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Phytochemical Constituents of Medicinal Plants: Advancing Diabetes Management and Human Health

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ABSTRACT:
Diabetes mellitus is a chronic metabolic disorder with a rising global prevalence, leading to significant health complications and economic burden. Although conventional pharmacotherapy remains vital in glycemic management, plant-based therapies—rooted in traditional medicine—have gained renewed attention due to their multifaceted effects and lower incidence of adverse outcomes (Sivakumar, 2024; Sknepnek, 2025). This review comprehensively examines the ethnobotanical knowledge and phytochemical evidence supporting the use of medicinal plants in diabetes management. Traditional systems across diverse cultures have utilized numerous plant species for glycemic control, many of which are now being validated by contemporary scientific research (Skalli, 2019; Khajuria et al., 2025). The review highlights key classes of bioactive plant compounds—alkaloids, flavonoids, terpenoids, phenolics, saponins, and glycosides—detailing their mechanisms of action, including the enhancement of insulin secretion, modulation of glucose uptake, inhibition of carbohydrate-hydrolyzing enzymes, and antioxidant activities (Mahmoud et al., 2024; Lee, 2021; Przeor, 2022). Experimental and clinical findings for prominent antidiabetic plants such as Gymnema sylvestre, Momordica charantia, Trigonella foenum-graecum, Aloe vera, Ocimum sanctum, and Tinospora cordifolia are discussed, alongside challenges in standardization, safety assessment, and integration with modern therapeutics (Ramadaini, 2024; Matalqah & Al-Tawalbeh, 2025). By bridging traditional wisdom and modern pharmacology, this review provides a well-rounded perspective on the potential and limitations of plant-based approaches in diabetes care, calling for further clinical validation and policy support to realize their full therapeutic value (Sknepnek, 2025; Lee, 2021).

Introduction

Diabetes mellitus is a group of metabolic disorders characterized by high blood glucose levels due to defects in insulin secretion, insulin action, or both. Its increasing global prevalence has made it a major public health challenge, contributing to complications such as neuropathy, nephropathy, retinopathy, and cardiovascular diseases (Vishwakarma, 2025; Sknepnek, 2025). While pharmaceutical interventions with insulin and oral hypoglycemic agents are standard, there are limitations relating to side effects, cost, and long-term efficacy (Sivakumar, 2024; Mahmoud et al., 2024). Alternative food and plants have been used in diabetes management e.g. Mushrooms (Telang, et al., 2010). Traditional medicine systems—including Ayurveda, Traditional Chinese Medicine, and folk practices worldwide—have long used plants for managing diabetes (Kothari and Baig, 2013). This resurgence of interest in botanicals is supported by ethnobotanical data, demonstrating their use across cultures, and phytochemical studies that uncover the mechanisms and efficacy of plant-derived compounds (Skalli, 2019; Khajuria et al., 2025; Matalqah & Al-Tawalbeh, 2025). Leveraging both perspectives allows for a deeper understanding of how plant-based therapies can complement or enhance conventional diabetes management.

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Table 1: Plant and their mechanism in diabetes management

Plant Name	Key Compounds	Mechanisms	Study Type
Gymnema sylvestre	Gymnemic acids	Insulin secretion, β-cell regeneration	In vivo/Clinical (Sivakumar, 2024)
Momordica charantia	Charantin, polypeptide-p	Insulin mimetic, enzyme inhibition	In vivo/Clinical (Ramadaini, 2024)
Trigonella foenum-graecum	4-hydroxyisoleucine, saponins	Insulin release, glucose uptake	Clinical (Przeor, 2022)
Aloe vera	Polysaccharides, anthraquinones	Antioxidant, glucose metabolism modulation	Experimental (Mahmoud et al., 2024)
Ocimum sanctum	Eugenol, ursolic acid	Enzyme inhibition, hypoglycemic effect	In vivo (Przeor, 2022)
Tinospora cordifolia	Alkaloids, glycosides	Insulin sensitivity, antioxidant action	Experimental (Sivakumar, 2024)

Ethnobotanical Perspective

Medicinal plants have played a vital role in diabetes management across traditional societies worldwide (Skalli, 2019). Surveys from regions such as Morocco, India, and various African countries consistently report the use of numerous plant species for glycemic control (Khajuria et al., 2025; Skalli, 2019). Ethnobotanical investigations document not only the species but also the plant parts used (leaves, seeds, roots), methods of preparation (infusions, decoctions, powders), and cultural rationales. For instance, an urban ethnobotanical survey in Jammu, India, identified 20 species used for diabetes treatment, highlighting both common and unique local traditions (Khajuria et al., 2025).

Table 2: Ethnobotanical plants used for diabetes management

Plant Name	Part Used	Region/Tradition	Preparation Method
Trigonella foenum-graecum	Seeds	India, Morocco	Powder, infusion
Momordica charantia	Fruit	Asia, Africa	Juice, cooked Dish
Gymnema sylvestre	Leaves	India	Chewing, extract
Aloe vera	Leaf gel	Global	Juice, oral gel
Ocimum sanctum	Leaves	India	Infusion/tea
Tinospora cordifolia	Stem	India	Decoction
Salvia officinalis	Leaves	Mediterranean	Infusion
Alstonia scholaris	Leaves	Jammu, India	Decoction

Phytochemical Constituents

Plants with antidiabetic properties are rich in several classes of biologically active compounds. Key groups include:

- **Alkaloids**, such as berberine, which influence insulin signalling (Rawat et al., 2025).
- **Flavonoids**, including quercetin and resveratrol, known for enhancing insulin sensitivity and providing antioxidant effects (Rawat et al., 2025; Matalqah & Al-Tawalbeh, 2025).
- **Terpenoids**, such as gymnemic acids and momordicosides, noted for glucose-lowering effects (Mahmoud et al., 2024).
- **Phenolics**, such as chlorogenic acid, with effects on carbohydrate metabolism (Sivakumar, 2024).
- **Saponins and glycosides**, which delay glucose absorption and modulate glucose metabolism (Sivakumar, 2024; Ramadaini, 2024).

Mechanisms of Action

Several complementary pathways have been reported by which phytochemicals regulate blood glucose:

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- **Stimulation of insulin secretion** and beta-cell protection (Mahmoud et al., 2024).
- **Increased glucose uptake** into cells (Lee, 2021).
- **Inhibition of carbohydrate-hydrolyzing enzymes** (e.g., α-amylase, α-glucosidase), leading to reduced postprandial glucose levels (Przeor, 2022).
- **Antioxidant activity**, which helps prevent oxidative damage to pancreatic β-cells (Rawat et al., 2025; Lee, 2021).
- **Modulation of intracellular signaling** such as AMPK and PI3K/Akt pathways, key mediators of glucose homeostasis (Mahmoud et al., 2024; Lee, 2021).

Promising Medicinal Plants

Several well-studied antidiabetic plants showed the key compounds in the treatment of diabetes. Studies have identified key compounds their role and mechanism of action, these studies varied from *in vivo* studies to clinical trials.

Table 3: Major phytochemicals with antidiabetic mechanisms

Compound Name	Plant Source	Mechanism	Reference
Gymnemic acids	*Gymnema sylvestre*	Insulin secretion, enzyme inhibition	Sivakumar, 2024
Charantin	*Momordica charantia*	Insulin mimetic, glucose uptake	Ramadaini, 2024
4-hydroxyisoleucine	*Trigonella foenum-graecum*	Stimulates insulin release	Przeor, 2022
Berberine	Various herbs	AMPK activation, insulin sensitivity	Matalqah & Al-Tawalbeh, 2025
Saponins	Multiple plants	Enzyme inhibition, glucose absorption	Mahmoud et al., 2024
Flavonoids (quercetin, resveratrol)	Fruits, vegetables	Antioxidant, improves insulin action	Rawat et al., 2025

Experimental and Clinical Evidence

A growing experimental *(in vitro, in vivo*) and clinical evidence supports the efficacy of medicinal plants in diabetes management (Mahmoud et al., 2024; Ramadaini, 2024). For example, clinical trials on fenugreek (*Trigonella foenum-graecum*), bitter gourd (*Momordica charantia*), and *Gymnema sylvestre* have shown promising reductions in blood glucose and improvement in metabolic markers among diabetic patients (Sivakumar, 2024; Ramadaini, 2024; Przeor, 2022). These results substantiate ethnobotanical claims and guide safe dosages and use in humans.

Limitations and Future Prospects

Despite encouraging data, plant-based diabetes therapies face several challenges. The lack of standardization and consistency in plant material and preparations can complicate reproducibility and safety (Matalqah & Al-Tawalbeh, 2025; Mahmoud et al., 2024). Comprehensive toxicological assessments are often missing, and many promising results derive from small or preliminary studies (Lee, 2021; Sknepnek, 2025). Additionally, clear guidelines are needed for integrating herbal remedies with conventional treatments. Thus, future research should emphasize robust clinical trials, standardization, and safety for optimal therapeutic integration (Mahmoud et al., 2024; Sknepnek, 2025).

Conclusion

Plants have played a central role in the ethnobotanical management of diabetes and increasingly gain scientific support for their multifaceted effects and low side-effect profiles (Sivakumar, 2024; Sknepnek, 2025; Rawat et al., 2025; Matalqah & Al-Tawalbeh, 2025; Przeor, 2022). Integrating traditional wisdom with modern phytochemical and clinical research helps unlock the therapeutic potential of medicinal plants in diabetes care. However, coordinated research focusing on standardization, safety validation, and clinical applicability is needed to realize the full benefits of plant-based therapies.

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