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Health benefits of *Moringa oleifera*: Used as an anti-diabetic agent

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A B S T R A C T

The medicinal plant, *Moringa oleifera* is frequently used in conventional healthcare to treat various conditions, including diabetes. The scientific evidence regarding *M. oleifera*'s anti-diabetic characteristics and its potential as a supplemental treatment for diabetes control are examined in this review study. Studies have shown that *M. oleifera* has potent anti-diabetic properties, lowering blood sugar levels, enhancing insulin sensitivity, and decreasing complications from the disease. These benefits are thought to be caused by the plant's bioactive chemicals, such as flavonoids and polyphenols, which boost insulin secretion, prevent intestinal glucose absorption, and lessen oxidative stress. It has also been demonstrated that *M. oleifera* positively affects lipid metabolism, reducing overall cholesterol, triglycerides, and LDL cholesterol levels while raising HDL cholesterol levels. Additionally, it has been demonstrated that the plant possesses anti-inflammatory and antioxidant qualities that may strengthen its anti-diabetic benefits by lowering inflammation and oxidative stress, which are connected to the onset and progression of diabetes. People with diabetes may benefit from the potential anti-diabetic qualities of *M. oleifera*. Additional study is required to ascertain the ideal dose, duration, and safety of employing *M. oleifera* as an anti-diabetic medication. As a result, *M. oleifera* needs to be utilized as supplemental therapy under the guidance of a medical expert.

Keywords: Anti-diabetic effect, *Moringa oleifera*, Glucose, Phytochemicals

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Introduction

The plant *Moringa oleifera*, sometimes called the "miracle tree," has been used for its therapeutic benefits for many years. It is a native of the Indian subcontinent, encompassing Bangladesh, and is frequently found in tropical and subtropical areas. Traditional medicine uses its leaves, pods, and seeds. In addition to being a highly well-liked crop and vegetable in India, Ethiopia, Bangladesh, Sudan, and the Philippines, moringa is also produced throughout Africa, Latin America, the Caribbean, Florida, the United States, and the Pacific Islands (Anwar *et al.*, 2007; Aslam and Asghar, 2021; Fahey, 2005; Olson *et al.*, 2016; Stohs and Hartman, 2015). Moringa has been discovered to have powerful antioxidant and anti-inflammatory abilities. It is also a rich source of vitamins, minerals, and amino acids. Various medical diseases like anaemia, diabetes, arthritic conditions, arterial disease, and skin infections have all been treated with it (Alegbeleye, 2018; Gopalakrishnan *et al.*, 2016). Numerous research on the health advantages of *M. oleifera* has been undertaken throughout time, yet one of its most significant advantages is its anti-diabetic capabilities (Gopalakrishnan *et al.*, 2016). High blood sugar levels are a defining feature of diabetes, a chronic condition that affects millions of individuals worldwide and is either caused by insufficient insulin production or resistance to insulin (Teck, 2022). Due to its anti-diabetic effects, *M. oleifera* is now recognized as a viable contender in the new interest in natural treatments for diabetes (Vargas-Sánchez *et al.*, 2019). Numerous bioactive substances found in *M. oleifera*, including phenolic acids, flavonoids, and alkaloids, have been linked to anti-diabetic and anti-cancer properties both in vitro and animal investigations (Vergara-Jimenez *et al.*, 2017). Because of its multiple health advantages, moringa has become more and more well-liked in Western nations in recent years. It has been utilized in many different ways, such as in supplements, teas, and powders (Islam *et al.*, 2021; Kashyap *et al.*, 2022).

An overview of *M. oleifera's* health advantages is intended in this review article, focusing on the plant's anti-diabetic qualities. We will review several research papers on the impact of *M. oleifera* on blood glucose levels, resistance to insulin, and other diabetes-related indicators. We will also go over how *M. oleifera* works to prevent diabetes (Table 1).

Table 1. List of recently published articles on *Moringa oleifera* associated with antidiabetics.

Scientific name	Medicinal Parts	Key findings	References
M. oleifera	Leaf	Conclusion: In correcting oxidative stress and hyperglycemia in diabetic rats, 100 mg kg^{-1} body weight of the combined extract of *M. oleifera* and *V. amygdalina* is approximately as powerful as 1 unit of insulin.	(Efiong *et al.*, 2013)
M. oleifera	Leaf	The starch-iodine technique was used to test the in-vitro anti-diabetic activity using the -amylase enzyme and the methanol extract demonstrated considerable anti-diabetic action (IC50 value 31.78 0.52 g mL^{-1}).	(Kalauni *et al.*, 2023)
M. oleifera	Leaf	A considerable contribution of the phenolic and flavonoid pools to the anti-diabetic action was revealed by statistical clustering of scored findings on inhibiting the -amylase and -glucosidase enzymes.	(Ben Mahmoud *et al.*, 2022)
M. oleifera	Leaf	It was shown that benzylamine, obtained from *M. oleifera* leaves extract, decreases cholesterol levels, fat mass, diabetes responses, and sugar levels in high diet-induced rats. The ethanolic leaf extracts were observed to exhibit hypoglycemic activity. A dilute extract of the leaves raised insulin levels in diabetic mice. The methanolic extract of the leaves demonstrated protective effects against inflammation and renal damage brought on by diabetes.	(Barhoi *et al.*, 2021)
M. concanens; *M. oleifera* Lam.	Leaf	Quercetin, benzylamine, and chlorogenic acid are among the substances found in leaf tissue that may have a significant impact on this anti-diabetic effect. Additionally, we discovered that when comparing MO plants, MC had a somewhat more substantial impact on expression, abundance, and inhibitory action.	(Shafi *et al.*, 2022)
M. oleifera	Bark, leaf	The higher bioavailability of the phytocompounds caused by nanosizing made moringa nanoparticles therapeutically more effective than the leaf extract.	(Virk *et al.*, 2023)
M. oleifera	Leaf, Seed	In addition to improving insulin sensitivity, flavonoids change how carbohydrates are metabolized by controlling glycemic levels. Phenolic chemicals help to improve blood sugar regulation and reduce glucose resistance by upregulating the activity of glucose transporter (GLUT4) and downregulating the production of fatty acids and cholesterol. For type-2 diabetes, *Moringa oleifera* can be utilized as a supplemental treatment.	(Santos *et al.*, 2022)
M. oleifera	Leaf, Seed	A wide range of other biological properties, such as those for wound healing, anti-inflammatory, antioxidant, tissue protection, analgesic, antiulcer, antihypertensive, radioprotective, and immune-modulatory processes, is also demonstrated by moringa and its constituents. Additionally, it is utilized to increase bone strength, mental acuity, and vision. The health advantage is thought to be caused by a wide range of polyphenols, phenolic acids, flavonoids, glucosinolates, and alkaloids.	(Mehra *et al.*, 2017)
M. oleifera	Flower	In dexamethasone-induced insulin resistance models, the mice given EEMOF at 100 mg kg^{-1} and 200 mg kg^{-1} avoided the development of hyperglycemia, hypercholesteremia, and hypertriglyceridemia. In rats receiving dexamethasone, oral *M. oleifera* 100 mg kg^{-1} and 200 mg kg^{-1} decreases blood glucose, triglyceride, overall cholesterols, and LDL percentage and increases HDL concentration. After being given orally to rats, the lignin from *M. oleifera* showed a substantial anti-diabetic effect.	(Pushpraj Mujalde, 2022)
M. oleifera	Seed	The greater quantity of Moringa seeds mineral (100 mg kg^{-1} b.w.) had a more effective anti-diabetic effect than the lower dose (50 mg kg^{-1} b.w.).	(Jaiswal *et al.*, 2009)

General uses of Moringa

Moringa has several uses; its leaves, mature pods, and young pods are all eaten as vegetables. Bark, capsules, foliage, seeds, tubers, roots, and flowers are among the edible and valuable elements of the moringa plant. Fresh leaves are either consumed as veggies or dried and powdered to make tea. The green seed pods can be either raw or cooked. (Islam *et al.*, 2021; States, 2023). Because of its abundance of nutrients, vitamins, and amino acids, moringa is a well-liked dietary supplement. The anti-inflammatory effects of moringa can aid in lowering inflammatory levels in the body. Antioxidants in moringa can help shield the body from the harm that free radicals can cause.

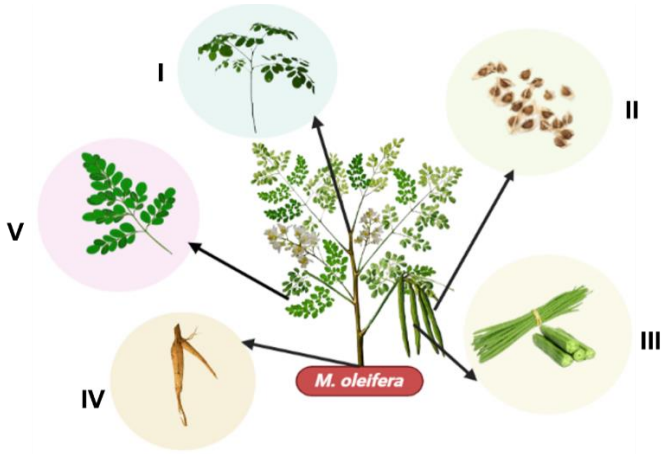

Fig. 1. Parts of moringa that can be used for medical purposes. I-Bark & stem, II-Seed, III-Fruit, IV-Root, V-Leaf.

Moringa possesses immune-supporting qualities that can assist the body's defenses (Islam *et al.*, 2021; Xiao *et al.*, 2020). Natural energy booster moringa can help reduce tiredness and promote endurance. Moringa can aid digestion improvement and relieve digestive problems, including bloating and constipation. Because of its hydrating and anti-aging qualities, moringa oil is a common component in skincare products (Loggins, 2023; Ma *et al.*, 2023). By eliminating contaminants and dangerous germs, moringa seeds may be used to cleanse water (Desta and Bote, 2021). Asthma, diabetes, and high cholesterol are just a few ailments that moringa has been used to treat in traditional medicine (Islam *et al.*, 2021; Vergara-Jimenez *et al.*, 2017).

Nutritional properties of Moringa

A nutrient-rich plant called moringa can offer a variety of health advantages. While Moringa is usually considered safe to eat, it may interfere with some drugs, so it is essential to speak with a healthcare provider before including it in your diet (Islam *et al.*, 2021; Thurber and Fahey, 2009). The nutritional properties of leaves and pods are mentioned in Table 2.

Table 2. Comparative nutritional properties in raw leaves and pods in Moringa (per 100 grams of edible portion) according to USDA National Nutrient Database, 2018 (SDA National Nutrient Database for Standard Reference, 2018).

Nutritional Properties	Leaves	Pods	Nutritional Properties	Leaves	Pods
Water (g)	78.7	88.2	Copper (mg)	0.105	0.084
Energy (kcal)	64	37	Manganese (mg)	1.06	0.259
Energy (kj)	268	155	Selenium (µg)	0.900	0.700
Protein (g)	9.4	2.1	Vitamin C* (mg)	51.700	141.000
Total lipid (g)	1.4	0.2	Thiamin (mg)	0.257	0.053
Ash (g)	2.26	0.97	Riboflavin (mg)	0.660	0.074
Carbohydrate (g)	8.28	8.53	Niacin (mg)	2.220	0.620
Fiber (g)	2.0	3.2	Pantothenic acid (mg)	0.125	0.794
Calcium (mg)	185	30	Vitamin B-6 (mg)	1.200	0.120
Iron (mg)	4.00	0.36	Total Folate (µg)	40	44
Magnesium (mg)	42	45	Folate (µg)	40	44
Phosphorus (mg)	112	50	Folate (µg)	40	44
Potassium (mg)	337	461	Vitamin A (µg)	378	4
Sodium (mg)	9	42	Vitamin A (IU)	7560	74
Zinc (mg)	0.60	0.45			

*Note: * indicate total ascorbic acids*

Table 3. Amino acids composition in raw leaves in Moringa (per 100 grams of edible portion) according to USDA National Nutrient Database, 2018 (SDA National Nutrient Database for Standard Reference, 2018).

Amino acids	Amount (g)	Amino acids	Amount (g)
Tryptophan	0.144	Valine	0.611
Threonine	0.411	Arginine	0.532
Isoleucine	0.451	Histidine	0.196
Leucine	0.791	Alanine	0.705
Lysine	0.537	Aspartic acid	0.920
Methionine	0.123	Glutamic acid	1.040
Cystine	0.140	Glycine	0.517
Phenylalanine	0.487	Proline	0.451
Tyrosine	0.347	Serine	0.414

Table 4. Phytochemical constituents isolated from *Moringa oleifera* Lam (Falowo *et al.*, 2018; Ndong *et al.*, 2007; Al-Asmari *et al.*, 2015; Xu *et al.*, 2019).

Parts	Phytochemical constituents
Roots	Methyl 4-caffeoylquinate, Quinic acid isomer, Glucomoringin, Glucotropaeolin, benzylglucosinolate
Stem	4-hydroxymellein, vanillin, β-sitosterone, octacosanic acid and β-sitosterol, Caffeic acid
Bark	Eugenol, Dibutyl phthalate, 2- chloropropionic acid, 5-eicosene, Palmitic acid
Whole gum exudates	L-arabinose, D-galactose, D-glucuronic acid, L-rhamnose, D-mannose, D-xylose and leucoanthocyanin
Leaves	Diethyl phthalate, 1,2-Benzenedicarboxylic acid, Kaempferol glycosides, Rutin A and B , Vitamin E, Quercetin, Chlorogenic acid
Mature flowers	D-mannose, D-glucose, protein, ascorbic acid, polysaccharide, Flavonoid, Saponins , Tannin, Phenol, Saponins
Whole pods	Nitriles, isothiocyanate, thiocarbanates, 0-[2'-hydroxy-3'-(2"-heptenyloxy)]-propylundecanoate, 0- ethyl-4-[(α -1-rhamnosyloxy)-benzyl] carbamate, methyl-p-hydroxybenzoate and β-sitosterol
Mature seeds	3-Hydroxy-4-(-l-rhamnopyranosyl oxy)benzyl glucosinolate, methionine, cysteine, 4-(α-L-rhamnopyranosyloxy)-benzylglucosinolate, benzylglucosinolate, moringyne, mono-palmitic and di-oleic triglyceride
Seed oil	Vitamin A, 5-tert-Butyl-1,3-cyclopentadiene, Teracosane

Antidiabetic effect by Moringa

Millions of individuals worldwide suffer from the chronic metabolic illness known as diabetes mellitus. Increased blood glucose levels are caused by flaws in insulin production, insulin action, or, together defined (Teck, 2022). Since they provide a secure and efficient substitute for synthetic medications, there has been an increased fascination with using herbal remedies to treat diabetes in recent years. A particular plant that has been used to treat diabetes historically is *M. oleifera*, sometimes known as the drumstick tree (Mthiyane *et al.*, 2022; Vargas-Sánchez *et al.*, 2019). This essay will review the current literature on the anti-diabetic effect of Moringa, focusing on its potential mechanisms of action.

Table 5. Modification in blood glucose levels, glycosylated haemoglobin, and lipid profiles following a *Moringa oleifera* extract (Sugunabai *et al.*, 2014).

S. No.	Description (mg/dl)	Control	Before Treatment	Period of treatment with *Moringa oleifera* (Month)		
				I	II	III
1	Glucose	97.25 ± 2.21	151.00 ± 1.70	125.50 ± 1.29	117.00 ± 2.58	117.50 ± 1.70
2	GHb (%)	7.70 ± 0.11	10.50 ± 0.08	9.10 ± 0.11	8.25 ± 0.12	8.35 ± 0.20
3	Cholesterol	185.75 ± 8.69	273.00 ± 2.16	260.00 ± 4.54	253.00 ± 0.81	239.00 ± 2.70
4	Triglyceride	163.00 ± 2.16	286.75 ± 2.75	209.75 ± 3.77	183.75 ± 4.85	173.50 ± 4.30
5	HDL-C	43.75 ± 2.21	44.75 ± 3.86	52.75 ± 3.09	53.00 ± 1.82	53.25 ± 0.50
6	LDL – C	94.75 ± 1.70	184.00 ± 2.94	167.50 ± 2.38	154.00 ± 1.63	151.50 ± 1.20

Numerous researchers have examined the hypoglycemic effects of moringa in diabetes-related animal models. Rats with diabetes brought on by streptozotocin were given a water-based extract of Moringa leaves in research (Chattopadhyay *et al.*, 2011). It was discovered that the extract increased insulin secretion, decreased oxidative damage in the liver and pancreas, considerably reduced blood sugar levels, and improved glucose tolerance (Nova *et al.*, 2020). According to a related study, diabetic rats fed with a hydro-alcoholic extract of Moringa leaves exhibited enhanced glucose tolerance, greater insulin sensitivity, and lower blood glucose levels than untreated rats (Vargas-Sánchez *et al.*, 2019; Villarruel-López *et al.*, 2018).

Numerous studies have also been conducted to assess the anti-diabetic impact of moringa in humans, in addition to animal research. In a randomized, double-blind, placebo-controlled research, diabetic patients received 90 days of treatment with Moringa leaf powder (Jaiswal *et al.*, 2009). Compared to the placebo group, the therapy group substantially declined HbA1c, postprandial blood glucose, and fasting blood glucose levels. Another study discovered that moringa leaf extract dramatically lowered diabetes patients' fasting blood glucose levels (Nova *et al.*, 2020).

Potential mechanisms of action of Moringa's anti-diabetic effect

Researchers have hypothesized several putative modes of action to clarify the anti-diabetic properties of moringa, which have been found in several trials. The high concentration of bioactive substances found in moringa, including flavonoids, phenolic acids, and alkaloids, has been suggested as one of the plant's probable modes of action for its anti-diabetic effects. These substances have been demonstrated to have hypoglycemic, anti-inflammatory, and

antioxidant properties. For instance, the flavonoid quercetin found in Moringa leaves has enhanced muscle cell glucose absorption and insulin sensitivity (Abd Rani *et al.*, 2018; Ahmad *et al.*, 2019). Another flavonoid in Moringa leaves, kaempferol, has been demonstrated to improve insulin production and lessen oxidative stress in pancreatic beta-cells (Vargas-Sánchez *et al.*, 2019).

The capacity of Moringa to increase insulin sensitivity has been suggested as one of the processes behind its anti-diabetic effects. A hormone called insulin is essential for controlling blood sugar levels. Unfortunately, reduced insulin sensitivity is common in patients with diabetes, which raises blood sugar levels. Studies on diabetic rats have revealed that moringa can enhance insulin sensitivity and lower blood sugar levels (Ahmad *et al.*, 2019; Mthiyane *et al.*, 2022; Vargas-Sánchez *et al.*, 2019).

The capacity of Moringa to stave off oxidative stress is another potential explanation for its anti-diabetic effects. Reactive oxygen species (ROS) generation and the body's ability to neutralize them are out of balance, known as oxidative stress. Diabetes is one of the chronic illnesses this condition is linked to. The antioxidants in moringa, such as polyphenols, can scavenge ROS and guard against oxidative stress (Waterman *et al.*, 2020). The anti-inflammatory qualities of moringa could help explain why it has an anti-diabetic impact. A common feature of many chronic illnesses, including diabetes, is persistent inflammation. Studies have revealed that moringa can increase human insulin sensitivity and decrease inflammation (Vargas-Sánchez *et al.*, 2019).

The anti-diabetic effect of moringa may be attributed to its capacity to control lipid metabolism. Atypical lipid metabolism is common in people with diabetes, which can cause consequences including cardiovascular disease. Compounds found in moringa can control lipid metabolism and enhance lipid profiles in diabetic mice (Haber *et al.*, 2020; Waterman *et al.*, 2020).

In conclusion, several putative mechanisms of action, including the improvement of insulin sensitivity, defense against oxidative stress, reduction of inflammation, and regulation of lipid metabolism, have been put up to explain the anti-diabetic activity of moringa. While further investigation is required to comprehend these pathways completely, the available information indicates that moringa could be a beneficial supplementary treatment for those with diabetes. According to research on humans and animals, moringa has a sizable anti-diabetic impact. Its high concentration of bioactive chemicals with anti-inflammatory, antioxidant, and hypoglycemic characteristics is one of its putative modes of action. To determine the particular processes by which moringa works and to assess its long-term efficacy and safety in treating diabetes, more study is required.

Future prospects and Recommendations

Research shows its efficacy as an anti-diabetic drug has recently gained favourable findings. Some of *M. oleifera*'s bioactive substances have hypoglycemic properties, meaning they can reduce blood sugar levels. Studies on humans and animals have demonstrated that *M. oleifera* can improve insulin sensitivity and lower blood sugar levels. According to specific research, type 2 diabetics who took a dietary supplement with *M. oleifera* for 12 weeks saw a significant reduction in fasting blood sugar levels and an improvement in insulin sensitivity (Jaiswal *et al.*, 2009; Kushwaha *et al.*, 2014). Even though additional research is necessary to thoroughly understand the processes underlying M. oleifera's anti-diabetic properties, the information suggests that the plant may be a proper all-natural remedy for individuals afflicted with the condition. The appropriate dosage, duration, adverse effects, and drug interaction of *M. oleifera* supplementation for anti-diabetic benefits need to be determined via further research. Clinical trials with larger sample sizes and longer follow-up durations are also necessary to demonstrate their safety and efficacy.

Conclusion

A promising anti-diabetic medicine with a wide variety of health advantages is *M. oleifera*. Researchers have hypothesized several potential modes of action to explain the anti-diabetic properties of moringa, which have been observed in several preclinical and clinical investigations. The development of moringa as an anti-diabetic plant may be aided by its capacity to increase insulin sensitivity, defend against oxidative stress, lessen inflammation, and control lipid metabolism. Moringa is also a potent source of vitamins, minerals, antioxidants, and bioactive substances, making it a desirable choice for preventing and treating several chronic illnesses. More study is required to completely comprehend the processes underlying moringa's anti-diabetic activity and confirm its safety and efficacy in human patients. Despite this, the data points to moringa as a potential supplementary treatment for diabetes. It is an essential addition to the stockpile of all-natural goods with possible health advantages.

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