

**MEDICINAL PLANTS WITH ANTIDIABETIC POTENTIAL: A CRITICAL NARRATIVE REVIEW OF PHYTOCHEMICAL BASIS, MECHANISMS AND CLINICAL EVIDENCE****Chakali Kalpana***

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ABSTRACT Diabetes mellitus is a group of metabolic disorders characterized by chronic hyperglycemia resulting from impaired insulin secretion, insulin action, or both. Type 2 diabetes mellitus (T2DM) is a major global health concern associated with serious complications. Medicinal plants have attracted considerable attention because of their hypoglycemic, antioxidant, anti-inflammatory, and insulin-sensitizing properties. This review critically evaluates the phytochemical composition, antidiabetic mechanisms, and experimental and clinical evidence of selected medicinal plants, including *Gymnema sylvestre*, *Momordica charantia*, *Cinnamomum verum*, and *Trigonella foenum-graecum*. Relevant literature published from 2000 onward was identified through PubMed, Scopus, and Google Scholar using predefined search terms, and the evidence was critically synthesized. Across the selected plants, reported effects include modulation of glucose metabolism, insulin action, oxidative stress, inflammation, and related metabolic pathways. However, differences in plant material, extract preparation, phytochemical composition, dosage, intervention duration, and clinical study design limit direct comparison and translation of findings into clinical practice.

KEYWORDS : *Gymnema Sylvestre*; Medicinal Plants; Phytochemicals; Antidiabetic Activity.**I. INTRODUCTION**

Type 2 Diabetes Mellitus (T2DM) is a chronic metabolic disorder and a major global public health problem, with prevalence increasing worldwide across both developed and developing countries. The disorder is characterized by chronic hyperglycemia resulting primarily from insulin resistance, impaired insulin secretion, or both, leading to disturbances in carbohydrates, lipids and protein metabolism. Persistent hyperglycemia leads to the development of long-term complications, including neuropathy, nephropathy, retinopathy, and cardiovascular diseases [1].

Although several pharmacological therapies, including biguanides, sulfonylureas, insulin and other glucose-lowering agents, are available for glycemic control, treatment may be limited by factors such as cost, accessibility, adverse effects, hypoglycemia risk for some agents, weight-related effects for some therapies, and adherence challenges. [2]

Traditional medical systems, including Ayurveda, have historically documented the use of medicinal plants for the management of conditions described as madhumeha, which has been broadly associated with diabetes mellitus. [3]. Due to their accessibility, affordability and therapeutic effects, several medicinal plants have been used in indigenous healthcare systems for generations. The presence of various bioactive phytochemicals such as polyphenols, flavonoids, alkaloids and terpenoids, which exhibit biological activities associated with glycaemic control, may contribute to their reported biological activities [4]. Numerous clinical and experimental studies have shown that medicinal plants possess antidiabetic potential through multiple mechanisms, including enhancement of insulin secretion, improvement of insulin sensitivity, inhibition of intestinal glucose absorption, and antioxidant activity [5].

Among the various medicinal plants investigated for diabetes management, *Gymnema sylvestre* has received scientific interest for its potential antidiabetic properties. Commonly known as "Gurmar" or sugar destroyer, it has been extensively used in ayurvedic medicine for the management of diabetes. The therapeutic activity of *Gymnema sylvestre* is attributed to gymnemic acids, flavonoids and other bioactive constituents that regulate glucose homeostasis through multiple pathways. Experimental studies have suggested that *Gymnema sylvestre* stimulates insulin secretion, enhances β -cell regeneration and reduces intestinal glucose absorption [6]. The plant has gained importance in development of functional foods and nutraceuticals for glycemic control. Apart from *Gymnema sylvestre*, a number of medicinal plants such as *Momordica charantia*, *Trigonella foenum-graecum*, and *Cinnamomum verum* have demonstrated potential antidiabetic effects in both experimental and clinical studies.

Although several reviews have examined the antidiabetic properties of

individual medicinal plants or broader groups of herbal interventions, differences in botanical material, extraction procedures, phytochemical composition, dosage, formulation and clinical study design continue to complicate interpretation of the available evidence. A comparative synthesis that considers phytochemical characteristics alongside proposed mechanisms, experimental findings, clinical evidence and standardization challenges may therefore provide a more useful perspective for assessing their translational potential.[7]

Therefore, the present review critically evaluates the phytochemical composition, proposed antidiabetic mechanisms, experimental findings and available clinical evidence concerning selected medicinal plants, with particular emphasis on *Gymnema sylvestre*. The review further examines differences in plant material, preparation, dosage, standardization and study design that may influence interpretation of the reported antidiabetic effects. By integrating these aspects, the review aims to identify important evidence gaps and highlight requirements for more standardized and clinically relevant investigations of plant-based approaches to T2DM management.

II. Literature Search Methodology

A narrative literature search was conducted using PubMed, Scopus, Web of Science and Google Scholar to identify publications addressing the phytochemical composition, antidiabetic activity, mechanisms of action, experimental findings, clinical evidence and translational aspects of *Gymnema sylvestre*, *Momordica charantia*, *Cinnamomum verum*, and *Trigonella foenum-graecum*. Search terms included combinations of "type 2 diabetes mellitus," "medicinal plants," "*Gymnema sylvestre*," "*Momordica charantia*," "*Cinnamomum verum*," "*Trigonella foenum-graecum*," "phytochemicals," "antidiabetic activity," "mechanism of action," "clinical trial," and "standardization." Literature published from 2000 onward was considered, with emphasis on recent clinical studies, mechanistic investigations and high-quality evidence. Peer-reviewed original research articles, randomized controlled trials, experimental studies, systematic reviews, meta-analyses and relevant review articles published in English were considered. Conference abstracts, duplicate publications and articles lacking sufficient relevance to the objectives of the review were excluded. The literature was narratively synthesized with particular attention to differences in plant material, extraction procedures, phytochemical composition, dosage, formulation, intervention duration, study design and reported outcomes.

III. Medicinal Plants and their Anti-diabetic Properties**3.1 *Gymnema Sylvestre*****3.1.1 Botanical Profile and Traditional Use**

Gymnema sylvestre is a perennial woody climber widely distributed in the central and western regions of India and also reported in tropical parts of Africa and Australia. It has been employed for centuries in

Ayurvedic, folk, and homeopathic systems of medicine, particularly for the management of diabetes, earning the traditional name “sugar destroyer” because of its characteristic ability to temporarily suppress sweet taste perception [6,8].

Botanically, *G. sylvestre* belongs to the family Asclepiadaceae (often placed under Apocynaceae in modern classifications). The plant bears elliptic to ovate leaves with an acuminate apex and is commonly found across the Deccan peninsula and northern–western India. The leaves are the principal medicinal part and are also used in traditional preparations.

3.1.2 Phytochemical Composition

The leaves are considered the principal medicinal part and contain a diverse spectrum of triterpenoid saponins, flavonoids, and glycosides. Gymnemic acids represent the most studied bioactive constituents responsible for hypoglycemic activity. Quantitative analyses have shown that gymnemic acid concentration is highest in the leaf shoot tips and substantially lower in seeds, highlighting the leaf as the preferred raw material for therapeutic preparations[9,10]. Structurally, gymnemic acids are oleanane-type triterpenes often bearing β -glucuronic acid substitutions, while related compounds such as gymnemasaponins and gymnemasides fall under oleanane and dammarane saponin classes. Extensive phytochemical investigations have characterized numerous oxidized triterpenoids from *G. sylvestre* with diverse biological activities[11,10].

3.1.3 Proposed Antidiabetic Mechanisms of *Gymnema Sylvestre*

Multiple mechanisms have been proposed to explain the antidiabetic potential of *G. sylvestre* leaf extracts:

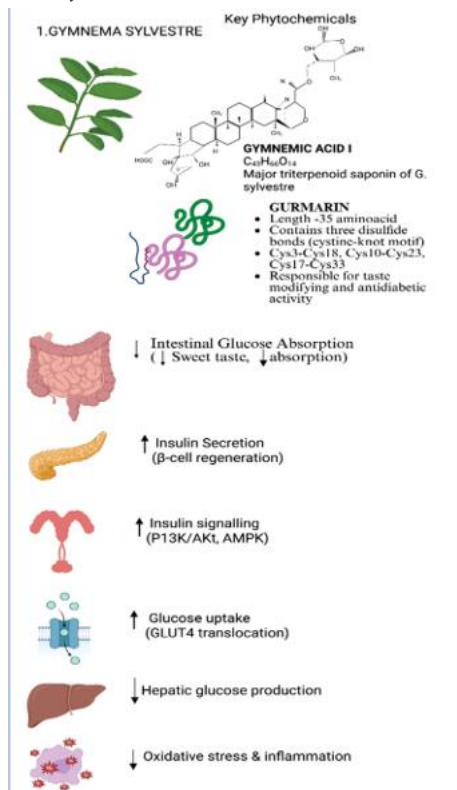


Figure 1. Key Phytochemicals and Proposed Antidiabetic Mechanisms of *Gymnema Sylvestre*.

- Suppression of sweet taste receptors, which may reduce sugar cravings and dietary sugar intake
- Stimulation of pancreatic β -cells and enhancement of insulin secretion[6].
- Improved peripheral glucose utilization through modulation of key metabolic enzymes involved in glycolysis and phosphorylation pathways.[12]
- Inhibition or delay of intestinal glucose absorption, thereby attenuating post-prandial glycemic spikes.
- Emerging molecular evidence also suggests GLP-1–related signalling and cAMP pathway activation, which may further support insulinotropic effects [8,12,13].

Collectively, experimental evidence suggests that *G. sylvestre* may influence glucose homeostasis through multiple complementary pathways involving glucose absorption, insulin secretion, pancreatic β -cell function and peripheral glucose metabolism.

3.1.4 Experimental and Clinical Studies

Gymnema sylvestre is widely studied for its ability to suppress sweet taste perception and support the regeneration of pancreatic beta cells. In an open-label uncontrolled clinical trial, Supplementation of 6g of *gymnema sylvestre* daily for 4 weeks has shown a decrease in fasting and post-prandial glucose levels of the participants by 19.3% and 16.7% [14]. A randomised controlled trial demonstrated that *G. sylvestre* intake significantly lowered 2-hour OGTT and HbA1c values and improved insulin sensitivity in subjects with impaired glucose tolerance compared to placebo[15]. Meta-analyses demonstrated that *G. sylvestre* supplementation contributes to significant reductions in fasting glucose, post-prandial glucose, and serum lipids in type 2 diabetes. Animal studies indicated that *G. sylvestre* supplementation normalises glucose levels and improves lipid profiles in diabetic rats by regulating pancreatic and hepatic gene activity[16].

Table 1: Experimental and Clinical Studies on *Gymnema Sylvestre* in Diabetic Management

S. No	Author & year	Study type	Sample/Model	Dose/ form	Duration	Key findings
1	Karthigesu et al., 2024	double-blind randomised controlled phase III trial	T2DM Patients	Tea brew (1.5g in 200ml hot water)	3 months	Reduction in HbA1c, Blood pressure and FBG
2	Gaytan Martinez et al., 2021	A randomized Double blind placebo controlled clinical trial	T2DM patients	300mg/ oral capsules	12 weeks	2-h OGTT, A1C, Body weight, LDL cholesterol, and improved insulin sensitivity
3	Kashif et al., 2023	Animal study	Diabetic Rabbits	300mg/ Leaf extract	28 days	Rise in insulin secretion, FBG, serum urea, creatinine
4	Chen et al., 2023	Animal study	Diabetic Rat	125, 250 and 500mg/ kg/Leaf extract	30 days	FBG, TC, TG and LDL-C. HDL-C

However, differences in extract standardization, dosage, treatment duration, phytochemical composition, and study design limit direct comparison among investigations.

3.1.5 Critical Analysis

Experimental and clinical investigations have evaluated *G. sylvestre* preparations for their effects on glycemic control, insulin secretion, insulin sensitivity and related metabolic outcomes. An open-label clinical study reported reductions in fasting and postprandial glucose following supplementation with *G. sylvestre*; however, the uncontrolled design limits causal interpretation. Other human studies have examined standardized or defined preparations in individuals with impaired glucose tolerance or type 2 diabetes mellitus, while animal studies have investigated effects on glucose metabolism, lipid profiles and pancreatic or hepatic pathways. Small sample sizes, short intervention periods, heterogeneous preparations, and concomitant use of conventional antidiabetic therapies further limit clinical interpretation. These limitations highlight the need for standardized preparations and well-designed clinical studies to establish reproducible therapeutic outcomes.

3.2. *Momordica Charantia*

3.2.1 Botanical Profile and Traditional Use

Momordica charantia L. is commonly known as bitter melon, bitter melon or karela, it is a climbing plant belonging to the Cucurbitaceae family [21], and is widely cultivated and consumed in Asia, Africa, and the Americas, across tropical, subtropical, and temperate regions [22]. The plant is valued for its nutritional and medicinal value, and its fruit and other plant parts have traditionally been used for the management of diabetes and other metabolic conditions[23].

3.2.2 Proposed Antidiabetic Mechanisms of *Momordica Charantia*

The antidiabetic effects reported for *M. charantia* have been associated with bioactive constituents, including cucurbitane-type triterpenoids, charantin, peptides and other secondary metabolites.

Experimental studies suggest that these constituents may influence

Table 2: Experimental and Clinical Studies on *Momordica Charantia* in Diabetic Management

S.NO	Author & year	Study type	Sample/Model	Dose/form	Duration	Key findings
1	Prabhulal et al., 2014	Clinical study	T2DM patients	10g/Bitter gourd powder	30 days	FBG and post prandial blood sugar levels
2	Mes et al., 2025	Randomized, placebo-controlled	Prediabetic	Freeze-dried bitter gourd fruit (approx. 2.4–3.6 g/day)	12 weeks	Significant ↓ fasting plasma glucose and fasting insulin; improved HOMA-IR
3	Khalid MK et al., 2025	Randomized RCT (T2DM)	T2DM patients	Bitter melon powder (~½ tsp/day ≈ 1–2 g	6months	↓ random blood glucose, fasting blood glucose, and HbA1c
4	Malik et al., 2025	Clinical study	T2DM patients	2g Bitter melon capsule/day	30 days	FBG, TC and TG

Preclinical studies provide substantial evidence of antihyperglycemic activity, whereas clinical findings are more variable. Differences in plant part, preparation, dose, intervention duration and participant characteristics limit direct comparison between studies.[28,29].

Critical Analysis

Although *Momordica charantia* has been extensively investigated for its antidiabetic properties, considerable heterogeneity exists across experimental and clinical studies. Experimental studies consistently indicate that the plant exerts antihyperglycemic effects through multiple mechanisms, including insulin-mimetic activity, stimulation of peripheral glucose uptake, suppression of hepatic gluconeogenesis, inhibition of carbohydrate-digesting enzymes, and reduction of oxidative stress. However, the translation of these promising preclinical findings into consistent clinical outcomes remains challenging.

One of the major limitations is the lack of standardization among herbal preparations used in different studies. Considerable variations exist in the plant part utilized (fruit, seeds, or leaves), maturity stage, extraction techniques, formulation (fresh juice, dried powder, aqueous or alcoholic extract, and capsules), dosage, and duration of treatment. These methodological differences substantially influence the concentration of bioactive constituents such as charantin, polypeptide-p, and vicine, thereby contributing to inconsistent therapeutic responses observed across clinical investigations.

Although some randomized controlled trials have reported improvements in fasting blood glucose and glycemic control, systematic reviews and meta-analyses have shown inconsistent findings across different populations. Variations in disease severity,

Table 3: Experimental and Clinical Studies on *Cinnamomum* in Diabetic Management

S.NO	Author & year	Study type	Sample/Model	Dose/form	Duration	Key findings
1	Kutbi et al. 2022	Systematic review and dose-response meta-analysis	T2DM patients	2.2 g/day	11 weeks	FPG (↓), HOMA (↓), HbA1C(↓)
2	Dilma'aarij Agustia et al., 2025	randomised controlled trial	T2DM patients	Cinnamon extract 10mg/day	1 month	Lowered fasting blood sugar levels
3	Yaoyao Liu et al., 2022	Animal study	Diabetic mice	Cinnamon powder 200, 400, or 800 mg/kg	8 weeks	FBG, improved glucose tolerance and fasting serum insulin levels
4	Hajra Ahmad et al., 2022	A randomized controlled trial	T2DM patients	3 doses of Capsule, 500mg	90 days	FBG, TC, TG and LDL-C. HDL-C

Critical Analysis

Despite extensive research on the antidiabetic properties of *Cinnamomum* species, clinical evidence remains heterogeneous. Experimental studies indicate effects on insulin receptor signalling, glucose uptake, oxidative stress, and inflammatory pathways associated with insulin resistance, but these findings have not consistently translated into clinical benefits. Randomized controlled trials and meta-analyses have reported varying effects on fasting blood glucose, HbA1c, and insulin sensitivity.

A major limitation is the lack of uniformity in the botanical species studied. Several clinical studies fail to distinguish between *Cinnamomum verum* (true cinnamon) and *Cinnamomum cassia*, despite differences in phytochemical composition and coumarin content. Variations in extraction methods, dosage, intervention duration, participant characteristics, and concurrent pharmacological therapy further complicate comparisons. Therefore, therapeutic responses should not be assumed to be equivalent across different

glucose homeostasis through insulin-like activity, stimulation of glucose uptake, modulation of insulin secretion, inhibition of carbohydrate-digesting enzymes, suppression of hepatic glucose production and modulation of oxidative stress

3.2.3 Experimental and Clinical Evidence

concurrent pharmacotherapy, dietary habits, treatment adherence, and study design may contribute to these discrepancies. Therefore, the available clinical evidence should be interpreted cautiously.

Overall, *M. charantia* warrants further investigation as a potential adjunctive dietary or nutraceutical intervention. Standardized preparations and well-designed clinical studies are needed to clarify its clinical relevance.

3.3 Cinnamomum Spp.

3.3.1 Botanical Profile and Traditional Use

Cinnamomum spp. are aromatic evergreen trees belonging to the family Lauraceae. Several species, including *Cinnamomum verum* and *Cinnamomum cassia*, are widely used as culinary spices and in traditional medicine. Cinnamon bark has traditionally been used in various medicinal systems for digestive and metabolic disorders, including diabetes mellitus. Differences among *Cinnamomum* species are important because their phytochemical composition, particularly cinnamaldehyde and coumarin content, may vary substantially.[31].

3.3.2 Proposed Antidiabetic Mechanisms of Cinnamon

Experimental studies suggest that cinnamon-derived bioactive compounds may influence glucose metabolism through several mechanisms, including modulation of insulin receptor signalling, enhancement of glucose uptake and GLUT4 translocation, inhibition of carbohydrate-digesting enzymes such as α -glucosidase, and modulation of hepatic glucose metabolism. These mechanisms may contribute to improved insulin sensitivity and postprandial glucose regulation; however, their clinical relevance may depend on cinnamon species, preparation, dose and bioactive composition.[39,40].

species and preparations, and the available clinical evidence requires cautious interpretation.

3.4 Fenugreek

3.4.1 Botanical Profile and Traditional Use

Trigonella foenum-graecum is commonly known as fenugreek and belongs to the Fabaceae family, widely cultivated in the Mediterranean region, Western Asia and Southern Europe[41]. Fenugreek seeds and leaves contain macronutrients, vitamins, minerals and are rich in bioactive compounds like alkaloids (trigonelline), flavonoids (quercetin, luteolin), saponins and steroidal sapogenins. Additionally, fenugreek seeds are palatable and nutritionally dense, containing carbohydrates, proteins, lipids and volatile oils [42]. Fenugreek seeds possess anti-inflammatory, antioxidant, hypoglycemic, hypocholesterolemic and antiulcerogenic effects [43]. In traditional medicine, fenugreek has been used for centuries to treat a wide range of conditions, including digestive disorders and skin inflammation.[44]. Fenugreek seeds and leaves have been extensively used in traditional

systems of medicine, including Ayurveda and Unani, particularly for the management of metabolic disorders such as type 2 diabetes mellitus (T2DM) [45].

Fenugreek seeds are rich in bioactive constituents such as galactomannan (soluble dietary fibre), 4-hydroxyisoleucine, an amino acid derivative present in fenugreek seeds, has been investigated for its potential insulinotropic effects. [46].

3.4.2 Proposed Antidiabetic Mechanism of Fenugreek

The potential antidiabetic effects of fenugreek appear to involve both nutritional and pharmacological mechanisms. Its soluble fibre,

Table 4: Experimental and Clinical Studies on Fenugreek in Diabetic Management

S.NO	Author & year	Study type	Sample/Model	Dose/form	Duration	Key findings
1	Hadi et al., 2020	clinical trial	T2DM patients	15g powder	8 weeks	FBG
2	Khatun et al., 2023	clinical trial	T2DM patients	10 g/day	60 days	FBG and post prandial blood sugar levels
3	Hassani SS et al., 2019	clinical trial	T2DM patients	10 g powder	8 weeks	FBG and HbA1c
4	Shabil et al., 2023	Systematic review and meta-analysis	-	-	-	FBG, HbA1c, creatinine, and triglycerides

Critical Analysis

Clinical investigations of *T. foenum-graecum* have reported effects on several glycemic and metabolic outcomes, including fasting blood glucose, postprandial glucose, HbA1c and insulin-related measures. However, considerable variation in preparation, dose and study design limits direct comparison across trials.

The relatively high daily doses used in many clinical investigations may reduce long-term patient adherence because of bitterness and gastrointestinal discomfort. Future research should prioritize standardized fenugreek preparations with clearly defined phytochemical and fibre characteristics, appropriate dosing, longer follow-up and well-designed randomized controlled trials.

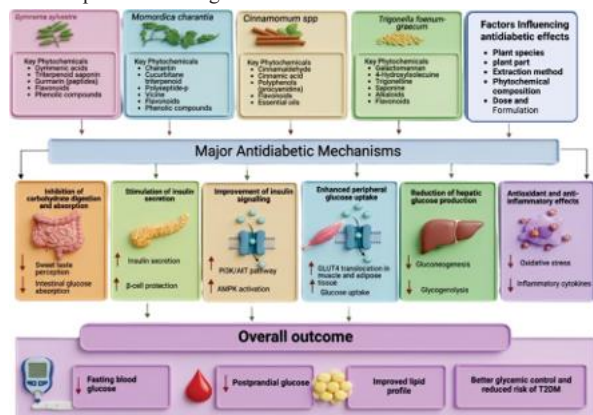


Figure 2. Comparative Overview of Key Phytochemicals and Proposed Antidiabetic Mechanisms of Selected Medicinal Plants.

IV. Challenges and Future Perspectives

Despite the promising antidiabetic potential of medicinal plants, several challenges limit their clinical application. Variations in plant species, cultivation conditions, extraction methods, and phytochemical composition can affect their biological activity and reproducibility. Therefore, standardization of herbal extracts and quality control measures are essential for ensuring consistent results.

Although numerous in vitro and animal studies support the antidiabetic activity of medicinal plants, well-designed clinical trials remain limited. Future research should focus on adequately powered clinical studies to establish effective dosage, long-term safety, and clinical efficacy. Advanced analytical techniques are also required for the identification and quantification of relevant bioactive compounds and for establishing suitable phytochemical markers for standardization.

Furthermore, potential herb–drug interactions and safety concerns require systematic evaluation. The development of standardized plant-based formulations and nutraceutical products, supported by scientific validation, may facilitate their potential application in diabetes management. Future studies should integrate phytochemical characterization, mechanistic investigations, safety assessment, and clinical validation to establish the reproducibility and clinical relevance of medicinal plant preparations.

particularly galactomannan, may slow gastric emptying and carbohydrate absorption, thereby attenuating postprandial glucose excursions. Other constituents, including 4-hydroxyisoleucine, trigonelline and steroidal saponins, have been investigated for effects on insulin secretion, insulin sensitivity and glucose metabolism. [47,48].

Several clinical and experimental studies have reported reductions in fasting or postprandial glucose and, in some studies, HbA1c following fenugreek supplementation[49,50]. However, differences in dose, formulation and intervention duration limit direct comparison among studies

V. CONCLUSION

Medicinal plants represent promising sources of bioactive compounds with potential applications in diabetes management due to their diverse pharmacological activities, including glucose regulation, antioxidant effects, and improvement of metabolic abnormalities. Among the various plants reviewed, *Gymnema sylvestre* has gained considerable attention because of its traditional importance, presence of gymnemic acids, and reported anti-diabetic activity through multiple mechanisms.

Although preclinical and limited clinical studies support the therapeutic potential of medicinal plants such as *Gymnema sylvestre*, *Momordica charantia*, *Trigonella foenum-graecum*, *Cinnamomum verum*, challenges related to standardization, dosage optimization, safety evaluation, and limited large-scale clinical trials remain. Future research should focus on scientifically validated, standardized herbal formulations supported by robust clinical evidence to establish their role as complementary approaches in diabetes management.

VI. Funding

The first author gratefully acknowledges the financial support provided by the University Grants Commission (UGC), Government of India, through the UGC-NET Junior Research Fellowship (JRF) for pursuing doctoral research. This review was prepared as part of the doctoral research work.

VII. Author Contributions

Both authors contributed to the conceptualization of the review. Literature search, critical analysis, manuscript drafting, review and editing, supervision, validation, and final approval of the manuscript were jointly performed by the authors.

VIII. Declaration of Competing Interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

IX. Data Availability Statement

No new datasets were generated or analyzed during this study. All information presented in this review was obtained from previously published literature.

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