

# Assessing the Role of Medicinal Plants in Preventing Diabetes-Related Complications

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## ABSTRACT

Diabetes mellitus, a chronic metabolic disorder, continues to be a global health burden, affecting millions and contributing to significant morbidity and mortality due to its associated microvascular and macrovascular complications. Conventional pharmacological treatments, while effective in glycemic control, often induce adverse side effects and may be inaccessible in low-resource settings. Consequently, the exploration of medicinal plants as therapeutic agents has garnered increasing scientific interest. These plants, rich in bioactive compounds such as flavonoids, alkaloids, tannins, and phenolics, exhibit diverse mechanisms of action, including enhancement of insulin secretion, inhibition of glucose absorption, regeneration of pancreatic  $\beta$ -cells, and modulation of key metabolic pathways like AMPK and PI3K. Clinical and preclinical studies on commonly used plants, such as cinnamon, garlic, turmeric, Aloe vera, and *Momordica charantia* demonstrate significant antidiabetic potential with lower toxicity profiles. However, challenges such as insufficient clinical validation, variability in phytochemical content, and lack of regulatory standardization hinder their integration into mainstream treatment. This paper assesses the role of medicinal plants in managing diabetes and preventing its complications, highlights key mechanisms of action, and underscores the need for rigorous scientific evaluation to harness their full therapeutic potential.

**Keywords:** Medicinal plants, diabetes mellitus, antidiabetic phytochemicals, insulin resistance,  $\beta$ -cell regeneration, oxidative stress, traditional medicine, natural therapeutics.

## INTRODUCTION

Despite many anti-diabetic drugs available, treatment using medicinal plants shows significant efficacy. There is growing interest in their potential for developing new drugs targeting diabetes-related complications. Herbal medicines with low toxicity and side effects are becoming important therapeutic alternatives. Hypoglycemic plants demonstrate clear benefits in managing diabetes, thanks to bioactive compounds like flavonoids, tannins, phenolics, and alkaloids. Tannins improve pancreatic beta-cell function and boost insulin secretion, while quercetin acts as an antioxidant that neutralizes radicals and reduces lipid damage. Mechanisms for hypoglycemic plants include stimulating insulin secretion, enhancing glucose uptake in muscle and fat, inhibiting intestinal glucose absorption, and reducing liver glucose production, all helping reduce diabetes complications. Streptozotocin (STZ) rats are commonly used in research for anti-diabetic efficacy of plant extracts. Natural products from plants have shown health benefits for both animals and humans. Traditional plant-derived medicines are often more effective and affordable with fewer side effects than modern pharmaceuticals. Secondary metabolites like steroids, alkaloids, and glycosides from plants exhibit various biological properties, including anti-diabetic effects. Diabetes mellitus is a chronic condition due to pancreatic  $\beta$ -cell dysfunction leading to high blood sugar levels. Different types exist: Type 1 due to insulin deficiency and Type 2 due to insulin resistance. While current treatments manage blood sugar, they can have severe side effects. Traditional medicines with a long history of use serve as effective alternatives. Some plant-based compounds have shown stronger anti-diabetic effects than many commercial drugs. The World Health Organization emphasizes

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prevention as crucial for reducing diabetes prevalence and complications, highlighting the active compounds and pharmacological effects of medicinal plants in diabetes treatment [1, 2].

### UNDERSTANDING DIABETES AND ITS COMPLICATIONS

Diabetes mellitus (DM) is a metabolic disorder characterized by chronic hyperglycemia, a consequence of defects in insulin secretion, insulin action, or both. In the case of type 2 diabetes (T2D), patients do not produce enough insulin, or their cells do not respond properly to insulin. Traditional treatments include insulin injections for absolute insulin deficiency and oral glucose-lowering drugs such as  $\alpha$ -glucosidase inhibitors, biguanides (e.g., metformin), and sulphonylureas (e.g., glibenclamide) for insulin resistance. Chronic exposure to abnormally high glucose concentrations also leads to long-term macrovascular complications and microvascular complications impacting various structures such as the retina, peripheral nerves, and kidneys. Medicinal herbs are a rich source of T2D remedies, acting through multiple metabolic pathways. Around 40 native plant extracts and numerous isolated compounds have been described as effective in preventing and treating T2D. These regulate key biological processes including insulin resistance,  $\beta$ -cell function, incretin activity, and glucose absorption. Despite the commercial availability of many effective pharmaceutical drugs, T2D continues to cause significant mortality and morbidity. Anti-diabetic medicinal herbs therefore remain an attractive alternative source of therapeutic agents for diabetes prevention and treatment [3, 4].

### TYPES OF DIABETES

“Diabetes mellitus (DM) is a chronic disease caused by metabolic disorders in pancreatic  $\beta$ -cells that result in hyperglycemia. The underlying hyperglycemia can arise from insulin deficiency, leading to Type 1 diabetes, or from insulin resistance, characteristic of Type 2 diabetes. Management of blood glucose levels remains the mainstay of diabetes treatment, yet current medications often induce side effects. Traditional medicine is widely applied to manage diabetes and related complications. Plants constitute a promising source for antidiabetic agents as they have the potential to minimize adverse effects and are more affordable. Numerous bioactive natural and semi-synthetic compounds with antidiabetic properties are derived from plants, underscoring the ongoing significance of ethnomedicine in diabetes care. “Patients with complete insulin deficiency are administered insulin injections. In cases of cellular insulin resistance, various drugs address impairments in carbohydrate metabolism. Glucosidase inhibitors—including acarbose, miglitol, and voglibose—reduce glucose absorption by inhibiting carbohydrate elevation. Biguanides such as metformin enhance glucose uptake by peripheral tissues. Sulphonylureas like glibenclamide stimulate insulin secretion. Limitations of current therapies encompass high costs and adverse effects such as hypoglycemia, weight gain, gastrointestinal disturbances, and liver toxicity, motivating the search for suitable antidiabetic and antioxidant agents. Metformin itself originated from *Galega officinalis*, a plant rich in hypoglycemic guanidine compounds. Although over 400 traditional plant treatments for diabetes are identified, only a few boast scientific validation. While the World Health Organization advocates further research into herbal medicines, clinical evidence substantiating their efficacy and safety remains insufficient” [5, 6].

### COMMON COMPLICATIONS

Diabetes mellitus is widespread and affects individuals of all ages, including children and adolescents. Prolonged hyperglycemia leads to damage in various organs, including the heart, eyes, kidneys, and nerves, primarily through blood vessel deterioration. Microvascular complications such as retinopathy and nephropathy, along with macrovascular atherosclerotic disorders, are major contributors to morbidity and mortality in diabetic patients. Diabetic nephropathy is closely linked to increased cardiovascular mortality, with approximately one-third of affected individuals progressing to end-stage renal disease (ESRD). Hypertension further exacerbates the risk of ESRD in this population. Despite these associations, effective treatments for diabetic nephropathy remain unavailable, underscoring the importance of prevention. While certain plant extracts may support kidney function and modulate blood pressure, others have detrimental effects on renal health, necessitating careful selection in the management of diabetes-related complications [7, 8].

### PATHOPHYSIOLOGY OF DIABETES

Diabetes mellitus describes a cluster of endocrine diseases characterized by the inability of pancreatic islet beta cells to secrete sufficient insulin in response to blood glucose levels. Type 1 diabetes mellitus (T1DM) results from autoimmune destruction of pancreatic islet beta cells, leading to reduced insulin secretion. Type 2 diabetes mellitus (T2DM) is associated with obesity, insulin resistance, and eventual beta-cell failure. Both forms exhibit a reduction in beta-cell function or mass and cause secondary complications such as retinopathy, nephropathy, and cardiovascular disease. Approximately 462 million

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individuals—6% of the global population—have diabetes, accounting for 11.3% of deaths worldwide, making it the ninth leading cause of mortality. T1DM accounts for 5–10% of cases and affects children and adults equally, whereas T2DM—which accounts for the majority of patients—appears with overweight, chronic inflammation, and beta-cell dysfunction. In healthy individuals, pancreatic beta cells produce insulin—a major anabolic hormone essential for proper growth, metabolism, and reproduction. When insulin secretion is insufficient, metabolic alterations account for the majority of observed diabetic phenotypes. Maintaining beta-cell function and mass is therefore vital for proper metabolic control and the prevention of diabetes [9, 10].

### MEDICINAL PLANTS: AN OVERVIEW

Medicinal plants are significant in diabetes treatment globally due to their low toxicity and minimal side effects compared to conventional methods. Numerous studies highlight the benefits of plants with hypoglycemic properties in managing diabetes. Key active ingredients include flavonoids, tannins, phenolic compounds, and alkaloids. Tannins boost pancreatic beta cell function and insulin secretion, while antioxidants like quercetin prevent harmful lipid accumulation. Hypoglycemic plants regulate glucose homeostasis through various mechanisms: increasing insulin secretion from beta cells, enhancing glucose absorption in muscle and fat tissues, blocking intestinal glucose uptake, and suppressing liver glucose production, which helps mitigate diabetes-related complications. Researchers often use streptozotocin-induced diabetic rat models to evaluate the anti-diabetic effects of plant extracts. These plants act as natural antioxidants and effective treatments by promoting pancreatic function and insulin secretion or by decreasing intestinal glucose absorption. Phytomolecules from traditional antidiabetic plants target multiple physiological processes through interactions with proteins, possibly reducing toxicity via lower dosages. The antidiabetic properties stem from phytochemicals that modulate pathways like cyclic AMP, PI3K, and AMPK, promoting insulin release and enhancing glucose uptake and sensitivity. Some phytochemicals can regenerate pancreatic beta cells and inhibit enzymes like  $\alpha$ -amylase and  $\alpha$ -glucosidase, leading to reduced glucose reabsorption and lower blood glucose levels. As only a few plants have been scientifically proven effective against diabetes, further research is needed to identify active components and explore their molecular interactions to support potential therapeutic use [11, 12].

### MECHANISMS OF ACTION OF MEDICINAL PLANTS

Medicinal plants offer effective antidiabetic mechanisms by targeting various biochemical and cellular pathways. Their phytochemicals regulate carbohydrate metabolism, stimulate insulin secretion and cascade effects, promote glucose uptake, protect pancreatic beta cells, and modulate key enzymes involved in glucose production and absorption. Some plants contain active substances that prolong insulin release and protect pancreatic islets from oxidative damage, enhancing glycemic control. Others inhibit carbohydrate-digesting enzymes, slowing glucose absorption after high-starch meals. Certain constituents also increase glucose excretion by blocking renal sodium/glucose cotransporters, thereby lowering plasma glucose levels. By interacting with proteins such as G-proteins, protein tyrosine phosphatase 1B (PTP-1B), and enzymes including  $\alpha$ -amylase,  $\alpha$ -glucosidase, glucose-6-phosphate, and dipeptidyl peptidase IV (DPP-IV), the compounds influence multiple metabolic steps. Activation of signaling pathways like cyclic AMP (cAMP), phosphoinositide 3-kinase (PI3K), and AMP-activated protein kinase (AMPK) leads to increased insulin secretion, enhanced glucose uptake, and improved insulin sensitivity. As a result, gluconeogenesis and glycogenolysis are reduced, contributing further to blood glucose normalization [13, 14].

### KEY MEDICINAL PLANTS IN DIABETES MANAGEMENT

Using various medicinal plants has the potential to significantly help in delaying complications associated with diabetes. Notably, staples such as cinnamon, garlic, and turmeric have demonstrated various beneficial effects on health. For instance, cinnamon is known to improve lipid profiles and significantly enhance insulin sensitivity in those dealing with this condition. Garlic is effective in lowering glucose levels, as well as cholesterol and triglyceride levels, thereby contributing positively to overall metabolic health. Meanwhile, turmeric plays a crucial role in protecting the kidneys and nerves from damage, which helps mitigate complications such as diabetic nephropathy and neuropathy. Cinnamon has gained immense popularity among individuals with diabetes, with numerous studies reporting favorable outcomes, including improved blood glucose levels and enhancements in lipid profiles. The active compounds present in cinnamon, such as cinnamaldehyde, eugenol, and beta-caryophyllene, are believed to play a pivotal role in these beneficial effects. Garlic, on the other hand, contains a compound called alliin, which upon crushing, transforms into allicin, the key player in its health benefits. Additionally, garlic boasts a variety of sulfur-containing compounds, including allyl-propyl disulfide and S-allyl

cysteine sulfoxide, all of which contribute to its effectiveness against diabetes-related issues. Turmeric is distinguished by its rich content of polyphenols, specifically a group known as curcuminoids, with curcumin being the most well-known and studied for its health-promoting properties [15, 16].

#### **CLINICAL EVIDENCE AND STUDIES**

Public health and economic challenges from diabetes mellitus have prompted research into alternative medicines, specifically natural products from medicinal plants. Clinical trials necessitate proper identification and quality control of these products, as geographical and environmental factors affect the active phytochemicals. A systematic review indicated a significant lack of critical information in clinical trials regarding the plants studied, such as family, genus, species, origin, phytochemistry, and mechanisms of action. This information is vital for understanding plant efficacy in managing diabetes and related conditions. Increasing urbanization and lifestyle changes contribute to rising diabetes rates in Africa, especially in Ghana, where there is currently no cure. The limitations of pharmacological agents in terms of efficacy, safety, and cost drive many patients towards complementary and alternative medicine (CAM), including plant-based remedies. While many phytomedicines have been subjected to research, most studies lack robust experimental data to support their use. Traditional plant medicines play a crucial role in rural areas, yet there is a general lack of awareness about specific plants. Among the plants studied in Ghana, Aloe vera shows considerable evidence for managing complications, followed by Momordica charantia and Zingiber officinale with substantial preclinical and clinical backing. Many Ghanaian medicinal plants demonstrate potential antidiabetic effects, including insulin-like properties, glucose absorption inhibition, enhanced glycogenesis, insulin secretion, pancreatic  $\beta$ -cell regeneration, and antioxidant effects. Some have improved metabolic abnormalities and have shown better efficacy than conventional drugs in clinical trials, noting minimal adverse effects and highlighting their safety [17, 18].

#### **CHALLENGES IN RESEARCHING MEDICINAL PLANTS**

Active compounds from antidiabetic plants support their use in treating diabetes and its complications. However, more research is needed to establish the safety and therapeutic dosages of these phytomolecules. Medicinal plants are a valuable source for developing new antidiabetic drugs and formulations, although challenges exist for their integration into complementary medicine. In Asia, populations maintain traditional knowledge of herbal medicines. These plant-derived consumables help manage hyperglycemia symptoms and offer therapeutic benefits. Research challenges include isolating, identifying, and evaluating bioactive compounds. Numerous compounds with antidiabetic and antioxidant activities, such as alkaloids, terpenoids, and flavonoids, have been isolated. They often contain agents that promote insulin secretion, confirming their antidiabetic properties. High levels of free radicals and reactive oxygen species can cause oxidative stress and chronic hyperglycemia, leading to complications in diabetic patients [19, 20].

#### **INTEGRATING MEDICINAL PLANTS INTO DIABETES CARE**

The effectiveness, economic viability, and minimal adverse effects of medicinal plants on both Type 1 and Type 2 diabetes models have been well documented in numerous studies. Consequently, it is reasonable to recommend their use as complementary therapies or as the basis for identifying novel antidiabetic agents that could significantly improve diabetic care. A growing number of medicinal plants derived from traditional herbs have recently been employed for early-stage diabetes treatment in clinical settings. Currently available treatments often fail to provide sufficient control of hyperglycemia and other biochemical abnormalities, or often do not adequately minimize the secondary complications that arise from these diseases. Type 1 diabetes is an autoimmune disorder characterized by the progressive destruction of the insulin-secreting  $\beta$ -cells within the pancreatic islets of Langerhans. This destruction leads to significant challenges in normal glycemic control. Medicinal plants exert hypoglycemic activity and help reduce postprandial glucose levels by enhancing  $\beta$ -cell activity and recovery, although the precise mechanisms that underlie these beneficial effects remain largely unidentified and require further investigation to elucidate [21, 22].

#### **FUTURE DIRECTIONS IN RESEARCH**

Phytochemicals from medicinal plants that target multiple therapeutic areas show promise for future multitarget medications. Prioritizing standardization and quality control can enhance the efficacy and consistency of herbal remedies. While some natural products exhibit strong *in vitro* effects, they may be ineffective *in vivo* due to poor pharmacokinetic properties like absorption and bioavailability. Thus, developing advanced methods to improve these characteristics is critical. Regulatory bodies must establish benchmarks and safety standards to protect public health concerning herbal medicines. Plants such as *Aegle marmelos* and *Perilla frutescens* have been studied for aldose reductase activity, while

future research should explore their impact on various signaling pathways through diverse experimental models. Species like *Juglans regia* and *Vitex negundo* have shown antioxidant activity related to diabetic retinopathy, yet their mechanisms require deeper investigation. Inhibiting advanced glycation end-products (AGEs) is essential for prevention and treatment, with *Acanthopanax koraiensis* and others identified as potential inhibitors. Various signaling pathways involved remain to be fully understood. Ginger, particularly *Zingiber officinale*, helps regulate tissue glycogen levels in diabetic rats by promoting glucose utilization and liver repair. Its extracts also increase glucose uptake in myotubes and inhibit alpha-amylase and alpha-glucosidase. Diabetes mellitus poses significant economic challenges and leads to complications such as blindness and kidney failure. Interest in traditional medicines grows due to the side effects of conventional drugs, with herbal extracts potentially enhancing combination therapies. Future efforts will focus on isolating and identifying bioactive substances from plants, underscoring the potential of phytochemicals in managing diabetes through functional foods and drugs [23, 24].

### CONCLUSION

Medicinal plants present a promising avenue for the prevention and management of diabetes-related complications, particularly in the context of rising global diabetes prevalence and the limitations of current pharmacological interventions. Their efficacy stems from the diverse bioactive compounds they contain, which act on multiple physiological and biochemical pathways to improve glycemic control, protect pancreatic function, and reduce oxidative stress. Plant-based therapies such as cinnamon, garlic, and turmeric demonstrate both preclinical and clinical potential in mitigating complications like nephropathy and neuropathy, with fewer adverse effects compared to standard drugs. Nonetheless, challenges persist in translating traditional knowledge into clinically validated treatments. Future research must prioritize standardization, detailed phytochemical profiling, and high-quality clinical trials to ensure the safety, efficacy, and reproducibility of plant-based interventions. With adequate scientific backing, medicinal plants can be integrated into complementary diabetes care strategies, offering affordable and sustainable options, especially in resource-limited settings.

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