Keywords: *Moringa oleifera*, moringa leaves, leaf powder, drying, nutritional composition, phytochemicals, medicinal properties, functional foods, food fortification

Introduction

Moringa oleifera Lam. is one of the most widely studied multipurpose plants of the family Moringaceae. It is commonly known as moringa, drumstick tree or horseradish tree and is believed to have originated in the Indian subcontinent. It is now cultivated extensively in tropical and subtropical regions because of its rapid growth, tolerance to relatively dry conditions and usefulness as a food, medicinal and industrial crop. Almost every part of the plant—including leaves, flowers, pods, seeds, bark and roots—has traditional or commercial applications. Among these plant parts, the leaves are particularly important because they can be consumed directly as a vegetable or processed into dried powder, extracts and functional food ingredients.

Moringa leaves have traditionally been used in several Asian and African food systems. They can be consumed fresh, cooked as vegetables, incorporated into soups and sauces, or dried and powdered for use throughout the year. The leaves are particularly attractive from a nutritional perspective because they contain proteins, essential amino acids, dietary fibre, calcium, potassium, iron, carotenoids and several vitamins and phytochemicals. Their composition, however, varies considerably according to cultivar, geographical origin, soil conditions, maturity, harvesting season and post-harvest processing.

The increasing interest in plant-based foods and natural functional ingredients has stimulated research into moringa leaf processing and food applications. Moringa leaf powder has been incorporated into bread, biscuits, noodles, pasta, soups, beverages, dairy products and other formulations. Recent studies demonstrate that moderate incorporation can improve nutritional quality, whereas excessive addition may produce undesirable colour, bitterness and sensory characteristics.

Therefore, the objective of this review is to critically discuss the processing of moringa leaves, their nutritional and phytochemical composition, potential medicinal value, utilization in food products, limitations and future prospects.

Processing of Moringa Leaves

Processing is essential for extending the shelf life of fresh moringa leaves and converting them into convenient ingredients. Fresh leaves have high moisture content and are highly perishable. Appropriate processing can reduce microbial deterioration, improve storage stability and facilitate transportation and incorporation into foods.

1. Harvesting and preliminary handling

Young and tender leaves are generally preferred for culinary use because they have relatively better texture and

palatability. After harvesting, leaves should be sorted to remove damaged, diseased or excessively mature material. They are subsequently washed with potable water to remove soil and foreign matter.

Post-harvest handling is important because prolonged exposure to high temperatures, sunlight and moisture can accelerate nutrient deterioration. Rapid processing after harvesting is therefore desirable.

2. Blanching

Blanching involves short-term exposure of leaves to hot water or steam before drying or freezing. It can reduce microbial load, inactivate oxidative enzymes and modify colour and texture. However, blanching may cause leaching of water-soluble vitamins and minerals, particularly when leaves are immersed in water for prolonged periods.

Consequently, blanching conditions should be optimized according to the intended product. Steam blanching can potentially reduce nutrient losses associated with direct water contact.

3. Boiling and cooking

Fresh moringa leaves are traditionally cooked in curries, soups and vegetable preparations. Cooking improves palatability and may reduce some antinutritional factors. At the same time, prolonged boiling can result in losses of heat-sensitive and water-soluble nutrients.

Moringa leaves contain compounds such as phytates, oxalates and tannins that can interfere with nutrient utilization at high concentrations. Processing can reduce some of these compounds, although the extent depends on the processing method.

4. Drying

Drying is one of the most important processing techniques for moringa leaves. It converts the highly perishable leaves into a stable ingredient that can be stored and transported for longer periods.

Common drying methods include:

- Sun drying
- Shade drying
- Hot-air or oven drying
- Tray drying
- Solar drying
- Air drying
- Freeze-drying

Drying conditions significantly affect the nutritional and phytochemical quality of moringa powder. A study comparing freeze-, sun-, air- and oven-drying reported that drying substantially altered phenolics, flavonoids, vitamin C, tannins, saponins, phytates, oxalates and antioxidant activities. Freeze-drying showed the greatest overall retention of several nutraceutical characteristics, followed by air, sun and oven drying under the experimental conditions.

Freeze-drying can therefore be advantageous for high-value nutraceutical ingredients, although its energy requirement and capital cost can restrict its use for low-cost food production. Solar, shade and controlled hot-air drying may be more practical in rural and small-scale processing systems.

5. Powder production

After drying, leaves are separated from stems and ground into powder. The powder is generally sieved to obtain a relatively uniform particle size and stored in airtight, moisture-resistant containers.

Moringa leaf powder offers several advantages

1. Extended shelf life compared with fresh leaves.
2. Easy transportation and storage.
3. Convenient incorporation into food products.
4. Concentration of nutrients on a dry-weight basis.
5. Possibility of standardized formulation.
6. Potential use as a natural green functional ingredient.

However, powder quality depends on drying temperature, residual moisture, particle size, packaging and storage conditions.

6. Fermentation

Fermentation is another potential processing technique for improving the nutritional and functional characteristics of plant materials. It may modify phenolic compounds, reduce selected antinutritional factors and improve digestibility. Nevertheless, fermentation of moringa leaves remains less extensively studied than drying and requires optimization of microorganisms, fermentation time, temperature and substrate conditions. Reviews of wet and dry processing have highlighted drying, blanching, boiling and fermentation as important approaches for preserving or modifying moringa leaf nutritional quality.

Nutritional Composition of Moringa Leaves

Moringa leaves are recognized as nutrient-dense plant material containing macronutrients, micronutrients and bioactive compounds. However, reported nutrient concentrations vary substantially among studies because of differences in variety, growing environment, maturity and analytical procedures.

1. Protein and amino acids

Protein is one of the most important nutritional components of moringa leaves. Dried leaves contain substantially concentrated protein compared with fresh leaves because removal of water increases nutrient concentration on a weight basis.

Moringa leaf proteins contain several essential and non-essential amino acids. This makes the leaf powder potentially useful for improving the protein quality of cereal-based foods, which may otherwise be relatively limited in some essential amino acids.

The protein contribution is particularly relevant in the development of affordable plant-based foods and food products designed to improve dietary diversity.

2. Dietary fibre

Moringa leaves contain appreciable amounts of dietary fibre. Fibre contributes to gastrointestinal health, satiety and overall dietary quality. Incorporation of moringa leaf powder into cereal products can increase crude fibre content.

For example, studies on moringa-fortified noodles have reported increases in fibre and other nutritional components,

although higher levels of leaf powder can negatively influence sensory acceptability.

3. Minerals

Moringa leaves contain several nutritionally important minerals, including:

- Calcium
- Iron
- Potassium
- Magnesium
- Phosphorus
- Zinc

Calcium and iron are particularly relevant from a public-health perspective because inadequate intake of these minerals remains a nutritional concern in many populations. Moringa leaf powder has therefore been investigated as a natural mineral-rich ingredient for food fortification.

However, total mineral concentration should not be interpreted directly as mineral bioavailability because phytate, oxalate and other antinutritional compounds may interfere with absorption.

4. Vitamins and carotenoids

Moringa leaves provide several vitamins and provitamin compounds, including carotenoids. β -carotene and lutein are among the important carotenoids reported in moringa leaves. Carotenoids are of interest because some function as provitamin A compounds while others contribute antioxidant activity.

Vitamin C is also present in fresh leaves, although it is relatively sensitive to processing conditions. Drying and thermal treatments can substantially alter vitamin C content.

5. Phytochemicals

The nutritional significance of moringa leaves extends beyond conventional nutrients. Important phytochemical groups include:

- Phenolic acids
- Flavonoids
- Glucosinolates
- Isothiocyanates
- Tannins
- Saponins
- Alkaloids
- Carotenoids
- Sterols

Reported phenolic compounds include gallic, caffeic, ferulic, chlorogenic and related phenolic acids. Flavonoids such as quercetin, kaempferol and related compounds have also been identified.

The concentrations of these compounds can differ markedly according to genotype, cultivation conditions, leaf maturity, extraction procedure and processing method. Therefore, numerical values reported in individual studies should be interpreted cautiously.

Nutritional and Health Benefits

The combination of nutrients and phytochemicals gives moringa leaves considerable potential as a functional food ingredient.

1. Antioxidant activity

Phenolic compounds, flavonoids and carotenoids contribute to the antioxidant properties of moringa leaves. Extracts of moringa leaves have demonstrated free-radical-scavenging and reducing activities in laboratory assays.

However, antioxidant capacity measured by chemical assays should not automatically be interpreted as equivalent to clinical antioxidant effects in humans.

2. Anti-inflammatory potential

Moringa leaves contain phytochemicals that have demonstrated anti-inflammatory activity in experimental models. Phenolic compounds, flavonoids and isothiocyanate-related compounds have been investigated for their potential role in modulating inflammatory pathways.

3. Blood glucose regulation

Moringa has received considerable attention for its possible antihyperglycemic activity. Laboratory studies have reported inhibition of carbohydrate-digesting enzymes such as α -amylase and α -glucosidase, suggesting a possible role in postprandial glucose management. Processing can influence these activities; for example, drying method has been shown to alter α -amylase and α -glucosidase inhibitory properties.

Human evidence remains more limited. A randomized clinical study involving 40 adults with type 2 diabetes investigated different daily amounts of moringa leaves over 14 days and assessed blood glucose, blood pressure and lipid parameters. Such studies provide useful preliminary evidence, but larger and longer-duration clinical trials are necessary to establish efficacy and appropriate intake levels.

4. Lipid-modulating potential

Experimental studies have reported possible hypolipidemic effects of moringa preparations. Phenolics, flavonoids and other bioactive compounds may contribute to these effects. Human evidence, however, is not yet sufficient to establish moringa leaves as a treatment for dyslipidemia.

5. Antimicrobial activity

Moringa leaf extracts have demonstrated antimicrobial activity against selected microorganisms in laboratory studies. This property has generated interest in their use in functional foods and natural food-preservation systems.

Recent food research has also investigated moringa extracts in cereal products and reported antimicrobial effects and potential shelf-life benefits.

6. Potential hepatoprotective and cardioprotective effects

Preclinical research has reported hepatoprotective and cardiovascular-related effects of Moringa preparations. These effects have been associated with antioxidant and anti-inflammatory mechanisms. Nevertheless, evidence from human clinical studies remains insufficient to make therapeutic claims.

Medicinal Value of Moringa Leaves

Moringa has a long history of traditional medicinal use. Its leaves have traditionally been consumed for conditions involving inflammation, nutritional deficiencies, digestive

disorders and other ailments. Modern research has investigated several pharmacological activities.

Table 1: Major reported medicinal properties of Moringa leaves

Reported activity	Major contributing components	Evidence status
Antioxidant	Phenolics, flavonoids, carotenoids	Strong laboratory evidence
Anti-inflammatory	Flavonoids, phenolics, isothiocyanate-related compounds	Mainly experimental
Antihyperglycemic	Polyphenols and other bioactives	Experimental + limited human evidence
Antimicrobial	Phenolics, flavonoids and other secondary metabolites	Mainly laboratory evidence
Hypolipidemic	Polyphenols and related compounds	Experimental + limited human evidence
Hepatoprotective	Antioxidants and phenolic compounds	Mainly animal studies
Anti-ulcer/gastroprotective	Various phytochemicals	Mainly experimental
Wound-healing potential	Antioxidant and anti-inflammatory compounds	Mainly experimental

Moringa reviews have documented antioxidant, anti-inflammatory, antimicrobial, antihyperglycemic, hepatoprotective and other pharmacological activities. Importantly, medicinal potential should not be equated with proven clinical treatment. Much of the evidence is derived from *in-vitro* or animal research, and differences in extract preparation, dose and bioavailability make direct comparison difficult. Human clinical research is still required to establish standardized therapeutic doses, efficacy and long-term safety.

Utilization of Moringa Leaves in Food

Moringa leaves can be utilized as fresh leaves, dried leaves, leaf powder, extracts or incorporated ingredients.

1. Bakery products

Bakery products are among the most extensively investigated applications of moringa leaf powder. Bread, biscuits, cookies and other baked products can be fortified with moringa powder to increase protein, fibre, mineral and antioxidant content.

A study examining 5% and 10% moringa leaf powder in white and brown bread found that increasing moringa concentration increased nutrient content but also affected colour and consumer acceptability. Under the experimental conditions, 5% incorporation provided a practical balance for bread formulation. A 2023 study also demonstrated the potential of dehydrated moringa leaf powder in whole-wheat bread, with effects on nutritional, mineral and antioxidant properties. Recent work has further explored debittering strategies. A 2026 ^[33] study reported that oil-assisted debittering of moringa leaf powder reduced selected antinutritional factors and improved the nutritional and sensory characteristics of fortified biscuits.

2. Pasta and noodles

Moringa leaf powder can be incorporated into pasta and noodles as a source of fibre, minerals, protein and phytochemicals.

Recent research evaluating moringa incorporation into bread, noodles and pasta reported moderate levels of incorporation as more acceptable than excessive supplementation. The study found nutritional improvements in several formulations, while high concentrations negatively affected sensory properties.

This illustrates an important principle in functional food development: maximum nutritional enrichment does not necessarily correspond to maximum consumer acceptability.

3. Beverages

Moringa leaves can be used in:

- Herbal beverages
- Functional drinks
- Smoothies
- Infusions
- Nutritional beverages

Moringa powder may contribute minerals, carotenoids, polyphenols and other bioactive compounds. However, bitterness, suspended particles and green colour may limit consumer acceptance. Appropriate formulation, filtration or extraction can improve sensory characteristics.

4. Soups and sauces

Fresh or dried moringa leaves have traditionally been incorporated into soups, curries and sauces. Their strong green colour and characteristic flavour can provide both nutritional and sensory characteristics.

Dried powder can be particularly useful where seasonal availability of fresh leaves is limited.

5. Dairy and fermented products

Moringa leaf powder has been explored in yoghurt and other dairy products as a functional ingredient. Its incorporation may increase antioxidant and mineral content, although formulation must be optimized to avoid excessive bitterness, colour changes and texture defects.

6. Snack foods

Moringa can be incorporated into crackers, extruded products, energy bars and other snack foods. Such applications provide an opportunity to combine moringa with cereals, pulses, millets and other nutrient-rich ingredients.

7. Functional and nutraceutical foods

Because moringa contains both nutrients and bioactive compounds, it has potential as an ingredient in functional foods and nutraceutical formulations. Current research increasingly emphasizes standardized extracts, encapsulated bioactive compounds and food-grade delivery systems.

A recent review of Moringa leaves as a raw food material identified their potential for applications across food and agricultural industries while emphasizing the importance of processing, safety and functional properties.

Influence of Processing on Nutritional and Functional Properties

Processing creates a balance between preservation, safety, shelf stability and bioavailability.

Table 2: Effect of selected processing methods on Moringa leaves

Processing method	Major advantages	Potential limitations
Fresh consumption	Maximum freshness and minimal processing	Very short shelf life
Blanching	Enzyme inactivation, microbial reduction	Loss of water-soluble nutrients
Boiling	Improved palatability, possible antinutrient reduction	Nutrient leaching and thermal losses
Sun drying	Low cost and simple technology	Variable temperature, contamination and nutrient degradation
Shade/air drying	Relatively simple and inexpensive	Longer drying time
Hot-air drying	Better process control and faster drying	Heat-related nutrient losses
Freeze-drying	Excellent retention of many sensitive compounds	High cost and energy requirement
Fermentation	Potential improvement in digestibility and phytochemical profile	Requires process control
Milling	Convenient food ingredient	Oxidation and loss of volatile/sensitive compounds possible

The processing method should therefore be selected according to the intended end product and target nutrient.

Antinutritional Factors and Safety Considerations

Despite its nutritional value, moringa leaves contain antinutritional factors such as phytates, oxalates and tannins. These compounds may reduce mineral or protein bioavailability when consumed at sufficiently high concentrations.

Processing can modify these compounds. Blanching, boiling, drying, fermentation and other treatments can alter their concentrations. Recent research on debittered moringa leaf powder has demonstrated substantial reductions in tannins, phytates and trypsin inhibitors after processing and baking.

Another important consideration is sensory acceptability. Moringa leaves possess a characteristic bitter and grassy flavour. Increasing the proportion of moringa powder may produce darker colour and stronger flavour, reducing consumer acceptance. This relationship has been demonstrated in bread and noodle studies.

Safety reviews have generally described aqueous leaf preparations as having a favourable safety profile in available studies, but safety depends on plant part, extraction method, dose, duration and population.

For commercial food applications, attention should also be given to microbial quality, pesticide residues, heavy metals, authenticity of raw material, storage stability and compliance with applicable food regulations.

Challenges in Food Utilization

Although moringa leaves have considerable potential, several challenges must be addressed before their broader incorporation into mainstream food products.

1. Bitterness and strong flavour

The characteristic bitter flavour is one of the major limitations of high-level incorporation. Debittering, blending with complementary ingredients and optimization of processing conditions may improve acceptability.

2. Colour changes

Moringa powder can impart an intense green colour to foods. While this may be desirable in some products, it can be undesirable in conventional bakery products.

3. Nutrient losses during processing

Heat, oxygen, light and moisture can degrade sensitive compounds, particularly vitamin C and certain pigments. Processing therefore needs to be optimized to achieve an appropriate balance between shelf stability and nutrient retention.

4. Variation in composition

The chemical composition of moringa leaves varies with cultivar, maturity, geography, soil, climate and processing. Standardization is therefore necessary for commercial functional ingredients.

5. Bioavailability

The presence of phytate, oxalate and tannins may influence mineral and protein bioavailability. Future studies should therefore evaluate bioaccessibility rather than relying exclusively on total nutrient concentrations.

6. Limited clinical evidence

Although laboratory studies report numerous biological activities, relatively few well-controlled human studies have established clinically meaningful effects. Therefore, therapeutic claims should be made cautiously.

Future Perspectives

Future research should move beyond simply demonstrating that moringa increases nutrient content and should focus on developing standardized, safe and consumer-acceptable functional ingredients.

Important research areas include

1. Optimization of low-energy drying technologies.
2. Development of standardized moringa leaf powder.
3. Evaluation of nutrient bioavailability after processing.
4. Reduction of bitterness and undesirable flavour.
5. Encapsulation of sensitive bioactive compounds.
6. Development of clean-label natural food ingredients.
7. Investigation of moringa extracts as natural antioxidants.
8. Development of functional bakery, beverage and dairy products.
9. Evaluation of long-term storage stability.
10. Large-scale human clinical trials.
11. Establishment of scientifically supported intake levels.
12. Assessment of food safety and regulatory requirements.
13. Utilization of moringa in affordable foods for micronutrient improvement.
14. Life-cycle assessment and sustainable processing.
15. Integration with cereals, pulses and millets for nutritionally balanced food formulations.

Recent research demonstrates that the field is moving toward multifunctional food products rather than simple fortification. For example, moringa leaf powder and phenolic-rich extracts have been evaluated in cereal products for nutritional enhancement, antioxidant activity and microbial stability.

Conclusion

Moringa oleifera leaves represent a promising plant-based raw material with considerable nutritional, functional and food-processing potential. Their high-quality protein, dietary fibre, minerals, carotenoids, vitamins and diverse phytochemicals make them attractive for nutritional enrichment and functional food development. Processing plays a central role in determining their final nutritional and phytochemical characteristics. Drying and powder production provide practical approaches for improving shelf stability, while controlled blanching, fermentation and other technologies may help modify antinutritional factors and functional properties.

Moringa leaves have demonstrated antioxidant, anti-inflammatory, antimicrobial and antihyperglycemic potential in experimental studies, with some preliminary human evidence. However, these findings should be distinguished from established therapeutic effects, and further clinical research is necessary.

From a food technology perspective, moringa leaf powder can be incorporated into bakery products, pasta, noodles, beverages, soups, dairy products and snacks. The major challenge is to achieve an optimum balance between nutritional enhancement and sensory acceptability. Moderate incorporation levels, suitable processing and flavour-masking or debittering strategies appear particularly important.

Overall, moringa leaves have strong potential as a sustainable, nutrient-rich and multifunctional food ingredient. Future research should prioritize standardized processing, bioavailability, safety, consumer acceptance and clinical validation to support their wider application in functional foods and nutrition-oriented food systems.

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