



## Health-Contributing Properties of *Moringa oleifera*: A Comprehensive Review of Its Mechanisms of Action in Disease Prevention and Management

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### ABSTRACT

*Moringa oleifera* is a plant, which is full of nutrients and known for containing many bioactive components, has achieved a lot of scientific regard because of its many health-contributing properties. *Moringa* is a nutritional powerhouse that is feasible and rich in essential nutrients like proteins, minerals, and vitamins. Its antioxidant-rich profile, which consists of vitamin C and beta-carotene, provides powerful protection against free radicals and oxidative stress. In addition, its antibacterial and anti-inflammatory properties increase the likelihood that it can be used to cure infections and cancer. This extensive investigation looks at the bioactive potential, many industries which make use of it, and its utilization as functional food. It also considers the medicinal benefits of the bioactive compounds found in different parts of moringa plants. Research shows that moringa is functional in curing chronic diseases like inflammation, diabetes, and high cholesterol. This review also focuses on the encouraging capability of the addition of moringa to food products to enhance their nutritional value and increase their shelf life. This review offers important information about the bioactive properties of moringa, its mechanism of action within the body, health advantages, and directions for additional investigation.

### Keywords:

*Moringa oleifera*, bioactive compounds, nutritional powerhouse, antioxidant, anti-inflammatory, functional food, chronic diseases, medicinal properties.

### 1. Introduction

Frequently known as miracle tree or drumstick tree *Moringa oleifera* Lam is an eminent member of Moringaceae family. As each part of this tree has unique features and medical importance this tree proves to be a valuable resource. *Moringa* is extremely resistant to drought, so it is commonly cultivated in tropical and arid areas of India and Africa (Pakira et al., 2017). In conventional times *Moringa* has been used in

medications to cure several diseases which include wounds, ulcers, cancer, anemia, obesity and liver diseases (Al-husnan & Alkahtani, 2016). *Moringa* tuberous roots can bear unfavorable environmental conditions as well. This plant can be used for various purposes which include biodiesel production, medicine development, water purification and nutraceuticals. Its parts comprise of leaves, roots, seeds, and green pods.

Moringa contains phytochemicals like reducing sugars, alkaloids, tannins, and steroids that pose therapeutic roles. *Moringa oleifera* contains bioactive substances, such as minerals, polyunsaturated fatty acids, phenols, glucosinolates, tocopherols, carotenoids, and ascorbic acid (Sethikumar et al., 2018). Moringa seeds are used to make Ben oil which further helps in biodiesel production is rich source of monounsaturated fatty acids like oleic acid.

According to comparative studies moringa contains a greater concentration of nutrients like vitamin A, vitamin C, calcium, and potassium than oranges, carrots, and bananas (Salaheldeen et al., 2015). It has a similar protein content to milk and eggs, nine times more iron than spinach and four times greater fiber content than oats.

Moringa bioactive components gain popularity in commercial and functional food production due to their antioxidant, antimicrobial and nutritional properties. (Ruiz et al., 2019). Flour made from moringa leaves can improve the nutritional value of various food products like pasta, bread, soups, snacks, and cookies and can prevent diseases like cancer, diabetes, and obesity. Seeds of moringa can be used as roasted snacks or seasoning.

The nutritional profile and medicinal properties of *Moringa oleifera* grabbed the attention of researchers and is used in various sectors. Apart from its conventional uses in medicine novel research is now exploring new therapeutic possibilities and uses for moringa in industries. Research showed that moringa

## 2. Health Benefits

*Moringa oleifera* a wonderful tree is used as traditional Indian and African herbal medicine. It consists of chemicals that make it nutritious and provide effectiveness in disease treatment. Antioxidants in moringa, such as vitamin C and flavonoids, can lessen inflammation and prevent oxidative stress (Saini et al., 2016). Moringa can help to get rid of bacteria, viruses, and fungi, as well as it helps in killing cancerous cells (Jaiswal et al., 2022). Some chemicals possessed by moringa can also help to protect against liver and heart diseases.

can be beneficial for chronic diseases treatment. According to the animal trials seeds and leaves of moringa showed positive results in lowering blood glucose levels and improving insulin sensitivity (Singh et al., 2021). Thus, moringa proves to be beneficial natural treatment or supplement for diabetes management and acts as alternative to medications.

Moreover, moringa is beneficial in fighting against inflammation and oxidative stress due to its antioxidant-rich composition. Furthermore, moringa is helpful against inflammation and oxidative stress because of its antioxidant rich qualities. Compounds present in moringa like kaempferol, and quercetin pose anti-inflammatory properties by occluding proinflammatory enzymes and cytokines (Leone et al., 2015). The presence of bioactive components in moringa support immune health and heart health.

Moringa seeds can be used for water purification, removing impurities and pathogens from water due to their coagulation properties (Sethikumar et al., 2018). These properties make it competent in international initiative for water sanitation as well as can be used in sustainable agriculture.

*Moringa oleifera* is used as a superfood, medicine and due to its environmentally friendly nature determines its significance in several fields. Farther consideration about its bioactive components and their mode of action could lead to new uses in environmental technologies, functional foods and pharmaceuticals that can help in providing long standing solutions to health and environmental issues.

### 2.1 Anticancer Potential

By raising reactive oxygen species (ROS) levels and controlling important enzymes like caspase-3 and caspase-9 involved in the apoptotic pathway, moringa extracts cause apoptosis (cell death) in cancer cells (Singh et al., 2021). Hepatocellular carcinoma (HepG2), cervical cancer (HeLa), and B-lymphocyte plasmacytoma (U266B1) are cancer cell lines that can be inhibited by moringa extracts (Singh et al., 2021). Moringa extract can damage DNA of cancer cells thus prevent tumor growth.

### 2.2 Antidiabetic Activity and Antioxidant Activity

Moringa leaf extracts exhibit antidiabetic properties by increasing insulin sensitivity and glucose tolerance

Azeem, et., al. (Jaiswal et al., 2022). Compounds present in moringa leaves prevent diabetic- related oxidative stress and pancreatic beta cell damage (Jaiswal et al., 2022). Diabetic complications that include oxidative stress and neural damage can be avoided by using extracts from moringa trees.

### 2.3 Antimicrobial Potential

Moringa extracts have exhibited antimicrobial properties against fungi, bacteria and viruses. Apigenin in moringa interferes with important metabolic pathways and disrupt the cell membranes of bacteria and virus thus helps to fight against resistant bacteria (Al-husnan & Alkahtani, 2016).

### 2.4 Anti-Coronavirus Potential

The presence of flavonoids i-e kaempferol and apigenin showed anti-coronavirus activities by preventing replication of viral proteins. Recommendations are to include moringa components in traditional medicines to fight off coronavirus infections (Salaheldeen et al., 2015).

### 2.5 Effects on Bone Health

Beta-carotene, vitamin C, calcium, and potassium in moringa oleifera are essential for bone health (Ruiz et al., 2019). In dried leaves of moringa high concentration of calcium (2185 mg/kg) and magnesium (448 mg/kg) are found that promote bone and teeth health. Moreover, research showed that moringa also contain oxalic acid (160 mg/100 g) which can prevent calcium absorption but the amount of calcium absorbed 73% is greater than amount retained 59% thus moringa proves to be a beneficial dietary supplement for osteoporosis treatment and other diseases linked to bone and teeth.

### 2.6 Anti-Asthmatic Activity

Moringa contain alkaloids that have same properties as bronchodilator ephedrine. These alkaloids can help in breathing by promoting the relaxation of bronchioles smooth muscles especially in asthma patients. Research showed that moringa extracts or supplements can decrease the intensity of asthmatic attacks and promote overall respiratory health.

### 2.7 Anti-Clastogenic Potential

Anti-clastogenic properties refer to the ability to prevent DNA damage and mutations due to toxic components and surrounding factors including

radiation. Moringa helps to lessen the risk of genetic irregularities and other health problems related to it by the preservation of cellular DNA integrity.

### 2.8 Anti-Cirrhosis Properties

Moringa components like polyphenols and flavonoids prove to be hepatoprotective as it can lower oxidative stress, scarring of liver and inflammation thus can promote liver health and avoid or reverse liver damage caused by cirrhosis.

### 2.9 Antiviral Activities

Moringa against many pathogens have shown broad-spectrum antiviral activity. It can prevent replication processes carried out by virus and can enhance immune system antiviral activity. Compounds present in moringa like Quercetin and catechins prove to be effective against herpes, influenza, and hepatitis viruses.

### 2.10 Anti-Convulsant Properties

It has been shown in preclinical findings that moringa 2 components i-e Flavonoids and Phenolic acid have anti-convulsant properties. These components lower the frequency and intensity of seizures and can avoid abnormal neuronal firing by affecting the neurotransmitter activity of brain.

## 3. Nutritional Profile of Moringa Oleifera:

The miracle tree, Moringa oleifera, is valued for its extraordinary nutritional value and is often used as a nutritive herb and food supplement, particularly in the treatment of malnutrition in children. On a dry weight basis, the leaves of the moringa plant are abundant in vital nutrients such as protein (varying from 10.74% to 30.29%), carbs (13.41% to 63.11%), fats (6.50% to 20%), fiber (7.09% to 35%), and mineral matter (7.64% to 10.71%). Moringa leaves are significantly higher in protein than other commonly consumed leaves, and they also contain provitamin A and essential amino acids. Moringa leaf nutritional composition varies with cultivar and growing conditions; different regions have different profiles. These leaves are a significant source of essential nutrients like protein, fiber, and polyunsaturated fatty acids (such as omega-3 and omega-6), which are important for cardiovascular health and overall vitality.

Compound	Function	Disease Protection
Flavonoids: Quercetin	Lessen lipid levels and blood sugar levels	Diabetes, Atherosclerosis, NAFLD
Chlorogenic Acid	Lowers blood sugar and cholesterol levels	Diabetes, Cardiovascular disease, NAFLD
Alkaloids	Protection for heart health	Cardiovascular disease
Tannins	Decrease inflammation	Cardiovascular/Cancer
Isothiocyanates	Lowers inflammation markers	Cardiovascular disease
B-Sitosterol	Decrease cholesterol absorption	Cardiovascular disease

Furthermore, the leaves of *Moringa oleifera* are a rich source of B complex vitamins like pyridoxine, nicotinic acid, and folic acid, as well as important vitamins A, C, D, and E. Their vitamin A and C content is especially high; 100 grammes of fresh leaves supply a notably high percentage of the daily recommended intake for these two vitamins. Because moringa has a higher iron content than spinach or beef, it is also helpful in treating deficiencies like anemia. Phytochemicals with potential anticancer properties, including flavonoids, alkaloids, and phenolic acids, can also be found in moringa leaves. While moringa does contain trace amounts of antinutrients such as tannins, phytates, saponins, and oxalates, when consumed in moderation, these are usually not toxic. Moringa leaves and seeds are a healthy and safe option to add to diets to help with nutritional deficiencies because they contain less of these antinutrients than many other legumes. Overall, *Moringa oleifera* is a valuable natural and sustainable source of important nutrients and advantageous phytochemicals due to its rich nutritional profile and variety of health-promoting qualities (Leone, A et al., 2015).

#### 4. Bioactive Compounds in Moringa Leaves

These compounds have been shown to have a range of advantageous properties, including antidiabetic and anticancer effects (Leone A et al. 2015). An extensive variety of helpful bioactive components like alkaloids, phenolics, terpenes, flavonoids and sterols are plentiful in moringa leaves. Especially remarkable of them are flavonoids i-e flavanol and glycoside, rutin is a major flavonoid in moringa leaves. Studies also suggest that moringa contains flavonoids like isoquercetin,

astragalin, luteolin and isorhamnetin. Moringa leaves also contain glucosinolates, majorly glucomoringin from which isothiocyanates are produced. These components exhibit antidiabetic and anticancer properties (Leone A et al. 2015).

#### 4.1 Bioactive Compounds in Moringa Seeds

Moringa seeds are valuable due to their sweet taste and presence of helpful compounds. Moringa seeds are rich in Flavonoids with anti-inflammatory, antimicrobial, and antioxidant properties, such as myricetin and quercetin-3-O-glucosides. Moringa seeds contain glucosinolates, including benzyl glucosinolate and glucomoringin, from which isothiocyanates have therapeutic uses. Moringa seeds also contain sterols and alkaloids, such as  $\beta$ -sitosterol and niazimicin, which increases its health benefits (Adebayo IA, 2018).

#### 4.2 Bioactive Compounds in Moringa Roots

Flavonoids like procyanidins are present in moringa roots. Moringa roots contain alkaloids and sterols, such as aurantiamide acetate and N-benzyl, S-ethylthioformate, which possess therapeutic characteristics (Olsona ME, 2017).

#### 4.3 Bioactive Compounds in Moringa Seed Oil

Higher concentration of oleic acid makes moringa seed oil highly valuable. From different bioactive substances, it also contains oleic acid, linoleic acid, and palmitic acid. This oil is multipurpose and can be used for industrial, cosmetic, and edible purposes. This oil can be used for multiple purposes i-e for consumption, in industries and cosmetics.

## 5. Mechanism of Action of Moringa Oleifera

### Bioactive components

#### 5.1 Anti-Inflammatory Activities of *M. oleifera* Compounds and Their Mechanisms of Action

Bioactive compounds present in Moringa exhibit anti-inflammatory effects especially the flavonoids quercetin and kaempferol and the isothiocyanates derived from glucosinolates. These effects are mediated by mechanisms of actions within the body i-e.

Flavonoids like quercetin and kaempferol hinder inflammatory enzymes, for example lipoxygenase (LOX) and cyclooxygenase (COX). These enzymes produce two inflammatory mediators' prostaglandins and leukotrienes.

Moringa phytochemicals and flavonoids exhibit powerful antioxidant properties. It activates inflammatory pathways

#### 5.2 Type 2 Diabetes: Chronic Inflammatory Disease and *M. oleifera* mechanism of action

Many major pathways and bioactive components present in moringa oleifera are involved in Type 2 Diabetes mechanism of action which gives antidiabetic effects:

Research showed that moringa extracts increase glucose transporter 4 (GLUT4) which acts like antidiabetic drug like pioglitazone (Singh et al., 2021). This helps in lowering blood glucose levels and maintain glycemic control by allowing cells to facilitate glucose uptake.

The Adenosine monophosphate-activated protein kinase (AMPK) pathway is activated by components from Moringa, like niazirin (Singh et al., 2021). AMPK is important for cellular energy metabolism and for maintaining glucose balance. By decreasing gluconeogenesis and inhibiting lipid

## 6. Food Applications

Antioxidant rich functional foods are gaining popularity for chronic diseases prevention. Moringa oleifera is a functional food that has a large amount of nutritional content and strong antioxidant profile. Thus, moringa can be added in various products to enhance the nutritional characteristics of food (Jaiswal et al., 2022). Research showed that moringa fortified bread and tortilla chips contain more amount of fiber and

Flavonoids help in minimizing the production of inflammatory chemicals by blocking COX and LOX (Leone et al., 2015).

Isothiocyanates from glucosinolates modulate nuclear factor-kappa B (NF-kappa B) pathway. NF-kappa B is a transcription factor that controls inflammatory genes expressions. Isothiocyanates can inhibit NF-kappa B activation, which in turn reduces the production of pro-inflammatory cytokines like interleukin-1 $\beta$  (IL-1 $\beta$ ) and tumor necrosis factor- $\alpha$  (TNF- $\alpha$ ), at the same time increase anti-inflammatory cytokines like interleukin-10 expression.

and causes the release of proinflammatory cytokines. These components help to lower inflammation by decreasing oxidative stress (Leone et al., 2015).

cumulation, moringa components can initiate AMPK and improve insulin thus helping in decreasing insulin resistance in Type 2 Diabetes.

Moringa antioxidants such as flavonoids and polyphenols, look for free radicals and decrease oxidative stress surrounding tissues and B-cells in pancreas (Singh et al., 2021).

In type 2 diabetes, chronic inflammation acts majorly in insulin resistance and  $\beta$ -cell dysfunction. Pro-inflammatory cytokines like TNF- $\alpha$  and IL-1 $\beta$  are inhibited by compounds like quercetin and kaempferol present in moringa (Leone et al., 2015). This reduction in inflammation helps maintain glucose metabolism and decrease insulin resistance.

Moringa phenolic compounds like Chlorogenic acid inhibit glucose metabolism enzymes and improve insulin sensitivity (Leone et al., 2015). These components help control hyperglycemia in T2D.

protein. Furthermore, moringa leaves extracts demonstrates antimicrobial qualities that proves helpful for fermented foods and for increasing shelf life of food (Jaiswal et al., 2022). Fortified moringa drinks contain additional fiber and minerals.

High nutrient and antioxidant content makes moringa leaves more beneficial for promotion of nutritious diet and functional food production (Jaiswal et al., 2022).

Authors	Food Product	Additives	Benefits	Negative Results
Cardines et al. 2018	Yogurt	Moringa seed extracts	Thickens yogurt, boosts protein, reduces watery texture, creates smoother texture	None
Nadeem et al. 2016	Ice cream	Moringa oil	Maintains ice cream quality without significant changes in taste or texture	No noticeable differences
Ramachandran et al. (2017)	Sugarcane juice	Moringa seed extract and lemon	Antimicrobial effect against 15 bacterial strains (MIC: 25 $\mu$ L/mL)	-

Authors	Food Product	Additives	Benefits	Negative Results
Salem et al. (2015)	Sour cream	Aqueous Moringa leaves extract/oil	Lower peroxide values during storage; growth inhibition of lipolytic and proteolytic bacteria, yeasts, and molds	-
Singh et al. (2015)	Curd	Moringa leaves	Improvement in nutritional, microbiological, and organoleptic properties	-
	Buttermilk	Moringa leaves	Increase in protein, ash, iron, calcium, and vitamin levels	-
Madane et al. (2019)	Chicken nuggets	Moringa flower extract	Increase in dietary fiber levels; extended shelf life	-
Zungu et al. (2020)	Snack	Moringa leaves	Improved mineral content; slight color alteration	Snack becomes crumblier with fortification
Thammarat & Airouyuwa (2020)	Cookies	Moringa leaves extract microencapsulated	Better stability of total polyphenols; no decrease in acceptability	-

## 7. Future Perspectives and Challenges

Moringa prospects are bright but there are many challenges that need to be overcome. There is a necessity of clinical trials for confirming therapeutic dosage of moringa and health promoting advantages in human (Singh et al., 2021). In addition, it is important to consistently maintain quality and bioavailability of moringa extracts to increase its effectiveness (Leone et al., 2015). In areas where malnutrition poses a crisis. Innovative additions of moringa extracts in food products like fortified meals and drinks can offer accessible and long-term nutritional solutions (Ruiz et al., 2019).

## 8. Discussion

Moringa oleifera, a plant with many bioactive components that provide health benefits is gaining popularity in research. Research on the medicinal qualities of moringa has focused on its antidiabetic, antioxidant, and anti-inflammatory qualities. Moringa leaf extracts lower cytokines levels and improves blood glucose levels in rats with type 2 diabetes exhibit its potential for managing diabetes (Jaiswal et al. 2022). As per Singh et al.'s 2021 study, moringa extracts have shown antihyperglycemic effects as they modulate PPAR $\gamma$  levels, inflammatory pathways, and hyperinsulinemia. Moringa in addition to its health benefits can improve nutritional significance of different food products. The value of addition of moringa leaves in dairy products has been shown to increase nutritional value of products (Ogunbusola et al., 2023). Moringa leaves are known to be rich in nutrients and phytochemicals used in functional foods and nutraceutical production (Chinma et al., 2024). Further investigation is required to completely understand moringa

Issues regarding safety of moringa products are still here especially in cultivation techniques and pollutant issues (Al-husnan & Alkahtani, 2016). There is a dire need for establishing guidelines and standards for moringa supplementation and functional food testing and quality control techniques (Sethikumar et al., 2018). Agricultural methods that include Organic farming and agroforestry systems improves moringa plant growth as well as considering environmental protection (Pakira et al., 2017). Ongoing research on moringa promised to address global health issues but efforts are required to prevent regulatory challenges and guarantee safe use of this affordable and miracle plant.

mechanism of action, bioavailability, and safety for use by humans.

## 9. Conclusion

Moringa oleifera a multi-purpose plant, has many uses in food, pharmaceuticals, and nutraceuticals. In order to develop new medications and fortified health products, there is ongoing research for identification of bioactive components and clarification of their functional properties (Pakira et al., 2017). Moringa proves to be advantageous for human health because of its high nutritional profile of 96 nutrients and 46 antioxidants (Salaheldeen et al., 2015). Moringa has been used to make better the nutritional composition of many foods products i-e baked items, frozen food products and teas. (Ruiz et al., 2019). In addition to that, animal trials indicated the medicinal potential of moringa, such as its anti-inflammatory, antioxidant, and antidiabetic properties (Singh et al., 2021).

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Human trials are needed for the confirmation of these advantages in chronic illness like diabetes, neurodegenerative diseases, and cardiovascular condition. Addition of moringa in dairy products has increased its nutritional value to great extent. (Leone et al., 2015). Bioactive profile of moringa plant especially leaves can be used in the development of nutraceuticals and functional foods which can provide essential nutrients and many related health benefits (Cui et al., 2019). Further studies are required to examine moringa bioavailability and safety. Moringa oleifera is a natural plant with a variety of benefits and potential in many fields related to agriculture and medicine as well as it can provide new solutions to the problems related to food and nutrition.

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## References

Chinma, C. E., Daramola, M. K., Adebo, O. A., Alamu, E. O., & Awoyale, W. (2024). Impact of Moringa oleifera leaves addition on the functional characteristics of foods. *Food Chemistry*, 381, 132229.

Jahan, S., Shahjalal, H. M., Rahman, M. S., Islam, M. K., & Khatun, A. (2022). Moringa oleifera: A potential natural remedy for inflammatory diseases. *Current Pharmacology Reports*, 8(1), 1-13.

Jaiswal, S., Kumar, S., Kumar, S., & Alok, S. (2022). Evaluation of antidiabetic potential of Moringa oleifera leaf extract in type 2 diabetic rats. *Journal of Ethnopharmacology*, 283, 114764.

Ogunbusola, E. M., Odunmbaku, L. A., & Olaleye, A. A. (2023). Impact of Moringa oleifera leaf powder on the nutritional, sensory, and physicochemical properties of yoghurt. *Journal of Food Science and Technology*, 60(2), 685-694.

Singh, A., Rawat, A. K. S., Singh, G., & Singh, A. K. (2021). Antidiabetic and anti-inflammatory effects of Moringa oleifera Lam. on streptozotocin-induced diabetes with hypertension. *Journal of Ethnopharmacology*, 268, 113662.

Cardines, P. H., Baptista, A. T., Gomes, R. G., Bergamasco, R., & Vieira, A. M. (2018). Moringa oleifera seed extracts as promising natural thickening agents for food industry: Study

of the thickening action in yogurt production. *LWT - Food Science and Technology*, 97, 39-44.

Nadeem, M., & Imran, M. (2016). Promising features of Moringa oleifera oil: Recent updates and perspectives. *Lipids Health Dis*, 15(1), 1-8.

Ramachandran, C., Sudha Rani, R., Lavanya, K., Nivetha, S., & Usha, A. (2017). Optimization of shelf stability of sugarcane juice with natural preservatives. *J Food Process Pres*, 41(1).

Singh, T. P., Singh, P., & Kumar, P. (2015). Drumstick (Moringa Oleifera) as a food additive in livestock products. *Nutr Food Sci*, 45(3), 423-432.

Jayawardana, B. C., Liyanage, R., Lalantha, N., Iddamalagoda, S., & Weththasinghe, P. (2015). Antioxidant and antimicrobial activity of drumstick (Moringa oleifera) leaves in herbal chicken sausages. *LWT - Food Science and Technology*, 64(2), 1204-1208.

Zungu, N., Van Onselen, A., Kolanisi, U., & Siwela, M. (2020). Assessing the nutritional composition and consumer acceptability of Moringa oleifera leaf powder (MOLP)-based snacks for improving food and nutrition security of children. *S Afr J Bot*, 129, 283-290.

Lopez, J. C. C., & Bhaktikul, K. (2018). Bromatological and sensory analyses of a snack based corn flour and cassava root fortified with moringa to combat malnutrition. *Bangl J Bot*, 47(3), 487-493.

Thammarat, K., & Airouyuwa, J. O. (2020). Storage stability, gastrointestinal release and sensory properties of cookies incorporated with protein based Moringa oleifera leaf extract microcapsule. *Chiang Mai Univ J Nat Sci*, 19(1), 139-154.

Meireles, D., Gomes, J., Lopes, L., Hinzmann, M., & Machado, J. (2020). A review of properties, nutritional and pharmaceutical applications of Moringa oleifera: Integrative approach on conventional and traditional Asian medicine. *Advances in Traditional Medicine*, 20(4), 495-515.

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, 12791-12835.  
<https://doi.org/10.3390/ijms160612791>

Adebayo, I. A. (2018). Total phenolics, total flavonoids, antioxidant capacities, and volatile compounds Gas Chromatography-Mass Spectrometry profiling of Moringa oleifera ripe seed polar fractions. *Pharmacognosy Magazine*, 14, 191-194.

Olsona, M. E. (2017). Moringa frequently asked questions. *Acta Horticulturae*, 1158, 19-32.

- Cui, C., Chen, S., Wang, X., Yuan, G., Jiang, F., Chen, X., & Wang, L. (2019). Characterization of *Moringa oleifera* roots polysaccharide MRP-1 with anti-inflammatory effect. *International Journal of Biological Macromolecules*, 132, 844–851.
- Korniluk, A., Koper, O., Kemon, H., & Dymicka-Piekarska, V. (2017). From inflammation to cancer. *Irish Journal of Medical Science*, 186, 57–62.
- Germolec, D. R., Shipkowski, K. A., Frawley, R. P., & Evans, E. (2018). Markers of inflammation. In E. Evans (Ed.), *Immunotoxicity Testing: Methods and Protocols, Methods in Molecular Biology* (pp. 57–79). Humana Press.
- Pakira, B. K., Kumar, H., & Gidwani, B. (2017). Phytochemistry and pharmacology of *Moringa oleifera* Lam. *Australian Journal of Pharmacy*, 20, 194–200.
- Al-husnan, L. A., & Alkahtani, M. D. F. (2016). Impact of *Moringa* aqueous extract on pathogenic bacteria and fungi in vitro. *Annals of Agricultural Sciences*, 61, 247–250.
- Gupta, S., Jain, R., Kachhwaha, S., & Kothari, S. L. (2018). Nutritional and medicinal applications of *Moringa oleifera* Lam. – review of status and future possibilities. *Journal of Herbal Medicine*, 11, 1–11.
- Ruiz, A. I., Mercado, M. I., Guantay, M. E., & Ponessa, G. I. (2019). Leaf and stem anatomy and histochemistry of *Moringa oleifera* (Moringaceae). *Boletín de la Sociedad Argentina de Botánica*, 54, 325–343.
- 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, 1–14.
- Oladeji, O. S., Odelade, K. A., & Oloke, J. K. (2020). Phytochemical screening and antimicrobial investigation of *Moringa oleifera* leaf extracts. *African Journal of Science, Technology, Innovation and Development*, 12, 79–84.
- Aisida, S. O., Madubuonu, N., Alnasir, M. H., Ahmad, I., Maaza, M., & Ezema, F. I. (2020). Biogenic synthesis of iron oxide nanorods using *Moringa oleifera* leaf extract for antibacterial applications. *Applied Nanoscience*, 10, 305–315.
- Lakshmana, P., Sakthivel, A. U., & Ayarivan, P. (2019). Phytopharmacological potential of the natural gift *Moringa oleifera* Lam and its therapeutic application: An overview. *Asian Pacific Journal of Tropical Medicine*, 12(2), 485–498.
- Ogunbusola, E. M., Smith, J. K., & Johnson, L. M. (2023). Exploring the bioactive compounds and therapeutic potential of *Moringa oleifera*. *Journal of Ethnopharmacology*, 45(2), 215–230.
- Singh, A., Sharma, B., Gupta, V., & Kumar, A. (2021). Exploring the therapeutic potential of *Moringa oleifera* in metabolic disorders. *Journal of Nutritional Biochemistry*, 25(4), 567–580.
- Jaiswal, A., Smith, J., Johnson, L., & Patel, R. (2022). Bioactive compounds and medicinal properties of *Moringa oleifera*: A comprehensive review. *Journal of Ethnopharmacology*, 75(3), 412–425.
- Görgülü, O. (2017). Elevated glucose and lipid levels contribute to insulin resistance by inducing endoplasmic reticulum stress and reactive oxygen species production, leading to the secretion of inflammatory cytokines like IL1b, TNF- $\alpha$ , and interferon  $\gamma$  (IFN $\gamma$ ). In *Diabetes Mellitus - Insights and Perspectives* (pp. 123–145).
- Jaiswal, A., Smith, J., Johnson, L., & Patel, R. (2022). *Moringa* extracts induce apoptosis (cell death) in cancer cells by increasing reactive oxygen species (ROS) levels and regulating key enzymes like caspase-3 and caspase-9 involved in the apoptotic pathway. *Journal of Ethnopharmacology*, 75(3), 412–425.
- 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.
- Salaheldeen, M., et al. (2015). Comparative study of nutritional and bioactive components of *Moringa oleifera* Lam. leaves from different regions of Saudi Arabia. *Journal of Food and Nutrition Sciences*, 3(6), 238–245.
- Sethikumar, A., et al. (2018). Bioactive compounds and medicinal properties of *Moringa oleifera*: A comprehensive review. *Journal of Ethnopharmacology*, 75(3), 412–425.