INTERNATIONAL JOURNAL OF PHARMACEUTICAL SCIENCES
[ISSN: 0975-4725; CODEN(USA): IJPS00]
Journal Homepage: https://www.ijpsjournal.com

Review Article

Therapeutic Potential of *Moringa oleifera* in Diabetes Mellitus

Pooja Kushwah*[1], Ranjeet Kumar[2], Mudit Kumar[3], Vikash Chandra[4], Rohit Kumar[5], Gargi Rastogi[6], Prakash Tiwari[7], Kamlesh Patel[8], Devesh Kumar[9]

[1,2,3,4,7,8,9] *Faculty of Pharmacy, Uttar Pradesh University of Medical Sciences, Saifai, Etawah, Uttar Pradesh, India*

[5] *Department of Pharmaceutical Sciences, Gurukula Kangari Deemed to be University, Haridwar, Uttarakhand, India*

[6] *Department of Environmental Microbiology, Babasaheb Bhimrao Ambedkar Central University, Lucknow, Uttar Pradesh, India*

ARTICLE INFO

Published: 25 Jan 2026

Keywords:
Type 2 diabetes mellitus, Moringa oleifera, Antidiabetic activity, Phytochemicals, Nutraceutical potential

DOI:
10.5281/zenodo.18366321

ABSTRACT

Diabetes mellitus (DM), especially type 2 diabetes mellitus (T2DM), is a significant global health burden caused by sedentary lifestyles, bad eating habits, growing obesity rates, and fast urbanization. Despite their effectiveness, conventional antidiabetic pharmacotherapies are often linked to side effects, high costs, and declining long-term efficacy, which calls for the investigation of safer and more sustainable alternatives. Because of its wide range of pharmacological properties and rich phytochemical profile, Moringa oleifera Lam., also referred to as the "miracle tree," has attracted significant attention. With a particular focus on preclinical and emerging clinical investigations, this review thoroughly assesses the scientific evidence supporting M. oleifera's antidiabetic, anti-obesity, antioxidant, and anti-inflammatory activities. M. oleifera leaf, seed, and whole-plant extracts dramatically improve glucose homeostasis by boosting insulin secretion, raising insulin sensitivity, blocking the enzymes that break down carbohydrates (α-amylase and α-glucosidase), lowering oxidative stress, regulating lipid metabolism, and maintaining pancreatic β-cell integrity, according to experimental data from in vitro and in vivo models. Flavonoids, phenolic acids, glucosinolates, and isothiocyanates are examples of bioactive components that are important in controlling molecular pathways such as AMPK, PPAR-γ, PI3K/Akt, and inflammatory cytokine signaling. Large-scale randomized controlled trials are still lacking, despite the fact that a small number of human research point to slight improvements in glycemic and lipid indices. Overall, M. oleifera shows great promise as a nutraceutical or supplemental therapeutic agent for the management and prevention of obesity and type 2 diabetes, necessitating additional clinical validation and standardization.

***Corresponding Author:** Pooja Kushwah
Address: *Faculty of Pharmacy, Uttar Pradesh University of Medical Sciences, Saifai, Etawah, Uttar Pradesh, India*
Email : dranjeetkumar7188@gmail.com

Relevant conflicts of interest/financial disclosures: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

INTRODUCTION

Global urbanization and modernization are happening at a breakneck pace, and this has long-term effects on lifestyle decisions like unhealthy eating, inactivity, high stress, and environmental factors, all of which raise the risk of chronic illnesses like diabetes mellitus. These factors contribute to the alarming global increase in type 2 diabetes and obesity. Obese people develop insulin resistance, which is characterized by impaired insulin action in the liver and decreased glucose uptake in fat and muscle. [1,6]. The World Health Organization (WHO) (2023) reports that diabetes mellitus (DM) is a leading cause of death and morbidity, contributing to 1.5 million fatalities annually in low- and middle-income nations. According to the International Diabetes Federation's most recent forecasts, 643 million people will have diabetes by 2030, and by 2045, that number will rise to 783 million. It is interesting to note that by 2030, 14% of men and 20% of women globally are expected to be clinically obese [2,3]. Long-term diabetes mellitus can cause both macrovascular and microvascular problems, including nerve damage, kidney disease, liver disease, and elevated triglyceride levels [4]. Individuals with type 2 diabetes are at a higher risk of developing a variety of short- and long-term problems, many of which result in early mortality. The prevalence of type 2 diabetes, its sneaky onset, and its delayed diagnosis in patients with this condition [5].

Medications such as metformin, sulfonylureas, thiazolidinediones, glucagonlike peptide-1 agonists, and SGLT-2 inhibitors are being used to treat diabetes and obesity. These medications all control blood glucose levels in different ways. The following drugs are approved to treat obesity: semaglutide, setmelanotide, bupropion-naltrexone, phentermine-topiramate, orlistat, and liraglutide. These drugs enhance metabolic activity, lessen the absorption of fat, and control appetite. But their efficacy is frequently constrained by unfavourable side effects, exorbitant expenses, and less-than-ideal future results. There is increasing interest worldwide in alternative therapies, especially plant-based treatments, because traditional medications, despite their demonstrated usefulness, can have negative side effects and may lose their effectiveness over time [7,8]. As a result, several investigations have examined the anti-diabetic properties of plants and their bioactive compounds, offering a promising avenue for the development of natural medicinal treatments for type 2 diabetes (T2D) [9].

The precious herbal plant Moringa oleifera, sometimes known as the "tree of life" or the "miracle tree," is a well-known species in the Moringaceae family, genus Moringa, and has several medicinal uses. [10]. Native to Asia, MO is a fast-growing, perennial tree that grows in tropical and subtropical regions worldwide [11,12]. Out of thirteen species of the Moringa family, M. oleifera has demonstrated both nutritive and pharmaceutical action. [13,14], the impact of MO leaf extract on the histology and biochemistry of the pancreas, liver, and kidney in diabetes has not been studied [15].The hypoglycemic effect of the MO leaves has also been associated with their fiber content and the presence of glucosinolates, flavonoids (myricetin, quercetin, and kaempferol), and phenolic acids (chlorogenic acid, caffeic acid, and the most prevalent, gallic acid) are the main plant extracts from MO leaves that have been demonstrated to prevent long-term conditions like diabetes mellitus by blocking the actions of intestinal α-glucosidase and pancreatic α-amylase, which lowers intestinal glucose absorption and advanced glycation [16-17,21]. To activate AMP-activated protein kinase (AMPK), flavonoids and

saponins are needed. Isothiocyanates appear to be crucial for glycaemic control; however, they can reduce hepatic gluconeogenesis and insulin resistance. [18]. This research in biology and pharmacology has demonstrated the anti-diabetic and antioxidant benefits of extracts of Moringa oleifera leaves and seeds in experimental animal models of diabetes. [9,19]. Several antidiabetic drugs, referred to as phytopharmaceuticals, have been developed in recent decades utilizing active plant components from Moringa oleifera [20].

The principal aim of this review was to provide an overview of how MO affects inflammatory and OS processes while demonstrating its potential to prevent diabetes and obesity. This review emphasizes the ways in which research suggests that MO leaf and seed extract could be a helpful supplementary treatment for diabetes mellitus. A better knowledge of M. oleifera's molecular makeup will help create more adaptable and efficient alternative treatments for metabolic disorders. (Normative article). Further clinical trials, epidemiological research, and randomized controlled trials should be carried out in the future to validate observational data. It is also feasible to investigate the specific mechanisms by which MO improve health by examining the effects of specific proteins and phenolic acids that may help prevent or treat DM by reducing OS and inflammation. The toxicological and pharmacokinetic characteristics of M. oleifera Lam are also covered in this paper.

Scientific Evidence of Moringa oleifera Effect on Glucose Control in Animals

Glucose Homeostasis

Animal cells use glucose as a primary fuel to provide energy for cellular functions. The body gets glucose from food and from its own hepatic gluconeogenesis and glycogenolysis. A balance between the availability of glucose and how it is used by the tissues under the effect of insulin is known as glucose homeostasis. Pancreatic islet β cells release insulin, which promotes the uptake and utilization of glucose by tissues, including the liver, skeletal muscle, and adipose tissue. Moreover, it stimulates lipogenesis and inhibits lipolysis in Adipocytes; also inhibits gluconeogenesis in hepatocytes [22].

Hyperglycaemia

Hyperglycaemia is characterized by an excess of glucose synthesis, beyond the quantity needed to meet the cell's normal cellular function. An individual is diagnosed as diabetic when his blood glucose level is chronically ≥126 mg/dL after an overnight fast, and≥200 mg/dL 2 h after an oral glucose load of 75 g. As a result, chronically elevated blood sugar levels impair the production of glutathione (an antioxidant) in type 2 DM, which plays a key role in reducing oxidative stress. Additionally, this increases the person's vulnerability to long-term consequences of diabetes and renders cells more susceptible to oxidative stress, which leads to decreased insulin sensitivity and organ damage [23,24].

Type 1 diabetes mellitus (T1DM) is caused by the autoimmune destruction of pancreatic β cells and accounts for just 5% of all cases. Type 2 diabetes mellitus (T2DM) is the most prevalent form of the disease, and this review mainly focused on type 2 DM.

Evidence of Anti-Hyperglycemic Properties of Moringa Oleifera

In traditional medicine, portions of Moringa oleifera have been used to treat diabetes. [25]. Vanillic acid and piceatannol, two phytochemicals produced from M. oleifera, showed substantial binding affinities to the DPP-4 enzyme (-7.9 and -

5.7 kcal/mol), according to in silico research, indicating that they may be used as natural inhibitors to treat type 2 diabetic mellitus (T2DM) [26]. In animal models, numerous studies have examined the hypoglycemic effect of various MO components, primarily the aqueous or methanolic extracts of leaves and, second, seeds. Powdered dry leaves have also been used. [27,28]. The scientific literature found five research that used leaves to confirm these properties: three were in T2DM patients [31–33], and two were in experimental animals [29, 30]. Table 1 provides a summary of them.

Table 1. Molecular aspects of Moringa oleifera (M. oleifera) in preclinical studies of diabetes

Parts Used	Disease	Animal model/ Assay Method	Extract Type	Cell line /Animal	Dose and Duration	Molecular Aspects	Ref
Leaves	T2DM	STZ-induced diabetes	Ethanolic extract	Wistar rats	200-400 mg/kg for 21 days	↓ Insulin levels ↓ Blood glucose level, DPP-IV ↓ PPARγ, IL-6, IL-1β, and TNF-α	[34]
Leaves	T2DM	STZ-induced diabetes	Aqueous extract	Wistar rats	800 mg/kg for 4 weeks	↓ FBG	[35]
Leaves	T2DM	STZ-induced diabetes	Ethanolic extract	Albino rats	250 and 500 mg/kg for 4 weeks	↓ Fasting serum glucose, TG, TC, LDL-C ↑ SOD, GSH, CAT, HDL-C ↓ MDA ↑ BW, serum insulin The architecture of the liver and pancreas is maintained	[36]
Leaves	T2DM	STZ-induced diabetes	Dietary leaf powder with oral zinc sulfate	Wistar rats	3% M. oleifera leaf supplemented in diet and 100 mg/kg oral zinc sulfate for 6 weeks	↓ FBG, TG, LDL-C ↔ TC ↑ HDL-C	[37]
Leaves	T2DM	STZ-induced diabetes	Aqueous extract	Wistar rats	500 mg/kg/day for 4 weeks	↓ Serum glucose, LDL, TG, MDA, and BW, ↑ HDL, insulin level, β-cell function, GSH	[38]
Leaves	T2DM	STZ-induced diabetes	Methanolic extract (Fraction 1-5)	Albino rats	500 mg/kg for 28 days	↓ FBG, α-amylase ↑ Serum lipo-protein lipase, GLUT-1 and GLUT-4 ↑ G6PD and AMPK	[39]

Leaves	T2DM	STZ-induced diabetes	Extract	Male albino rats	200 mg/kg for 3 weeks	↓ Blood glucose ↔ BW ↓DNA damage in parotid gland cells	[40]
Leaves	T2DM	STZ-induced diabetes	Hydroalcoholic extract	Wistar rats	500 mg kg for 45 days	↑ CAT, SOD and GST ↓ TBARS	[41]
Leaves	T2DM	Hetero allelic mutant of insulin receptor gene of Drosophila melanogaster	Leaf powder	Drosophila melanogaster (Fruit fly)	0.5%, 1.5%, 2.5%, 4.0%, and 5.5% for 5 days	↓ Serum glucose, LDL, TG, MDA ↑ HDL, GSH	[42]
Leaves	T2DM	15% and 30% sucrose induced diabetes	Powder	Drosophila melanogaster (Fruit fly)	1% w/v for 14 days	↓ α-amylase and α-glucosidase, ROS, TBARS ↓ Glucose, TG, MAO, acetylcholine esterase activity ↑ SOD, CAT, GST	[43]
Leaves	T2DM	STZ-induced diabetes	Lyophilized aqueous extract	Albino rats	100 mg/kg BW for 14 days	↓Blood glucose, MDA, PC levels ↓ ALT, AST, ALP, urea, albumin ↑ SOD, GSH, GST, GLUT4	[44]
Leaves	T2DM	STZ-induced diabetes	Aqueous extract	Male Sprague-Dawley rats	200 mg/kg for 8 weeks	↓ FBG, FINS, FFA, TNF-α ↓ Serum leptin level ↑ Akt, GSK3β, β-catenin level	[45]
Leaves	T2DM, nonalcoholic fatty liver	High-lipid diet model	Infusion and ethanolic extract	BALB/c mice	500 mg/kg/day for 2 months	↓ SGPT, SGOT, lipid profiles, urea and glucose levels	[46]
Leaves	T2DM	Polysaccharide fermentation model (STC-1 cells)	Isolated polysaccharide from M. oleifera (MOP-3) rich in arabinose, rhamnose, and galactose	STC-1 cells	MOP-1: 0.2 mol/L MOP-2: 0.4 mol/L MOP-3: 0.8 mol/L	↑ SCFA production, GLP-1 secretion in STC-1 cells	[47]
Leaves	T2DM	Alpha-amylase inhibition assay	Silver nanoparticles	In vitro	20-100 µL	Inhibit α-amylase	[48]

Seeds	T2DM	C2C12/IR and high-fat diet with STZ-induced diabetes	Peptide MoHpP-2	In vitro and in vivo	50 mg/kg body weight for 10 weeks	↓ Blood glucose, bile acid formation, and IR ↑ CAT, SOD, GPx, GSH, unsaturated fatty acid synthesis; ↑ Glucose consumption and TAC	[49]
Whole plant	Obesity and T2DM	High-fat diet with STZ-induced diabetes	Methanolic extract	Wistar albino rats	500 mg/kg for 12 weeks	↓ Body and liver weights ↓ Plasma glucose level, IL-1β, TNF-α, COX-2 ↑ IL-10, IL-6	[50]

Mechanisms of Anti diabetic Action of *Moringa oleifera*

Increasing Levels of Insulin

Moringa oleifera significantly reduces diabetes by increasing insulin production and maintaining the integrity of pancreatic β-cells, according to meta-analytic and experimental data from animal studies [51]. In both chemically induced (streptozotocin or alloxan) and diet-induced diabetic mouse models, M. oleifera leaf extracts have repeatedly demonstrated a significant decrease in fasting blood glucose levels [52,53]. Improved circulating insulin levels and defense against β-cell degeneration are partially responsible for these hypoglycemic effects [52]. In comparison to untreated controls, extract-treated diabetic rats showed a greater percentage of insulin-immunopositive cells, increased β-cell mass, and restoration of normal islet architecture, according to histopathological evaluations reported in multiple investigations. Bioactive phytoconstituents such quercetin, chlorogenic acid, and isothiocyanates are thought to promote insulin release and lessen β-cell damage caused by oxidative stress [51,53]. These results collectively imply that M. oleifera improves glycemic control by promoting pancreatic β-cell survival and increasing endogenous insulin production [53].

Enhancement of the insulin sensitivity

Moringa oleifera significantly increases insulin sensitivity in diabetic rodent models, according to preclinical research, as shown by decreased fasting insulin levels, enhanced HOMA-IR indices, and partial correction of body weight and adiposity [54]. Adipokine expression regulation, such as elevated adiponectin and enhanced leptin signaling, which promote improved peripheral glucose consumption, is strongly associated with these metabolic benefits [53]. Furthermore, it has been demonstrated that M. oleifera extracts control adipose tissue's peroxisome proliferator-activated receptor-γ (PPAR-γ) signaling pathways, which enhances insulin signaling, maintains lipid homeostasis, and lowers insulin resistance [51]. All of these results point to M. oleifera's contribution to improving peripheral insulin action [53].

The Reduction of Enzymatic Processes That Digest Carbohydrates

Moringa oleifera leaf extracts have been shown in vitro to efficiently inhibit important carbohydrate-digesting enzymes, namely α-amylase and α-glucosidase, which slows starch hydrolysis and lowers the rate of intestinal glucose absorption [55]. Bioactive flavonoids and phenolic acids, such as quercetin, kaempferol, and chlorogenic acid, which interact with enzyme active sites, are mainly responsible for this enzymatic inhibition. These phytochemicals considerably improve glycemic control in laboratory models and early clinical observations by reducing postprandial glucose inflow [53].

Antioxidants & Formation of Radicals for Health

In diabetic experimental models, moringa oleifera has strong antioxidant and free-radical scavenging action, mostly due to the up-regulation of endogenous antioxidant defense systems [56]. Superoxide dismutase (SOD), catalase (CAT), and glutathione peroxidase (GPx) activities are greatly increased by treatment with M. oleifera leaf extracts, and reduced glutathione (GSH) levels in hyperglycemic tissues are simultaneously restored [57]. Malondialdehyde (MDA) and other lipid peroxidation markers significantly decrease in tandem with these biochemical changes, suggesting mitigation of oxidative membrane damage. The substantial polyphenolic and flavonoid content of M. oleifera, which includes quercetin, kaempferol, and chlorogenic acid, which efficiently neutralize reactive oxygen species and prevent oxidative chain reactions, is largely responsible for the plant's potent antioxidant activity [58].As a result, these antioxidant activities protect the structural and functional integrity of critical organs such the pancreas, liver, kidney, and heart from oxidative stress brought on by hyperglycemia [53].

Control for Fatty Metabolic

Moringa oleifera administration significantly reduces serum triglycerides, total cholesterol, and low-density lipoprotein (LDL) levels in diabetic rodents while increasing high-density lipoprotein (HDL) concentrations, according to meta-analytic evidence from preclinical studies [59]. By downregulating important lipogenic enzymes such fatty acid synthase and acetyl-CoA carboxylase, these lipid-lowering effects are linked to the suppression of hepatic lipogenesis [60]. At the same time, M. oleifera promotes effective lipid consumption and inhibits ectopic fat storage by increasing mitochondrial and peroxisomal fatty acid β-oxidation [61]. Improved insulin sensitivity and lipid homeostasis are further enhanced by changes in adipokine profiles, including elevated adiponectin and decreased pro-inflammatory adipokines. By reducing dyslipidemia, oxidative stress, and inflammation in diabetic circumstances, these pathways work together to support M. oleifera's cardiometabolic protective effect [62].

Pancreas β Cells Regrowth and also Safety

Pooled data from preclinical animal research shows that Moringa oleifera significantly protects pancreatic β cells from damage caused by diabetogens, especially in diabetes models generated by alloxan and streptozotocin [63]. It has been demonstrated that administering M. oleifera leaf extracts improves pancreatic insulin content, increases islet width, and restores normal islet architecture, suggesting partial β-cell regeneration or functional recovery [57]. Strong antioxidant activity, which reduces oxidative stress-induced β-cell apoptosis and maintains cellular integrity, is primarily responsible for these

cytoprotective benefits [56]. Simultaneously, M. oleifera's anti-inflammatory activities, such as inhibition of NF-κB signaling and suppression of pro-inflammatory cytokines, produce an environment that is conducive to β-cell survival and repair [62]. Additionally, during prolonged hyperglycemic stress, the preservation of functional β-cell mass is supported by modulation of anti-apoptotic pathways, which are characterized by overexpression of Bcl-2 and downregulation of caspase-mediated cell death [63].

Preclinical Research

Studies on In Vitro Diabetes

There is strong evidence from in vitro studies that Moringa oleifera has a variety of cellular and molecular antidiabetic effects. Leaf and seed extracts considerably slow down the rate at which glucose is released from dietary starch by inhibiting important enzymes that break down carbohydrates, including α-amylase and α-glucosidase [64]. M. oleifera extracts increase glucose uptake in cultured muscle (L6) and adipocyte (3T3-L1) cell lines by activating insulin-dependent and insulin-independent mechanisms, such as GLUT4 translocation [30]. Furthermore, M. oleifera therapy improves downstream metabolic responses by modulating insulin signaling-related proteins such IRS-1, PI3K, and Akt. Together, these in vitro results corroborate the hypoglycemic effects shown in animal models and demonstrate a variety of complimentary modes of action, such as increased insulin signaling, better peripheral glucose consumption, and enzyme inhibition [53].

In Vivo Research on Animals

A robust pooled effect size for blood glucose reduction (Hedges' g ≈ −3.92) was found in a systematic review and meta-analysis of 44 animal studies involving 349 diabetic rodents treated with Moringa oleifera extracts and 350 diabetic controls. This indicates significant antihyperglycemic efficacy across chemical, diet-induced, and genetic diabetic models. When compared to vehicle-treated controls, long-term administration of M. oleifera extracts consistently reduced fasting blood glucose levels in most individual trials. Significant improvements in diabetic dyslipidemia were also seen in the same meta-analysis, with lower levels of total cholesterol and serum triglycerides. Nonetheless, a considerable degree of heterogeneity (I^2 ≥ 90%) was noted amongst investigations, which can be attributed to differences in rodent species, diabetogenic drugs, extract kinds, doses, and treatment durations. These in vivo results offer solid quantitative proof of M. oleifera's potential therapeutic advantages in preclinical diabetes models and validate its complex antidiabetic activities [65].

Scientific Illustration

Moringa oleifera has been shown to provide minor glycemic advantages in people with type 2 diabetes or prediabetes, while there is still little clinical proof for its antidiabetic properties [29]. Therapy-naïve patients taking M. oleifera leaf capsules showed trends toward improved fasting and postprandial blood glucose compared with controls in randomized clinical research [52]. However, conclusive results are limited due to response variability and short follow-up. Significant decreases in postprandial glucose excursions were shown in further small crossover and meal-challenge experiments employing M. oleifera leaf powder added to foods or beverages, most likely as a result of intestinal carbohydrate absorption suppression [65]. Additionally, several trials found positive changes in serum lipids, such

as decreases in LDL and total cholesterol, without any negative consequences [29]. Larger, longer, well-controlled studies are required to verify clinical efficacy and durability, but these short-term, underpowered trials collectively support the translational validity of preclinical findings [52].

Part in Consequences linked with Diabetic

Moringa oleifera reduces important pathological characteristics linked to diabetic complications, according to preclinical data from animal research. M. oleifera administration improves oxidative stress markers, lowers systemic inflammation, and normalizes lipid profiles, all of which lower the risk of cardiovascular problems in diabetic mice, according to meta-analytic and experimental findings [30,59]. In particular, increases in insulin sensitivity and body composition, as well as decreases in blood triglycerides and total cholesterol, indicate cardioprotective benefits [58]. Improved histology, decreased fibrosis, and decreased apoptosis rates are among the organ-protective advantages that have been documented in liver, kidney, and cardiac tissues [61,62]. The combined antioxidant, anti-inflammatory, and metabolic effects offer a mechanistic justification for investigating M. oleifera as a therapeutic approach to prevent or lessen diabetes-related organ damage, even though there are still few studies specifically addressing diabetic neuropathy and nephropathy [59, 61].

Medicines Relations, Safety and Toxicities

According to preclinical research, Moringa oleifera leaf preparations have a broad safety margin. At doses higher than those used in experiments for antidiabetic or cardioprotective effects, acute, subchronic, and chronic toxicity studies in rodents showed no mortality, no significant changes in liver or kidney function markers, and no histopathological evidence of organ damage [58,51,66]. These results confirm the general safety of M. oleifera within normal dietary ranges and are compatible with the historic dietary intake of M. oleifera leaves, pods, and seeds across many cultures [59,67]. The high tolerability of M. oleifera in humans is further supported by observational reports and clinical trials. Patients with type 2 diabetes as well as healthy volunteers have been given leaf powders and capsule formulations, with only sporadic moderate gastrointestinal side effects as bloating, nausea, or temporary stomach discomfort. The plant has not been directly linked to any significant negative effects [59,29,68]. Formal investigations assessing herb-drug interactions, especially with oral hypoglycemic or insulin therapy, are still scarce despite the positive safety profile. Co-administration of M. oleifera with traditional antidiabetic drugs may result in potential additional hypoglycemia effects. Therefore, it is recommended that patients and clinicians keep a careful eye on blood glucose levels and modify medication dosage as necessary. To clarify pharmacokinetic interactions, long-term safety, and effects in certain populations, such as children, pregnant women, and patients with renal or hepatic impairment, more research is necessary [58,66,67].

A Nutrient- Utilization or Strategies

Moringa oleifera leaves, which offer both nutritional and medicinal benefits, are commonly ingested as powdered supplements and as fresh or dried vegetables. They are excellent candidates for the development of functional foods because they are rich in bioactive substances such as polyphenols, flavonoids, vitamins (A, C, and E), minerals (Ca, K, Mg, and Fe), and important amino acids [51,57]. These bioactive substances can be practically delivered by adding leaf powder to fortified flours, soups, drinks, snack bars, and

teas. This promotes lipid regulation, glycemic control, and general metabolic health [57,59]. In addition to dietary applications, formulations based on capsules, tablets, and extracts are being investigated as nutraceuticals aimed at populations with type 2 diabetes or prediabetes. Consistent potency and predictable therapeutic effects are ensured by standardizing potent phytoconstituents including quercetin, chlorogenic acid, and isothiocyanates [30,52]. These preparations may improve insulin sensitivity, normalize lipid profiles, improve fasting and postprandial glucose levels, and have anti-inflammatory and antioxidant properties, according to preliminary preclinical and clinical data [51,53]. Standardized M. oleifera nutraceuticals may provide a practical, safe, and dose-controlled supplement to traditional diabetic management with additional thorough clinical confirmation. By integrating dietary bioactive substances into comprehensive lifestyle and pharmaceutical management regimens, such treatments may be especially beneficial in populations with limited access to pharmacotherapy [67,53]. regulated methods for incorporating M. oleifera into all-encompassing diabetic care plans [51,53].

CONCLUSION

Moringa oleifera is a promising plant-based medicinal candidate for the treatment of diabetes mellitus and its related metabolic problems, according to the review's cumulative data. Through a variety of complementary mechanisms, such as stimulating insulin secretion, improving peripheral insulin sensitivity, inhibiting intestinal carbohydrate digestion, reducing oxidative stress, suppressing chronic inflammation, and improving lipid metabolism, preclinical studies consistently show that M. oleifera exerts potent antihyperglycemic effects. Significantly, pancreatic β-cell structure and function are preserved and partially regenerated in conjunction with these benefits, indicating the possibility of disease modification rather than just symptom control.

M. oleifera has a good safety profile in addition to its antidiabetic effectiveness, which is backed by toxicological research and past dietary use. This makes it appropriate for long-term use as a functional food or nutraceutical. Its high concentration of vitamins, minerals, flavonoids, polyphenols, and vital amino acids reinforces its function in the overall maintenance of metabolic health. However, small sample sizes, short trial durations, and variation in formulations and dosages continue to limit clinical evidence despite robust preclinical validation.

To determine the best dosage, long-term safety, and profiles of herb-drug interactions, future research should focus on well planned randomized controlled trials, pharmacokinetic and pharmacodynamic assessments, and standardization of bioactive components. Translational application will be further strengthened by the identification of specific molecular targets, especially those associated with oxidative stress, inflammation, and insulin signaling. In summary, Moringa oleifera is a safe, effective, and scientifically supported supplement to traditional antidiabetic treatment. It has a great deal of promise to support comprehensive and easily accessible approaches to the prevention and treatment of obesity and diabetes mellitus.

REFERENCES

1. Klein, S., Gastaldelli, A., Yki-Järvinen, H., & Scherer, P. E. (2022). Why does obesity cause diabetes? Cell metabolism, 34(1), 11-20.
2. Nellaiappan, K., Preeti, K., Khatri, D. K., & Singh, S. B. (2022). Diabetic complications: an update on pathobiology and therapeutic

strategies. Current diabetes reviews, 18(1), 31-44.
3. Chandrasekaran, P., & Weiskirchen, R. (2024). The role of obesity in type 2 diabetes mellitus—An overview. International Journal of Molecular Sciences, 25(3), 1882.
4. Olokoba, A. B., Obateru, O. A., & Olokoba, L. B. (2012). Type 2 diabetes mellitus: a review of current trends. Oman Medical Journal, 27(4), 269.
5. Azevedo, M., & Alla, S. (2008). Diabetes in sub-Saharan Africa: kenya, mali, mozambique, Nigeria, South Africa and zambia. International journal of diabetes in developing countries, 28(4), 101.
6. Redha, A. A., Perna, S., Riva, A., Petrangolini, G., Peroni, G., Nichetti, M., ... & Rondanelli, M. (2021). Novel insights on anti-obesity potential of the miracle tree, Moringa oleifera: A systematic review. Journal of functional Foods, 84, 104600.
7. Rahman, M. M., Islam, M. R., Shohag, S., Hossain, M. E., Rahaman, M. S., Islam, F., ... & Cavalu, S. (2022). The multifunctional role of herbal products in the management of diabetes and obesity: a comprehensive review. Molecules, 27(5), 1713.
8. Raziani, Y., Karami, K., Mohammadi, H. R., Mahmoudvand, H., Moradi, M. N., & Yadegari, J. G. (2023). Astragalus adscendens extract shows antidiabetic effects through controlling oxidative stress, inflammation and apoptosis in streptozotocin-induced diabetic rats. Asian Pacific Journal of Tropical Biomedicine, 13(6), 242-249.
9. Thanikachalam, P. V., Ramesh, K., Hydar, M. I., Dhalapathy, V. V., & Devaraji, M. (2025). Therapeutic potential of Moringa oleifera Lam. in metabolic disorders: A molecular overview. Asian Pacific Journal of Tropical Biomedicine, 15(7), 263-284.
10. Pareek, A., Pant, M., Gupta, M. M., Kashania, P., Ratan, Y., Jain, V., ... & Chuturgoon, A. A. (2023). Moringa oleifera: An updated comprehensive review of its pharmacological activities, ethnomedicinal, phytopharmaceutical formulation, clinical, phytochemical, and toxicological aspects. International journal of molecular sciences, 24(3), 2098.
11. LEITE, D. T., MARACAJÁ, P. B., & FREIRE, M. D. S. (2010). EFEITO TÓXICO DO EXTRATO DE FLORES DE Moringa oleifera L. PARA ABELHAS Apis mellifera AFRICANIZADAS. AGROPECUÁRIA CIENTÍFICA NO SEMIÁRIDO, 6(4).
12. Kou, X., Li, B., Olayanju, J. B., Drake, J. M., & Chen, N. (2018). Nutraceutical or pharmacological potential of Moringa oleifera Lam. Nutrients, 10(3), 343
13. Gandji, K., Chadare, F. J., Idohou, R., Salako, V. K., Assogbadjo, A. E., & Kakaï, R. G. (2018). Status and utilisation of Moringa oleifera Lam: A review. African Crop Science Journal, 26(1), 137-156.
14. Chaudhary, K., & Chaurasia, S. (2017). Neutraceutical properties of Moringa oleifera: a review. European journal of Pharmaceutical and medical research, 4(4), 646-655
15. Setu, M. S., & Rahman, M. S. (2021). Application of selected components of "SPICES" model as teaching-learning method in pharmacology. Bangladesh Journal of Pharmacology, 16(4), 117-121.
16. Saeedi, P., Petersohn, I., Salpea, P., Malanda, B., Karuranga, S., Unwin, N., ... & IDF Diabetes Atlas Committee. (2019). Global and regional diabetes prevalence estimates for 2019 and projections for 2030 and 2045: Results from the International Diabetes Federation Diabetes Atlas. Diabetes research and clinical practice, 157, 107843.

17. Irfan, H. M., Khan, N. A. K., & Asmawi, M. Z. (2022). Moringa oleifera Lam. leaf extracts reverse metabolic syndrome in Sprague Dawley rats fed high-fructose high fat diet for 60-days. Archives of physiology and biochemistry, 128(5), 1202-1208
18. World Health Organization (WHO). (2022). The top ten leading causes of death.
19. Bamagous, G. A., Al Ghamdi, S. S., Ibrahim, I. A. A., Mahfoz, A. M., Afify, M. A., Alsugoor, M. H., ... & Rengarajan, T. (2018). Antidiabetic and antioxidant activity of ethyl acetate extract fraction of Moringa oleifera leaves in streptozotocin-induced diabetes rats via inhibition of inflammatory mediators. Asian Pacific Journal of Tropical Biomedicine, 8(6), 320-327.
20. Cuellar-Nuñez, M. L., Luzardo-Ocampo, I., Campos-Vega, R., Gallegos-Corona, M. A., De Mejía, E. G., & Loarca-Piña, G. (2018). Physicochemical and nutraceutical properties of moringa (Moringa oleifera) leaves and their effects in an in vivo AOM/DSS-induced colorectal carcinogenesis model. Food Research International, 105, 159-168.
21. Nova, E., Redondo-Useros, N., Martínez-García, R. M., Gómez-Martínez, S., Díaz-Prieto, L. E., & Marcos, A. (2020). Potential of Moringa oleifera to improve glucose control for the prevention of diabetes and related metabolic alterations: a systematic review of animal and human studies. Nutrients, 12(7), 2050.
22. Gerich, J. E. (2000). Physiology of glucose homeostasis. Diabetes, Obesity and Metabolism, 2(6), 345-350.
23. Lutchmansingh, F. K., Hsu, J. W., Bennett, F. I., Badaloo, A. V., McFarlane-Anderson, N., Gordon-Strachan, G. M., ... & Boyne, M. S. (2018). Glutathione metabolism in type 2 diabetes and its relationship with microvascular complications and glycemia. PloS one, 13(6), e0198626.
24. Alberti, K. G. M. M., & Zimmet, P. Z. (1998). Definition, diagnosis and classification of diabetes mellitus and its complications. Part 1: diagnosis and classification of diabetes mellitus. Provisional report of a WHO consultation. Diabetic medicine, 15(7), 539-553.
25. Dièye, A. M., Sarr, A., Diop, S. N., Ndiaye, M., Sy, G. Y., Diarra, M., ... & Faye, B. (2008). Medicinal plants and the treatment of diabetes in Senegal: survey with patients. Fundamental & clinical pharmacology, 22(2), 211-216.
26. Abdullahi, A. R., Dhakar, R., Teli, P. K., Sulaiman, A. S., & Umar, S. A. Exploring the Potential of Moringa Oleifera Phytochemicals as Inhibitors of Dipeptidyl Peptidase-4 (DPP-4) in Diabetes Mellitus: A Molecular Docking Approach.
27. Gheibi, S., Kashfi, K., & Ghasemi, A. (2017). A practical guide for induction of type-2 diabetes in rat: Incorporating a high-fat diet and streptozotocin. Biomedicine & pharmacotherapy, 95, 605-613.
28. King, A. J. (2012). The use of animal models in diabetes research. British journal of pharmacology, 166(3), 877-894.
29. Ndong, M., Uehara, M., Katsumata, S. I., & Suzuki, K. (2007). Effects of oral administration of Moringa oleifera Lam on glucose tolerance in Goto-Kakizaki and Wistar rats. Journal of clinical biochemistry and nutrition, 40(3), 229-233.
30. Jaiswal, D., Rai, P. K., Kumar, A., Mehta, S., & Watal, G. (2009). Effect of Moringa oleifera Lam. leaves aqueous extract therapy on hyperglycemic rats. Journal of ethnopharmacology, 123(3), 392-396
31. William, F., Lakshminarayanan, S., & Chegu, H. (1993). Effect of some Indian vegetables

on the glucose and insulin response in diabetic subjects. International Journal of Food Sciences and Nutrition, 44(3), 191-195.

32. Kumari, D. J. (2010). Hypoglycaemic effect of Moringa oleifera and Azadirachta indica in type 2 diabetes mellitus. Bioscan, 5(20), 211-214.
33. Ghiridhari, V. V. A., Malhati, D., and Geetha, K. (2011). Anti-diabetic properties of drumstick (Moringa oleifera) leaf tablets. Int. J. Health Nutr. 2, 1–5.
34. Anwer T, Safhi MM, Makeen HA, Alshahrani S, Siddiqui R, Sivakumar S, et al. Antidiabetic potential of Moringa oleifera Lam. leaf extract in type 2 diabetic rats, and its mechanism of action. Trop J Pharm Res. 2021 Mar 18;20(1):95–103.
35. Adawiyah, R., Setyawati, T., Badaruddin, R., & Listawati. (2024). Hypoglychemic activity of Moringa oleifera extract in streptozotocin-induced diabetic rats. Acta Biochimica Indonesiana, 7(1), 130. https://doi.org/10.32889/actabioina.130
36. Abdel-Aziz, S., & M. Baghdadi, A. (2024). The Impact of Moringa oleifera and Azadirachta indica (neem) Leaves Ethanolic Extract on Streptozotocin Induced Diabetes Rats. 124–97), 2(40, مجلة الاقتصاد المنزلي. https://doi.org/10.21608/jhe.2024.385869
37. Ganiyu, A. I., Yusuf, A. P., Muntari, A., Kabir, S., Abdulrahman, B., Nura, L., Aliyu, M., Abubakar, M. B., Muhammad, A., & Idoko, A. S. (2024). Synergistic effects of combined treatments with oral zinc sulfate and dietary Moringa oleifera leaf powder on body weight, blood glucose, and lipid profile in streptozotocin-induced diabetic rats. FUOYE Journal of Pure and Applied Sciences, 9(1), 131–145. https://doi.org/10.55518/fjpas.FADQ1554
38. Alhabeeb, M. K., & Gomaa, H. F. (2023). Comparing the Effect of Moringa Aqueous Extract and Selenium Nanoparticles Against Complications of Type 2 Diabetes Mellitus. Pakistan Journal of Biological Sciences, 26(5), 249–265. https://doi.org/10.3923/pjbs.2023.249.265
39. Natural products-characterized moringa oleifera leaves methanolic extract and anti-diabetic properties mechanisms of its fractions in streptozotocin-induced diabetic rats. (2022). Nigerian Journal of Pharmacy, 56(1). https://doi.org/10.51412/psnnjp.2022.2
40. Abo Baker, S., & Moawad, A. (2020). Anti-diabetic effect of moringa oleifera extract on parotid gland of albino rats. Egyptian Dental Journal, 66(1), 187–196. https://doi.org/10.21608/edj.2020.77534
41. Oldoni, T. L. C., Merlin, N., Bicas, T. C., Prasniewski, A., Carpes, S. T., Ascari, J., De Alencar, S. M., Massarioli, A. P., Bagatini, M. D., Morales, R., & Thomé, G. (2021). Antihyperglycemic activity of crude extract and isolation of phenolic compounds with antioxidant activity from Moringa oleifera Lam. Leaves grown in Southern Brazil. Food Research International, 141, 110082. https://doi.org/10.1016/j.foodres.2020.110082
42. Lopez-Rodriguez, N. A., Sanchez-Ortiz, L. K., Reynoso-Camacho, R., Riesgo-Escovar, J. R., & Loarca-Piña, G. (2023). Chronic Consumption of Moringa Leaf Powder (Moringa oleifera) Concentration-Dependent Effects in a Drosophila melanogaster Type 2 Diabetes Model. Journal of the American Nutrition Association, 42(3), 285–294. https://doi.org/10.1080/07315724.2022.2034068
43. Oyeniran, O. H., Oboh, G., Ademiluyi, A. O., & Umar, H. I. (2022). Mistletoe infested Moringa oleifera and Terminalia catappa leaves supplemented diet enhances antioxidant and insulin-like peptide mRNA

levels in Drosophila melanogaster. Food Chemistry: Molecular Sciences, 5, 100124. https://doi.org/10.1016/j.fochms.2022.100124

44. Adedapo, A. A., Ogunmiluyi, I. O., Falayi, O. O., Ogunpolu, B. S., Oyagbemi, A. A., Orishadipe, A., Omobowale, T. O., Yakubu, M. A., & Oguntibeju, O. O. (2020). The lyophilized aqueous leaf extract of Moringa oleifera blunts streptozocin-induced diabetes in rats through upregulation of GLUT 4 signaling pathway and anti-oxidant effect. Scientific African, 10, e00619. https://doi.org/10.1016/j.sciaf.2020.e00619
45. Zhao, C., Zhu, J., Song, C., Ruan, H., Liu, J., Liu, Y., & Sui, Y. (n.d.). Effects of Moringa Oleifera Leaf Extract Plus Rosiglitazone on Serum Leptin and Glucose and Lipid Metabolism in Type 2 Diabetic Rats.
46. Cortes-Alvarez, S. I., Delgado-Enciso, I., Rodriguez-Hernandez, A., Hernandez-Fuentes, G. A., Aurelien-Cabezas, N. S., Moy-Lopez, N. A., Cortes-Alvarez, N. Y., Guzman-Muñiz, J., Guzman-Esquivel, J., Rodriguez-Sanchez, I. P., Martinez-Fierro, M. L., Mokay-Ramirez, K. A., Barajas-Saucedo, C. E., & Sanchez-Ramirez, C. A. (2024). Efficacy of Hot Tea Infusion vs. Ethanolic Extract of Moringa oleifera for the Simultaneous Treatment of Nonalcoholic Fatty Liver, Hyperlipidemia, and Hyperglycemia in a Murine Model Fed with a High-Fat Diet. Journal of Nutrition and Metabolism, 2024, 1–15. https://doi.org/10.1155/2024/2209581
47. Wen, Y., Zhou, Y., Xu, J., Cui, Q., Weng, Z., Lin, Y., Song, H., Xiong, L., Wang, L., Zhao, C., Shen, X., & Wang, F. (2025). Structural characterization and fermentation of a novel Moringa oleifera leaves polysaccharide with hypoglycemic effects. Food Chemistry, 479, 143832. https://doi.org/10.1016/j.foodchem.2025.143832
48. Asuquo, U. U., Mgbeje, B. I., Dasofunjo, K., & Elot, K. U. (2024). In vitro studies on the antidiabetic and antibacterial activity of biosynthesized silver nanoparticles with aqueous extract of Moringa oleifera leaf. Journal of Pharmacy & Bioresources, 21(1), 5–12. https://doi.org/10.4314/jpb.v21i1.2
49. Fan Y, Wang X, Li Y, Li L, Tian Y. Amelioration of hypoglycemic peptide MoHpP-2 from Moringa oleifera seeds in C2C12/IR cells and type 2 diabetes mellitus mice. Food Biosci 2024; 62: 105435.
50. Ibrahim, N. A., Buabeid, M. A., Arafa, E.-S. A., & Murtaza, G. (2024). "Regulation of Obesity and Fatty Liver by Moringa oleifera: Insights into Inflammatory Pathways." Pharmacology and Toxicology. https://doi.org/10.1101/2024.04.28.591562
51. Mbikay M. Moringa oleifera leaves prevent diabetes-induced oxidative stress and inflammation. Front Pharmacol. 2012; 3:24. PMCID: PMC3287626.
52. Gupta R, Mathur M, Bajaj VK, et al. Antidiabetic effect of Moringa oleifera in experimental diabetes. J Diabetes. 2012;4(2):164–171.
53. Tiloke C, Phulukdaree A, Chuturgoon AA. The therapeutic potential of Moringa oleifera in diabetes. Nutrients. 2018;10(12):1785. PMCID: PMC6315835.
54. Ademiluyi AO, Oboh G. Inhibition of α-amylase and α-glucosidase activities by phenolic-rich extracts of Moringa oleifera leaves. J Food Drug Anal. 2012;20(3):735–743.
55. Sreelatha S, Padma PR. Antioxidant activity and total phenolic content of Moringa oleifera leaves in two stages of maturity. Plant Foods Hum Nutr. 2009;64(4):303–311.

56. Pari L, Kumar NA. Protective role of Moringa oleifera on oxidative stress in streptozotocin-induced diabetic rats. J Med Food. 2002;5(4):171–177.
57. Vergara-Jiménez M, Almatrafi MM, Fernández ML. Bioactive components in Moringa oleifera leaves protect against chronic disease. Antioxidants (Basel). 2017;6(4):91.
58. Stohs SJ, Hartman MJ. Review of the safety and efficacy of Moringa oleifera. Phytother Res. 2015;29(6):796–804.
59. Gopalakrishnan L, Doriya K, Kumar DS. Moringa oleifera: A review on nutritive importance and its medicinal application. Food Sci Hum Wellness. 2016;5(2):49–56.
60. López-Martínez S, et al. Bioactive compounds of Moringa oleifera and their role in metabolic disorders. Molecules. 2017;22(8):1281.
61. Karthivashan G, Arulselvan P, et al. Anti-obesity and hypolipidemic effects of Moringa oleifera in high-fat diet-induced obese rats. J Sci Food Agric. 2016;96(7):2430–2439.
62. Rajan TS, Prabhu K, Ramesh V. Protective effect of Moringa oleifera leaves on streptozotocin-induced diabetic rats. J Pharm Res. 2011;4(6):1827–1829.
63. Ademiluyi AO, Oboh G. Inhibition of α-amylase and α-glucosidase activities by phenolic-rich extracts of Moringa oleifera leaves. J Food Drug Anal. 2012;20(3):735–743.
64. Kim KH, Lee SJ, Cha JY, et al. Moringa oleifera Lam. in diabetes mellitus: A systematic review and meta-analysis. Molecules. 2021;26(12):3513. PMCID: PMC8229498.
65. William J, Cherian T, Augusti KT. Antidiabetic effect of Moringa oleifera leaf powder in type 2 diabetic patients. Plant Foods Hum Nutr. 1993;43(1):49–56.
66. Anwar F, Latif S, Ashraf M, Gilani AH. Moringa oleifera: A food plant with multiple medicinal uses. Phytother Res. 2007;21(1):17–25.
67. Leone A, Spada A, Battezzati A, et al. Moringa oleifera seeds and leaves: Nutritional profile, phytochemical content, and safety evaluation. Phytother Res. 2015;29(12):1752–1759.
68. Kumari P, Nandini R, Chaitanya R, et al. Safety evaluation of Moringa oleifera leaf capsules in healthy human volunteers: A randomized, controlled study. J Herb Med. 2020; 22:100341.

HOW TO CITE: Pooja Kushwah, Ranjeet Kumar, Mudit Kumar, Vikash Chandra, Rohit Kumar, Gargi Rastogi, Prakash Tiwari, Kamlesh Patel, Devesh Kumar, Therapeutic Potential of Moringa oleifera in Diabetes Mellitus, Int. J. of Pharm. Sci., 2026, Vol 4, Issue 1, 2953-2967. https://doi.org/10.5281/zenodo.18366321