



International Journal of Indigenous Herbs and Drugs

Content Available at www.saapjournals.org

ISSN: 2456-7345



MORINGA OLEIFERA LEAVES: A RICH RESERVOIR OF NUTRIENTS AND NUTRACEUTICALS-A SUPERFOOD FOR HUMAN HEALTH

A. SHOBHA RANI¹, E. BHUVANESWARI², K.S. SHANTHI SREE³, G. SAVITHRI^{4*}^{1, 3, 4*}Department of Biosciences and Sericulture, Sri Padmavati Mahila Visvavidyalaya, Tirupati- 517 502, Andhra Pradesh, India.² Scientist-D, Research Extension Centre, Chebrolu, Central Silk Board, Ministry of Textiles, Chebrolu-533449, Andhra Pradesh.DOI: <https://doi.org/10.46956/ijihd.v11i3.972>

ARTICLE INFO

Article History

Received on: 19-06-2026

Revised on: 11-08-2026

Accepted on: 06-09-2026

*CORRESPONDING AUTHOR

G. Savithri

ABSTRACT

Moringa oleifera leaves have gained significant noticed as a rich source of nutrients and nutraceutical compounds due to their exceptional nutritional composition and diverse bioactive compounds. The leaves are rich in proteins, vitamins, minerals, polyphenols, flavonoids, carotenoids, glucosinolates, and other phytochemicals, while containing relatively low levels of anti-nutritional factors. Many *in vitro* and *in vivo* studies have demonstrated their broad spectrum of biological activities, including antioxidant, antimicrobial, anti-inflammatory, antidiabetic, and anticancer effects, largely assignment to their high concentration of bioactive compounds. As consequence *Moringa oleifera* leaves are increasingly being incorporated into functional foods to enhance their nutritional value and wellness benefits. Despite investigation research on the identification and quantification of these compounds, limited information is available regarding their bio accessibility and bioavailability, which are necessary for understanding their physiological effectiveness. This study highlights the current scientific evidence on the nutritional and bioactive composition, bioavailability, health benefits, and applications of *Moringa oleifera* leaves in functional food products.

Keywords: *Moringa oleifera* leaves, antioxidant, antimicrobial, anti-inflammatory and anticancer.

This article is licensed under a Creative Commons Attribution-Non-commercial 4.0 International License. Copyright © 2026 Author(s) retains the copyright of this article.



INTRODUCTION

Medicinal plant research has obtained considerable momentum in recent years owing to the growing interest in therapeutic phytochemicals as potential sources of novel drugs and health-promoting agents. Plants are rich in a diverse range of bioactive compounds like carotenoids, phenolic acids, flavonoids, tannins, saponins, alkaloids, and glucosinolates, which exhibit significant pharmacological and nutraceutical properties. These phytochemicals are naturally occurring secondary metabolites that play an essential role in plant defence and contribute to the prevention and management of various human diseases. Extensive scientific evidence indicates that they pose antioxidant, anti-inflammatory, antimicrobial, and anticancer activities, thereby helping to reduce the risk of chronic disorders such as cancer, cardiovascular diseases, and neurodegenerative conditions. Their ability to regulate oxidative stress, inflammation, and other cellular processes has made medicinal plants an important focus of research for the development of innovative pharmaceuticals, nutraceuticals, and functional foods [1]. The drumstick tree, scientifically familiar as *Moringa oleifera* Lam., belongs

to the family Moringaceae and is widely recognized for its exceptional nutritional, medicinal, and socio-economic importance. It is a fast-growing, drought-resistant tree native to the Indian subcontinent but is now cultivated widely across tropical and subtropical regions of the world. Due to its adaptability to diverse environmental conditions and its ability to thrive in arid and semiarid regions, *Moringa oleifera* is often regarded as a miracle tree or tree of life.

In India, moringa is popularly such as the Kalpa Vruksha due to its remarkable nutritional and medicinal properties, which are believed to help rejuvenate and sustain life.

All parts of the plant like leaves, pods, seeds, flowers, resin and roots are utilized for various purposes especially; the leaves are highly valued for their rich nutritional profile and therapeutic properties. Leaves are good source of essential nutrients including proteins, vitamins, minerals, dietary fiber, and a broad range of bioactive phytochemicals. Traditional medicine systems includes Ayurveda and Unani have long used moringa for treating various ailments, such as inflammation, infections, digestive disorders, and malnutrition. In recent years,

scientific interest in *Moringa oleifera* has increased significantly due to its demonstrated antioxidant, antimicrobial, anti-inflammatory, antidiabetic, and anticancer activities. These health benefits are primarily attributed to the presence of bioactive compounds like flavonoids, phenolic acids, carotenoids, and glucosinolates. Consequently, *Moringa oleifera* has gained importance as a functional food ingredient and nutraceutical resource.

The use of herbal medicines has increased substantially in recent years due to growing interest in natural and plant-based therapies for disease prevention and health benefits. In many developing countries, medicinal plants remain a primary source of healthcare because they are reasonable, accessible and culturally accepted. Among these, *Moringa oleifera* leaves are arising as a valuable natural resource owing to their rich nutritional profile and diverse therapeutic properties, making them a practical alternative in regions with limited access to conventional healthcare services. Appropriate dietary utilization of moringa, supported by scientific evidence may contribute to the prevention and management of different chronic diseases. Although number of studies have characterized the nutritional and phytochemical composition of moringa leaves, comprehensive information on their bioactive constituents, bio accessibility and health benefits. Therefore, this study aims to provide a comprehensive and updated overview of the nutritional composition, major bioactive compounds, health benefits, and potential applications of *Moringa oleifera* in food fortification and human nutrition.

Nutritive Composition of *Moringa oleifera* Leaves

Moringa oleifera leaves are recognized as one of the most nutrient-dense plant materials and are widely valued for their exceptional nutritional composition. They contain a balanced combination of macronutrients and micronutrients, making them an important ingredient in functional foods and dietary supplements. Both fresh and dried leaves are rich in proteins, essential amino acids, vitamins, minerals, dietary fiber, and bioactive phytochemicals that contribute to human health [2,3].

The leaves contain approximately 20–30% protein on a dry weight basis and provide all essential amino acids like lysine, leucine, methionine, valine, and tryptophan, making them a good source of high-quality plant protein. This high protein content makes moringa leaves particularly valuable in combating protein-energy malnutrition, especially in developing countries [4].

Moringa oleifera leaves are a good source of vitamins, particularly provitamin A (β -carotene), vitamin C, vitamin

E, and several B-complex vitamins like thiamine, riboflavin, niacin, and folate. Vitamin A supports vision, immune function, and epithelial health, while vitamins C and E act as powerful antioxidants that protect cells from oxidative damage. The B-complex vitamins play essential roles in energy metabolism and nervous system function [5].

The leaves are also rich in essential minerals, including calcium, iron, potassium, magnesium, phosphorus, zinc, manganese, and copper. Calcium supports bone and dental health, iron supports haemoglobin synthesis and oxygen transport, potassium contributes to regulate blood pressure and muscle function, and magnesium helps as a cofactor for numerous enzymatic reactions. The high

mineral content makes moringa leaves beneficial for addressing micronutrient deficiencies [6].

In addition to their protein, vitamin and mineral content, moringa leaves provide large amounts of dietary fiber, which promotes gastrointestinal health, enhances satiety, and supports healthy blood glucose and cholesterol levels. They also contain small quantities of healthy lipids including polyunsaturated fatty acids like α -linolenic acid (omega-3) and linoleic acid (omega-6), which support cardiovascular health [7].

A salient feature of *Moringa oleifera* leaves is their rich amount of phytochemicals including polyphenols, flavonoids, phenolic acids, carotenoids, glucosinolates, tannins, and saponins. These bioactive compounds exhibit potent antioxidant, anti-inflammatory, antimicrobial, antidiabetic and anticancer activities, further enhancing the nutritional and therapeutic value of the leaves [1].

The exceptional nutrient density and diverse bioactive composition of *Moringa oleifera* leaves make them a valuable functional food ingredient. Their regular incorporation into the diet may support and improve nutritional status, prevent micronutrient deficiencies, and reduce the risk of several chronic diseases.

Bioactive Profile of *Moringa oleifera* Leaves

Moringa oleifera leaves are recognized as a rich reservoir of diverse bioactive compounds that play a major role in nutritional, therapeutic, and functional food applications. The bioactive profile of the leaves is primarily made up of polyphenols, flavonoids, phenolic acids, carotenoids, glucosinolates, tannins, saponins, and alkaloids, along with essential vitamins and minerals that enhance their overall biological activity [1].

Among the major elements, polyphenolic compounds such as chlorogenic acid, gallic acid, caffeic acid, and ferulic acid play an important role in antioxidant defence by neutralizing free radicals and reducing oxidative stress [8]. Flavonoids, including quercetin, kaempferol, and isorhamnetin, exhibit strong anti-inflammatory, antimicrobial, cardioprotective and anticancer activities through modulation of cellular signalling pathways and inhibition of oxidative damage [9].

Carotenoids such as β -carotene, lutein, and zeaxanthin contribute to provitamin A activity and support visual health while also acting as effective antioxidants. Glucosinolates and their breakdown products, particularly isothiocyanates, have been associated with detoxification processes and potential chemo preventive effects. In addition tannins and saponins contribute to antimicrobial and anti-inflammatory properties, while alkaloids are known for their pharmacological potential in different biological systems [10]. The synergistic interaction of these phytochemicals enhances the overall biological efficacy of *Moringa oleifera* leaves, making them highly valuable in the prevention and management of chronic diseases like diabetes, cardiovascular disorders, neurodegenerative diseases and certain types of cancer. Due to this high bioactive composition, moringa leaves are increasingly incorporated into functional foods, nutraceuticals and herbal formulations aimed at improving human health and wellbeing.

HEALTH BENEFITS OF MORINGA OLEIFERA LEAVES

Moringa oleifera leaves are widely recognized for their far-reaching health-promoting properties which are attributed to their high content of essential nutrients and diverse bioactive compounds. These leaves have been traditionally used in various systems of medicine and are increasingly supported by modern scientific research for their therapeutic potential.

i. Antioxidant Properties

Moringa oleifera leaves are widely recognized for their strong antioxidant potential, which plays an important role in their health-promoting and therapeutic effects. The antioxidant activity is primarily attributed to the presence of a wide range of bioactive compounds, including polyphenols, flavonoids, carotenoids, vitamins, and phenolic acids.

Polyphenolic compounds like chlorogenic acid, gallic acid, caffeic acid, and ferulic acid are among the major contributors to antioxidant activity. These compounds act by scavenging free radicals, chelating metal ions, and inhibiting lipid peroxidation, thereby protecting cells from oxidative damage. Similarly, flavonoids like quercetin, kaempferol and isorhamnetin enhance the endogenous antioxidant defense system by modulating enzyme activity and reducing oxidative stress at the cellular level [11].

Carotenoids, including β -carotene, lutein, and zeaxanthin, further contribute to antioxidant protection by neutralizing reactive oxygen species and supporting cellular integrity. In addition, vitamins C and E present in moringa leaves act as potent non-enzymatic antioxidants that help regenerate other antioxidant elements and maintain the redox balance in biological systems.

The synergistic interaction among these bioactive constituents increases the overall antioxidant capacity of *Moringa oleifera* leaves. This strong antioxidant potential has been linked to the prevention of oxidative stress-related disorders like cardiovascular diseases, diabetes, neurodegenerative conditions and different types of cancer.

ii. Antimicrobial Activity

Moringa oleifera leaves have been extensively studied for their antimicrobial properties which contribute to their traditional and modern medicinal applications. The antimicrobial activity is mainly attributable to the presence of various bioactive compounds, including flavonoids, phenolic acids, tannins, saponins, alkaloids, and glucosinolates, which exhibit inhibitory effects against a broad range of pathogenic microorganisms.

Phenolic compounds such as chlorogenic acid, gallic acid, and caffeic acid disrupt microbial cell walls and membranes leading to leakage of cellular components and eventual cell death. Flavonoids, including quercetin and kaempferol, interfere with microbial enzyme systems and nucleic acid synthesis, thereby inhibiting bacterial growth and replication. Tannins help with antimicrobial action by precipitating microbial proteins and reducing the availability of essential nutrients required for microbial survival.

Glucosinolates in moringa leaves are hydrolysed into isothiocyanates, which possess strong antibacterial, antifungal and antiviral activities. These compounds are well known to inhibit microbial metabolism and disrupt

cellular respiration processes. In addition saponins exert antimicrobial effects by increasing membrane permeability while alkaloids may interfere with DNA replication and protein synthesis in microorganisms [12].

The combined and synergistic effects of these phytochemicals make *Moringa oleifera* leaves effective against various Gram-positive and Gram-negative bacteria, along with certain fungi and viruses. This broad-spectrum antimicrobial activity supports their traditional use in treating infections and highlights their potential application in developing natural preservatives, herbal drugs and functional food products with antimicrobial benefits.

iii. Anti-Cancerous Properties

The anti-cancer potential of *Moringa oleifera* leaves is attributed to multiple interconnected molecular and cellular mechanisms driven by their rich profile of bioactive phytochemicals such as flavonoids, phenolic acids, glucosinolates, isothiocyanates, carotenoids, alkaloids and other antioxidant elements. These phytoconstituents provide antioxidant, anti-inflammatory, antiproliferative, and chemopreventive activities, supporting the potential role of *M. oleifera* as a functional bioactive plant in cancer research [13,14].

One of the primary mechanisms involves oxidative stress reduction. Bioactive compounds such as quercetin, kaempferol, chlorogenic acid, and vitamins C and E exhibit free-radical scavenging activity by reducing reactive oxygen species, thereby reducing oxidative DNA damage, lipid peroxidation and protein modification. Since oxidative stress contributes significantly to cancer initiation and progression, modulation of redox balance by *M. oleifera* phytochemicals may play a key role in cancer prevention [13,15].

Moringa oleifera leaves have also been investigated for anticancer activity through induction of apoptosis (programmed cell death). Flavonoids, phenolics and isothiocyanate derivatives have been reported to influence mitochondrial apoptotic pathways by altering mitochondrial membrane potential enhancing pro-apoptotic proteins such as Bax, reducing anti-apoptotic proteins like Bcl-2 and promoting cytochrome c release and caspase activation. These molecular events facilitate selective elimination of cancer cells [14,16].

Another important mechanism is cell cycle regulation, where *M. oleifera*-derived phytochemicals inhibit aggressive cancer cell proliferation by inducing cell cycle arrest at critical checkpoints, including G0/G1, S and G2/M phases. This stopping limits tumor cell growth and may contribute to its reported antiproliferative effects in different cancer models [14,17].

Additionally, isothiocyanates generated from glucosinolates present in *M. oleifera* leaves may increase cellular detoxification mechanisms by regulating phase I and phase II metabolizing enzymes. These elements facilitate carcinogen elimination and reduce the metabolic activation of potentially harmful compounds, thereby contributing to chemopreventive effects [13].

Moringa oleifera bioactive compounds also inhibit angiogenesis the formation of vasculogenesis required for tumor growth and metastasis. Recent preclinical findings suggest that moringa phytochemicals can regulate angiogenic signaling pathways, including suppression of

vascular endothelial growth factor (VEGF)-associated pathways thereby limiting tumor vascularization [16].

Additionally, *M. oleifera* modulates inflammatory pathways involved in cancer progression. Its phytochemicals suppress pro-inflammatory mediators like nuclear factor kappa B (NF- κ B), cyclooxygenase-2 (COX-2) and inflammatory cytokines, reducing the chronic inflammatory microenvironment that promotes tumor initiation and progression [13,18].

The anti-cancer activity of *Moringa oleifera* leaves results from a synergistic interaction of antioxidant, pro-apoptotic, anti-proliferative, anti-angiogenic, anti-inflammatory and detoxification-enhancing mechanisms. Although current evidence highlights *M. oleifera* as a promising candidate for cancer prevention and supportive therapy further standardized experimental studies and clinical trials are required to confirm its therapeutic efficacy and safety [14,16].

iv. Antidiabetic Properties

Moringa oleifera leaves exhibit high antidiabetic potential through multiple biochemical and physiological mechanisms, largely attributed to their rich amount of bioactive compounds such as flavonoids, phenolic acids, isothiocyanates, vitamins, minerals and dietary fibre. These phytochemicals afford glucose-lowering, antioxidant, anti-inflammatory and metabolic regulatory activities, supporting the potential use of *M. oleifera* as a functional food ingredient for diabetes management [15,19,20].

One of the primary mechanisms is the increase in insulin secretion and pancreatic β -cell protection. Bioactive compounds such as quercetin, kaempferol, and chlorogenic acid protect pancreatic β -cells against oxidative stress-induced damage, preserve cellular integrity and improve insulin secretion. These effects are associated with improved glucose homeostasis and reduced pancreatic dysfunction in experimental diabetes models [13,15].

Another important mechanism involves improvement of insulin sensitivity in peripheral tissues such as skeletal muscle and adipose tissue. Flavonoids and phenolic compounds present in *M. oleifera* leaves increase insulin receptor signaling pathways, stimulate glucose transporter activity, particularly GLUT4 translocation and promote glucose uptake by peripheral tissues, thereby improving insulin responsiveness [10,21].

Moringa oleifera leaves also contribute to inhibition of carbohydrate-digesting enzymes such as α -amylase and α -glucosidase. Phenolic compounds and flavonoids interact with these enzymes and reduce carbohydrate hydrolysis, resulting in delayed intestinal glucose absorption and attenuation of postprandial hyperglycemia [13].

The antioxidant activity of moringa plays a key role in diabetes regulation by reducing oxidative stress which is strongly associated with insulin resistance, β -cell dysfunction and diabetic complications. Polyphenols, carotenoids and vitamins C and E present in *M. oleifera* leaves neutralize reactive oxygen species (ROS), enhance endogenous antioxidant defenses, and protect metabolic tissues from oxidative injury [15,22].

In addition, the high dietary fiber content of *M. oleifera* leaves contributes to glycemic control by delaying gastric emptying, reducing intestinal glucose absorption, and improving postprandial glucose responses. Dietary fiber

also supports beneficial gut microbiota, which may influence glucose metabolism and insulin sensitivity [10,13].

Moringa oleifera also exhibits anti-inflammatory effects that may help reduce chronic low-grade inflammation associated with type 2 diabetes. Its phytochemicals suppress inflammatory mediators such as tumor necrosis factor-alpha (TNF- α), interleukin-6 (IL-6), and nuclear factor kappa B (NF- κ B), thereby improving insulin signalling and metabolic homeostasis [18,21].

Overall, the antidiabetic effects of *Moringa oleifera* leaves arise from a synergistic combination of insulin-modulating, β -cell protective, enzyme-inhibitory, antioxidant, anti-inflammatory, and glucose-regulating mechanisms. These properties highlight *M. oleifera* as a promising natural adjunct for diabetes prevention and supportive management; however, further well-designed clinical trials are required to establish optimal dosage, safety, and therapeutic efficacy [13,14].

V. Anti-inflammatory activity

The anti-inflammatory activity of *Moringa oleifera* leaves plays a central role in their overall therapeutic potential, particularly in the prevention and management of chronic inflammatory disorders. This activity is primarily attributed to the presence of bioactive compounds including flavonoids (quercetin, kaempferol, isorhamnetin), phenolic acids (chlorogenic acid, caffeic acid), glucosinolates, isothiocyanates, tannins, saponins, carotenoids, and antioxidant vitamins. These phytoconstituents exhibit immunomodulatory, antioxidant, and inflammation-regulating properties through multiple molecular mechanisms [13,15].

At the molecular level, *M. oleifera* phytochemicals regulate inflammatory responses by targeting major intracellular signaling pathways. A key mechanism involves suppression of the nuclear factor kappa B (NF- κ B) pathway, a central transcription factor responsible for regulating inflammatory gene expression. Inhibition of NF- κ B activation reduces the expression of pro-inflammatory mediators, including tumor necrosis factor-alpha (TNF- α), interleukin-1 β (IL-1 β), interleukin-6 (IL-6), and inducible nitric oxide synthase (iNOS), thereby limiting inflammatory signaling and tissue injury [18,21].

Another important mechanism involves regulation of cyclooxygenase-2 (COX-2) and lipoxygenase (LOX) pathways, which contribute to the synthesis of inflammatory mediators such as prostaglandins and leukotrienes. Polyphenols and isothiocyanates from *M. oleifera* leaves have demonstrated inhibitory effects on these enzymes, suggesting their potential role in reducing inflammatory symptoms including pain, edema, and vascular inflammatory responses [10,13].

The anti-inflammatory activity of *M. oleifera* is also associated with modulation of mitogen-activated protein kinase (MAPK) signaling pathways, including extracellular signal-regulated kinase (ERK), c-Jun N-terminal kinase (JNK), and p38 MAPK. Regulation of these pathways contributes to decreased cytokine production, reduced immune cell activation, and improved control of cellular stress responses [18,21].

Additionally, the antioxidant capacity of moringa leaves contributes significantly to inflammation regulation. Excessive production of reactive oxygen species (ROS)

promotes activation of inflammatory pathways and enhances tissue damage. Polyphenols, flavonoids, carotenoids, and vitamins C and E present in *M. oleifera* leaves neutralize ROS, enhance antioxidant defense systems, and interrupt the oxidative stress–inflammation cycle [15,22].

Glucosinolates and their hydrolysis products particularly isothiocyanates further contribute to anti-inflammatory activity by regulating detoxification pathways and reducing inflammatory gene expression. These elements influence macrophage polarization, decrease excessive nitric oxide production and regulate immune responses involved in chronic inflammation [13,14].

The anti-inflammatory activity of *Moringa oleifera* leaves is characterized by multi-target regulation of inflammatory pathways including inhibition of NF- κ B and MAPK signaling, suppression of pro-inflammatory enzymes and cytokines, reduction of oxidative stress and modulation of immune responses. These integrated mechanisms explain the therapeutic relevance of *M. oleifera* in inflammation-associated disorders, like arthritis, cardiovascular diseases, diabetes-related inflammation and neuroinflammatory conditions. However, further clinical studies are required to confirm its efficacy, bioavailability and therapeutic applications [13,14].

vi. Cardiovascular Activity

Moringa oleifera leaves have significant cardioprotective potential due to their high composition of bioactive phytochemicals, essential nutrients and antioxidant compounds. These include flavonoids (quercetin, kaempferol, isorhamnetin), phenolic acids (chlorogenic acid, caffeic acid), glucosinolates, isothiocyanates, carotenoids, vitamins C and E, minerals like potassium and magnesium, and dietary fiber. These bioactive constituents contribute to cardiovascular protection through antioxidant, lipid-regulating, antihypertensive, anti-inflammatory and endothelial-protective mechanisms [13,15,22].

One of the primary mechanisms behind the cardioprotective effects of *M. oleifera* is the reduction of oxidative stress and lipid peroxidation. Polyphenols, antioxidant and vitamins present in moringa leaves scavenge reactive oxygen species (ROS), increase endogenous antioxidant enzyme activity and prevent oxidative damage to vascular tissues and lipoproteins. This activity is particularly relevant in reducing low-density lipoprotein (LDL) oxidation a critical process involved in endothelial dysfunction and atherosclerotic plaque development [10,21].

Moringa oleifera leaves also contribute to the regulation of lipid metabolism. Experimental studies suggest that moringa-derived phytochemicals can reduce total cholesterol, LDL cholesterol and triglyceride levels while improving high-density lipoprotein (HDL) cholesterol levels. These lipid-modulating effects may reduce cholesterol accumulation in arterial walls and help prevent the progression of cardiovascular risks [13,21].

Another important mechanism involves blood pressure regulation and vascular function improvement. Bioactive compounds such as quercetin and phenolic acids may promote vasodilation by increasing endothelial nitric oxide (NO) availability, reducing oxidative degradation of NO and enhancing vascular relaxation. In addition,

potassium-rich mineral present in *M. oleifera* leaves may support electrolyte balance and contribute to the maintenance of normal blood pressure [15,22].

In addition *M. oleifera* exhibits anti-inflammatory activity by regulating inflammatory pathways associated with cardiovascular disease development. Its phytochemicals suppress nuclear factor kappa B (NF- κ B) signaling and decrease the expression of inflammatory mediators including tumor necrosis factor- α (TNF- α), interleukin-6 (IL-6), cyclooxygenase-2 (COX-2) and inducible nitric oxide synthase (iNOS). These effects may help decrease chronic vascular inflammation involved in atherosclerosis and hypertension [13,18].

The leaves also play key role in endothelial health by improving nitric oxide bioavailability and vascular responsiveness. Enhanced endothelial function promotes vascular relaxation, improves blood circulation, and contributes to reduced cardiovascular stress. Antioxidant and anti-inflammatory phytochemicals in moringa further protect endothelial cells against oxidative and inflammatory injury [21].

Dietary fiber present in *M. oleifera* leaves also contributes to cardiovascular benefits by decreasing intestinal cholesterol absorption, improving lipid metabolism and supporting healthier blood lipid profiles. Fiber-associated raise in gut microbiota composition may also influence metabolic pathways linked with cardiovascular health [10,13].

The cardiovascular activity of *Moringa oleifera* leaves is moderate through multiple complementary mechanisms including antioxidant protection, lipid-lowering activity, blood pressure regulation, anti-inflammatory effects, improved endothelial function and dietary fiber-mediated metabolic regulation. These characteristics highlight *M. oleifera* as a promising functional food ingredient for cardiovascular disease prevention and supportive management; however, further successful clinical trials are needed to establish its therapeutic efficacy, optimal dosage, and long-term safety [13,14].

BIO ACCESSIBILITY AND BIOAVAILABILITY

The health benefits of *Moringa oleifera* leaves depend not only on their rich nutritional and phytochemical content but also on how well these nutrients are released, absorbed, and utilized by the human body. This is described by two important concepts: bioaccessibility and bioavailability. Bio accessability refers to the fraction of nutrients or bioactive compounds released from the food matrix during digestion and made available for absorption, whereas bioavailability refers to the proportion of these compounds that enters systemic circulation and becomes available for biological functions [13,23]. *Moringa oleifera* leaves contain proteins, vitamins, minerals, dietary fiber and various bioactive compounds like flavonoids, polyphenols, carotenoids, and glucosinolates. These compounds contribute to the nutritional and therapeutic properties of moringa; however, their physiological effects depend on their release from the plant matrix, stability during digestion, and absorption in the gastrointestinal tract [10,19,24].

During digestion moringa leaf components are broken down and released from the plant structure but not all compounds are equally accessible or absorbed by the

body. The high dietary fiber content of moringa leaves may influence mineral bioavailability because fiber, phytates and tannins can interact with minerals like iron, calcium, and zinc, forming complexes that reduce their absorption [23].

Plant-derived compounds such as flavonoids and polyphenols generally show limited absorption in their original forms. Many polyphenols undergo extensive transformation by intestinal enzymes and gut microbiota into smaller metabolites which may retain biological activities like antioxidant and anti-inflammatory effects [23,25].

Carotenoids obtained in moringa leaves, including β -carotene and lutein have low water solubility and their absorption is increased when consumed with dietary fats. The presence of lipids improves micelle formation and facilitates intestinal uptake of carotenoids, increasing their bioavailability [26].

Glucosinolates present in *Moringa oleifera* leaves can be hydrolysed during digestion by myrosinase enzymes to form isothiocyanates and related compounds. These metabolites are more easily absorbed and have been associated with antioxidant, anti-inflammatory and protective biological effects [19,24].

Treatment methods used for moringa leaves, including drying, boiling, fermentation, and encapsulation, can significantly influence nutrient retention, release, and bioavailability. Appropriate processing conditions may increase the accessibility of bioactive compounds, whereas excessive heat or improper processing may lead to nutrient degradation [27,28].

Interactions with other dietary components also affect nutrient absorption. The gut microbiota play an important role in metabolizing plant-derived compounds into bioactive metabolites that may contribute to health benefits [23,25].

Although *Moringa oleifera* leaves are high in nutrients and bioactive compounds their health-promoting effects depend on the extent to which these compounds are released, absorbed, metabolized and utilized by the body. Further studies are required to optimize processing techniques and develop functional food formulations that improve the bioavailability of moringa-derived nutrients and maximize their potential health benefits [24, 28].

DIETARY APPLICATION OF MORINGA OLEIFERA LEAVES IN FOOD PRODUCTS

Moringa oleifera leaves are generally used in the development of functional and enriched food products due to their rich nutritional composition and health-promoting bioactive compounds. Their high levels of proteins, vitamins, minerals, dietary fiber, phenolic compounds, flavonoids, carotenoids and other phytochemicals make them valuable elements for improving the nutritional quality and functional properties of conventional foods [22,29].

The most common application is the use of moringa leaf powder as a food fortificant. It is incorporated into staple foods such as wheat flour, rice-based products, complementary foods and porridges to increase protein, iron, calcium, and micronutrient content. Such applications have been observed as strategies to combat nutrient deficiencies and improve dietary quality,

particularly in vulnerable populations in developing areas [21, 30].

Moringa oleifera leaves are rich in iron, vitamin C, folates and other essential micronutrients that support hemoglobin synthesis. Supplementation and fortification with *Moringa leaf* powder have been reported to enhance hemoglobin levels and decrease iron-deficiency anemia among women, especially pregnant and lactating women [31,32]. With its exceptional nutritional profile, medicinal and socioeconomic benefits, *Moringa* is traditionally revered as a Kalpavruksha (wish-fulfilling tree) in several parts of South India, where almost every part of the plant is utilised for food, health, and livelihood purposes [33].

Moringa oleifera leaves are also included in bakery products like bread, biscuits, cakes, and cookies. The addition of moringa powder enhances nutritional value and increases antioxidant potential due to its phenolic and flavonoid content. However, high inclusion levels may negatively influence sensory characteristics such as colour, taste, aroma, and texture. Therefore optimization of formulation is essential for consumer acceptance [10,34].

In addition, moringa leaves are increasingly used in beverages and health-oriented products such as smoothies, herbal teas, and functional drinks. These applications are associated with increased consumer demand for natural ingredients with antioxidant and nutritional benefits. *Moringa leaf*-based beverages supply an opportunity to deliver plant-derived bioactive elements in convenient food formats [29,35].

The incorporation of moringa leaf powder and extracts into dairy products like yogurt, cheese, and flavored milk has also gained attention. *Moringa* supplementation can increase antioxidant activity, mineral content and functional properties while maintaining the nutritional profile of dairy foods when appropriate concentrations are used [35,36].

Moringa oleifera leaves are applied in soups, sauces, noodles, pasta and snack products where they function as both nutritional enhancers and sources of bioactive compounds. Their inclusion can improve antioxidant capacity and increase the health-promoting potential of processed foods [10,30]. The moringa leaf powder and extracts are increasingly used in dietary supplements and nutraceutical formulations, including capsules, tablets and functional powders. These products are marketed for potential health benefits related to antioxidant protection, metabolic health, immune function and cardiovascular wellness. Further clinical investigations are required to confirm specific health claims [20,24].

Despite these advantages, challenges including bitterness, strong herbal flavour, green coloration, and potential losses of heat-sensitive nutrients during processing remain important limitations. Food formulation strategies, encapsulation technologies, fermentation, and optimized drying methods are being explored to improve sensory acceptance, stability, and nutrient retention [23,28].

The *Moringa oleifera* leaves have broad applications in functional food development and nutraceutical innovation. Their integration into different food systems provides opportunities to improve nutritional quality, support dietary diversity, and contribute to strategies aimed at

enhancing human health and preventing nutrition-related disorders [21,24].

SAFETY ASPECTS OF MORINGA OLEIFERA LEAVES

Moringa oleifera leaves are generally regarded as safe for human consumption and have been traditionally used as food and medicine in many regions worldwide. Their high nutritional value and abundance of bioactive compounds support their use as a dietary ingredient; however, safety considerations related to dosage, processing, and individual health conditions must be considered to ensure their appropriate utilization [20,24].

The major safety consideration is the presence of anti-nutritional factors such as phytates, tannins and oxalates. These compounds may reduce the bioavailability of essential minerals like iron, calcium, and zinc, through the formation of complexes that limit intestinal absorption. Although the levels of these compounds in *Moringa oleifera* leaves are widely moderate compared with several other plant-based foods, excessive consumption or inadequate processing may influence nutrient utilization [10,21].

The another important factor is dosage and consumption level. Moderate dietary consumption of moringa leaves is considered beneficial, whereas excessive intake particularly in concentrated extracts or supplement formulations may result in adverse effects such as gastrointestinal discomfort, nausea or diarrhea in sensitive individuals. Therefore, appropriate dosage recommendations and standardization of moringa-based products are necessary, especially for therapeutic applications [20,24].

Moringa oleifera leaves are generally considered safe when consumed as part of a normal diet during pregnancy and lactation; however, high-dose supplementation requires caution because clinical safety data remain limited. Food-based consumption is generally preferred over concentrated extracts during these physiological stages, and further research is required to establish safe therapeutic doses [19,21].

Drug–nutrient interactions must also be considered because moringa leaves exhibit biological activities, including antihyperglycemic and antihypertensive effects. Consumption of large amounts of moringa products together with antidiabetic or blood pressure-lowering medications may theoretically enhance pharmacological effects, potentially causing hypoglycemia or hypotension. Individuals using such medications should seek professional guidance before consuming concentrated moringa supplements [20,24].

Some studies have expressed that routine use of moringa leaf supplement throughout pregnancy is still limited. Importantly, roots, bark, and some extracts of moringa should be avoided during pregnancy, animal studies have shown anti-fertility and abortifacient effects. The quality of commercial moringa powder is important because contamination with microorganisms has been reported in some products with these plant parts [20,31].

Moringa oleifera leaves contain anti-nutritional factors such as phytates, oxalates, and tannins that can reduce nutrient absorption. These compounds can be minimized through blanching, boiling, fermentation, soaking, and appropriate

drying methods. Among these, blanching followed by shade drying is considered an effective approach to improve nutrient bioavailability [19,3]. Furthermore, quality control during cultivation, harvesting, processing, and storage is essential to prevent contamination from pesticides, heavy metals, mycotoxins, and microorganisms and to ensure the safety of commercial moringa-based foods and supplements [23,28].

The *Moringa oleifera* leaves have considerable potential as a safe nutritional and functional food ingredient when consumed appropriately. Future research should focus on establishing standardized dosage recommendations, evaluating long-term safety, and improving quality assurance systems for moringa-derived products [20,24].

CONCLUSION

Moringa oleifera leaves are a highly rich nutritious and functional plant material with significant health-promoting potential. They are rich in essential nutrients such as proteins, vitamins, minerals, dietary fiber, and bioactive phytochemicals including flavonoids, phenolic acids, carotenoids, and glucosinolates. These compounds are responsible for a wide range of biological activities, including antioxidant, anti-inflammatory, antimicrobial, antidiabetic, anticancer and cardioprotective effects.

The moringa leaves play an important role in improving nutrition and supporting the prevention of chronic diseases. Their incorporation into functional foods, nutraceuticals, and dietary supplements offers an effective and sustainable approach to addressing malnutrition and promoting public health.

However, challenges such as variability in composition, limited bioavailability of certain nutrients, and lack of standardized processing methods still need to be addressed. Further research and clinical validation are necessary to fully confirm their therapeutic potential and ensure safe, effective use.

FUNDING

No external funding was received for this study.

ACKNOWLEDGEMENTS

The authors have no acknowledgements to declare.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

INFORMED CONSENT

Informed consent was obtained from all authors, as applicable.

ETHICAL STATEMENT

Not applicable.

AUTHOR CONTRIBUTIONS

Dr. A. Shobha Rani, Dr. E. Bhuvaneswari, and Dr. K. S. Shanthi Sree contributed to data collection and manuscript writing. Prof. G. Savithri contributed to the conceptualization of the study.

REFERENCE

1. Kashyap, P.; Kumar, S.; Riar, C.S.; Jindal, N.; Baniwal, P.; Guiné, R.P.F.; Correia, P.M.R.; Mehra, R.; Kumar,

2. H.(2022). Recent Advances in Drumstick (*Moringa oleifera*) Leaves Bioactive Compounds: Composition, Health Benefits, Bioaccessibility, and Dietary Applications. *Antioxidants* 2022, 11, 402. <https://doi.org/10.3390/antiox11020402>
3. Fuglie, L.J. (1999). *The Miracle Tree: Moringa oleifera*, Natural Nutrition for the Tropics; Church World Service: New York, NY, USA, 17.
4. Moyo, B.; Masika, P.J.; Hugo, A.; Muchenje, V. (2011). Nutritional Characterization of *Moringa* (*Moringa oleifera* Lam.) Leaves. *Afr. J. Biotechnol.* 10, 12925–12933.
5. Falowo, A.B.; Mukumbo, F.E.; Idamokoro, E.M.; Lorenzo, J.M.; Afolayan, A.J.; Muchenje, V. (2018). Multi-Functional Application of *Moringa oleifera* Lam. in Nutrition and Animal Food Products: A Review. *Food Res. Int.* 106, 317–334.
6. Mbikay, M. (2012). Therapeutic Potential of *Moringa oleifera* Leaves in Chronic Hyperglycemia and Dyslipidemia: A Review. *Front. Pharmacol.* 3, 24
7. Stevens, G.C.; Baiyeri, K.P.; Akinnnagbe, O. (2013). Ethno-Medicinal and Culinary Uses of *Moringa oleifera* Lam. in Nigeria. *J. Med. Plants Res.* 7, 799–804.
8. Tshabalala, T.; Ndhlala, A.R.; Ncube, B.; Abdelgadir, H.A.; Van Staden, J.(2020). Potential Substitution of the Root with the Leaf in the Use of *Moringa oleifera* for Antimicrobial, Antidiabetic and Antioxidant Properties. *S. Afr. J. Bot.* 129, 106–112.
9. Makita, C.; Chimuka, L.; Steenkamp, P.; Cukrowska, E.; Madala, E. Comparative Analyses of Flavonoid Content in *Moringa oleifera* and *Moringa ovalifolia* with the Aid of UHPLC-QTOF-MS Fingerprinting. *S. Afr. J. Bot.* 2016, 105, 116–122
10. Matshediso, P.G.; Cukrowska, E.; Chimuka, L. (2015). Development of Pressurised Hot Water Extraction (PHWE) for Essential Compounds from *Moringa oleifera* Leaf Extracts. *Food Chem.* 172, 423–427.
11. Saini, R.K.; Sivanesan, I.; Keum, Y.-S. (2016). Phytochemicals of *Moringa oleifera*: A Review of Their Nutritional, Therapeutic and Industrial Significance. *3 Biotech*, 6, 203
12. Wang, Y.; Gao, Y.; Ding, H.; Liu, S.; Han, X.; Gui, J.; Liu, D.(2017). Subcritical Ethanol Extraction of Flavonoids from *Moringa oleifera* Leaf and Evaluation of Antioxidant Activity. *Food Chem.* 218, 152–158
13. Rocchetti, G.; Pagnossa, J.P.; Blasi, F.; Cossignani, L.; Piccoli, R.H.; Zengin, G.; Montesano, D.; Cocconcelli, P.S.; Lucini, L. (2020). Phenolic Profiling and in Vitro Bioactivity of *Moringa oleifera* Leaves as Affected by Different Extraction Solvents. *Food Res. Int.* 127, 108712
14. Carbonell-Capella JM, Buniowska M, Barba FJ, Esteve MJ, Frígola A. (2014). Analytical Methods for Determining Bioavailability and Bioaccessibility of Bioactive Compounds from Fruits and Vegetables: A Review. *Compr Rev Food Sci Food Saf.* 13(2):155–171. doi: 10.1111/1541-4337.12049.
15. Rajkumar C, Ramsridhar S, Veeraraghavan VP (2024). Anticancer effect of *Moringa oleifera* in oral squamous cell carcinoma: a systematic review. *Discover Oncology.* 15:688
16. Abd Rani NZ, Husain K and Kumolosasi E (2018). *Moringa* Genus: A Review of Phytochemistry and Pharmacology. *Front. Pharmacol.* 9:108. doi: 10.3389/fphar.2018.00108
17. Masri El L, El Masri Y, Tlayss M, Patra D. (2026). Anticancer Potential of *Moringa Oleifera* in Lung Cancer: A Mini Review of In vitro and In vivo Evidence. *Mini Rev Med Chem.* doi: 10.2174/0113895575450429260422051704. Epub ahead of print. PMID: 42136470
18. Adeyemi, O. S. and T. C. Elebiyo (2014). *Moringa oleifera* Supplemented Diets Prevented Nickel-Induced Nephrotoxicity in Wistar Rats, *Journal of nutrition and metabolism*, doi: <https://doi.org/10.1155/2014/958621>.
19. Wang et al (2023). The anti-inflammatory activity of GABA-enriched *Moringa oleifera* leaves and regulation of NF-κB signaling pathways. *Frontiers in Nutrition.*
20. Leone, A., Spada, A., Battezzati, A., Schiraldi, A., Aristil, J., & Bertoli, S. (2015). Cultivation, genetic, ethnopharmacology, phytochemistry and pharmacology of *Moringa oleifera* leaves: An overview. *International Journal of Molecular Sciences*, 16(6), 12791–12835.
21. Stohs, S. J and Hartman (2021). Safety and efficacy of *Moringa oleifera* leaf products: A review. *Phytotherapy Research*, 35, 1–15.
22. Kou, X., Li, B., & Olayanju, J. B. (2022). Nutritional and functional properties of *Moringa oleifera* and its applications in food systems. *Foods*, 11, 1–18.
23. Gopalakrishnan L, Doriya K, Kumar DS. (2016). *Moringa oleifera*: a review on nutritive importance and its medicinal application. *Food Sci Hum Wellness.* 5(2):49–56. doi:10.1016/j.fshw.2016.04.001
24. Dini, I. (2020). Bioavailability and bioaccessibility of bioactive compounds from natural products. *Foods*, 9(11), 1–18.
25. Dhakad AK, Ikram M, Sharma S, Khan S, Pandey VV, Singh A. (2019). Biological, nutritional, and therapeutic significance of *Moringa oleifera* Lam. *Phytother Res.* 33(11):2870-2903. doi: 10.1002/ptr.6475.
26. Gibson GR, Hutkins R, Sanders ME, Prescott SL, Reimer RA, Salminen SJ, Scott K, Stanton C, Swanson KS, Cani PD, Verbeke K, Reid G. (2017). Expert consensus document: The International Scientific Association for Probiotics and Prebiotics (ISAPP) consensus statement on the definition and scope of prebiotics. *Nat Rev Gastroenterol Hepatol.* 14(8):491-502. doi: 10.1038/nrgastro.2017.75.
28. Saini, R. K. and Keum, Y. S. (2018). Carotenoid extraction methods: A review of recent developments. *Food Chemistry*, 240, 90–103
29. Vongsak, B., Sithisarn, P., & Gritsanapan, W. (2013). Bioactive contents and free radical scavenging activity of *Moringa oleifera* leaf extract under different extraction conditions. *Industrial Crops and Products*, 44, 566–571.
30. Fernandes, A. C., and de Souza, L. P. (2021). Bioaccessibility and bioavailability of plant bioactive

- compounds: Influence of food processing and digestion. *Food Research International*, 140, 109855.
31. Daba, M. H., et al. (2020). Nutritional composition and functional properties of *Moringa oleifera* leaves for food applications. *Journal of Food Processing and Preservation*, 44, e14800. Sultana S. Nutritional and functional properties of *Moringa oleifera*. *Metabol Open*. 2020 Oct 9;8:100061. doi: 10.1016/j.metop.2020.100061.
32. Abdull Razis AF, Ibrahim MD, Kntayya SB (2014). Health benefits of *Moringa oleifera*. *Asian Pac J Cancer Prev*. 15(20):8571-6. doi: 10.7314/apjcp.2014.15.20.8571.
33. Sánchez-Muniz, F. J., et al. (2023). *The Impact of Moringa oleifera Supplementation on Anemia and Other Variables during Pregnancy and Breastfeeding: A Narrative Review*. *Nutrients*, 15(13), 2914.
34. Nambiar, V. S., Mehta, R., and Daniel, M. (2003). *Potential functional implications of drumstick (Moringa oleifera) leaves in nutritional improvement of women*. *Indian Journal of Nutrition and Dietetics*, 40, 75–82.
35. Anwar, F., Latif, S., Ashraf, M., & Gilani, A. H. (2007). *Moringa oleifera: A food plant with multiple medicinal uses*. *Phytotherapy Research*, 21(1), 17–25.
36. Moyo, B., et al. (2021). Effect of *Moringa oleifera* leaf powder incorporation on nutritional quality and sensory properties of bakery products. *Food Science and Nutrition*, 9, 1–10.
37. Zhang, Y., et al. (2023). Development of plant-based functional foods enriched with bioactive compounds: Applications of *Moringa oleifera*. *Journal of Functional Foods*, 101, 105398.
38. Khan, I., et al. (2022). Application of *Moringa oleifera* in functional foods and nutraceutical development: Current trends and future perspectives. *Trends in Food Science & Technology*, 119, 1–12.