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# Medicinal Plants in Diabetes Management

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## ABSTRACT

Diabetes mellitus is a chronic metabolic disorder characterized by persistent hyperglycemia, insulin resistance, and progressive β-cell dysfunction, leading to severe microvascular and macrovascular complications. Despite the availability of conventional therapies, challenges such as side effects, high costs, and limited accessibility have prompted growing interest in medicinal plants as complementary or alternative treatments. Numerous plants, including Momordica charantia (bitter melon), Trigonella foenum-graecum (fenugreek), Cinnamomum verum (cinnamon), Panax ginseng (ginseng), and Aloe vera, have shown hypoglycemic, insulin-sensitizing, antioxidant, and anti-inflammatory activities through diverse mechanisms such as β-cell regeneration, modulation of glucose metabolism, inhibition of carbohydrate-digesting enzymes, and enhancement of insulin sensitivity. Preclinical and clinical studies suggest that phytochemicals, including flavonoids, alkaloids, saponins, and phenolic compounds, exert significant anti-diabetic effects. However, concerns remain regarding standardization, safety, herb–drug interactions, and regulatory oversight. This review synthesizes current evidence on medicinal plants in diabetes management, highlighting mechanisms, clinical findings, safety considerations, and future perspectives for their integration into modern healthcare.

**Keywords:** Medicinal plants**,** Diabetes mellitus**,** Phytochemicals**,** Insulin sensitization, and Complementary medicine.

## INTRODUCTION

Diabetes mellitus is a chronic metabolic disease characterized by elevated glucose levels in the blood. Insulin deficiency results in high blood glucose concentrations, increased glucose in the urine, and changes in lipid, protein, and mineral metabolism [1]. Type 1 diabetes mellitus is an autoimmune disease resulting from the destruction of pancreatic β-cells. The cause of this destruction is sometimes unknown but is believed to be related to environmental factors and genetics. Approximately 5 % of people with diabetes have type 1 diabetes [2]. The most common types of diabetes are type 2, which accounts for approximately 90 % of diabetes cases globally, and gestational diabetes, which occurs during pregnancy. These suggest that about 382 million adults were living with diabetes worldwide in 2013. This number is projected to increase to 592 million by 2035. In the USA, 12.3 % of all adults aged 20 years or older had diabetes in 2012; its incidence in adults aged 65 or older was 25.9 %. Currently available chemical drugs for diabetes treatment are not completely safe and effective, and have side effects. Medicinal plants and their constituents, however, are important alternatives worldwide owing to their minimal side effects and low costs [1, 2]. The pancreas is a key organ that regulates blood sugar. When a meal is consumed, the pancreas releases insulin, stimulating body cells such as fat and muscle cells to absorb glucose and use it as a source of energy. In insulin resistance, cells, such as muscle, fat, and liver cells, do not respond properly to insulin, and continued release of more insulin is needed for glucose entry into cells, as seen in the fasting state when the liver secretes glucose. Blood glucose, therefore, remains high since glucose entry into cells is diminished and the production of glucose continues. In diabetes, the ability of β-cells to produce enough insulin to overcome the effect of the insulin resistance is lost, and the person is unable to regulate glucose levels [1, 2]. Diabetes mellitus (DM) is a complex metabolic disease of diverse etiology. The main complications of DM include

microvascular and macrovascular diseases, neuropathies, nephropathies, and retinopathies. Many medicinal plants have been used in treating diabetes and its complications. There is considerable research on their hypoglycaemic activity, with several active principles, including trigonelline, alkaloids, and flavonoids, being isolated from plants that have shown anti-hyperglycaemic and hypoglycaemic effects. The presence of flavonoids in these plants has contributed decisively to the effectiveness, and therefore, more scientific studies need to be carried out on identifying their chemical components and their mechanism of action. Therapeutic effects and adverse side effects should also be thoroughly investigated [1, 2].

## Overview of Medicinal Plants

The use of medicinal plants to treat various ailments is a tradition deeply embedded in human civilization. Historically isolated to regions such as Bangladesh, Europe, and Africa, the recognition of medicinal plants has expanded globally through intensive scientific investigations, revealing their potential in managing complex health conditions like diabetes [3]. Plant materials continue to serve as viable sources of medicine for a vast portion of the global population employed either exclusively or alongside conventional therapies. Sowing, harvesting, and processing of these plants for medicinal purposes constitute prime sources of rural unemployment worldwide, reflecting socio-economic dimensions interlinked with health practices [1]. Several drugs derived from plants have demonstrated significant efficacy in managing complex health conditions, underscoring the crucial role phytochemicals can play in contemporary healthcare frameworks [3, 1].

## Role of Medicinal Plants in Diabetes Management

Diabetes management continues to present a significant global health challenge, with a growing population of individuals diagnosed each year [3]. The limitations of current drug therapies, which may be inaccessible or unaffordable for many, alongside the documented adverse effects of prolonged synthetic drug use, have spurred interest in alternative treatment modalities [2]. Medicinal plants have long served as a foundation for primary healthcare worldwide and constitute a viable complement to pharmaceutical treatments. Their appeal in the context of diabetes stems from multiple factors: a broad spectrum of substitutes is available to meet escalating demand; a perception of inherent safety relative to synthetic drugs prevails; and many exhibit considerable therapeutic efficacy [3, 4, 1].

## Common Medicinal Plants Used in Diabetes

Several plants are often suggested to have antidiabetic properties. Bitter melon (Momordica charantia), fenugreek (Trigonella foenum-graecum), cinnamon (Cinnamomum verum), ginseng (Panax ginseng), and aloe vera (Aloe barbadensis miller) are among those receiving significant attention. They have been widely used for both nutrition and in traditional systems of medicine [3].

## Bitter Melon

Bitter melon (Momordica charantia L.), a member of the Cucurbitaceae family, has been extensively studied for its hypoglycemic effects. Varieties such as Karela, Balsam pear, and bitter cucumber are grown globally. The fruit is characterized by vertical ridges and a bitter taste. Examination of the skin, flesh, and whole fruit containing seeds revealed bioactives charantin and vicine, compounds with potential for diabetes prophylaxis and treatment [5]. Administration of bitter melon at 300 mg/kg improved diabetic status in experimental models [5]. Reduced water intake in hyperglycemic rats indicated an improvement in metabolic function. Although feed intake decreased slightly, the impact was minimal. Normal controls exhibited gradual body weight gain, and diabetic rats fed with bitter melon demonstrated weight improvement. The fruit also prevented diabetes-associated polyuria and reduced sugar excretion in the urine [5]. Moreover, supplementation produced a significant decrease in the kidney-to-body weight ratio, indicating a reduction in kidney enlargement related to diabetes. These findings support the potential use of bitter melon bioactives as dietary agents for diabetes management [5].

## Fenugreek

Fenugreek (Trigonella foenum-graecum L., Fabaceae family) represents one of the few medicinal plants studied extensively in the management of diabetes. Fenugreek consists of various bioactive compounds in its seed, including soluble fiber, saponins, trigonelle, diosgenin, and 4-hydroxyisoleucine, substances that exhibit hypoglycemic, anti-inflammatory, and hypocholesterolemic properties 6. Both animal and human studies describe antidiabetic effects [7, 8]. Analysis of diabetic rats demonstrates that water extracts of fenugreek seed slow carbohydrate digestion and moderate glucose absorption, an effect attributable to the plant's high soluble-fiber content. As a result, glucose delivery to the circulation diminishes and postprandial glycemic rise attenuates. Fenugreek also enhances peripheral glucose uptake and exhibits insulinotropic activity in rat pancreatic islet cells [7]. In diabetic volunteers, oral fenugreek seed consumption acutely reduces postprandial blood glucose and serum insulin concentrations. The totality of clinical data on fenugreek accords with laboratory research. Short-term fenugreek administration consistently attenuates glycemic and insulinemic responses to carbohydrate

ingestion. With longer-term use, fenugreek tends to reduce fasting blood glucose, postprandial glycemia, and glycated hemoglobin (HbA1c), albeit with heterogeneous effects in some trials. Given its affordability and negligible adverse effects, clinicians regard fenugreek as a potentially versatile herb to supplement standard antidiabetic therapies [8].

**Cinnamon**

Cinnamon is a spice obtained from the inner bark of trees of the genus Cinnamomum that has been traditionally used as a condiment or a flavouring material in foods and beverages. Recent studies have investigated cinnamon for the treatment of various disorders, including diabetes mellitus. Varieties of bioactive components such as cinnamaldehydes, cinnamic acid, and cinnamate have been isolated from cinnamon and have demonstrated insulin-like biological activity [9]. Results from several clinical trials suggest that cinnamon lowers plasma glucose and improves lipids in people with type 2 diabetes [10]. However, the effectiveness of cinnamon for reducing blood glucose has been questioned by others, and further studies on the long-term intake of cinnamon are required to determine whether cinnamon is truly effective for the treatment of type 2 diabetes. Cinnamon is usually ingested as a beverage or as an extract in capsules, and commonly studied doses have ranged from 500 mg to 6 g daily [10].

**Ginseng**

The extract and individual compounds of Panax ginseng, a perennial herbaceous plant commonly consumed as a beverage, exhibit a remarkable capacity to improve fasting blood glucose and glucose tolerance in preclinical studies [11]. A review of six clinical trials involving doses ranging from 1 to 20 g/day for 4–24 weeks found modest but significant reductions in fasting blood glucose [12], confirming traditional use as a tonic for wellbeing. Herbal constituents show a diverse array of benefits beyond glycemic control. Ginseng total saponins mitigate hyperglycemia by raising glucagon-like peptide-1 levels in streptozotocin (STZ)-induced diabetic rats, while fractionated polysaccharides modulate energy metabolism. Protopanaxadiol- and protopanaxatriol-type saponins elicit favourable effects such as fasting blood glucose reduction, improved glucose tolerance, and alleviated insulin resistance in diabetic animals. The mechanisms include downregulation of pro-inflammatory cytokines, enhanced endogenous antioxidant defences, and suppression of gluconeogenic enzymes. Compound K, a panaxadiol intestinal metabolite, decreases fasting glucose and enhances insulin sensitivity through upregulation of key insulin signalling proteins [11, 12]. Ginsenoside-Rg1 augments angiogenesis and restrains apoptosis in streptozotocin-nicotinamide-induced diabetic mice. Treatment with ginsenoside-Rg3 lowers serum glucose, glycosylated proteins, and oxidative stress markers with concurrent improvements in renal function and overall metabolism [11].

**Aloe Vera**

Aloe barbadensis Miller, synonym A. vera, a member of the Liliaceae family, is a perennial, succulent, xerophyte plant that exhibits traditional and complementary medicinal applications worldwide [13]. The plant's leaves, containing mucilaginous gel, are widely distributed and processed into various formulations for therapeutic use. A substantial body of research, comprising both in vitro and in vivo studies, supports the use of Aloe vera as an adjunct in the management of diabetes and its complications [13].

**Mechanisms of Action**

Medicinal plants used against diabetes exert glycemic control through various complementary actions, including insulin sensitization, potentiation of insulin release, regeneration of damaged pancreatic beta-cells, antioxidant activity, inhibition of glucose absorption from the intestine, enzymatic regulation involved in carbohydrate metabolism, and anti-inflammatory effects [4]. Stimulation of insulin synthesis and secretion by pancreatic beta-cells, enhancement of insulin sensitivity, insulin-mimetic activity, and retardation of carbohydrate absorption, alteration of glucose-metabolizing enzymes, beta-cell regeneration, and mitigation of oxidative stress represent additional pathways embracing the antidiabetic properties of these herbs [14].

**Insulin Sensitization**

Insulin sensitization increases glucose uptake in response to insulin by promoting receptor phosphorylation, thereby activating downstream signaling pathways such as PI3K-PKB-Akt [15]. Experimental studies have shown that several common medicinal plants enhance insulin sensitivity through these mechanisms [4]. Bitter melon (Momordica charantia), for example, has demonstrated insulin-sensitizing effects in clinical trials [11]. Similarly, fenugreek (Trigonella foenum-graecum) reduces insulin resistance by enhancing receptor phosphorylation. Cinnamon (Cinnamomum verum) and ginseng (Panax ginseng) also improve insulin sensitivity; their active constituents stimulate insulin receptor activity and facilitate glucose uptake. Aloe vera exhibits comparable mechanisms, contributing to its insulin-sensitizing properties. In addition to these targeted effects,

many medicinal plants possess antioxidant and anti-inflammatory activities that further support insulin action and glycemic control [4, 11, 15].

**Antioxidant Properties**

Oxidative stress plays a significant role in the pathogenesis of multiple metabolic diseases, including diabetes and hyperglycemia. Therefore, agents exhibiting antioxidant properties could be crucial in managing diabetes [16]. Oxidative stress emerges from an imbalance between free radical generation and the body's antioxidant defenses, leading to damage of biomolecules such as lipids, proteins, carbohydrates, and nucleic acids. Elevated levels of reactive oxygen species are implicated in the onset and progression of various chronic diseases, most notably diabetes and obesity [17]. In settings of metabolic disturbance, oxidative stress and inflammation serve as early markers of cellular dysfunction. Medicinal plants are renowned sources of natural antioxidants and continue to attract considerable research interest. Aqueous extracts of various species from Reunion Island have been shown to possess antioxidant absorption capacity; these species could be utilized for developing herbal infusions capable of protecting human cells (e.g., red blood cells and preadipocytes) against oxidative stress and thereby offer benefits to diabetic individuals [16, 17].

**Anti-inflammatory Effects**

Many medicinal plants act as powerful anti-inflammatory agents. Inflammation plays a major role in diabetes, and many plant- and herb-derived bioactive compounds exhibit antidiabetic activities through anti-inflammatory mechanisms. Several herbs enhance glycemic control by boosting plasma insulin levels or promoting glucose uptake [16]. Alkaloids from Melia azadirachta, Momordica charantia, and Gymnema sylvestre exhibit anti-inflammatory, hypoglycemic, and lipid-lowering effects [4].

**Clinical Studies and Evidence**

Clinical trials and case studies have demonstrated that medicinal plants can achieve adequate glycaemic control and improve patients' quality of life without undesirable side effects [11, 18]. Phytotherapy has been applied for the treatment of diabetes mellitus since ancient times; many species and herbal medicines act at key points of the glucose metabolism, for example, through the inhibition of α-glucosidase, the increase in GLUT-4 and PPARs expression, and antioxidant activity [11]. A study identified 76 plant species used to manage diabetes mellitus, most commonly from the Euphorbiaceae, Lamiaceae, Asteraceae, and Apocynaceae families. Leaves represent the principal part utilized, often prepared as decoctions. Only 12 plants and their bioactive compounds have evidence from both preclinical and clinical investigations. The phytomedicines extenuate diabetes mellitus pathology mainly through mechanisms such as restoration of pancreatic β-cell function, improvement of insulin sensitivity, stimulation of insulin secretion, inhibition of hepatic gluconeogenesis, enhancement of glucose absorption, and suppression of enzymes including G-6-Pase, α-amylase, and α-glucosidase [18].

**Clinical Trials**

Clinical trials (CTs) on plants used in the management of diabetes provide imperative information regarding treatment efficacy and dosing, while also identifying safety concerns such as potential side effects and adverse reactions. Of equal importance are the studies demonstrating a lack of efficacy. Well-designed, rigorously conducted clinical trials carry significant importance for advancing a treatment from empirical use into modern medical practice [19]. Before initiating a clinical trial, the selection of the source material is crucial, with quality control playing a pivotal role throughout the drug discovery and development process. Detailed characterization covering positioning, identity, and physico-chemical properties of the starting material (natural product) is essential. A precise chemical characterization of both the natural product and the formulated product is mandatory to ensure reproducible quality and pharmacological activity [19]. Promising natural sources require unambiguous characterization and evaluation for safety and efficacy parameters. The fate of the natural product during the formulation process must be examined, necessitating detailed documentation of all procedures. Additionally, CTs demand comprehensive preclinical data, including target validation, mode of action, and toxicology [19]. This approach is exemplified by several plants under investigation for diabetes therapeutics. Passage of Reclining dayflower (Commelina obliqua Roxb.) 示回闷 dayflower (Commelina obliqua Roxb.) through a CT resulted in the recovery, except for 1 in the Dessa (Trichosanthes dioica Roxb.) group, of the lowered hemoglobin and RBC counts. In contrast, dài yè (Phyllanthus amarus Schumach. & Thonn.) has yet to progress beyond cellular and chemical evaluation. Other promising, but so far unvalidated, species are zì cǎo (Arnebia euchroma (Royle) Johnst.), Makhana (Euryale ferox Salisb.), and cǎo meí (Rubus fruticosus L.) [19].

**Case Studies**

Severe worldwide epidemics of several infectious and chronic diseases are accelerating. Diabetes Mellitus (DM) has become a leading cause of mortality and morbidity worldwide and is rising at an alarming rate every year [20]. DM is characterized by a state of metabolic disorder resulting from defects in both insulin secretion and

insulin action. It is a group of metabolic diseases characterized by hyperglycemia resulting from defects in insulin secretion or insulin action or both. Type 1 diabetes mellitus (T1DM) results from pancreatic β-cell destruction, usually leading to absolute insulin deficiency, whilst type 2 diabetes mellitus (T2DM) results from a progressive insulin secretory defect on the background of insulin resistance [20]. Medicinal plants, including many polyherbal formulations currently in use currently are potential sources for the discovery and development of new drugs and also provide alternative means of treatment to the existing synthetic and semi-synthetic drugs for the future [21]. Diabetes mellitus, a chronic metabolic disorder characterized by hyperglycemia, accounts for 10.7% of all-cause mortality [22]. Natural plant compounds that show antidiabetic activity are prepared from a variety of plant parts, including leaves, roots, flowers, and seeds, and act in many ways, such as increasing insulin secretion, preventing insulin resistance, promoting glucose utilization, and inhibiting glucose absorption in the intestines. Its rising global prevalence has increased the need to search for novel agents, more efficient in activity and at the same time less toxic. Moringa, curcumin, fenugreek, and ginger are reported to be the most effective antidiabetic herbs worldwide. Phytocompounds in these plants are discussed as insulin mimetics [22].

## Safety and Side Effects

The safety of medicinal plants depends on the dosage, administration schedule, plant parts used, preparation methods, duration of consumption, and health status of individuals. Some plants contain anti-nutritional factors, toxic components, allergens, heavy metals, or have herb-drug interactions leading to adverse effects [3]. During the COVID-19 crisis, the inappropriate use of traditional medicines without necessary precautions caused safety concerns. Despite discouragement by researchers and clinicians, the high use of unproven natural remedies raises the risk of potentially harmful side effects and interactions, often due to insufficient evidence regarding their pharmacology, clinical benefits, toxicology, and interactions with conventional drugs. The widespread use of plants for antidiabetic purposes underscores the necessity to evaluate their safety profile extensively [4]. About 120 plant species with proven antihyperglycemic effects in vivo and in vitro are employed to regulate blood glucose and treat diabetes-associated complications. Nonetheless, few have undergone clinical evaluation, and many lack convincing evidence of safety and efficacy [2].

## Potential Risks

Medicinal plants historically have been consumed as pills, teas, tinctures, powders, and topical extracts [4]. Strictly speaking, herbs refer to the dried or fresh parts of plants, which distinguish them from processed products. Worldwide, the pharmaceutical industry uses phytomedicine and offers various conventional drugs, which are obtained directly from plants or their compounds [4]. For example, the World Health Organization (WHO) reports that approximately 80 % of people worldwide still rely primarily on herbal remedies for basic health needs, especially in underdeveloped countries. Consequently, various pharmaceutical industries are focusing on phytomedicine [4]. Plants have an essential role in health care and disease management systems, as plant active compounds are sources and precursors of important modern medicines. Potential risks include safety and side effects from taking certain medicinal plants, as well as potential herb-drug interactions with medications used to manage diabetes.

## Drug Interactions

Patients with diabetes are particularly vulnerable to drug interactions, either through changed pharmacokinetics or changes in the normal pharmacodynamic response to a drug. The array of drugs used in diabetes management presents numerous opportunities for such interactions [4]. Plants frequently used by diabetic patients are characterized to help identify potential drug interactions and to highlight likely areas of serious adverse reactions. Those most often concomitantly used with prescription pharmaceuticals are identified according to an Australian survey based exclusively on medicinal plant products acquired by patients with diagnosed diabetes [4]. Extensive literature searches have been conducted to identify ethnopharmacological use, evidence of toxicity to support inclusion as potentially hazardous, as well as known herb–drug interactions attributed to the individual species. Several of the individual medicinal plants or herbal extracts are convincing candidates for either adverse pharmacokinetic or pharmacodynamic interactions and require investigation by both researchers and health care professionals in the formulation of drug treatment plans for patients diagnosed with diabetes [4].

## Traditional vs. Modern Approaches

Medicinal plants have a long history of use in diabetes management, with widespread application in various cultures [23]. Traditional healers are often the first point of contact for diabetic patients, indicating that the use of herbal medicines has persisted as an alternative treatment since the early period of diabetes [14]. While the majority of contemporary medical practitioners remain skeptical and prefer the prescription of allopathic agents, public interest in ethnopharmacology and traditional medicines continues to increase internationally. Ethnopharmacological surveys lend insight into the level of dependence on traditional medicine in the context of

diabetes across cultures, and they provide a rational starting point for the identification of medicinal plants with hypoglycaemic activity in a geographic region [4]. In Mexico, a total of 163 species belonging to 62 botanical families are employed in the management of type 2 diabetes, and 25% of these are used explicitly for this purpose. Of the reported species, 104 have been the subject of pharmacological studies, with 61.5% of this subset showing positive effects on diabetes and/or diabetic symptoms. A similar survey among the Huichol, a northern Mexican ethnic group, identified 30 species used in the treatment of 19 different ailments, with four employed in the treatment of diabetes [4]. In regions where Western pharmaceutical preparations are prohibitively expensive or otherwise inaccessible, the use of indigenous medicinal plants is regarded as an invaluable resource for diabetes control. Although they offer potential benefits, they also pose risks, as most users are not fully aware of the physiological effects of the materials being ingested. Consequently, an expansion of studies to identify bioactive compounds and to validate the efficacy and safety of these traditional preparations is imperative [23]. The cautious and scientifically grounded integration of traditional medicinal plants into contemporary diabetes management protocols may offer a complementary approach to address the global rise of this disease [23].

**Cultural Practices**

Diabetes is a chronic metabolic disorder characterized by elevated blood glucose levels, resulting from defects in insulin secretion or insulin action [24]. The two most common types, Type 1 and Type 2, increase the risk of complications such as cardiovascular and renal diseases, often leading to premature death. Although large-scale clinical trials have demonstrated the efficacy of existing treatments in reducing these risks, hypoglycemia is a common side effect of intensified glycemic control, complicating disease management. Consequently, there is a growing interest in exploring medicinal plants as alternative therapies for diabetes. Plants have played a significant role in health maintenance and restoration since prehistoric times, with many traditional medicines derived directly from plants or developed through testing natural products [23]. The World Health Organization estimates that about 65%–80% of the global population depends primarily on plants for healthcare. Measurement of blood glucose concentration serves as the primary diagnostic tool for diabetes, enabling early detection. Recognizing the limitations of current treatments and the cultural significance of plants, numerous medicinal herbs are under investigation for antidiabetic properties [23].

**Integration into Healthcare**

Complementary and alternative medicines can be defined as health care practices not widely used or taught in medical schools and hospitals, but they are gaining interest among patients. Herbal medicine accounts for 80% of complementary and alternative medicine use worldwide, especially in rural areas [15]. This is significant considering that herbal remedies contain multiple active components in complex mixtures and that about 40% of modern drugs are derived from plants, highlighting the therapeutic potential of botanical species[15]. In particular, medicinal plants and their extracts are particularly applicable to the treatment and management of diabetes. World Health Organization member states strongly recommend traditional and complementary medicine as a means of delivering quality, cost-effective, and accessible healthcare, and the integration of medicinal plants into conventional medical practice is now acknowledged by the WHO [15].

**Future Directions in Research**

Diabetes mellitus has emerged as a major public health crisis, especially in underdeveloped countries. Research continues to identify novel natural sources of antidiabetic therapies and to explore traditional plants of known antidiabetic activity for new targets, mechanisms, and routes of administration [4]. Plant-derived antidiabetic medicines are inexpensive, widely accessible, and have a low incidence of side effects, characteristics that make them outstanding candidates for treatment [4]. Consequently, biomedical scientists and pharmaceutical industries are developing new classes of antidiabetic drugs based on phytochemicals isolated from traditionally antidiabetic plants. Growing interest in such agents implies that additional studies should be undertaken to investigate their utility at the molecular, therapeutic, and physiological levels with the ultimate aim of improving the global management of diabetes and its related conditions [4]. Numerous studies continue to suggest that bioactive compounds from medicinal plants can support and supplement synthetic drugs, especially by reducing side effects in patients with type 2 diabetes [1]. Extracts of plants such as Zingiber officinale Roscoe have been shown both to enhance the low level of glucose uptake, reported in diabetic muscle cells, by stimulating the transport of glucose across the cell membrane into the cell and to improve tissue glycogen content. Many of the bioactive plant components that have therapeutic activity are phenolic (e.g., gingerol constituents of ginger root), demonstrating effective inhibition of some enzymes such as α-amylase and α-glucosidase, associated with diabetes and hypertension [1]. Because type 2 diabetes has been recognised as a metabolic disorder with serious complications, including blindness, renal failure, and heart failure, research continues to focus on the development of novel antidiabetic agents. Medicines based on traditional herbs and herbal extracts are increasingly valued by patients in

parallel with standard drugs to reduce blood sugar, not only in the diabetic state but also in the management of adverse complications [1]. An important topic for future research and development is therefore the isolation, purification, and identification of novel bioactive substances from natural plants with demonstrated antidiabetic activity, which can contribute both to the preparation of functional foods and to the standardisation and large-scale commercial production of novel medicines [1].

## Emerging Trends

Medicinal plants have accumulated a great therapeutic reputation since ancient times. Special interest has been focused on the discovery of effective and safe drugs from alternative and complementary sources, mainly from medicinal plants used traditionally, owing to the continual rise in the number of drug-resistant microbial strains and the side effects associated with the synthetic drugs [4]. Researchers have made continuous efforts to find more effective therapies; an important step in this direction is the use of natural products of biological origin, which constitute an important source of remedies for many diseases. Medicinal plants are used throughout the world, even in developed countries, because of their easy availability, economic affordability, cultural acceptability, and fewer side effects [25]. Diabetes mellitus is one of the largest health concerns worldwide today, with an estimated 422 million diabetic patients suffering from this disease. Changes in lifestyle and food habits are responsible for the alarming rate at which people are developing type 2 diabetes [4, 25]. This metabolic disorder renders the body inefficient in utilizing glucose, resulting in disturbances within the body. Therefore, to counter this illness, many antidiabetic medicinal plants have been used traditionally all over the world for controlling the symptoms of diabetes as well as to limit the complications due to a shortage of insulin production.

## Innovative Therapies

Beyond the conventional oral hypoglycemic agents, recent research highlights a growing interest in the utilization of natural sources to inhibit diabetes-linked enzymes and alleviate symptoms. Specifically, several medicinal plants have emerged as promising alternatives for diabetes mellitus (DM) treatment [26]. Among the plethora of reported antidiabetic plants, Palmyra palm pollen pollenites, Thymelaea hirsuta, and Origanum majorana, among others, attract considerable scientific interest for their pharmacological potential and therapeutic applications against chronic diseases. Additional species exhibiting potent antidiabetic properties include Carpobrotus edulis, Acalypha integrifolia, Rhus lancea, and Hypoxis argentea [11]. The intended structure of this article systematically elucidates the contemporary understanding and therapeutic application of medicinal plants in diabetes management. A subsequent section offers a detailed account of prevalent herbs employed around the globe, complete with botanical illustrations and insights into their pharmacological mechanisms [11, 26].

## Regulatory Considerations

Herbal medicines enjoy worldwide popularity. In the context of the therapeutic management of diabetes, the regulation of phytomedicines remains an important topic [11]. Proposals to develop simple protocols for conducting community-based herbal diabetic treatment programmes are available. Industrialised countries show great attention towards safety, quality, and efficacy of phytomedicines; numerous models of guidelines and technical documents are available to reduce several cases of side effects, plant toxicity, or drug-herb interactions. A major concern of regulatory bodies and authorities is quality control of herbal plants and their products [4]. Herbal raw materials must comply with standards and requirements that assess their plant identification (botanical and chemical), foreign organic matter content, ash, heavy metals, pesticides, and active constituents. Final products have stringent indispensable criteria of manufacturers (analytical tests, good manufacturing practice) and analytical quality control tests (organoleptic, purity, chemical, physical, and microbiological), affecting the finished herbal medicinal products/effective pharmaceutical products prior to availability on the market [11, 4].

## Herbal Medicine Regulations

The herbal industry is gaining recognition as a legitimate health care system in the contemporary environment. The use of precise herbal formulations for the cure or treatment of certain diseases has been gaining significant attention. Consequently, the development of homogeneous herbal formulations has become considerably challenging and costly [15]. In the last few decades, crude drugs and their formulation from the plants have been gaining interest due to their secure natural origin. The current products in the market contain active therapeutic agents, either isolated or as an active fraction of the extract of the plants often used for the standardized objective [27]. Market quality of herbal formulations has become a significant concern, along with the safety of consumers, for their proper action. Problems of constant quality and contamination of the herbal formulation may arise due to improper manufacturing practices, wrong identification of the plants, wrong or insufficient harvesting, drying, and storage conditions [15, 27].

## Quality Control

Quality control is a vital concern in the preparation of herbal medicines to ensure maximum efficacy, reproducibility, safety, and tolerance. This is especially relevant for anti-diabetic herbal drugs, where the quality control of the raw powder material and extract plays a key role in predicting the therapeutic potential of the final formulation [28]. Herbal medicines have experienced a recent surge in popularity, but this growth has resulted in a decline in quality because of inadequate regulations. Standardization of herbal raw materials can be pursued through detailed examination of popular anti-diabetic herbs that are widely used in pharmaceutical formulations by companies and herbal drug manufacturers [28]. Both in-house extracts and marketed formulations can be evaluated using physicochemical parameters, phytochemical screening, polyphenol quantification, and high-performance thin-layer chromatography (HPTLC) fingerprint profiling with reference to marker compounds. Such studies often reveal that in-house extracts are of superior quality compared to marketed products. These findings can be used to establish limits for relevant phytoconstituents and thereby contribute to quality control and assurance of anti-diabetic herbal drugs [28]. By contrast, a lack of information about the raw herbs used, such as family, genus, species, geographical origin, phytochemistry, and mechanism of action, is a major shortcoming in research on antidiabetic therapies based on natural products. This knowledge is nevertheless essential to understand mechanisms and to isolate compounds for effective control of diabetes and related comorbidities [19]. Proper evidence regarding the ethnopharmacological and ethnomedicinal value of the plants is also of prime importance. The quality of the source material requires particular attention, since plants may vary in terms of the quality and quantity of their active principles as a function of geographical origin. Differences in environment, temperature, irrigation, salinity, stress, altitude, and seasonal variation can all influence the composition of plant phytochemicals [19]. Madhu zam, a polyherbal formulation commonly used in Northeast India for controlling blood sugar in diabetic patients, exemplifies a popular mixture whose phytochemical content can be subjected to scientific analysis. The systematic approach developed for such systems involves phytochemical screening, quantification of total phenolic and flavonoid contents, Fourier transform infrared spectroscopy (FT-IR), and high-resolution liquid chromatography–mass spectrometry (HR-LC/MS). These experimental studies are complemented by in silico characterization of potential bioactive compounds based on known protein targets of diabetes [29].

## Patient Education and Awareness

Effective patient education and awareness through distinct approaches help people make informed decisions and ensure safe and beneficial use of medicinal plants in managing diabetes [15]. Establishing reliable online resources informs patients, family members, and the wider society about medicinal plants, especially those effective against diabetes [23]. Internet resources enable patients to obtain evidence-based information and practical guidance for daily life [20].

## Informing Patients

Accurate information about the therapeutic, pharmacological, and toxicological effects of medicinal plants is fundamental for ensuring both the safety and effectiveness of herbal products among diabetic patients. Educating the population about application methods and the preparation of these plants is essential [15]. Once the properties of potential medicinal plants have been studied and their efficacy tested, disseminating this knowledge empowers patients to identify natural remedies geared toward glycemic reduction and comprehensive diabetes management. Qualified personnel in diabetes care can provide further guidance on the appropriate use of standardized commercial products or preparations formulated in specialized herbal services [23]. Patient education is crucial in all aspects to minimize adverse effects and guard against the consumption of products that are counterfeit, adulterated, or contain undesirable substances.

## Resources for Patients

Increasing the availability of patient-centered information resources will raise awareness regarding the therapeutic potential of medicinal plants and will enhance the quality of life of individuals afflicted with diabetes [30]. To fulfill the need for accessible information, data on over 800 medicinal plants used worldwide have been compiled and organised into a comprehensive database [30]. The database, PhytoDiabCare, was developed using traditional pharmacopoeias, scientific compendia, and ethnobotanical studies as sources. The database facilitates both general and targeted searches, table generation, and the export of publication-ready data. Biological classification and phytochemical composition are included for all documented species [30].

## CONCLUSION

Medicinal plants have long played an essential role in diabetes management, offering diverse mechanisms of action including insulin sensitization, β-cell protection, enzyme inhibition, and antioxidant activity. Well-studied species such as bitter melon, fenugreek, cinnamon, ginseng, and aloe vera demonstrate consistent benefits in both

experimental and clinical settings, though with varying levels of efficacy. Beyond glycemic control, many plants provide additional advantages such as improved lipid metabolism and reduced inflammation. Despite their promise, challenges persist, including limited clinical validation, variability in plant preparations, safety concerns, and potential herb–drug interactions. Regulatory standardization, rigorous clinical trials, and mechanistic studies are urgently needed to bridge the gap between traditional use and evidence-based medicine. With proper integration into healthcare systems, medicinal plants can serve as safe, cost-effective, and accessible adjuncts to conventional therapies, ultimately contributing to better management of diabetes and its complications.

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