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# MEDICINAL PLANTS WITH ANTI-DIABETIC POTENTIAL: A REVIEW

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**ABSTRACT**
Diabetes mellitus (DM) is a chronic metabolic disorder characterized by hyperglycemia due to defects in insulin secretion, insulin action, or both. The global prevalence of DM has reached epidemic proportions, necessitating the search for effective, affordable, and safe therapeutic options. Medicinal plants have been used for centuries in traditional medicine systems for the prevention and treatment of diabetes. Their bioactive compounds, such as polyphenols, alkaloids, terpenoids, and saponins, possess antihyperglycemic properties through multiple mechanisms, including enhancing insulin secretion, improving insulin sensitivity, inhibiting carbohydrate-digesting enzymes, and modulating glucose uptake. This review focuses on six medicinal plants—*Cinnamomum verum* (cinnamon), *Momordica charantia* (bitter melon), *Trigonella foenum-graecum* (fenugreek), *Gymnema sylvestre* (gymnema), *Aloe barbadensis miller* (aloe vera), and *Curcuma longa* (turmeric)—highlighting their phytochemistry, pharmacological activities, and potential mechanisms of action in diabetes management. We also discuss challenges, limitations, and future perspectives in integrating these plants into mainstream diabetes care. The evidence suggests that these plants hold significant promise as complementary therapies; however, standardization, dosage optimization, and large-scale clinical trials are essential to confirm their efficacy and safety.

**KEYWORDS:** Anti-diabetic plants, *Cinnamomum verum*, *Momordica charantia*, *Trigonella foenum-graecum*, *Gymnema sylvestre*, *Aloe vera*, *Curcuma longa*, insulin sensitivity, phytotherapy, diabetes mellitus.

## 1. INTRODUCTION

Diabetes mellitus (DM) is a chronic metabolic disorder characterized by persistent hyperglycemia, resulting from defects in insulin secretion, insulin action, or both (American Diabetes Association, 2023). It is one of the most significant public health challenges of the 21st century, with its prevalence steadily increasing worldwide. According to the International Diabetes Federation (IDF, 2023), an estimated 537 million adults aged 20–79 years are currently living with diabetes, and this figure is projected to rise to 643 million by 2030. Type 2 diabetes mellitus (T2DM) accounts for approximately 90–95% of all cases and is strongly associated with sedentary lifestyles, poor dietary habits, obesity, and genetic predisposition.

Conventional management of diabetes includes pharmacological interventions such as insulin therapy, sulfonylureas, biguanides, dipeptidyl peptidase-4 inhibitors, and sodium-glucose cotransporter-2 inhibitors. While these drugs are effective, they are often associated with side effects including weight gain, gastrointestinal discomfort, hypoglycemia, and, in some cases, cardiovascular risks (Zhou et al., 2021). Additionally, the cost of lifelong therapy can impose a significant financial burden on patients, particularly in low- and middle-income countries.

Given these limitations, there is growing global interest in alternative and complementary therapeutic approaches, including the use of medicinal plants with anti-diabetic potential. For centuries, plant-based remedies have been integral to traditional medicine systems such as Ayurveda, Traditional Chinese Medicine (TCM), and Unani medicine. Many plants contain bioactive phytochemicals—such as flavonoids, alkaloids, terpenoids, saponins, and phenolic acids—that have been reported to exert hypoglycemic effects through various mechanisms, including.

- **Enhancing insulin secretion** from pancreatic β-cells
- **Improving insulin sensitivity** in target tissues
- **Inhibiting carbohydrate-digesting enzymes** such as α-amylase and α-glucosidase
- **Modulating glucose uptake** in peripheral tissues

- **Protecting pancreatic cells** from oxidative damage

Recent scientific investigations have validated the anti-diabetic properties of several medicinal plants, and in some cases, plant-derived compounds have inspired the development of modern hypoglycemic drugs (e.g., metformin derived from *Galega officinalis*). The World Health Organization (WHO, 2013) has encouraged the integration of evidence-based traditional medicine into national health systems, especially for chronic diseases such as diabetes.

This review aims to explore selected medicinal plants—*Cinnamomum verum* (cinnamon), *Momordica charantia* (bitter melon), *Trigonella foenum-graecum* (fenugreek), *Gymnema sylvestre* (gymnema), *Aloe barbadensis miller* (aloe vera), and *Curcuma longa* (turmeric)—that have shown significant anti-diabetic potential. We will discuss their phytochemistry, pharmacological activities, mechanisms of action, and clinical evidence. Furthermore, the review will address current challenges, research gaps, and future directions for the use of these plants in diabetes management.

1. Cinnamomum verum (Cinnamon)

*Cinnamomum verum*, commonly known as "true cinnamon" or "Ceylon cinnamon," is a small evergreen tree native to Sri Lanka and parts of southern India. The dried inner bark of its stems is used as a spice and has a long history in traditional medicine, particularly for metabolic disorders such as diabetes mellitus. Phytochemical analyses reveal that cinnamon contains a variety of bioactive compounds, including cinnamaldehyde, cinnamic acid, eugenol, and procyanidins, which are responsible for its pharmacological activities (Ranasinghe et al., 2013).

Several experimental and clinical studies have demonstrated the anti-diabetic potential of cinnamon. In vitro and in vivo research suggests that cinnamon enhances insulin receptor activity, increases glucose transporter type 4 (GLUT4) expression, and stimulates glycogen synthesis in skeletal muscle (Anderson et al., 2004). Cinnamaldehyde, one of its major constituents, is believed to mimic insulin action, thereby promoting cellular glucose uptake and improving glycemic control (Qin et al., 2010). Additionally, cinnamon polyphenols have been shown to inhibit intestinal α-glucosidase and pancreatic α-amylase enzymes, reducing postprandial hyperglycemia (Kim et al., 2006).

Clinical trials provide promising, though sometimes inconsistent, results. For example, Khan et al. (2003) reported significant reductions in fasting blood glucose, triglycerides, and low-density lipoprotein cholesterol levels in patients with type 2 diabetes after daily supplementation with cinnamon powder. However, other studies have failed to replicate these findings, potentially due to variations in cinnamon species, dosages, and study durations (Allen et al., 2013). It is noteworthy that *C. cassia*—a related species often sold as cinnamon—contains higher levels of coumarin, a compound that may cause hepatotoxicity when consumed in excess, highlighting the importance of species identification and dosage standardization.

Mechanistically, cinnamon's anti-diabetic effects appear to be multifactorial. In addition to improving insulin sensitivity, it exerts antioxidant and anti-inflammatory effects, which may help mitigate oxidative stress and low-grade inflammation associated with diabetes pathophysiology (Mang et al., 2006). By modulating multiple pathways, cinnamon offers potential as a complementary therapy in diabetes management, though further well-designed clinical trials are warranted to determine optimal preparations, dosages, and long-term safety profiles.

2. Momordica charantia (Bitter Melon)

*Momordica charantia* L., commonly known as bitter melon, bitter gourd, or karela, is a climbing vine belonging to the family Cucurbitaceae. Widely cultivated in tropical and subtropical regions, including India, China, and parts of Africa, the plant's immature fruit is consumed as both a vegetable and traditional medicine. For centuries, bitter melon has been used in Ayurveda, Traditional Chinese Medicine, and folk remedies to treat diabetes, gastrointestinal issues, and infections (Grover & Yadav, 2004).

The anti-diabetic potential of bitter melon is attributed to its diverse array of phytochemicals, including charantin, vicine, polypeptide-p (often referred to as plant insulin), cucurbitane-type triterpenoids, and phenolic compounds (Tan et al., 2016). These compounds work synergistically to regulate glucose metabolism through multiple mechanisms. Charantin, a steroidal saponin mixture, has been reported to lower blood glucose levels in animal models (Joseph & Jini, 2013). Polypeptide-p is structurally similar to bovine insulin and can mimic its glucose-lowering action when administered subcutaneously (Raman & Lau, 1996). Additionally, bitter melon extracts have been shown to stimulate pancreatic β-cell regeneration, increase glycogen synthesis in liver and muscle tissues, and improve peripheral glucose utilization (Ahmed et al., 2001).

In vitro studies demonstrate that bitter melon inhibits key carbohydrate-digesting enzymes such as α-glucosidase and α-amylase, thereby reducing the rate of glucose absorption and postprandial blood glucose spikes (Kumar et al., 2018). Furthermore, the plant exhibits antioxidant and anti-inflammatory activities, which are beneficial in mitigating oxidative stress-induced pancreatic β-cell damage, a hallmark of diabetes progression (Tan et al., 2016).

Clinical trials on bitter melon have produced mixed results. While some studies report significant reductions in fasting blood glucose and HbA1c levels after oral

administration of bitter melon juice or capsules (Dans et al., 2007), others have found little to no improvement compared to placebo (Ooi et al., 2012). The variability in outcomes may be due to differences in dosage, preparation (fresh juice, dried powder, or extracts), and patient characteristics. Importantly, excessive consumption may lead to gastrointestinal discomfort and, in rare cases, hypoglycemia, especially when combined with anti-diabetic medications.

Overall, *M. charantia* presents a promising natural adjunct in diabetes management owing to its multifaceted mechanisms, including insulin-mimetic activity, enzyme inhibition, and β-cell protection. However, standardization of active compounds, optimization of dosing regimens, and larger randomized controlled trials are needed to establish its clinical efficacy and safety.

3. Gymnema sylvestre (Gurmar)

*Gymnema sylvestre* R. Br., commonly referred to as "gurmar" in Hindi, meaning "sugar destroyer," is a perennial woody climbing plant belonging to the family Apocynaceae. Native to the tropical forests of central and southern India, Africa, and Australia, it has been widely recognized in Ayurveda for over two millennia for its role in managing "Madhumeha" (diabetes mellitus) (Persaud et al., 1999). The therapeutic use of *G. sylvestre* extends to weight management, hyperlipidemia, and digestive disorders.

The key bioactive constituents of *G. sylvestre* are gymnemic acids, a group of triterpenoid saponins, along with gymnemasaponins, flavones, and anthraquinones (Sinsheimer et al., 1970). Gymnemic acids are structurally similar to glucose and can bind to intestinal receptors, thereby blocking sugar absorption in the gut (Liu et al., 2009). This "sugar-mimicking" mechanism is also responsible for its unique ability to temporarily suppress the perception of sweet taste when the leaves are chewed (Shanmugasundaram et al., 1990).

In addition to reducing intestinal glucose uptake, *G. sylvestre* has been shown to stimulate pancreatic β-cell regeneration and insulin secretion (Shanmugasundaram et al., 1990). Animal studies indicate that gymnemic acid supplementation leads to significant reductions in fasting blood glucose and glycosylated hemoglobin (HbA1c), while enhancing hepatic and skeletal muscle glycogen storage (Prakash et al., 2006). The herb also improves lipid profiles by lowering serum triglycerides and low-density lipoprotein cholesterol, thereby reducing cardiovascular risk in diabetic patients (Kumar et al., 2012).

Human clinical trials provide supportive evidence. Shanmugasundaram et al. (1990) reported that type 2 diabetic patients receiving 400 mg/day of *G. sylvestre* extract for 18–20 months experienced a marked reduction in insulin requirements and improved glycemic control. Similarly, Kumar et al. (2012) found that supplementation with standardized *G. sylvestre* extract significantly lowered fasting and postprandial blood glucose compared to baseline.

The safety profile of *G. sylvestre* is generally favorable; however, hypoglycemia may occur if combined with conventional antidiabetic drugs, necessitating dose adjustments. Gastrointestinal discomfort and mild nausea are infrequent but reported adverse effects (Persaud et al., 1999).

Overall, *G. sylvestre* exhibits potent antidiabetic potential through mechanisms such as inhibition of glucose absorption, β-cell regeneration, and enhancement of insulin secretion. While promising, future research should focus on standardized extract formulations, optimal dosing strategies, and large-scale randomized controlled trials to confirm long-term efficacy and safety.

4. Cinnamomum verum (Cinnamon)

*Cinnamomum verum* J. Presl, also known as "true cinnamon" or "Ceylon cinnamon," belongs to the family Lauraceae and is native to Sri Lanka and southern India. Cinnamon has been traditionally valued for its aromatic bark and medicinal properties in Ayurveda, Unani, and traditional Chinese medicine. Beyond its culinary use as a spice, it has been recognized for its potential in glycemic control, lipid regulation, and antioxidant support (Ranasinghe et al., 2012).

The main bioactive components of *C. verum* include cinnamaldehyde, eugenol, and procyanidins. These phytochemicals exhibit antioxidant, anti-inflammatory, and insulin-sensitizing effects (Anderson et al., 2004). Cinnamaldehyde, in particular, has been reported to enhance insulin receptor activity and increase glucose transporter type 4 (GLUT4) translocation, leading to improved glucose uptake in skeletal muscle and adipose tissue (Qin et al., 2003).

In vitro studies have shown that aqueous cinnamon extracts can mimic insulin activity by phosphorylating the insulin receptor, thereby potentiating insulin signaling pathways (Imparl-Radosevich et al., 1998). Moreover, cinnamon polyphenols have been observed to delay gastric emptying and inhibit intestinal α-glucosidase and pancreatic α-amylase, contributing to a reduction in postprandial hyperglycemia (Ranasinghe et al., 2012).

Clinical evidence supports these findings. Khan et al. (2003) conducted a double-blind, placebo-controlled trial in which type 2 diabetic patients received 1–6 g/day of cinnamon powder for 40 days. The intervention resulted in significant reductions in fasting blood glucose (18–29%), triglycerides (23–30%), low-density lipoprotein cholesterol (7–27%), and total cholesterol (12–26%) compared to baseline. Similarly, Mang et al. (2006) reported that cinnamon extract supplementation

improved insulin sensitivity in glucose-intolerant individuals.

The antioxidant potential of cinnamon is another critical aspect of its antidiabetic effect. By reducing oxidative stress, cinnamon may help preserve pancreatic β-cell function and prevent diabetes-related microvascular complications (Anderson et al., 2004). Additionally, cinnamaldehyde has demonstrated anti-inflammatory activity through the inhibition of nuclear factor-kappa B (NF-κB) signaling, further contributing to its therapeutic potential (Qin et al., 2003).

Cinnamon is generally safe in dietary amounts; however, excessive consumption of *Cinnamomum cassia* (a common substitute for *C. verum*) can lead to coumarin-related hepatotoxicity. Therefore, standardized *C. verum* preparations are preferable for long-term therapeutic use (Wang et al., 2014).

In summary, *Cinnamomum verum* exhibits multifaceted antidiabetic properties, including enhancement of insulin sensitivity, reduction of postprandial glucose spikes, and improvement of lipid profiles. While existing data are promising, further large-scale randomized controlled trials are warranted to standardize dosages and assess long-term safety and efficacy.

5. Momordica charantia (Bitter Melon)

*Momordica charantia* L., commonly known as bitter melon, bitter gourd, or karela, is a tropical and subtropical vine belonging to the family Cucurbitaceae. It is widely cultivated in Asia, Africa, and the Caribbean for its edible fruit, which is recognized for its characteristic bitter taste. Bitter melon has been used traditionally in Ayurvedic, Chinese, and African medicine for the management of diabetes mellitus and related metabolic disorders (Joseph & Jini, 2013).

The antidiabetic activity of *M. charantia* is attributed to multiple bioactive compounds, including charantin, vicine, and a polypeptide known as polypeptide-p (Bashir et al., 2020). Charantin, a steroidal saponin mixture, has been shown to exert hypoglycemic effects by enhancing peripheral glucose utilization. Polypeptide-p, a plant insulin analogue, demonstrates insulin-like activity by directly lowering blood glucose levels when administered subcutaneously (Raman & Lau, 1996).

Mechanistically, bitter melon appears to act through several pathways. It has been reported to stimulate glucose uptake in skeletal muscle cells by promoting the translocation of GLUT4 transporters, enhance glycogen synthesis in the liver, and inhibit key gluconeogenic enzymes, thereby reducing hepatic glucose output (Tan et al., 2008). Additionally, bitter melon may inhibit intestinal glucose absorption and modulate gut microbiota, further contributing to improved glycemic control (Krawinkel & Keding, 2006).

Animal studies have demonstrated that *M. charantia* supplementation can significantly reduce fasting blood glucose, improve oral glucose tolerance, and increase serum insulin levels in streptozotocin-induced diabetic rats (Chaturvedi, 2012). In human studies, results have been mixed but encouraging. For example, Ahmad et al. (1999) found that daily administration of bitter melon juice for three weeks led to a significant reduction in fasting blood glucose in type 2 diabetic patients. Similarly, a randomized clinical trial by Dans et al. (2007) reported that 2,000 mg/day of bitter melon capsules modestly reduced fructosamine levels in newly diagnosed diabetics, although the effect was less pronounced than with standard hypoglycemic drugs like metformin.

The antioxidant and anti-inflammatory properties of bitter melon further support its potential role in diabetes management. By scavenging free radicals and reducing oxidative stress, *M. charantia* may help preserve pancreatic β-cell function and prevent diabetic complications (Bashir et al., 2020). Additionally, the regulation of adipokine secretion and lipid metabolism has been noted, suggesting broader benefits in metabolic syndrome (Tan et al., 2008).

Despite its promising pharmacological profile, bitter melon should be used with caution in certain populations. Excessive intake can cause gastrointestinal discomfort, hypoglycemia in combination with antidiabetic medications, and in rare cases, favism in individuals with glucose-6-phosphate dehydrogenase (G6PD) deficiency (Basch et al., 2003). Pregnant women are generally advised to avoid high doses due to potential uterotonic effects.

In summary, *Momordica charantia* offers a multifaceted approach to glycemic control through insulin-mimetic activity, enhancement of glucose utilization, inhibition of gluconeogenesis, and modulation of gut health. While preclinical and some clinical findings are encouraging, more standardized human trials are needed to establish optimal dosing, formulation, and long-term safety.

## DISCUSSION

The present review examined the antidiabetic potential of three medicinal plants — *Gymnema sylvestre*, *Cinnamomum verum*, and *Momordica charantia* — each of which offers unique and overlapping mechanisms of action for glycemic control.

*Gymnema sylvestre* demonstrates its primary efficacy through suppression of sweet taste sensation, regeneration of pancreatic β-cells, stimulation of insulin secretion, and enhancement of glucose uptake by peripheral tissues. Its active component, gymnemic acid, structurally resembles glucose, enabling competitive inhibition at the intestinal absorption level and suppression of postprandial hyperglycemia (Baskaran et al., 1990).

*Cinnamomum verum*, on the other hand, acts predominantly by improving insulin sensitivity and mimicking insulin activity. Cinnamaldehyde and other polyphenols present in cinnamon facilitate glucose transport via GLUT4 activation, inhibit α-glucosidase and α-amylase enzymes, and modulate insulin receptor phosphorylation (Anderson et al., 2004). These effects collectively help reduce fasting plasma glucose, improve lipid profiles, and lower oxidative stress in diabetic patients.

*Momordica charantia* provides a multifaceted approach to diabetes management, functioning both as an insulin mimetic and insulin secretagogue. Charantin, vicine, and polypeptide-p have been shown to enhance glucose utilization, inhibit hepatic gluconeogenesis, and potentially modulate gut microbiota. Bitter melon also exhibits antioxidant activity, protecting β-cell integrity and reducing inflammatory damage (Tan et al., 2008).

A comparative analysis suggests that all three plants influence both insulin-dependent and insulin-independent pathways. While *Gymnema sylvestre* is notable for β-cell regeneration and reduced intestinal glucose absorption, *Cinnamomum verum* excels in enhancing insulin receptor activity and improving lipid metabolism, and *Momordica charantia* offers a combination of insulin-like action, enzyme inhibition, and antioxidant defense.

Despite promising results, several limitations hinder clinical adoption. First, most clinical trials have small sample sizes, short durations, and varied dosages, making direct comparison difficult. Second, the bioactive constituents in these plants can vary widely depending on cultivation, harvesting, and extraction methods, affecting reproducibility. Finally, potential herb–drug interactions — such as additive hypoglycemic effects when combined with standard antidiabetic drugs — require careful monitoring.

Future research should focus on well-designed, multicenter randomized controlled trials with standardized extracts to establish optimal dosages, safety profiles, and long-term efficacy. Additionally, exploring synergistic combinations of these plants may provide enhanced antidiabetic effects through complementary mechanisms.

## CONCLUSION

Medicinal plants remain a promising adjunct or alternative for managing diabetes mellitus, particularly in resource-limited settings where access to pharmaceuticals may be restricted. *Gymnema sylvestre*, *Cinnamomum verum*, and *Momordica charantia* each offer distinct but complementary mechanisms for improving glycemic control, ranging from β-cell regeneration to enhanced insulin sensitivity and inhibition of glucose absorption.

The available evidence, while encouraging, is not yet sufficient to replace conventional therapy. These plants should be considered as supportive interventions alongside lifestyle modifications and prescribed medication, with medical supervision to avoid adverse effects. Future large-scale studies are necessary to translate preclinical findings into robust clinical guidelines.

In conclusion, integrating traditional herbal knowledge with modern pharmacological research may pave the way for safe, effective, and affordable antidiabetic therapies, benefiting millions worldwide who suffer from this chronic metabolic disorder.

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