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Medicinal Plant Formulations For The Prevention And Management Of Diabetes: A Comprehensive Review

Preeti Kaushik[1], Anjela Gahalayan[2]

[1]*Assistant Professor, Department of Microbiology, Chaudhary Bansilal University, Bhiwani, Haryana, India.*
[2]*Assistant Professor, Department of Zoology, Govt College, Sector-1, Panchkula, Haryana, India.*
**Corresponding Author: Preeti Kaushik*

Abstract:

Diabetes mellitus is a multifactorial metabolic disorder characterized by chronic hyperglycemia resulting from impaired insulin secretion, insulin resistance, or both. The rapidly increasing global burden of diabetes poses a significant challenge to public health systems, highlighting the need for safer, cost-effective, and sustainable therapeutic approaches. Medicinal plants have long been utilized in traditional medicine for the prevention and management of diabetes, owing to their diverse bioactive compounds and relatively low incidence of side effects.

This review comprehensively explores the role of medicinal plant formulations in diabetes prevention and management, with a focus on their phytochemical constituents, pharmacological activities, and underlying mechanisms of action. Plant-derived compounds such as alkaloids, flavonoids, terpenoids, and phenolics have been reported to exert antidiabetic effects through multiple pathways, including enhancement of insulin secretion, improvement of insulin sensitivity, stimulation of glucose uptake via glucose transporter proteins, inhibition of carbohydrate-hydrolyzing enzymes, and attenuation of oxidative stress and inflammation.

Furthermore, recent advancements in phytopharmacology, formulation technologies, and nanotechnology-based delivery systems have improved the efficacy and bioavailability of plant-based therapeutics. Despite substantial preclinical evidence supporting their antidiabetic potential, the translation of these findings into clinical practice remains limited due to insufficient clinical trials, lack of standardization, and variability in plant preparations.

Keywords: Diabetes mellitus, medicinal plants, herbal formulations, antidiabetic activity, phytochemicals, prevention.

1.Introduction

Diabetes mellitus is a chronic, multifactorial metabolic disorder characterized by persistent hyperglycemia resulting from defects in insulin secretion, insulin action, or both. It is broadly classified into type 1 diabetes, caused by autoimmune destruction of pancreatic β-cells, and type 2 diabetes, which is primarily associated with insulin resistance and relative insulin deficiency. The global prevalence of diabetes has increased dramatically over the past few decades, driven by rapid urbanization, sedentary lifestyles, unhealthy dietary habits, and genetic predisposition. According to recent global health estimates, diabetes represents a major public health concern due to its associated complications, including cardiovascular diseases, neuropathy, nephropathy, and retinopathy(Zimmet et al.,2014).

Conventional antidiabetic therapies, including insulin injections and oral hypoglycemic agents such as sulfonylureas, biguanides, and α-glucosidase inhibitors, have proven effective in controlling blood glucose levels. However, these treatments are often associated with limitations such as adverse side effects, high cost, risk of hypoglycemia, and reduced efficacy over long-term use. Consequently, there is an increasing interest in alternative and complementary approaches that are safer, more accessible, and sustainable(Kokil et al.,2015).

Medicinal plants have been used for centuries in traditional systems of medicine such as Ayurveda, Traditional Chinese Medicine, and Unani for the management of diabetes and its complications. These plants are rich sources of bioactive phytochemicals, including alkaloids, flavonoids, tannins, saponins, terpenoids, and phenolic compounds, which exhibit a wide range of pharmacological activities. Scientific investigations have demonstrated that these phytoconstituents exert antidiabetic effects through diverse mechanisms, such as enhancing insulin secretion from pancreatic β-cells, improving insulin sensitivity, promoting glucose uptake in peripheral tissues, inhibiting carbohydrate-digesting enzymes, and reducing oxidative stress and inflammation(Mamun et al.,2014).

In recent years, significant advancements in phytochemistry, molecular biology, and drug delivery systems have facilitated a deeper understanding of the therapeutic potential of medicinal plants. Novel approaches, including the development of standardized herbal formulations and nanotechnology-based delivery systems, have further improved the bioavailability and efficacy of plant-derived compounds. Despite these promising developments, challenges such as lack of standardization, variability in phytochemical composition, limited clinical validation, and concerns regarding safety and herb–drug interactions remain major obstacles to their widespread clinical application(Patil et al.,2011).

Therefore, this review aims to provide a comprehensive overview of medicinal plant formulations used in diabetes prevention and management, focusing on their phytochemical profiles, mechanisms of action, commonly used plant species, and recent advancements. Additionally, the review highlights existing gaps and future perspectives to facilitate the integration of plant-based therapeutics into modern healthcare systems.

2. Pathophysiology of Diabetes

Diabetes mellitus is a heterogeneous metabolic disorder characterized by chronic hyperglycemia resulting from defects in insulin secretion, insulin action, or both. Under normal physiological conditions, glucose homeostasis is tightly regulated by insulin secreted from pancreatic β-cells, which facilitates glucose uptake in peripheral tissues such as skeletal muscle and adipose tissue, while suppressing hepatic glucose production. In diabetes, this regulatory system is disrupted, leading to sustained elevations in blood glucose levels and widespread metabolic derangements. The pathophysiology varies between major forms of the disease, primarily Type 1 diabetes mellitus (T1DM) and Type 2 diabetes mellitus (T2DM), although both ultimately converge on hyperglycemia and its complications (Zimmet et al.,2014;Papatheodorou et al.,2018).The diabetes pathophysiology mechanism shown in Figure 1.

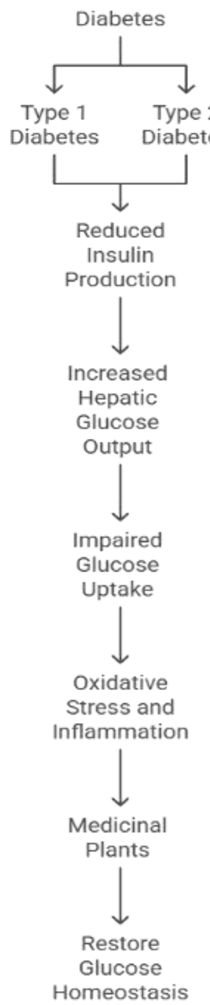

Figure 1: Understanding Diabetes Pathophysiology

In T1DM, the disease is primarily caused by autoimmune-mediated destruction of pancreatic β-cells, leading to absolute insulin deficiency. Genetic susceptibility, particularly involving HLA class II alleles, along with environmental triggers such as viral infections, initiates an immune response characterized by T-cell infiltration of pancreatic islets (insulitis). Progressive β-cell loss results in an inability to produce insulin, thereby impairing cellular glucose uptake. Consequently, glucose accumulates in the bloodstream while peripheral tissues experience an energy deficit. This metabolic state promotes lipolysis and proteolysis, with free fatty acids being converted into ketone bodies in the liver, predisposing individuals to diabetic ketoacidosis, a life-threatening acute complication(Quattrin et al.,2023).

In contrast, T2DM is characterized by a combination of insulin resistance and relative insulin deficiency. Insulin resistance occurs when peripheral tissues, particularly muscle, adipose tissue, and liver, exhibit a diminished response to insulin signaling. This is often associated with obesity, chronic inflammation, and ectopic lipid accumulation, which interfere with insulin receptor signaling pathways. Initially, pancreatic β-cells compensate by increasing insulin secretion, resulting in hyperinsulinemia. However, prolonged metabolic stress, glucotoxicity, and lipotoxicity eventually lead to β-cell dysfunction and decreased insulin secretion. Additionally, increased hepatic gluconeogenesis and impaired glucose uptake further exacerbate hyperglycemia (Chatterjee et al.,2017).

The persistent hyperglycemic state in diabetes leads to significant alterations in carbohydrate, lipid, and protein metabolism. Increased hepatic glucose production through gluconeogenesis and glycogenolysis, coupled with reduced peripheral glucose utilization, contributes to elevated blood glucose levels. Enhanced lipolysis results in elevated free fatty acids, promoting ketogenesis in T1DM and dyslipidemia in T2DM. Simultaneously, increased protein catabolism leads to muscle wasting and negative nitrogen balance. Chronic hyperglycemia also activates several pathogenic pathways, including the polyol pathway, advanced glycation end-product (AGE) formation, protein kinase C activation, and oxidative stress, all of which contribute to cellular and tissue damage(Watkins et al.,1990).

Over time, these metabolic disturbances result in both microvascular and macrovascular complications. Microvascular complications include diabetic retinopathy, nephropathy, and neuropathy, primarily due to capillary basement membrane thickening and endothelial dysfunction. Macrovascular complications involve accelerated atherosclerosis, increasing the risk of cardiovascular diseases such as coronary artery disease, stroke, and peripheral arterial disease. Thus, the pathophysiology of diabetes is multifactorial and progressive, involving complex interactions between genetic, immunological, and environmental factors that ultimately disrupt metabolic homeostasis and lead to systemic complications(Nazarian et al.,2018).

3. Role of Medicinal Plants in Diabetes Prevention

Medicinal plants have gained considerable attention in recent years for their potential role in the prevention and management of Diabetes Mellitus, a chronic metabolic disorder characterized by persistent hyperglycemia resulting from defects in insulin secretion, insulin action, or both. The increasing global prevalence of diabetes, coupled with the limitations and side effects of conventional antidiabetic drugs, has prompted a growing interest in plant-based therapeutics. Medicinal plants are rich sources of bioactive compounds such as flavonoids, alkaloids, terpenoids, glycosides, and phenolic acids, which exhibit significant antihyperglycemic, antioxidant, and anti-inflammatory properties. These phytochemicals act through multiple mechanisms, including stimulation of insulin secretion from pancreatic β-cells, enhancement of insulin sensitivity in peripheral tissues, inhibition of carbohydrate-digesting enzymes such as α-amylase and α-glucosidase, and reduction of intestinal glucose absorption. Furthermore, the antioxidant properties of these plants play a crucial role in mitigating oxidative stress, which is a major contributor to β-cell dysfunction and insulin resistance(Arumugam et al.,2013).

Several medicinal plants have been extensively studied for their antidiabetic potential. For instance, Gymnema sylvestre has been reported to promote pancreatic regeneration and reduce glucose absorption, while Momordica charantia contains bioactive compounds such as charantin and polypeptide-p that exhibit insulin-like effects. Similarly, Trigonella foenum-graecum is known for its high soluble fiber content, which helps in delaying glucose absorption and improving insulin sensitivity. Other plants, such as Azadirachta indica and Ocimum sanctum, also demonstrate significant hypoglycemic and antioxidant activities. Collectively, these plants not only aid in glycemic control but also contribute to the prevention of diabetes-related complications, including neuropathy, nephropathy, and cardiovascular disorders(Kooti et al.,2016).

In addition to their therapeutic efficacy, medicinal plants offer several advantages such as affordability, accessibility, and relatively fewer side effects, making them particularly valuable in resource-limited settings. Their use as functional foods and dietary supplements further enhances their role in preventive healthcare. However, despite their promising potential, challenges such as lack of standardization, variability in phytochemical composition, limited clinical validation, and possible herb–drug interactions need to be addressed. Therefore, future research should focus on the identification of active compounds, elucidation of molecular mechanisms, and large-scale clinical trials to validate their safety and efficacy. Overall, medicinal plants represent a promising and sustainable approach for the prevention and management of Diabetes Mellitus, supporting their integration into modern therapeutic strategies(Jung et al.,2006).

4. Phytochemicals Responsible for Antidiabetic Activity

Phytochemicals responsible for antidiabetic activity primarily encompass diverse classes of natural compounds derived from plants, including alkaloids, flavonoids, terpenoids, polyphenols, and complex polysaccharides. These bioactive substances contribute to diabetes management through multiple mechanisms, including improving insulin sensitivity, modulating glucose metabolism, reducing oxidative stress, and exerting anti-inflammatory and epigenetic effects. antidiabetic activity of phytochemicals is primarily attributed to alkaloids (notably from Catharanthus roseus), flavonoids, polyphenols (resveratrol, curcumin, sulforaphane), terpenoids, and polysaccharides such as pectin. These compounds mitigate diabetes through multifaceted mechanisms encompassing metabolic regulation, oxidative stress suppression, anti-inflammatory effects, epigenetic modulation, and gut microbiome interaction. Continued research is essential to overcome translational barriers and fully unlock their therapeutic potential in diabetes management (Malhotra et al., 2024; Pham et al., 2020; Soomro et al., 2024; Mattson et al., 2007).

4.1. Alkaloids and Indole Alkaloids:

Found in plants like Catharanthus roseus, alkaloids such as vindoline, vindolidine, vindolicine, and vindolinine have demonstrated significant in vitro antidiabetic effects. These compounds contribute by enhancing insulin secretion, protecting β-cells, and modulating glucose levels (Malhotra et al., 2024; Pham et al., 2020). The therapeutic potential of C. roseus alkaloids is well recognized and continues to be a promising source for antidiabetic drug discovery.

4.2. Flavonoids and Polyphenols:

Common dietary phytochemicals such as curcumin, resveratrol, sulforaphane, and catechins have been shown to act as epigenetic modulators, influencing DNA methylation, histone acetylation, and non-coding RNA regulation. Such epigenetic reprogramming leads to improved insulin sensitivity, enhanced pancreatic β-cell survival, and attenuation of systemic inflammation associated with diabetes (Mattson et al., 2007). For instance, resveratrol and curcumin activate adaptive cellular stress response pathways like Nrf-2 and sirtuins, which bolster antioxidant defenses and cellular resilience against diabetic complications.

4.3. Terpenoids and Other Heterocyclic Phytochemicals:

Terpenoids also contribute significantly to antidiabetic effects by modulating key molecular signaling pathways associated with glucose homeostasis and oxidative stress reduction. This includes anti-inflammatory properties that mitigate diabetes-induced tissue damage (Singh et al.,2022).

4.4. Polysaccharides (Pectin):

Pectin, a complex plant polysaccharide found in fruits and vegetables, exhibits antidiabetic effects by regulating glucose metabolism, reducing oxidative stress, increasing insulin sensitivity, suppressing appetite, and modulating gut microbiota composition. Supplementation studies indicate pectin’s ability to control blood glucose levels, particularly in type 2 diabetes, and it can synergistically enhance the efficacy of conventional antidiabetic drugs (Soomro et al., 2024).

5. Mechanisms of Action

Medicinal plants exert their therapeutic effects through bioactive phytochemicals such as alkaloids, flavonoids, terpenoids, and phenolic compounds, which interact with biological systems at the molecular and cellular levels. These compounds may act as antioxidants by scavenging free radicals, anti-inflammatory agents by inhibiting pro-inflammatory pathways (e.g., COX and cytokines), antimicrobial agents by disrupting microbial cell walls or enzymes, and metabolic regulators by modulating enzymes, receptors, and signalling pathways such as insulin signalling or apoptosis. Collectively, these mechanisms help restore physiological balance and protect against disease. The phytochemicals act by various mechanisms represented in Figure 2.

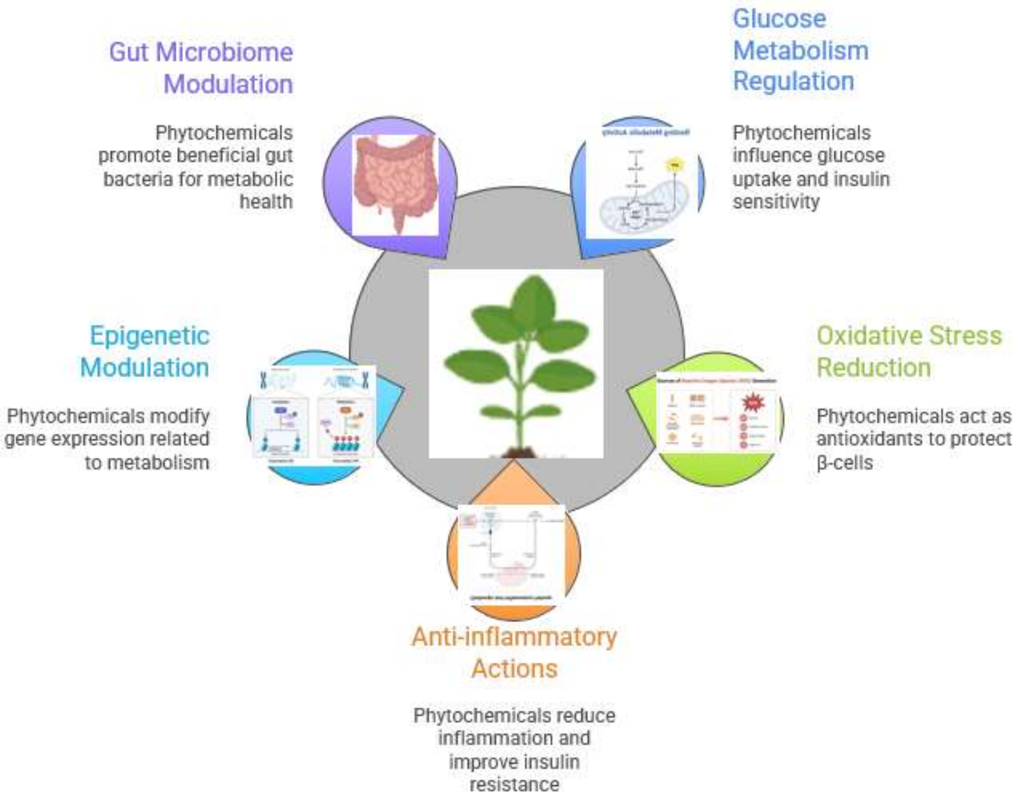

Figure 2: Mechanisms Underlying Antidiabetic Activity of Phytochemicals

5.1. Glucose Metabolism Regulation:

Phytochemicals influence glucose uptake and utilization by peripheral tissues, enhance insulin receptor sensitivity, and stimulate insulin secretion from pancreatic β-cells. Phytochemicals regulate glucose metabolism by modulating key pathways involved in glucose production, utilization, and storage. Compounds such as flavonoids and polyphenols enhance cellular glucose uptake by activating insulin signalling pathways (e.g., PI3K/Akt) and promoting GLUT4 translocation in muscle and adipose tissue. They also suppress hepatic gluconeogenesis by downregulating enzymes like PEPCK and glucose-6-phosphatase, thereby reducing endogenous glucose production. Activation of AMPK activation further improves energy balance by increasing glycolysis and fatty acid oxidation. Additionally, antioxidant and anti-inflammatory effects of phytochemicals help maintain metabolic homeostasis and prevent insulin resistance(Zaid et al.,2018).

5.2. Oxidative Stress Reduction:

Many phytochemicals serve as antioxidants or induce endogenous antioxidant pathways, which counteract diabetes-associated oxidative stress contributing to β-cell dysfunction and insulin resistance. Phytochemicals reduce oxidative stress by neutralizing reactive oxygen species (ROS) and enhancing the body's endogenous antioxidant defence systems. Bioactive compounds such as flavonoids, phenolics, and carotenoids directly scavenge free radicals and inhibit lipid peroxidation. They also upregulate antioxidant enzymes like superoxide dismutase (SOD), catalase, and glutathione peroxidase through activation of cellular pathways such as the Nrf2 signalling pathway. Additionally, these compounds suppress oxidative damage to proteins, lipids, and DNA, thereby protecting pancreatic β-cells and improving overall metabolic function(Shah et al.,2023).

5.3. Anti-inflammatory Actions:

Chronic low-grade inflammation is integral to diabetes pathogenesis. Phytochemicals reduce pro-inflammatory cytokine production and inflammatory signalling, thereby ameliorating insulin resistance.

Anti-inflammatory actions refer to the ability of substances (especially medicinal plants and phytochemicals) to reduce inflammation by modulating key cellular and molecular pathways. These agents primarily act by inhibiting pro-inflammatory mediators such as cytokines (e.g., TNF-α, IL-6), prostaglandins, and nitric oxide. Many plant-derived compounds suppress the activation of transcription factors like NF-κB, which plays a central role in regulating inflammation-related genes. Additionally, they inhibit enzymes such as Cyclooxygenase (COX) and lipoxygenase, thereby reducing the synthesis of inflammatory mediators. Antioxidant properties also contribute by scavenging reactive oxygen species, further limiting tissue damage and inflammatory responses(Datta et al.,2022).

5.4. Epigenetic Modulation:
Select phytochemicals affect the epigenetic landscape, controlling genes relevant to insulin signalling and glucose metabolism, providing a promising therapeutic avenue with durable effects on diabetes progression (Keating & Osta,2013). These effects occur through reversible chemical modifications such as DNA methylation, histone modification, and regulation of non-coding RNAs. Phytochemicals can inhibit or activate enzymes like DNA methyltransferases (DNMTs) and histone deacetylases (HDACs), leading to the suppression of pro-inflammatory genes and activation of protective genes. For instance, modulation of transcription factors such as NF-κB can be epigenetically controlled, thereby reducing inflammation. Additionally, plant compounds can influence microRNAs (miRNAs), which play a critical role in post-transcriptional gene regulation, ultimately contributing to improved metabolic balance and disease prevention (Shanak et al.,2019).

5.5. Gut Microbiome Modulation:
Certain phytochemicals, like pectin, exert prebiotic effects that foster beneficial gut microbiota, indirectly influencing metabolic health and glucose regulation (Soomro et al., 2024).Gut microbiome modulation refers to the ability of medicinal plants and their phytochemicals to beneficially alter the composition and activity of intestinal microorganisms. These compounds act as prebiotics or antimicrobial agents, promoting the growth of beneficial bacteria such as Lactobacillus and Bifidobacterium while inhibiting pathogenic microbes. This balance enhances gut barrier integrity, reduces endotoxin leakage, and lowers systemic inflammation. Additionally, fermentation of plant-derived fibres by gut microbes produces short-chain fatty acids (SCFAs) like butyrate, which improve metabolic health, regulate immune responses, and enhance insulin sensitivity. Through interactions with pathways such as the gut–brain axis, microbiome modulation also influences overall physiological homeostasis and disease outcomes (Lau et al.,2021).

5.6. Enhancement of Insulin Secretion:
Phytochemicals enhance insulin secretion primarily by stimulating pancreatic β-cells through multiple complementary mechanisms. Compounds such as flavonoids, alkaloids, and terpenoids can increase intracellular calcium influx by modulating ATP-sensitive K^+ channels (K_ATP), leading to membrane depolarization and insulin exocytosis. Some phytochemicals also activate signalling pathways like cAMP/PKA and PI3K/Akt, which improve β-cell responsiveness to glucose. Additionally, their antioxidant properties protect β-cells from oxidative stress, preserving insulin-producing capacity. Certain plant-derived compounds further upregulate genes involved in insulin synthesis and secretion, thereby contributing to improved glycemic control(Patel et al.,2012).

5.7. Improvement of Insulin Sensitivity:
They enhance glucose uptake in muscle and adipose tissues. Phytochemicals improve insulin sensitivity by enhancing the efficiency of insulin signalling pathways in peripheral tissues such as muscle, liver, and adipose tissue. Bioactive compounds like flavonoids, polyphenols, and terpenoids activate key pathways, including PI3K/Akt and AMPK activation, which promote glucose uptake by increasing GLUT4 translocation to the cell membrane. They also reduce insulin resistance by inhibiting inflammatory mediators (e.g., TNF-α, NF-κB) and decreasing oxidative stress. Additionally, these compounds help regulate lipid metabolism and prevent ectopic fat accumulation, further restoring cellular responsiveness to insulin and improving overall glucose homeostasis (Patel et al.,2012).

5.8. Inhibition of Carbohydrate Digestion:

Certain phytochemicals inhibit enzymes like α-amylase and α-glucosidase, reducing glucose absorption. Phytochemicals inhibit carbohydrate digestion by targeting key digestive enzymes such as alpha-amylase and alpha-glucosidase in the gastrointestinal tract. Bioactive compounds like flavonoids, tannins, and phenolic acids bind to these enzymes and reduce their activity, slowing the breakdown of complex carbohydrates into glucose. This delay in carbohydrate digestion leads to a reduced rate of glucose absorption, thereby lowering postprandial blood glucose spikes and improving glycaemic control. Additionally, some phytochemicals may form complexes with carbohydrates, further limiting their accessibility to digestive enzymes(Sompong et al.,2016).

6. Important Medicinal Plants Used in Diabetes

Several medicinal plants play an important role in diabetes prevention and management through diverse mechanisms. Gymnema sylvestre (Gudmar), commonly known as the "sugar destroyer," contains gymnemic acids that reduce intestinal sugar absorption and enhance insulin secretion(Singh et al.,2021). Momordica charantia (bitter gourd) is rich in bioactive compounds such as charantin and polypeptide-p, which exhibit insulin-like activity and help lower blood glucose levels. Trigonella foenum-graecum (fenugreek) is a valuable source of soluble fiber and 4-hydroxyisoleucine, contributing to improved glucose tolerance and delayed carbohydrate absorption(Nadig et al.,2012). Azadirachta indica (neem) enhances insulin receptor sensitivity and aids in reducing blood glucose levels. Syzygium cumini (jamun) contains jamboline and ellagic acid, which help slow down the release of glucose into the bloodstream. Tinospora cordifolia (guduchi) promotes insulin secretion and provides antioxidant protection, thereby reducing oxidative stress associated with diabetes. Ocimum sanctum (tulsi) is known to lower fasting blood glucose levels and improve lipid profiles, supporting overall metabolic health. Collectively, these medicinal plants offer multi-targeted approaches for effective diabetes prevention and management(Przeor, 2022) . All the medicinal plants efficient in diabetes control are mentioned in Table 1.

S. No.	Plant Name	Common Name	Key Bioactive Compounds	Mechanism of Action
1	Gymnema sylvestre	Gudmar	Gymnemic acids	Inhibits glucose absorption, enhances insulin secretion, β-cell regeneration
2	Momordica charantia	Bitter Gourd	Charantin, Polypeptide-p	Insulin-mimetic activity, activates AMPK, reduces gluconeogenesis
3	Trigonella foenum-graecum	Fenugreek	4-hydroxyisoleucine, fiber	Improves insulin secretion, delays carbohydrate absorption
4	Azadirachta indica	Neem	Azadirachtin, flavonoids	Enhances insulin receptor sensitivity, antioxidant action
5	Syzygium cumini	Jamun	Jamboline, ellagic acid	Inhibits α-glucosidase, slows glucose release
6	Tinospora cordifolia	Guduchi	Tinosporin, alkaloids	Stimulates insulin secretion, antioxidant, immunomodulatory
7	Ocimum sanctum	Tulsi	Eugenol, ursolic acid	Reduces fasting glucose, improves lipid metabolism
8	Curcuma longa	Turmeric	Curcumin	Improves insulin sensitivity, reduces inflammation (via NF-κB inhibition)
9	Allium sativum	Garlic	Allicin	Enhances insulin secretion, reduces oxidative stress
10	Zingiber officinale	Ginger	Gingerol	Improves glucose uptake, anti-inflammatory effects
11	Aloe vera	Aloe	Aloin, polysaccharides	Improves insulin sensitivity, reduces fasting glucose
12	Berberis vulgaris	Barberry	Berberine	Activates AMPK, reduces insulin resistance
13	Ficus religiosa	Peepal	Flavonoids, alkaloids	Inhibits DPP-4 enzyme, improves glucose metabolism
14	Phyllanthus amarus	Bhumi amla	Phyllanthin, gallic acid	Antioxidant, improves glucose metabolism, reduces hyperglycemia
15	Cinnamomum verum	Cinnamon	Cinnamaldehyde	Enhances insulin sensitivity, slows gastric emptying

Table 1: Compilation of Medicinal Plants Efficient in Diabetes Control

7. Herbal Formulations for Diabetes Prevention

Herbal combination therapies are considered more effective in diabetes prevention due to their synergistic effects, where multiple bioactive compounds work together to enhance therapeutic outcomes. Unlike single-herb treatments, these combinations target various physiological pathways simultaneously, such as insulin secretion, glucose absorption, and insulin sensitivity. This multi-targeted approach not only improves overall efficacy but also reduces the required dosage of individual components, thereby minimizing potential side effects and improving safety(Soomro et al., 2024).

Polyherbal formulations are widely used to achieve this synergistic benefit. Common examples include combinations like Gymnema, fenugreek, and bitter gourd, as well as neem, jamun, and guduchi. These formulations act through diverse mechanisms, including enhancing pancreatic β-cell function, inhibiting carbohydrate-digesting enzymes, and improving peripheral glucose uptake. Additionally, they help regulate inflammatory pathways such as NF-κB, contributing to better metabolic control and long-term prevention of diabetes(Alam et al., 2022; Przeor, 2022).

Ayurvedic formulations, rooted in Ayurveda, have long utilized such combinations in standardized forms. Preparations like Nisha Amalaki (a combination of turmeric and amla), Chandraprabha Vati, and Triphala-based formulations are well-known for their ability to improve insulin sensitivity, reduce oxidative stress, and support overall metabolic health. These formulations not only address blood glucose levels but also help in maintaining lipid balance and digestive health, offering a holistic approach to disease prevention(Alam et al., 2022).

In recent years, the concept of nutraceuticals has further expanded the application of herbal therapies. Modern formulations include capsules containing standardized plant extracts and functional foods enriched with herbal compounds. These innovations provide convenient dosage forms, improved patient compliance, and scientifically validated efficacy. Overall, herbal combination therapies represent a promising integration of traditional knowledge and modern science, offering a comprehensive and effective strategy for diabetes prevention. All the herbal concentrations are tabulated in Table 2.

S. No.	Formulation Name	Type	Key Components	Mechanism/Action	Reference
1	Gymnema + Fenugreek + Bitter Gourd	Polyherbal	Gymnema sylvestre, Trigonella foenum-graecum, Momordica charantia	Enhances insulin secretion, improves glucose uptake, reduces sugar absorption	(Alam et al., 2022; Przeor, 2022)
2	Neem + Jamun + Guduchi	Polyherbal	Azadirachta indica, Syzygium cumini, Tinospora cordifolia	Improves insulin sensitivity, slows glucose release, antioxidant activity	(Raj et al., 2020)
3	Nisha Amalaki	Ayurvedic	Curcuma longa, Emblica officinalis	Reduces oxidative stress, improves insulin sensitivity	(Kumar et al.,2010)
4	Chandraprabha Vati	Ayurvedic	Multi-herbal formulation	Regulates metabolism, supports pancreatic function	(Przeor, 2022)

S. No.	Formulation Name	Type	Key Components	Mechanism/Action	Reference
5	Triphala Formulation	Ayurvedic	Emblica officinalis, Terminalia chebula, Terminalia bellirica	Improves digestion, antioxidant, regulates glucose metabolism	(Przeor, 2022)
6	Diabecon	Polyherbal	Multiple herbs including Gymnema, bitter gourd	Enhances insulin secretion, reduces blood glucose	(Alam et al., 2022)
7	Madhumehari Churna	Ayurvedic	Gymnema, neem, karela, jamun	Controls blood sugar, improves metabolism	(Raj et al., 2020)
8	Herbal Extract Capsules	Nutraceutical	Standardized plant extracts (curcumin, berberine)	Improves insulin sensitivity, anti-inflammatory	(Soomro et al., 2024)
9	Herbal Functional Foods	Nutraceutical	Fortified foods with plant bioactives	Delays glucose absorption, improves metabolic health	(Soomro et al., 2024)
10	Berberine-based Formulations	Nutraceutical	Berberis vulgaris extract	Activates the AMPK pathway, reduces insulin resistance	(Alam et al., 2022)

Table 2: Compilation of all the Plant-based Formulas to Control Diabetes

8. Advantages and Limitations of the Usage of Medicinal Plants

Herbal formulations for diabetes prevention offer several important advantages due to their multi-component and multi-target nature. One of the primary benefits, as shown in Figure 3, is their synergistic action, where different phytochemicals work together to enhance overall therapeutic efficacy. These formulations can simultaneously improve insulin secretion, increase insulin sensitivity, inhibit carbohydrate-digesting enzymes, and reduce oxidative stress and inflammation through pathways such as NF-κB. Additionally, herbal therapies are often considered safer with fewer side effects compared to synthetic drugs when used appropriately. They also provide a holistic approach, addressing not only blood glucose levels but also associated metabolic disturbances like dyslipidemia and oxidative damage. Furthermore, their availability in diverse forms such as powders, decoctions, capsules, and functional foods enhances patient compliance and accessibility (Shukia et al.,2000).

However, despite these advantages, herbal formulations also have notable limitations. One major challenge is the lack of standardization, as the concentration of active compounds can vary depending on plant source, processing, and formulation methods. This variability can lead to inconsistent therapeutic outcomes. Moreover, there is often limited clinical evidence and large-scale trials to fully validate their efficacy and safety compared to conventional medicines. Potential herb–drug interactions pose another concern, especially for patients already undergoing pharmacological treatment for diabetes. Issues related to dosage optimization, quality control, and regulatory approval further complicate their widespread acceptance in modern healthcare systems. Therefore, while herbal formulations hold significant promise, their integration into mainstream medicine requires rigorous scientific validation and standardization(Nazarian et al.,2018).

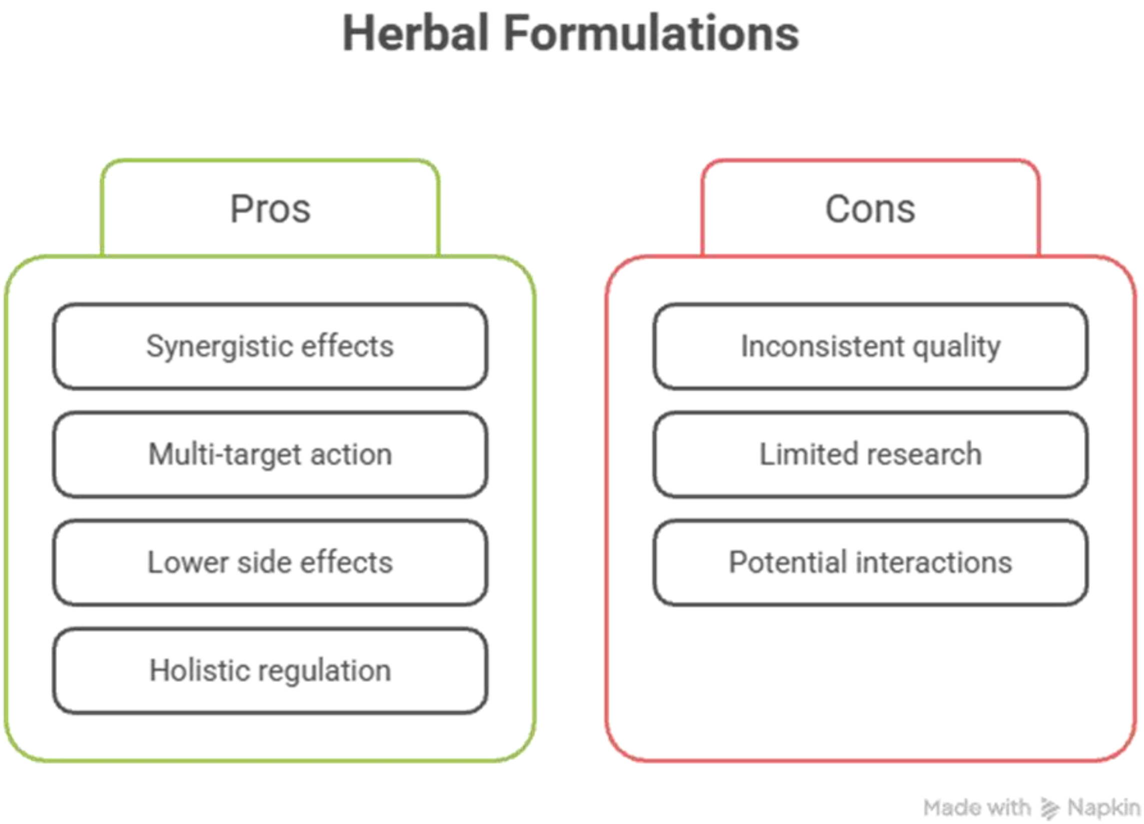

Figure 3: Advantages and Disadvantages of Medicinal Plant-based Compositions.

9. Conclusion and Future Prospects

Herbal formulations represent a promising and holistic approach for the prevention and management of diabetes, owing to their multi-targeted mechanisms and synergistic effects. Medicinal plants and their combinations act on key aspects of diabetes pathophysiology, including enhancement of insulin secretion, improvement of insulin sensitivity, inhibition of carbohydrate digestion, and reduction of oxidative stress and inflammation (Alam et al., 2022; Przeor, 2022). Their ability to modulate critical pathways such as NF-κB further supports their therapeutic potential (Ross et al.,2004). Additionally, the integration of traditional knowledge systems like Ayurveda with modern scientific approaches has led to the development of effective polyherbal formulations and nutraceuticals that are both accessible and relatively safe (Kavishankar et al.,2011).

Looking ahead, the future prospects of herbal therapies in diabetes prevention are highly encouraging but require a more evidence-based and standardized approach. Advances in phytochemistry, molecular biology, and biotechnology can help identify active compounds, elucidate precise mechanisms of action, and optimize formulations for better efficacy (Soomro et al., 2024). There is a growing need for well-designed preclinical and large-scale clinical studies to validate their safety, efficacy, and long-term effects. Furthermore, the application of modern technologies such as nanotechnology and targeted drug delivery systems may enhance the bioavailability and therapeutic potential of herbal compounds (Kooti et al.,2016). Standardization, quality control, and regulatory frameworks will play a crucial role in ensuring consistency and global acceptance. Overall, with continued scientific validation and innovation, herbal formulations have the potential to become an integral component of future strategies for diabetes prevention and management(Patel et al.,2012).

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