

The Role of Medicinal Plants in Providing Nutritional Support for Diabetic Patients

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ABSTRACT

Diabetes mellitus is a chronic metabolic disorder marked by persistent hyperglycemia, affecting millions globally and contributing to serious complications, including cardiovascular, renal, and neurological disorders. While pharmacological interventions are widely used to control blood glucose levels, their prolonged use often leads to adverse side effects and limited long-term efficacy. This has driven increased interest in plant-based remedies, particularly medicinal plants, which have been traditionally used across various cultures for their antidiabetic and nutritional benefits. This paper explores the potential of medicinal plants in managing diabetes, focusing on their mechanisms of action, phytochemical compositions, and nutritional value. It reviews key antidiabetic plant species, their bioactive compounds, and how they support metabolic functions and glycemic control. Furthermore, the study evaluates the integration of these plants into the diets of diabetic patients and the potential they offer as complementary or alternative therapeutic strategies. Through scientific validation and ethnopharmacological insights, this research advocates for the incorporation of medicinal plants into modern diabetes management frameworks, promoting safer, cost-effective, and culturally accepted approaches to diabetes care.

Keywords: Diabetes mellitus, medicinal plants, glycemic control, phytochemicals, nutritional support, antidiabetic agents, traditional medicine.

INTRODUCTION

Diabetes mellitus is one of the major diseases worldwide, characterized by chronic hyperglycemia, abnormal lipid metabolism, abnormal protein metabolism, and increased chances of microvascular and macrovascular diseases. Pharmacological agents are widely used for the control of blood glucose levels. Clinical usage of synthetic oral hypoglycemic agents has been associated with several side effects. To overcome this problem, medicinal plants have been used for the treatment of diabetes and related complications from time immemorial. It is estimated that more than 800 plant species are used by traditional practitioners. Some of these plants have been screened extensively for antidiabetic activity in their crude form. Traditional medicines are usually made from extracts of natural products, commonly plant extracts. Many studies conducted on plants and their active components have revealed a number of compounds that exert an anti-diabetic effect. The emerging generation of systems biology tools is useful to validate the efficacy of traditional medicines in silico as well as for the identification and isolation of target compounds. Phytochemical purification of active components or novel bioactive compounds might help develop modern medicines. Diabetes is a heterogeneous group of metabolic diseases characterized by chronic hyperglycemia due to insufficient insulin secretion, impaired insulin action, or both. The World Health Organization estimates that approximately 422 million adults were living with diabetes in 2014. This is expected to rise to 642 million by 2040. Diabetes is one of the great global health challenges with significant socio-economic and healthcare implications. It is a major risk factor for multiple complications, including cardiovascular diseases, nephropathy, retinopathy, and neuropathy. In addition, several

secondary conditions, including altered immune function and increased likelihood of trauma or burn injury, complicate the disease and impair quality of life even further [1, 2].

Understanding Diabetes

Diabetes mellitus (DM) encompasses chronic metabolic diseases marked by hyperglycemia. Type 1 diabetes (T1DM) arises from insulin deficiency due to pancreatic β -cell dysfunction, leading to unregulated blood glucose levels. Conversely, type 2 diabetes (T2DM) is characterized by insulin resistance or deficiency affecting the liver, muscle, or fat cells. Complications from diabetes include heart attacks, strokes, kidney damage, neuropathy, ischemia, and infections. Long-term hyperglycemia can lead to nephropathy and chronic kidney failure, potentially resulting in fatality. Addressing abnormal glucose metabolism may help prevent or delay diabetes and associated complications. Effective glucose-lowering strategies involve healthy weight loss, an active lifestyle, and medications, as well as natural dietary supplements like moraceae fruits and spices. The demand for treatment drives a global market for food products. Challenges like low compliance, high costs, and long-term side effects catalyze research into natural dietary options. Nutritional treatments with functional agents can safely and effectively reduce high blood glucose levels. Natural foods in their whole forms may provide additive effects, yet unselectively lower glucose. Purified active compounds could selectively modulate glucose levels. Investigating these candidates involves studying sub-compounds, structures, activities, and mechanisms. All DM types, particularly T2DM, prioritize carbohydrate absorption management. Various chemical drugs, traditional and folk medicines, and health supplements have been evaluated for their effects on dietary carbohydrates. Theoretical approaches leveraging medicinal chemistry also exist. Despite the global prevalence of untreated diabetes, both chemical and natural remedies are urgently needed, with natural dietary supplements presenting safer alternatives. Traditional medicines have been utilized for ages but often lack proper recognition [3, 4].

Types of Diabetes

Diabetes mellitus is a chronic disease characterized by persistent hyperglycemia in the body due to defects in insulin production or action. The prevalence of diabetes has increased dramatically in recent decades, and diabetes will soon be one of the most serious medical issues in developed countries. Hyperglycemia frequently leads to damage to vital organs, including the eyes, kidneys, nerves, heart, and blood vessels, which raises the risk of heart disease, stroke, kidney failure, blindness, nerve damage, and leg amputation. Chronic complications of diabetes include diabetic retinopathy, nephropathy, neuropathy, and foot disease. Diabetes is associated with several metabolic risk factors linked to cardiovascular disease. Impaired glucose metabolism can be caused by inactivity, genetic factors, being overweight, insulin resistance, and decreased β -cell function. A diagnosis of diabetes mellitus (DM) is made based on clinical symptoms or through laboratory tests. DM is classified into either type 1 or type 2, the former of which occurs when the immune system destroys the insulin-producing β pancreatic cells, and the latter, which occurs when the body does not produce enough hormones or the cells fail to respond. A newly engaged type of DM exists, gestational diabetes, which occurs when some women do not produce enough insulin during pregnancy. While they either have normal glucose levels before pregnancy or hyperglycemia during early pregnancy, they develop glucose intolerance during mid- to late pregnancy [5, 6].

Pathophysiology of Diabetes

Diabetes mellitus (DM) is a chronic metabolic disorder primarily characterized by high blood glucose levels (hyperglycemia) and can cause serious health problems. The classification of diabetes is made based on whether it is insulin-dependent or not. Based on aetiology, diabetes is classified as Type-1 diabetes mellitus (T1DM) and Type-2 diabetes mellitus (T2DM). In T1DM, a deficiency in insulin production as a result of autoimmune destruction of insulin-secreting β -cells in the pancreas is present. On the other hand, T2DM is described as episodic hyperglycemia that ultimately leads to chronic hyperglycemia. It can be the result of the simultaneous presence of excessive demand for insulin to control blood glucose level from the pancreas, insufficient insulin production from β -cells in response to insulin resistance, and/or immeasurable degradation of insulin. Various antidiabetic drugs are available to control hyperglycemia in diabetes patients. These first-generation antidiabetic medications have been developed over the last century. Insulin and sulfonylureas became classical drugs for the management of diabetes. Glucose-lowering medications are classified by their target organs or processes. Insulin is used for the treatment of all types of diabetes, irrespective of their mechanism, often combined with other oral

hypoglycemic agents in T2DM treatment. These oral medications mainly include biguanides, thiazolidinediones, and DPP-IV inhibitors. Metformin is still the first-line therapy for T2DM. But the long-term use of these medications causes side effects (sulfonylureas cause weight gain and hypoglycemia). Newer medications, including GLP-1 receptor agonists and SGLT-2 inhibitors, often lead to good weight reduction, better cardioprotection, and a well-tolerated safety profile. For precise glucose control, rapid-acting insulin analogs are more convenient than regular insulin. The amylin analog pramlintide has been represented in insulin-treated patients and caused weight reduction and a lower risk of hypoglycemia compared to regular insulin. Phytochemicals isolated from medicinal plants or herbs with hypoglycaemic potential are extremely diverse, effective, and culturally accepted in Asian countries and are less likely to induce side effects. Medicinal plants are sources of unique compounds and potential novel antidiabetic drugs. Some of the traditional plants have been explored with excellent pharmacological activities, effective components with targets, structure–activity relationships, and toxicology [7, 8].

Nutritional Needs of Diabetic Patients

Diabetes mellitus (DM) is the most common chronic disease. The living habits and dietary patterns of human populations have changed dramatically. Although the prevalence and incidence of type 1 diabetes (T1D) and type 2 diabetes (T2D) have increased dramatically in recent years, this increase is quite variable around the globe, and the reasons for this variability remain elusive. Diabetes is a common health problem resulting release of insulin, increased gluconeogenesis, kidney glucose absorption, and gluten intolerance. Medical services focus on controlling diabetes and its complications, and several effective medications have been introduced for clinical practice. However, commercially available diabetes drugs have significant weaknesses and side effects. Diabetic patients are recommended to avoid sugary foods, drink more water, and take barley or green tea, which leads to the improvement of their general condition within a month. Herbal remedies are very popular in the whole world and are the main form of treatment, reaching 89% in Cameroon. Herbal remedies are very efficient in the treatment of diabetes and/or hypertension, although the observation and adjustment of the treatment must be done under medical control. At least 18 plants used in the local traditional medicine of Cameroon were suspected to possess antidiabetic and/or antihypertensive activity, using clinical results obtained by the analysis of glycemic values and blood pressure of 182 patients with diabetes and/or hypertension who were not professionally followed. Predictive models of the glycemic decrease and the blood pressure regulation in function of the phytotherapeutic treatment were established [9, 10].

Medicinal Plants Overview

Medicinal plants have long been significant sources of bioactive compounds developed into various forms of medicines for their curative, preventive, and health-promoting potential. Various medicinal plants have been used in the form of decoction, infusion, powder, tea, juice, and capsules. More than 60 species of medicinal plants and more than a few bioactive Plant Secondary Metabolites (PSMs) are being claimed or are scientifically documented to exert anti-diabetic activity. In Bangladesh, 54 plants such as *Azadirachta indica*, *Curcuma longa*, *Ficus racemosa*, *Gymnema sylvestris*, *Phyllanthus emblica*, *Silybum marianum*, *Syzygium cumini*, etc. are used as anti-diabetic remedies. These species contain various PSMs such as alkaloids, flavonoids, glycosides, phenolics, essential oils, etc., which are modified into anti-diabetic drugs like phlorizin, vildagliptin, repaglinide, dapagliflozin, etc. Being rich in bioactive PSMs, medicinal plants can be good candidates for a source of new bioactive drugs and modern drug development [11, 12].

Nutritional Benefits of Medicinal Plants

Diabetes mellitus is a lifelong condition characterized by insulin resistance, leading to chronic hyperglycemia. This illness significantly impacts quality of life and can cause severe complications. Traditional medicine plays a vital role in both treating and preventing diabetes, with a significant portion of the global population utilizing medicinal plants for this purpose. Many plants have demonstrated effectiveness in lowering blood glucose levels and addressing other related health issues. Various types of diabetes exist, influenced by geographic and cultural factors. There are about 537 million adults aged 20–79 with diabetes, and 541 million have impaired glucose tolerance, risking type 2 diabetes. Major risk factors include obesity, poor diet, inactivity, high blood pressure, and smoking, leading to complications affecting cardiovascular, eye, kidney, nerve, and oral health. Countries are urged to combat this epidemic, with particular efforts in Latin America and the Caribbean aimed at health coverage and non-

communicable disease prevention, despite facing challenges. In Bangladesh, around 65 plant species used by indigenous populations for diabetes treatment have been documented along with their active compounds. The review encompasses insights from various stakeholders, highlighting ethnohyopathic and ethnochemoecological studies of these plants. Recent findings include new herbal plants identified for their antidiabetic properties, detailing their ethnomedicinal applications by various communities across Bangladesh [13, 14].

Key Medicinal Plants for Diabetes Management

The global prevalence of diabetes mellitus has drastically risen, potentially reaching 366 million by 2030. Complications related to diabetes lead to increased mortality and morbidity rates. Despite the availability of more effective antidiabetic agents and medicinal plants, no single antidiabetic agent is without adverse effects. Therefore, using multiple medicinal plants has become an accepted and economically viable method for managing diabetes, with many patients opting for these alternatives to synthetic agents. Numerous studies have explored the antidiabetic properties of various medicinal plants both in vitro and in vivo. Recent research highlights the pharmacological activities of these plants for diabetes management. Ayurveda, with its focus on holistic health, is gaining recognition for its effectiveness in treating diabetes through herbal medicine, which forms a core part of this traditional practice. Many medicinal plants have been historically used in Ayurveda for diabetes control, typically through single or multi-herb formulations available in the market, noted for lacking side effects. Recent work has verified the antidiabetic potential of some Ayurvedic formulations, yet new formulations await evaluation for their effects. While some reviews exist on the antidiabetic potentials of Ayurvedic formulations, a comprehensive review on the individual medicinal plants used in diabetes management is missing. This chapter aims to compile traditional knowledge of individual plants used in various indigenous medical systems, along with their phytochemical and pharmacological investigations for scientific validation [15, 16].

Mechanisms of Action

Aluminum, an environmental pollutant, complicates diabetes by altering DNA methylation, affecting the fucose58 gene and inhibiting insulin secretion, leading to high blood glucose levels. In aluminum-intoxicated rats, glucose tolerance tests reveal impaired glucose tolerance (IGT). *Gymnema sylvestre* (GS) extract lowers glucose absorption and α -glucosidase activity while down-regulating SGLT1 to reduce Na⁺/glucose cotransport in gut cells, preventing post-meal hyperglycemia. Excess free fatty acids (FFAs) in the liver from hyperlipidemia raise hepatic ATP levels and enhance glucose output, increasing blood glucose concentrations. GT extract effectively lowers fasting blood glucose in streptozotocin (STZ)-induced type-2 diabetic rats. It preserves β -cell mass in islets and mitigates STZ side effects. G6Pase activity increases in the liver but decreases in the kidney and muscle post-STZ induction; GT extract reduces liver G6Pase while normalizing kidney G6Pase levels. Type-2 diabetes impairs insulin action on peripheral tissues, where insulin promotes GLUT4 translocation in fat cells for glucose uptake. STZ reduces membrane GLUT4 levels in rat fat, but GS preserves protein and plasma membrane GLUT4 and translocation in diabetic rats, enhancing insulin sensitivity. *Gymnema sylvestre* phytochemicals prevent LPS-induced insulin signaling downregulation and, through reducing inflammation evidenced by decreased TNF- α , improve metabolic disturbances and complications in diabetic rats. GT also enhances impaired glucose tolerance by inhibiting α -amylase and α -glucosidase [17, 18].

Integrating Medicinal Plants into Diet

Medicinal plants are becoming more accepted as valuable curative agents in the treatment of various diseases. Evidence from various scientific and traditional pharmaceutical sources establishes the use of these herbs in diabetes management. Additionally, it is essential to explore plants for new phytochemical entities through a multidisciplinary investigation of plants for preventing or managing diabetes mellitus. Indeed, such efforts could yield novel therapeutic agents for their management. Understanding the relevance of medicinal plants as sources for bioactive compounds applicable in diabetes management at the molecular level can assist in efforts to integrate these plants into medical systems for healthcare delivery worldwide. A search of the literature was conducted, covering information on active compounds in plants used traditionally in the management of diabetes mellitus as therapeutic agents in drug discovery. There is considerable evidence of bioactive compounds from various classes of plants that are

active against different targets of Type 1 and Type 2 diabetes mellitus. The plants' early scientific evaluation led to the identification of distinct bioactive metabolites with significant antidiabetic activity and compatible bioavailability. However, the absence or inadequacy of current methodology to conduct high-throughput screening for antidiabetic activity limits the warranted consideration for the incorporation of plant-based drugs into treatments for diabetes. While currently approved medicines for type 2 diabetes mellitus based on plants have low occurrence rates and poor water solubility, plant-based drugs would lower duplication rates and bring about cost-effective alternatives. The significance of antidiabetic medicinal plants and related bioactive phytochemicals is discussed regarding the future of drug discovery methodologies and clinical treatments [19, 20].

Challenges and Considerations

The evaluation of natural products and medicinal plants poses significant challenges in drug development. Humans have historically utilized natural products, including herbs, to prevent and treat illnesses. As our understanding of health improves, we can identify bioactive compounds for health and food supplements. The increasing number of these compounds facilitates research into their health benefits, yet verifying their bioactivity and effects on wellness, especially related to side effects and safety, remains problematic. Diabetes mellitus is a global concern, and while advances in drug discovery are impressive, chemically synthetic drugs often dominate diabetes management. People fear injections, leading them to explore over-the-counter alternatives. Certain adjunctive treatments, such as glycosuria-producing agents, require high dosages, while non-absorptive medicines can cause gastrointestinal issues. Herbal medicines, long touted as safe alternatives, are often misunderstood due to myths surrounding ancient practices and off-prescription remedies. More controlled trials on anti-diabetic plants are needed to validate their efficacy and safety. Medicinal plants can support healthier lifestyles, although our understanding of their effects on human health remains limited. The introduction of modern strategies raises concerns about losing beneficial properties while minimizing negative effects. Data mining and biochemical validation are essential in identifying bioactive compounds through various health studies, and advanced biochemistry and biotechnology applications are crucial in uncovering the mechanistic pathways involved [21, 22].

Research and Evidence

In developing countries, many medicinal plants are used traditionally to manage diabetes due to their affordability, availability, and the wide rate of acceptance by society. However, there is a need for scientific validation of their antidiabetic claims. Today, there is an ample body of literature on the antidiabetic use of medicinal plants. Many of them have undergone extensive scientific scrutiny and are verified for their hypoglycemic activity. However, all such plants suffer from one or the other constraint, and none of them fulfill the criteria for being an ideal candidate in insulinoma studies. As a future biological tool, attention is diverted towards plants with an unexplored spectrum of ethnobotanical importance. A thorough analytical evaluation of the plants used in traditional medicine for the management of high blood glucose levels can lead to scientific validation, isolation, and characterization of new antidiabetic compounds. Although alloxan rat models are supposed to be a better system for assessing antidiabetic activity, further novel and better models should be designed, which would put up a stringent test in an assay of antidiabetic plant products while retaining the natural biological setup. Hence, this review deals with a detailed enumeration of the medicinal plants extensively studied for antidiabetic activity for ease of reading and referencing. The efficacy of medicinal plants in treating diabetes has been largely overlooked in the medical literature, despite the widespread use of herbal remedies for diabetes around the world. More recent investigations of the antidiabetic effects of certain medicinal plants have produced varying results in a variety of animal models as well as in humans. The available literature on the subject can be viewed from the perspective of ethno-medico-botanical, biological, and phytochemical avenues of research. Such a wide-ranging coverage provides an inclusive overview of published data on the subject that might facilitate comparative evaluation of findings from diverse studies, besides leading to the identification of gaps in knowledge worth exploring in future research efforts [23, 24].

Future Directions

Globally, 463 million people have diabetes, prompting efforts through diagnostics, diet, lifestyle changes, and medications to reduce this number. Traditional herbal medicine has shown effectiveness in treating diabetes with few side effects. In the era of globalization, successful herbal recipes are being integrated into modern pharmacology. There is enormous potential for new organic products, as academic

researchers and multinational companies explore native knowledge globally, with some case studies emerging in the literature. Medicinal plants retain their importance, with people using them as food, herbal teas, and preventive remedies. Increased interest from governments and funding agencies suggests this field will continue to grow, possibly leading to new medicinal compounds. A review of about 1600 publications revealed 1400 on related themes, indicating the need to substantiate this traditional knowledge. Consulting databases could uncover more plant species and hybrids. Targeted research is essential for better utilization of these natural resources. Traditional medicine, validated by time, highlights the longstanding relationship between humans and plants. Human selection pressure on these plants since ancient times guarantees the bioactive compounds they offer. Vast untapped biochemical resources await exploration, potentially leading to breakthroughs resembling the mythical "elixir of life" [25-29].

CONCLUSION

The global burden of diabetes demands innovative, safe, and sustainable management strategies. Medicinal plants have emerged as promising candidates for both glycemic regulation and nutritional support due to their rich phytochemical profiles and minimal side effects. Traditional knowledge, combined with modern scientific validation, reveals that many plant-based remedies possess potent antidiabetic properties, including the ability to improve insulin sensitivity, reduce oxidative stress, and modulate carbohydrate metabolism. Moreover, the nutritional value of these plants, such as vitamins, fiber, and essential micronutrients, adds further therapeutic advantage for diabetic patients. Despite their proven efficacy in several studies, the integration of medicinal plants into mainstream healthcare remains limited due to gaps in standardization, dosage formulation, and clinical validation. Going forward, multidisciplinary research is necessary to bridge these gaps and unlock the full potential of these natural resources. By leveraging the therapeutic synergy between nutrition and phytotherapy, medicinal plants can play a pivotal role in holistic diabetes management and prevention strategies.

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