

Herbal Remedies for Diabetes: Efficacy, Safety, and Standardization

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ABSTRACT

The global rise in diabetes mellitus has intensified the search for effective management strategies, including the use of herbal remedies. These natural interventions are increasingly recognised for their potential to complement conventional therapies, offering mechanisms such as enhancing insulin sensitivity, regulating glucose metabolism, and reducing oxidative stress. This review systematically evaluates the efficacy, mechanisms, and limitations of key herbal remedies in diabetes management. A comprehensive literature search was conducted using databases such as PubMed, Scopus, and Google Scholar, focusing on studies published between 2015 and 2023. The inclusion criteria comprised peer-reviewed clinical trials, meta-analyses, and *in vivo* studies with quantitative data. Keywords used included "herbal remedies," "diabetes management," and "glycemic control." The GRADE methodology was applied to assess the quality of evidence. The findings identify six prominent herbs: *Gymnema sylvestre*, *Momordica charantia* (Bitter Melon), Fenugreek, Aloe vera, Cinnamon, and Garlic. These herbs exhibit diverse mechanisms of action, including the inhibition of sugar absorption, stimulation of insulin secretion, and mitigation of oxidative stress. Clinical evidence suggests their potential to improve glycaemic control, but challenges such as lack of standardisation, limited large-scale trials, and herb-drug interactions persist. The review emphasises the need for rigorous clinical validation and standardised preparation methods to ensure safety and efficacy. Recommendations include integrating these remedies under professional supervision, educating patients on their use, and prioritising research to bridge gaps in evidence. By combining traditional knowledge with modern scientific rigour, herbal remedies can play a pivotal role in holistic diabetes care, potentially reducing dependency on pharmaceuticals and enhancing patient outcomes.

Keywords: Anti-diabetic herbs, Diabetes treatment alternatives, Glycaemic control, Herbal remedies.

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INTRODUCTION

Diabetes has evolved into a significant global health crisis, profoundly impacting economic, social, and healthcare systems. This chronic metabolic disorder is marked by the body's inability to effectively regulate blood glucose levels due to issues with insulin, a pancreatic hormone that facilitates cellular glucose absorption. The disease manifests in three primary forms: Type 1 diabetes, an autoimmune condition where the immune system attacks insulin-producing cells; Type 2 diabetes, accounting for

approximately 90-95% of cases and arising from insulin resistance and insufficient production; and gestational diabetes, which occurs during pregnancy and increases Type 2 diabetes risk later in life (Eizirik *et al.*, 2023). The global prevalence has surged alarmingly, with approximately 537 million adults affected as of 2021, projected to reach 783 million by 2045 (Siam *et al.*, 2024). The highest rates occur in the Middle East and North Africa, driven by increasing obesity, sedentary lifestyles, and ageing populations (El-Kebbi *et al.*, 2021). The economic burden is staggering, with global healthcare expenditures estimated at \$966 billion in 2021 (Hossain *et al.*, 2024). Effective management strategies are crucial, encompassing health screenings, weight maintenance, physical activity, and balanced diets. As diabetes management becomes increasingly complex, patients face multifaceted challenges beyond medication adherence. Conventional treatments present limitations, including potential side effects from long-term use, high costs, variable patient responses, and lack of holistic



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mechanisms. These challenges have sparked growing interest in Complementary and Alternative Medicine (CAM), particularly herbal remedies, as adjuncts to conventional therapies (Raja *et al.*, 2024). Herbal remedies offer promising exploration for diabetes management through various mechanisms. Herbs like *Gymnema sylvestre* enhance insulin sensitivity and regulate glucose metabolism (Gayt, 2021). *Momordica charantia* (Bitter Melon) contains insulin-like compounds supporting glucose metabolism, while Cinnamon (*Cinnamomum verum*) improves insulin sensitivity and reduces blood glucose levels (Chang *et al.*, 2021). Fenugreek (*Trigonella foenum-graecum*) seeds are rich in soluble fibre that slows sugar absorption (Dhull *et al.*, 2021). Despite potential benefits, scientific validation is crucial for integrating herbal interventions into diabetes management. Rigorous clinical trials, standardized extraction methods, comprehensive safety assessments, and understanding potential interactions with conventional medications are essential. While herbal remedies offer a promising complementary treatment avenue, their use requires caution and professional supervision. Combining traditional knowledge with modern scientific validation and personalized care may help patients achieve improved health outcomes. Herbal remedies are favoured over allopathic medications due to their natural origin, affordability, and multi-targeted effects. Many herbs, including *Gymnema sylvestre*, Fenugreek, *Aloe vera*, and Bitter Melon, demonstrate significant hypoglycaemic properties. Fenugreek seeds contain 4-hydroxyisoleucine, which stimulates insulin secretion and improves glucose metabolism (Srinivasa *et al.*, 2021). *Aloe vera* lowered fasting blood glucose from 250 mg/dL to 141 mg/dL over six weeks in clinical trials (Deora *et al.*, 2022). Unlike allopathic medications targeting single pathways, herbal remedies act on multiple fronts. Cinnamon increases insulin sensitivity and reduces postprandial glucose spikes, while Garlic enhances lipid metabolism and reduces oxidative stress (Weng *et al.*, 2021). Herbs like *Azadirachta indica* (Neem) and *Syzygium cumini* (Jamun) show potential in mitigating diabetes-related cardiovascular and renal complications (Balkrishna *et al.*, 2025). However, standardization and robust clinical validation remain necessary, as many studies lack large-scale randomized controlled trials and preparation methods vary. Nonetheless, integrating these remedies under medical supervision offers a promising complementary approach to reduce synthetic drug reliance and enhance patient outcomes described in Figure 1.

Research Gaps

The current landscape of herbal medicine research in diabetes management faces significant methodological limitations. Most research is confined to short-term clinical trials spanning weeks to months, providing inadequate insights into sustained efficacy, cumulative effects, and long-term safety profiles. Longitudinal studies spanning multiple years are essential to evaluate chronic impacts on metabolic health and physiological interactions.

Mechanistic insights require extensive investigation. While preliminary research has identified biochemical pathways through which herbs like *Gymnema sylvestre* and *Momordica charantia* influence glucose metabolism, intricate molecular mechanisms remain incompletely understood (Gayt, 2021). Advanced research utilizing proteomics, metabolomics, and genomic analysis could reveal how phytochemical compounds interact with cellular receptors, modulate enzyme activities, and influence insulin signalling pathways (Paul *et al.*, 2024), enabling more targeted, personalised herbal interventions. Demographic diversity represents a significant gap. Most clinical trials focus on specific age groups, ethnic populations, or limited geographic regions (Xiao *et al.*, 2023), severely constraining generalizability. Comprehensive studies must incorporate diverse populations, accounting for variations in genetic backgrounds, metabolic profiles, comorbidities, and environmental factors. Quality control emerges as a fundamental challenge (Wang *et al.*, 2023). The absence of standardised protocols for herbal product preparation, extraction, and testing introduces significant variability. Developing comprehensive standardisation frameworks involving rigorous guidelines for plant cultivation, harvesting, extraction, and phytochemical profiling is essential. International collaborations between regulatory bodies, research institutions, and pharmaceutical organisations could establish universal standards ensuring consistent quality, potency, and safety. Addressing these limitations requires a multidisciplinary approach involving pharmacologists, clinicians, ethnobotanists, and regulatory experts. Collaborative, long-term research initiatives with robust methodological designs can transform understanding of herbal interventions, potentially revolutionising diabetes treatment strategies. By systematically addressing these gaps, the scientific community can develop evidence-based approaches that validate traditional knowledge and create opportunities for innovative, personalized therapeutic interventions complementing conventional diabetes management.

Physiological Mechanisms

Insulin functions as a key that unlocks cellular doors, allowing glucose to enter cells for energy. In Type 1 diabetes, the immune system mistakenly attacks insulin-producing beta cells in the pancreas, leading to little or no insulin production and glucose accumulation in the bloodstream (Eizirik *et al.*, 2020). Type 2 diabetes arises from insulin resistance, where cells become less responsive to insulin, and pancreatic strain, where the pancreas compensates by overproducing insulin until exhaustion. Uncontrolled diabetes triggers metabolic changes, including increased inflammation, oxidative stress, blood vessel damage, and impaired immune function described in Figure 2. These effects highlight the importance of effective management to prevent complications. Diabetes is a global health challenge influenced by socioeconomic factors. Developed countries

benefit from advanced screening and management techniques, while developing nations often lack a comprehensive healthcare infrastructure. Nutritional transitions from traditional diets to processed foods further exacerbate diabetes risk.

Technological Innovations in Diabetes Management

Emerging technologies are revolutionizing diabetes management. Continuous Glucose Monitors (CGMs) provide real-time blood sugar tracking, allowing immediate lifestyle adjustments (Zahedani *et al.*, 2021). Artificial pancreas systems automate insulin delivery, mimicking natural pancreatic function for precise glucose management. Genetic research aims to identify markers for personalized prevention strategies and risk profiles. Effective diabetes prevention extends beyond medical interventions. Nutrition education, community health programs, workplace wellness initiatives, and early childhood nutrition interventions are essential components. Recognizing the psychological aspects is crucial; chronic conditions can lead to increased stress and anxiety about health complications.

Emerging Research Frontiers

Current research is exploring various frontiers in diabetes management: The role of the microbiome in diabetes development (Zhang *et al.*, 2021). Potential regenerative therapies aimed at restoring beta cell function (Nair *et al.*, 2020). Advanced genetic screening techniques for early detection and personalized treatment (Fitzgerald *et al.*, 2022). A comprehensive understanding of diabetes requires examining its physiological mechanisms, global prevalence trends, innovative management strategies, and socioeconomic factors. By considering personal risk factors and engaging with emerging research, individuals can take proactive steps toward managing their health. Diabetes management has significantly evolved, yet numerous challenges persist. The complexity requires a multifaceted approach beyond pharmaceutical interventions. Patients encounter intricate medication regimens, continuous lifestyle modifications, psychological stress management, and economic barriers. Conventional treatments present limitations, including potential side effects, high costs, variable patient responses, and lack of holistic healing mechanisms. In response, there is growing interest in herbal remedies as a complementary approach. Herbal medicines offer benefits through enhancing insulin sensitivity, regulating glucose metabolism, reducing inflammation, mitigating oxidative stress, and supporting pancreatic function (Mukai *et al.*, 2022). Notable interventions include Cinnamon (*Cinnamomum verum*), improving insulin sensitivity and reducing blood glucose levels (Shinjyo *et al.*, 2020); Bitter Melon (*Momordica charantia*), containing insulin-like compounds; *Gymnema sylvestre*, reducing sugar absorption; and Fenugreek (*Trigonella foenum-graecum*), rich in soluble fibre that slows sugar absorption (Dwivedi *et al.*, 2022). Despite potential benefits, scientific validation is crucial. Rigorous clinical

trials, standardized extraction methods, comprehensive safety assessments, and understanding interactions with conventional medications are essential. Challenges remain due to variability in plant compounds, limited large-scale trials, and standardization difficulties. An integrative approach bridging traditional and modern medicine is recommended, involving collaborative medical practices, professional supervision, patient education, personalized treatment protocols, and continuous monitoring. This model can lead to reduced medication dependency, improved metabolic health, enhanced patient empowerment, and long-term health benefits, offering a promising avenue for complementary treatment strategies.

Epidemiological Context

As of 2021, approximately 537 million adults aged 20-79 are living with diabetes, accounting for about 10.5% of the global population. This figure is projected to rise dramatically to 783 million by 2045, representing a 45% increase in two decades. The prevalence is particularly high in the Middle East and North Africa, where rates are expected to soar from 9.3% to 16.8% by 2050 (Al-Jawaldeh *et al.*, 2022). The disease is increasingly affecting younger populations and working-age adults, indicating demographic shifts with long-term implications for workforce productivity and healthcare demands. The economic implications are staggering. In 2021, global healthcare expenditures related to diabetes reached \$966 billion, projected to exceed \$1 trillion by 2045 (Rafi *et al.*, 2020). This burden encompasses direct treatment costs and indirect costs such as productivity losses, disability claims, and higher insurance premiums. In low and middle-income countries, the rapid increase poses significant challenges to healthcare infrastructure, exacerbating existing inequalities. Despite advancements, conventional treatment paradigms face several limitations. The one-size-fits-all approach often fails to address individual patient needs, leading to variable responses and side effects. High medication costs and complex management regimens contribute to psychological stress. Many individuals struggle with continuous self-monitoring and lifestyle adaptations necessary for effective management, as described in Figure 3.

Common Herbal Remedies

Several herbs have garnered attention for their potential anti-diabetic properties:

- ***Gymnema sylvestre***: Lowers blood sugar levels and improves glycemic control by regenerating pancreatic beta cells (Gao *et al.*, 2023).
- ***Momordica charantia* (Bitter Melon)**: Lowers fasting and postprandial glucose levels through insulin-mimicking effects (Liu *et al.*, 2021).
- ***Panax ginseng***: Enhances insulin secretion and improves glucose uptake (Saikat *et al.*, 2021).

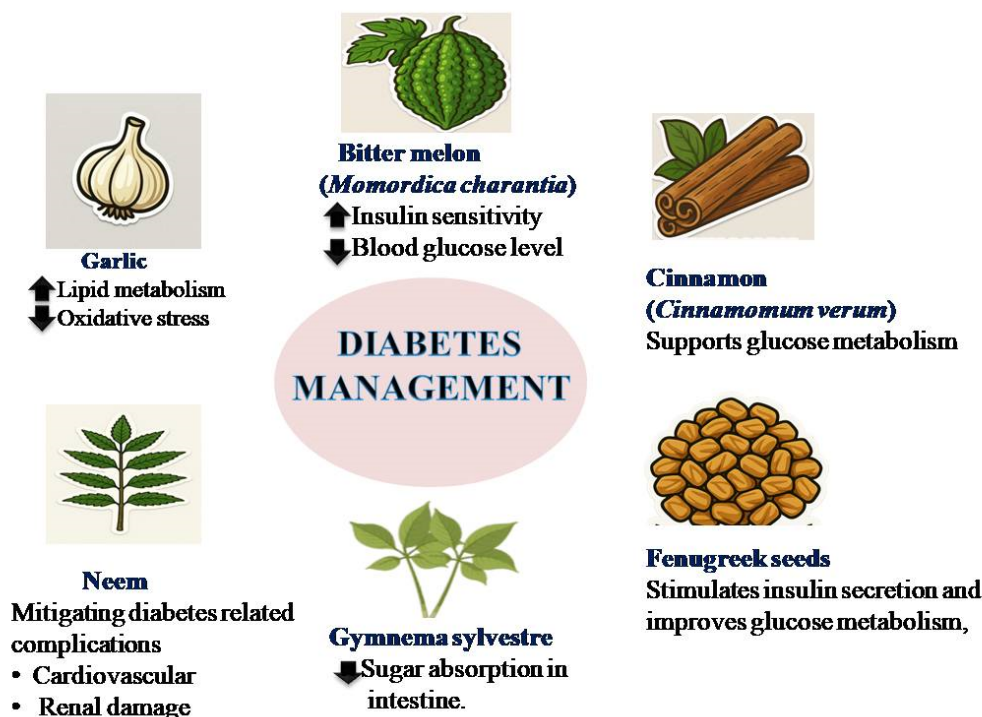


Figure 1: Herbal remedies in diabetes management.

- *Allium sativum* (Garlic): Demonstrates antihyperglycemic effects and enhances insulin sensitivity (Zelicha *et al.*, 2024).
- **Cinnamon:** Associated with reduced haemoglobin A1c levels in diabetic patients (Alzahrani *et al.*, 2022).
- *Momordica charantia*: Contains compounds that mimic insulin (Liu *et al.*, 2021),
- *Silybum marianum* (Milk Thistle): Improves insulin sensitivity (Syed *et al.*, 2020),

2. Insulin Sensitizers: Enhance the body's sensitivity to insulin:

- *Trigonella foenum-graecum* (Fenugreek): Contains soluble fibre that improves insulin sensitivity (Rahmani *et al.*, 2022),
- *Allium sativum* (Garlic): Enhances insulin sensitivity and lowers fasting blood glucose (Zelicha *et al.*, 2024).

3. Antioxidants: Combat oxidative stress:

- *Nigella sativa* (Black Seed): Exhibits antioxidant properties and improves glycaemic control (Jamrozik *et al.*, 2022),
- *Hibiscus sabdariffa*: Contains antioxidants that reduce diabetes complications (Vafaeipour *et al.*, 2022),

4. Anti-inflammatory Agents: Reduce inflammation linked to insulin resistance

- *Curcuma longa* (Turmeric): Contains curcumin with anti-inflammatory effects (Kausar *et al.*, 2021),
- *Zingiber officinale* (Ginger): Known for anti-inflammatory properties and potential to lower blood sugar (Mahendran *et al.*, 2021).

Patients turn to herbal remedies due to dissatisfaction with conventional treatments, cultural beliefs viewing herbal medicine as more "natural," and cost considerations, as herbal remedies are often less expensive than prescription medications (Alam *et al.*, 2021).

Risks and Considerations

Despite popularity, herbal remedy use carries risks. Many patients do not inform healthcare providers about herbal supplement use, potentially leading to interactions with prescribed medications. The efficacy and safety of many herbal treatments lack rigorous clinical trial validation. Some users may experience side effects (Mehrerjerd *et al.*, 2024). While many herbs show promise in aiding glycaemic control, patients must consult healthcare professionals before integrating these remedies into treatment plans.

Systematic Classification of Herbal Interventions

Herbal remedies can be classified based on their mechanisms of action:

1. Hypoglycemic Agents: Lower blood glucose levels:

- *Gymnema sylvestre*: Reduces sugar cravings and enhances insulin secretion (Gao *et al.*, 2023),

Comparative Effectiveness vs. Standard Treatments

Recent studies have evaluated herbal remedies' effectiveness in managing glycaemic control in T2DM patients. A systematic review highlighted comparative effectiveness:

- **Apple Cider Vinegar (ACV):** Most effective in reducing FBG levels (SMD of -28.99) (Heshmati *et al.*, 2021),
- **Cinnamon:** Significant FBG reduction (SMD of -9.73) (Mokgalaboni *et al.*, 2024),
- **Curcumin:** FBG reduction (SMD of -13.15) (Hassanzadeh *et al.*, 2024),
- **Fenugreek:** Effective (SMD of -19.64) (Chattopadhyay *et al.*, 2022).

For HbA_{1c} reduction, ACV and Fenugreek were notably effective. Another meta-analysis reported that *Aloe vera*, Psyllium fibre, and Fenugreek seeds reduced HbA_{1c} levels by -0.99%, -0.97%, and -0.85%, respectively (Al-Shuhaib *et al.*, 2024).

Pharmacological Interactions

Concurrent use of herbal remedies and conventional antidiabetic medications can lead to significant Herb-Drug Interactions (HDIs):

- **Additive Effects:** Some herbs may enhance antidiabetic drug effects, potentially causing hypoglycaemia. Cinnamon and Garlic can have additive effects with metformin or gliclazide (Willcox *et al.*, 2021).

- **Decreased Effectiveness:** Certain herbs may reduce medication efficacy. Green tea has been reported to decrease metformin and sitagliptin effectiveness (Al-Kuraishy *et al.*, 2022).

Potential Adverse Reactions

Common adverse reactions include gastrointestinal issues, allergic reactions, hypoglycaemia, and drug interactions. Herbs like *Ginkgo biloba* and *Hypericum perforatum* (St. John's wort) can interact with other medications, leading to increased bleeding risk or altered drug metabolism (Khoobchandani *et al.*, 2024).

Long-Term Safety Profiles

Long-term safety profiles remain inadequately studied. Herbal products lack the rigorous testing of pharmaceuticals, leading to variability in potency and purity (Rai *et al.*, 2024). Prolonged use may lead to cumulative toxicity or adverse effects not immediately apparent (Gouws *et al.*, 2020).

Recommendations for Clinical Monitoring

Healthcare providers should inform patients about potential risks and the importance of disclosing all supplements (Cock *et al.*, 2021). Regular monitoring of blood glucose levels is crucial when introducing herbal remedies (Auxtero *et al.*, 2021). Regular review of patient medication lists for potential herb-drug interactions and adjustment of treatment plans is necessary (Stanojević, 2022). Foster open communication between patients and healthcare providers regarding herbal supplement use (Zhu *et al.*, 2022).

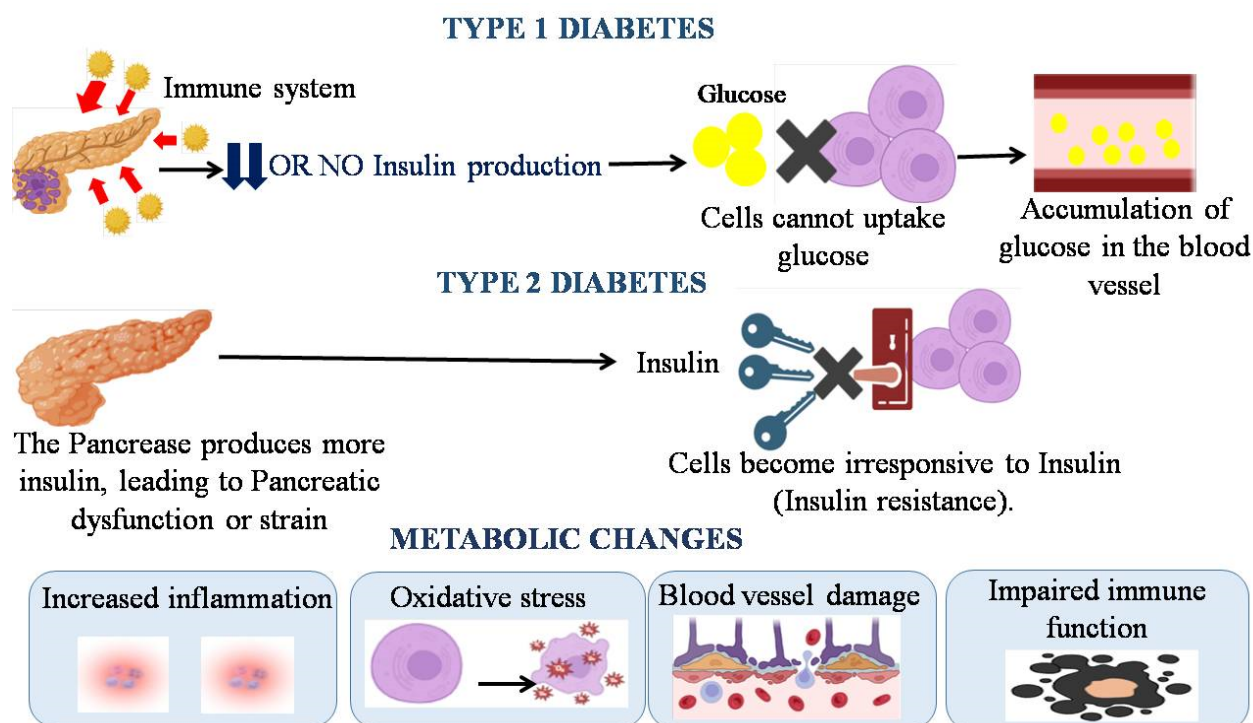


Figure 2: Physiological mechanism of Diabetes.

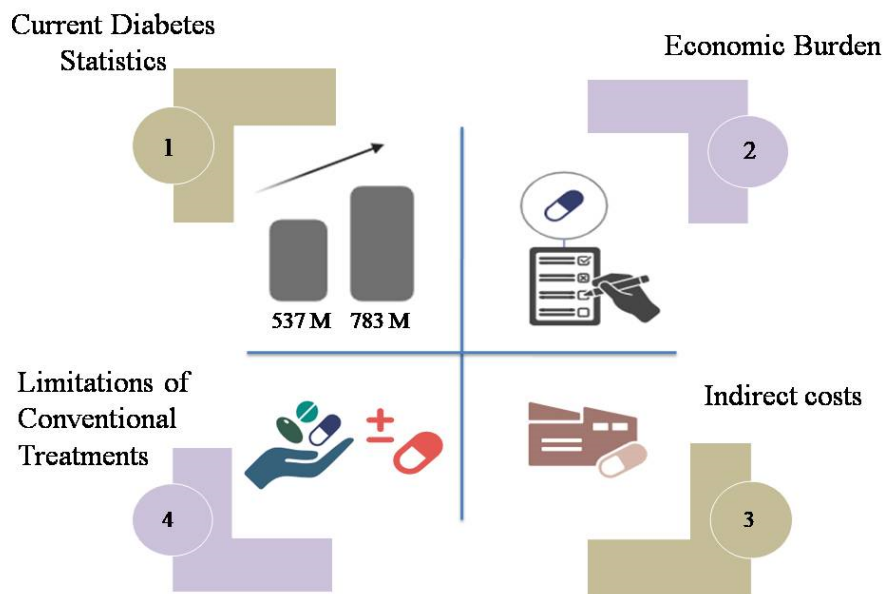


Figure 3: Epidemiological context of Diabetes.

Comparative Assessment

Comparative assessment of strengths and weaknesses of herbal remedies is discussed in below and described in Figure 4.

Strengths

- Natural origin with perceptions of safety (Krawczyk *et al.*, 2022),
- Demonstrated hypoglycaemic effects comparable to conventional medications (Dar *et al.*, 2024),
- Multi-mechanistic action (Jansen *et al.*, 2021),
- Cultural acceptance and accessibility (Wang *et al.*, 2023).

Weaknesses

- Lack of standardization (Mangara *et al.*, 2024),
- Limited research with insufficient evidence (Zhang *et al.*, 2021),
- Potential drug interactions (Chen *et al.*, 2021),
- Adverse effects deterring patient adherence (Carswell *et al.*, 2022).

Future Research Directions

Large-scale Randomized Controlled Trials with longer follow-up periods will establish effectiveness and safety profiles. Mechanistic studies can provide insights into pharmacological mechanisms. Research should explore integration with conventional care protocols. Patient education programs are essential for optimizing treatment outcomes (Nair *et al.*, 2024).

Unique Approach Strategies

Critical analysis is essential to evaluate herbal remedies' efficacy and safety compared to conventional treatments. While many herbal interventions show promising results, it is crucial to scrutinize evidence quality (Usai *et al.*, 2022). Many studies are limited by small sample sizes or lack rigorous design.

Emerging herbal interventions deserve attention. Recent studies on *Artemisia afra* and *Moringa oleifera* have indicated significant antidiabetic properties (Venugopal *et al.*, 2020).

Understanding molecular mechanisms is vital. *Momordica charantia* activates AMPK and increases GLUT4 expression, enhancing glucose uptake (Deora *et al.*, 2021). *Aloe vera* stimulates insulin secretion while exhibiting anti-inflammatory properties (Arunakumara *et al.*, 2023).

Interdisciplinary collaboration between traditional medicine practitioners and modern healthcare providers can foster integrated treatment approaches. Dietitians can work alongside herbalists to create dietary plans incorporating effective herbal remedies while considering patients' overall health profiles. This collaboration can lead to personalised treatment strategies that enhance patient outcomes and improve adherence to diabetes management plans.

Potential Herbal Remedies to Explore for Diabetes Management

Potential Herbal Remedies to Explore for Diabetes Management are discussed below and described in Table 1.

Gymnema sylvestre

Gymnema sylvestre, often referred to as the "destroyer of sugar," has been extensively studied for its antidiabetic properties. Research indicates that it can lower blood glucose levels by blocking sugar absorption in the intestines and stimulating insulin secretion from pancreatic beta cells. Clinical studies have demonstrated that doses ranging from 200 to 400 mg of gymnemic acid can effectively reduce post-meal blood sugar levels, contributing to improved long-term glycaemic control. Additionally, *Gymnema* has shown potential in reducing LDL cholesterol and triglycerides, which are critical factors in diabetes management. Its multifaceted benefits, including anti-inflammatory and anti-obesity effects, make it a promising candidate for further exploration in diabetes treatment strategies (Krawczyk et al., 2022).

Momordica charantia (Bitter Melon)

Bitter melon is a well-researched herbal remedy known for its hypoglycemic effects. It contains several bioactive compounds, including charantin and polypeptide-p, which mimic insulin and enhance glucose uptake in cells. Clinical trials have shown that consuming bitter melon can lead to significant reductions in fasting blood glucose levels and improved insulin sensitivity. Its ability to regulate blood sugar levels makes it a valuable addition to dietary interventions for individuals with Type 2 diabetes. Moreover, bitter melon is rich in antioxidants, which may help

mitigate oxidative stress associated with diabetes complications (Jamali et al., 2020).

Cinnamon

Cinnamon has garnered attention for its potential role in improving insulin sensitivity and lowering blood glucose levels. Studies suggest that Cinnamon can enhance glucose uptake by cells and inhibit enzymes involved in carbohydrate digestion, leading to reduced postprandial blood sugar spikes. A meta-analysis of clinical trials indicated that cinnamon supplementation could significantly lower fasting blood glucose and HbA_{1c} levels in individuals with Type 2 diabetes. Additionally, its anti-inflammatory properties may further benefit diabetic patients by reducing inflammation linked to insulin resistance (Gartoula et al., 2021).

Fenugreek

Fenugreek seeds are rich in soluble fibre and have been shown to improve glycaemic control by slowing carbohydrate absorption and enhancing insulin secretion. Clinical studies have reported that fenugreek supplementation can lead to significant reductions in fasting blood glucose levels and HbA_{1c} among diabetic patients. The presence of compounds like 4-hydroxyisoleucine is believed to play a crucial role in stimulating insulin release from pancreatic beta cells. Fenugreek's ability to improve lipid profiles also adds to its appeal as a complementary treatment for diabetes (Irfan et al., 2020).

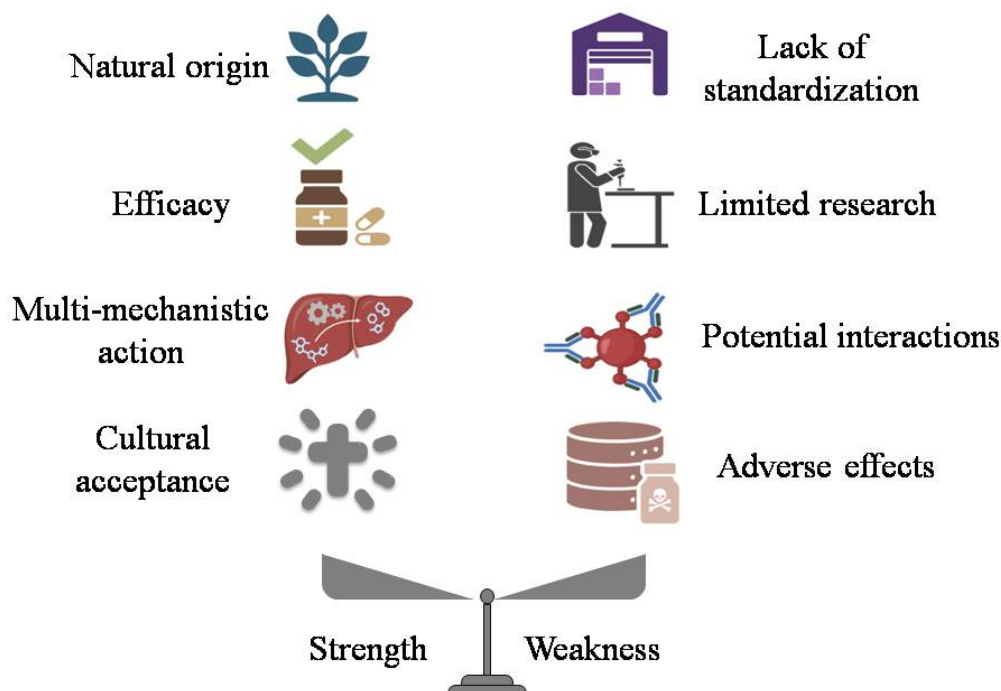


Figure 4: Comparative assessment of strengths and weaknesses of herbal remedies.

Table 1: Mechanism of Action and Evidence-Based Efficacy of Top Herbal Remedies for Diabetes Management.

Sl. No.	Name of the herb	Mechanism	Evidence
1	Gymnema sylvestre	<i>Gymnema sylvestre</i> contains gymnemic acids that inhibit sugar absorption in the intestines and enhance insulin secretion from pancreatic beta cells. It may also promote regeneration of pancreatic islet cells, leading to improved insulin production.	Studies have shown that Gymnema can significantly reduce blood glucose levels and improve HbA _{1c} in diabetic patients, demonstrating its potential as an effective adjunct therapy (Jamrozik <i>et al.</i> , 2022).
2	<i>Momordica charantia</i> (Bitter Melon)	Bitter melon acts through multiple pathways, including inhibition of glucose-6-phosphatase and stimulation of glucose uptake in peripheral tissues. It also enhances insulin sensitivity and mimics insulin-like effects by activating AMPK and increasing GLUT4 expression.	Clinical trials indicate that bitter melon can lower fasting blood glucose levels significantly, with some studies reporting effects comparable to those of standard diabetes medications (Jansen <i>et al.</i> , 2021).
3	<i>Trigonella foenum-graecum</i> (Fenugreek)	Fenugreek contains hydroxyisoleucine, which stimulates insulin secretion from beta cells. Additionally, it improves insulin sensitivity and inhibits carbohydrate digestion in the intestines, contributing to lower blood glucose levels.	Numerous clinical studies have confirmed Fenugreek's effectiveness in reducing fasting blood glucose and improving lipid profiles among diabetic patients (Kahraman <i>et al.</i> , 2020).
4	Aloe vera	<i>Aloe vera</i> enhances insulin secretion and improves glucose metabolism by protecting pancreatic beta cells from oxidative stress. It also exhibits anti-inflammatory properties that may benefit diabetic patients.	Research supports <i>Aloe vera</i> 's role in lowering blood glucose levels in both animal models and human subjects, indicating its potential as a complementary treatment for diabetes (Kahraman <i>et al.</i> , 2020).
5	Cinnamon	Cinnamon promotes insulin sensitivity and enhances glucose uptake by tissues. It also inhibits enzymes involved in carbohydrate digestion, thus reducing postprandial blood sugar spikes.	Clinical trials have reported significant reductions in fasting blood glucose and HbA _{1c} levels among participants consuming cinnamon supplements (Kausar <i>et al.</i> , 2021).
6	<i>Allium sativum</i> (Garlic)	Garlic improves insulin sensitivity and stimulates insulin secretion from the pancreas. It may also reduce oxidative stress, which is beneficial for managing diabetes-related complications.	Research indicates that Garlic can lower fasting blood glucose levels and improve overall glycaemic control in diabetic patients (Khoobchandani, 2024).

Ginseng

Ginseng, particularly *Panax ginseng*, has been traditionally used for its adaptogenic properties and potential benefits in managing diabetes. Research indicates that ginseng may enhance insulin sensitivity and promote glucose metabolism through various mechanisms, including the modulation of key metabolic pathways. Clinical trials have shown that ginseng supplementation can lead to significant improvements in fasting blood glucose levels and overall glycaemic control. Its antioxidant properties may also help reduce oxidative stress associated with diabetes complications (Shams *et al.*, 2024).

Berberine-Containing Plants

Berberine is a bioactive compound found in several plants, including *Berberis vulgaris* (barberry) and *Coptis chinensis* (goldenthrad). It has gained recognition for its potent antidiabetic effects, primarily through its ability to activate AMPK (AMP-Activated Protein Kinase), which enhances insulin sensitivity and promotes glucose uptake by cells. Clinical studies have demonstrated that berberine can effectively lower fasting blood glucose levels and improve lipid profiles comparable to metformin, a standard medication for Type 2 diabetes. Its multifaceted mechanisms make berberine a compelling candidate for further investigation as a therapeutic agent in diabetes management (Gupta *et al.*, 2021).

These herbal remedies-*Gymnema sylvestre*, bitter melon, Cinnamon, Fenugreek, ginseng, and berberine-containing plants-represent promising avenues for complementary treatments in diabetes management. Their diverse mechanisms of action and evidence-based efficacy highlight their potential roles alongside conventional therapies, warranting further research into their long-term safety profiles and clinical applications.

POTENTIAL CHALLENGES TO ADDRESS IN HERBAL REMEDIES FOR DIABETES MANAGEMENT

Variability in Herbal Preparation Methods

One of the significant challenges in utilizing herbal remedies for diabetes management is the variability in preparation methods. Different regions and cultures may employ distinct techniques for preparing herbal products, which can lead to inconsistencies in the active ingredients and overall potency. The extraction method, duration of processing, and part of the plant used can all influence the concentration of bioactive compounds. This variability can result in non-reproducible effects in clinical outcomes, complicating efforts to establish standardized treatment protocols (Vaou *et al.*, 2021).

Lack of Standardization

The lack of standardization in herbal medicine poses another critical challenge. Unlike pharmaceutical drugs, which undergo rigorous testing and quality control, herbal products often lack consistent manufacturing practices. This inconsistency can lead to variations in efficacy and safety profiles among different batches of the same herbal remedy. The World Health Organization has emphasized the need for standardization in herbal preparations to ensure their reliability and effectiveness. Without standardized dosages and formulations, healthcare providers may struggle to recommend specific herbal treatments confidently (Huang *et al.*, 2020).

Limited Large-Scale Clinical Trials

Although numerous studies have explored the antidiabetic properties of various herbs, there is a notable scarcity of large-scale clinical trials that validate these findings. Most existing research consists of small pilot studies or animal models, which may not accurately reflect human responses. The absence of extensive clinical trials limits the ability to draw definitive conclusions about the safety and efficacy of herbal interventions for diabetes management. Future research must prioritize large-scale, well-designed clinical trials that assess long-term outcomes and potential side effects (Shaikh *et al.*, 2020).

Potential Herb-Drug Interactions

Herbal remedies can interact with conventional diabetes medications, leading to either enhanced effects or diminished

efficacy. For example, herbs like Cinnamon and Garlic may potentiate the effects of antidiabetic drugs, increasing the risk of hypoglycaemia. Conversely, certain herbs might interfere with drug metabolism, reducing the effectiveness of medications like metformin or sulfonylureas. These potential herb-drug interactions necessitate careful monitoring by healthcare providers and highlight the importance of patient education regarding the concurrent use of herbal supplements with prescribed medications.

Addressing these challenges is crucial for integrating herbal remedies into diabetes management effectively. By focusing on standardization, conducting large-scale clinical trials, and understanding potential interactions with conventional treatments, researchers and healthcare professionals can enhance the safety and efficacy of herbal interventions.

CONCLUSION

The rising global diabetes epidemic underscores the urgent need for innovative and effective management strategies that extend beyond conventional treatments. This review has illuminated the promising role of herbal remedies as complementary interventions in diabetes care, showcasing their diverse mechanisms of action and clinical efficacy. Key herbal agents, including *Gymnema sylvestre*, *Momordica charantia*, Cinnamon, Fenugreek, Ginseng, and berberine-containing plants, have demonstrated potential in enhancing insulin sensitivity, regulating glucose metabolism, and reducing oxidative stress.

The integration of these remedies into mainstream diabetes management faces significant challenges, such as variability in preparation methods, lack of standardization, and limited large-scale clinical trials, which hinder the establishment of robust evidence for their use. Additionally, potential herb-drug interactions necessitate careful consideration to ensure patient safety.

To fully realize the benefits of herbal interventions while minimizing risks, it is essential to adopt an integrative approach that combines traditional knowledge with modern scientific validation. This includes conducting rigorous clinical trials to assess long-term efficacy and safety, standardizing herbal preparations, and educating patients on their appropriate use under professional supervision. By embracing a holistic perspective that incorporates both herbal remedies and conventional therapies, healthcare providers can enhance patient outcomes, empower individuals to take control of their health, and ultimately redefine diabetes management through innovative, evidence-based strategies that leverage the strengths of both traditional and modern medicine.

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ABBREVIATIONS

AMPK: AMP-activated protein kinase; **ACV:** Apple Cider Vinegar; **CAM:** Complementary and Alternative Medicine; **CGMs:** Continuous Glucose Monitors; **FBG:** Fasting Blood Glucose; **GLUT4:** Glucose Transporter Type 4; **GRADE:** Grading of Recommendations Assessment, Development and Evaluation; **HbA_{1c}:** Haemoglobin A_{1c}; **HDI:** Herb-Drug Interactions; **SMD:** Standardized Mean Difference; **T2DM:** Type 2 Diabetes Mellitus.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

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AUTHOR CONTRIBUTION

SK: Original Draft Preparation, YD: conceptualisation, PC: resources, SNK: data collection, GKR: Preparing figures, PAMS: Managing project timelines, VSG: Review & Editing.

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