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Exploring the Nutritional Benefits of Medicinal Plants in Diabetes Management

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ABSTRACT

Diabetes mellitus (DM), a chronic metabolic disorder characterized by persistent hyperglycemia, has reached epidemic proportions globally. Conventional antidiabetic medications, while effective, are often limited by side effects, high costs, and reduced long-term efficacy. In contrast, medicinal plants have gained prominence for their bioactive phytoconstituents, affordability, and cultural relevance, especially in traditional healthcare systems. This review examines the nutritional benefits and antidiabetic mechanisms of medicinal plants, highlighting their roles in modulating blood glucose, enhancing insulin sensitivity, and mitigating diabetes-related complications. Bioactive compounds such as flavonoids, alkaloids, saponins, and polyphenols exhibit promising hypoglycemic effects through various biochemical pathways. Furthermore, many medicinal plants offer vital micronutrients and antioxidants that support overall metabolic health. Clinical and ethnobotanical evidence supports their potential as complementary therapies in diabetes management. As global interest in plant-based interventions increases, scientific validation and standardization of these natural remedies remain critical for integrating them into mainstream diabetic care.

Keywords: Medicinal plants, Diabetes mellitus, Antidiabetic phytochemicals, Insulin sensitivity, Nutritional therapy, Flavonoids, Herbal medicine.

INTRODUCTION

Diabetes is considered a major public health problem worldwide, affecting over 463 million people in 2019, and is predicted to increase to over 578 million worldwide by 2030. Diabetes mellitus (DM) is a chronic metabolic disorder characterized by hyperglycemia. DM results from a deficiency in insulin secretion, insulin action or both. DM can be classified into type 1 DM (insulin-dependent DM) and type 2 DM (non-insulin-dependent DM). Type 1 DM is usually an immune-mediated destruction of the pancreatic β-cells, leading to complete insulin deficiency. The plants are an important source of medicinal compounds. The plant species that are used to treat diabetes are from various traditional medicinal systems in different countries. A large number of medicinal plants are associated with antidiabetic properties in folklore medicine. Traditional medicine is one of the sources of remedies for human diseases and plays an important role in the health care system, especially in developing countries. Traditional medicine is very cheap and easily accessible for people living in remote areas where conventional medicine is out of reach. Currently, the WHO encourages the knowledge of traditional medicine. Many phyto-medicines have been found to exhibit antidiabetic activity. For the past decades, a limited number of synthetic antidiabetic agents have been developed. The biguanides in the synthetic drugs are more attractive since they have been proven to be effective in lowering blood glucose by different mechanisms. There are many bioactive compounds in plant extracts, which exhibit a broad range of biological and pharmacological properties. There is an urgent need to find out safe blood glucose-lowering agents with no side effects. Several plants have been tested for their antidiabetic activity. Plants, derivatives, and herbal medicines are gathered and used widely for the management of diabetes, in addition to dietary and physical approaches. Ethnochemistry and traditional medicines are important criteria to discover new bioactive molecules in plants to manage diabetes. For centuries, plant and animal-derived products have

formed one of the principal coordinating parts of folklore medicine. These natural sources have been used in the prevention and treatment of diabetes by many civilizations, including Egyptians, Greeks, Romans, Chinese, and Indians. Likewise, many medicinal plants remain in countries like India and China, which have been used for diabetes treatment in traditional medicinal systems [1, 2].

Understanding Diabetes

Diabetes mellitus, affecting millions worldwide, is classified into type 1 and type 2 diabetes. Type 1 is due to autoimmune destruction of the pancreatic beta cells, leading to insulin deficiency. Type 2 is multifactorial, arising from genetic and environmental factors, causing pancreatic dysfunction, insufficient insulin secretion, and insulin resistance, which can lead to hyperglycemia. Insulin resistance is linked to increased glucose production, lipodystrophy, and fatty acid flux. Advances highlight the role of incretin hormones in insulin signaling. Many patients struggle to achieve optimal blood glucose control despite existing hypoglycemic agents, each with its pros and cons. The limitations of insulin and some oral drugs encourage the search for alternative antidiabetic agents, including herbal medicines, which are widely used in various cultures. Diabetes is characterized by chronic hyperglycemia and metabolic disturbances due to insulin secretion or action. Managing diabetes relies on complex interactions among insulin secretion, tissue glucose uptake, and liver glucose production. Various medicinal plants with hypoglycemic properties, including polysaccharides and flavonoids, have been employed in diabetes treatment. Notable plants like A. mexicana, Annona squamosa, and Momordica charantia play significant roles in traditional medicine. Additionally, the aqueous extract of G. sylvestre leaves emerges as a promising anti-diabetic agent, highlighting herbal plants' potential in diabetes management as complementary and alternative treatments [3, 4].

Types of Diabetes

In humans, there are mainly three types of diabetes: type 1 diabetes, type 2 diabetes, and gestational diabetes. Type 1 diabetes is the result of an autoimmune destruction of pancreatic β-cells leading to absolute insulin deficiency. This may lead to acute hyperglycaemia and diabetic ketoacidosis. Type 1 diabetes is more common in people under the age of 30 years and is known as juvenile diabetes or childhood diabetes. While the autoimmune basis for type 1 diabetes is not completely understood, certain genetic risk factors are known. These are related to the human leukocyte antigen system. Environmental factors like viruses, vaccines, diet, and the entry of gut bacteria into the bloodstream are thought to interact with genetic susceptibility to initiate autoimmunity. In type 2 diabetes, dysfunctional pancreatic β-cells fail to compensate for insulin resistance by hypersecretion of insulin, leading to insulin deficiency in inadequately controlled blood glucose levels. Insulin resistance affects insulin-target organs such as the liver, muscle, and adipose tissue. Development of metabolic syndromes includes central obesity and dyslipidaemia. Type 2 diabetes is known as adult-onset diabetes, and increasingly, very young children are found to have type 2 diabetes. Type 2 diabetes is more common in older communities, overweight and sedentary individuals, or those with a family history of diabetes. Gestational diabetes is described by glucose intolerance with onset during pregnancy or first recognition during pregnancy. Gestational diabetes has been classified as having three classes. Class A is further classified into A1 (diet-controlled) and A2 (requires insulin or sulfonylureas). Gestational diabetes typically resolves within 6 weeks after delivery; however, 50 % and 15 % of A1 and A2 classes are at high risk for type 2 diabetes, respectively. These women and their offspring are also at risk for other comorbidities such as obesity, metabolic syndrome, cardiovascular disease, etc [5, 6].

Pathophysiology of Diabetes

Diabetes mellitus (DM) is a metabolic disorder that advances when blood glucose levels are raised due to either insulin resistance or damage to pancreatic β-cells. Regulation of blood sugar levels is mainly under the control of insulin, and any defect in its action leads to diabetes. Oral hyperglycemic agents, also known as antidiabetics, are currently used to manage diabetes. The antidiabetic drugs in clinical use either increase insulin production from β-cells, enhance the transportation of glucose from the blood to cells, or directly decrease the production of glucose in the liver. However, they have several drawbacks, such as limited efficacy, unacceptable side effects, and poor compatibility. Therefore, extensive screening for new natural antidiabetics is warranted. Diabetes can now be classified as type 1, an autoimmune disease, or type 2, which is characterized by insulin resistance with a relative defect in insulin secretion. Additional subgroups of diabetes have been described and dichotomy into those with minimal or no residual β-cell function (i.e., type 1 and monogenic) and those with at least some remaining β-cell function

(i.e., type 2 and other). Diabetes can present in multiple ways: in childhood as classic hyperglycemic hyperosmolar new-onset diabetes or diabetic ketoacidosis due to avoidance or delay in treatment. In elderly individuals, it can present perturbation of consciousness due to hyperglycemia or, in a more fulminant fashion, due to immune-mediated β-cell loss leading to exclusive dependence on exogenous insulin. The hallmark of diabetes is hyperglycemia resulting from excessive hepatic glucose output, defective glucose utilization in insulin-dependent tissues, and excessive lipolysis resulting in hyperketonemia and consequent metabolic acidosis. It is accompanied by polydipsia, polyuria, polyphagia, weight loss, dehydration, hypovolemia, with metabolic acidosis in type 1 diabetes. The glycemic threshold for symptoms of osmotic diuresis is exceeded (i.e., >180 mg/dL) [7, 8].

Current Management Strategies

The World Health Organization (WHO) reports that diabetes is becoming an epidemic worldwide. This chronic condition results from a deficiency of insulin, disturbing carbohydrate, fat, and protein metabolism. Defined by the American Diabetes Association, diabetes mellitus causes hyperglycemia due to defects in insulin secretion or action. The rising prevalence has highlighted the need for new therapeutic strategies to lessen the economic burden on patients and healthcare systems. Plants have been valuable sources in discovering new drug candidates, as natural products have been instrumental in combating various diseases, including diabetes. Both plants and plant-derived compounds exhibit diverse biological activities such as antimicrobial, anti-inflammatory, and antioxidant effects that promote human health. Diabetes, marked by hyperglycemia, is classified into Type 1 and Type 2. Type 1 diabetes, due to autoimmune destruction of pancreatic β-cells, requires insulin treatment, while Type 2, characterized by insulin resistance, is more common. Various antidiabetic drugs, including thiazolidinediones and GLP-1 analogs, work through different mechanisms to improve insulin sensitivity and secretion or diminish glucagon action and glucose absorption. However, these medications can lead to severe side effects on non-target organs. The search has intensified for new drug candidates from traditional medicinal plants that can regulate blood glucose levels with fewer side effects. For centuries, medicinal plants have been fundamental in preventing and treating diseases, especially in developing countries where over 80% rely on traditional medicine. Such plant-based treatments are often considered more affordable and effective than synthetic drugs prone to toxicity and resistance. Consequently, global initiatives have been launched to explore plants for therapeutic benefits. Some drug candidates derived from plant extracts have shown efficacy surpassing conventional therapies. There is significant research dedicated to identifying bioactive compounds in medicinal plants with antidiabetic properties, essential for rational application in diabetes management [9, 10].

Medicinal Plants Overview

Diabetes mellitus (DM) is a chronic metabolic disorder marked by hyperglycemia stemming from impaired insulin secretion or action. It involves risk factors such as dyslipidemia, hypertension, and various complications, significantly impacting both health and mortality globally. The pancreas, an endocrine and exocrine gland, plays a crucial role in synthesizing digestive enzymes and regulating blood glucose through insulin and glucagon secretion. There are four main types of diabetes: Type 1, Type 2, Gestational, and Maturity Onset Diabetes of the Young. The global incidence of diabetes is sharply rising, increasing the demand for effective pharmaceuticals. Treatments primarily include oral hypoglycemic agents that inhibit enzymes like α-amylase and α-glucosidase, which hydrolyze carbohydrates. Researchers are focusing on medicinal plants documented for their historical use in diabetes treatment as potential sources for new agents. Traditional medicine offers cost-effective therapies utilizing local medicinal plants, which can help regulate blood glucose, promote insulin secretion, manage lipid profiles, and reduce protein breakdown. These plants can also mitigate complications associated with diabetes, such as retinopathy, neuropathy, nephropathy, foot ulcers, and impotence. Many urban populations utilize antidiabetic herbal products, although only a few plant species have been noted for their antidiabetic properties. Herbal agents with such properties include Azadirachta indica, Centella asiatica, Ficus racemosa, and others. Various parts of these plants' leaves, fruits, flowers, roots, bark, and seeds are utilized for their antidiabetic effects, with bioactive compounds isolated from roots, stems, and foliage demonstrating such activity [11, 12].

Nutritional Components of Medicinal Plants

Bioactive compounds are the ones that are produced by plants' secondary metabolism, which refers to chemical components of plants. They are a diversity of phytochemicals, including flavonoids, terpenoids,

alkaloids, phenolic acids, tannins, glycosides, saponins, coumarins, phytosterols, and others that have biological activity, and therefore are useful to the production of medicinal/therapeutic products. Medicinal plants studied for the preparation of teas, tinctures, and extracts worldwide typically contain those compounds that can lower blood sugar levels in mammalian subjects, particularly in those suffering from diabetes mellitus. These compounds act directly through a variety of mechanisms, including stimulating the pancreas to produce insulin and inhibiting glucose metabolism to slow down the absorption of glucose by the intestine. Some compounds enhance the efficacy of insulin and dihydroalpinidine, and others bind sodium glucose co-transporters, blocking glucose reabsorption. Medicinal plants are rich in components of dietary interest such as polysaccharides, peptides, polyunsaturated fatty acids, vitamins, and minerals, and due to such content, they are not exclusively medicinal. It is well known that a variety of herbs and spices included in the diet are actually used in traditional and folk medicine in many parts of the world, one of the most well-known examples being the Mediterranean Diet. Since the dawn of civilization, mankind has used herbs and spices for the preservation and flavoring of food, as well as in folk medicine and for religious rituals. For their activity in delaying the onset of a broad range of afflictions, many useful diet preventive properties have been proposed, yet, probably due to its complexity and the relatively low bioavailability of some of the ingredients, many of those proposed activities were nevertheless not been confirmed. A plant's medicinal function is often multi-component and poly-targeted area with a wide variety of compounds being present in the raw material [13, 14].

Key Medicinal Plants for Diabetes Management

Diabetes mellitus (DM) is a chronic condition marked by elevated blood glucose levels, caused by inadequate insulin production or insulin's ineffectiveness in helping glucose enter cells for energy. There are three types: Type I, Type II, and Gestational diabetes. Long-term hyperglycemia can cause severe organ damage, affecting the eyes, kidneys, nerves, heart, and blood vessels. Most diabetes cases are Type II, linked to sedentary lifestyles, poor diets, stress, pollution, and genetics. The global prevalence of diabetes is increasing, with projections rising from 537 million in 2021 to 643 million by 2030. Although several medications effectively control blood glucose, they can have side effects. Herbal medicine, using plants to treat diseases, has been part of traditional practices and is utilized for diabetes management. Natural anti-diabetic products hold promise for drug discovery and are preferred in developing countries due to their lower cost and safety compared to synthetic options. Current research focuses on medicinal plants for diabetes treatment. Advances in pharmacognosy and pharmaceutical techniques have facilitated the development of effective, low-side-effect anti-diabetic medicines, leading to greater use of these plants in long-term diabetes care [15, 16].

Mechanisms of Action

Discovery and detailed understanding of antidiabetic drugs in the present day are critical to the management of diabetes, and knowledge of many plant-based therapies has also been transmitted through generations. Understanding the contributing phytoconstituents actually responsible for the pharmacological activity, development of potent single drugs exhibiting higher potency or bioavailability with lesser side effects resembling the potent multiphytocomponent traditional medicine is a direction of this expertise. The results obtained from this study could be useful for the sustainable development of novel potent single anti diabetic drugs from the above plants. Due to the complexity of chemical contents of crude extract or polyherbal drugs, norms of drug discovery have been innovative and represent a new direction of research. Fifty-one pharmacologically active antidiabetic phytomolecules isolated from twenty-six traditional antidiabetic plants of Bangladesh have been comprehensively and critically reviewed and information has been provided on the traditional uses, target proteins/enzymes, categories, therapeutic role, active phytoconstituents, aqueous/ethanolic extract of plants, and structure enhancement as a direction of new drug discovery. As many of the mentioned plant-based therapies have been traditionally used for the management of diabetes in Bangladesh, there may be many other undiscovered/multi-target phytochemicals that may also effectively manage diabetes outside the given review. Plants are complex systems of chemical compounds of diverse structures and reactivity, and the antidiabetic activity is likely dependent upon the presence of selected phytochemicals with multiple actions on different biotargets. Bioactivity-directed molecule isolation from these plants may lead to the generation of potent single anti diabetic drugs or lead molecules similar or superior in activity/responsiveness to the potent multiphytocomponent traditional medicine [17, 18].

Clinical Evidence and Studies

Nicknamed “sugar disease” or “sugar urine disease” for the first appearance of “the thousand symptom diseases” in history, the very essence of diabetes mellitus is incorrectly categorized as glucose metabolism disorders. Due to hereditary defects of insulin action or secretion, patients suffer from insatiable thirst, weight loss, frequent urination, leg and foot diseases, coma, and many chronic complications (i.e., hypertension, atherosclerosis, nephropathy). Diabetes is one of the most common metabolic diseases in the world, resulting in huge social and economic costs. It has long been reported that medicinal plants have antidiabetic action, and are used with food in many societies. The antidiabetes plants could control glucose metabolism through various mechanisms. Several trials for efficacy and safety have been conducted in humans. Epidemiological observational studies indicate that it is possible to prevent diabetes with some foods and medicinal herbs. Despite promising clinical benefits, quality assessment, and possible mechanisms of herbal prescription, the current literature is reviewed. Phytotherapy has long been a source of significant medicinal products for the treatment of diabetes. Diabetes is one of the most widespread diseases, with many severe complications causing a heavy burden on afflicted patients and society as a whole. Over the past few decades, significant advancements have been made in prevention and treatment that considerably ameliorate symptoms. The pharmaceutical industry has developed several chemical drugs, including metformin, glinides, sulfonylureas, thiazolidinediones, and (for type 2 diabetes) DPP4 inhibitors and GLP1 receptor agonists, all of which have significantly improved patients' health. However, the long-term use of these drugs produces adverse side effects, including gastrointestinal discomfort, skin reaction, liver reaction, renal reaction, hypoglycemia, weight gain, and increased chances of heart attack. Moreover, they are too expensive for low-income patients in developing countries, who continue to seek other therapeutic agents for diabetes [19, 20].

Safety and Toxicity of Medicinal Plants

Diabetes mellitus is a chronic metabolic disorder characterized by hyperglycemia, which results from a deficiency in insulin production and/or failure of insulin to exert its action on the tissues. Plants are an excellent source of bioactive anti-diabetic agents that possess antioxidant properties and may enhance insulin sensitivity. The medicinal use of plants for the prevention and treatment of different diseases has been practiced for centuries; however, the utilization of plant-derived material as therapeutic agents warrants investigations for their safety and toxicity aspects. Studies emphasizing the safety and toxicity aspects of medicinal plants and their bioactive derivatives with anti-diabetic activity have been presented. Safety and toxicity issues regarding crude extracts or isolated phytoconstituents of different plant species, along with antidote agents, are also reviewed. Safety is the main concern for herbal medicine practitioners after obtaining the medicinal plant material. Insulin and biguanides, however, are not known to induce carcinogenic deposits in body tissues and are therefore safer to use for a prolonged duration. On the contrary, phenformin, validated for its anti-diabetic activity, is unsafe and retractable in many countries. The anticancer effect of dibenamine and phenformin is, however, worth noting. Some bitter herbal plants and thiazolidinedione anti-diabetic medicines have been reported to produce weight gain. These safety issues fail to include drug-herb interaction effects on the pharmacodynamics or pharmacokinetics of any drug. Antidotes of certain hypoglycemic agents like sulfonylureas are discussed. The advent of medication-based anti-diabetic agents is a boon, as these agents prevent the dreaded complications of diabetes and save many lives. However, the safety of prolonged use remains an open question for these agents, as the side effects also add to the risk-to-benefit ratio. Preclinical as well as clinical bio-assay studies quantifying endogenous bioactive constituents of the high-demand herbal nano-formulations with novel routes of administration for diabetes treatment need to be initiated. This will pave the path for the popularization and commercialization of herbal products for diabetes treatment [21, 22].

Integrating Medicinal Plants into Diabetes Care

Patients with diabetes need to adopt lifestyle modifications, including diet control, exercise, weight loss, abstinence from alcohol, reductions in smoking, and stress management. Proper diet management includes the proper choice of food for health, a carbohydrate-controlled diet to achieve normal body weight, and avoiding excessive sweet food. Herbal/medicinal plants or their formulations can be used as adjuncts along with lifestyle modifications. Several medicinal plants have been put forth for their anti-diabetic effects in traditional medicine practices. Recent pharmaceutical research has yielded medicinal plants with potent natural anti-diabetic molecules, and understanding their mechanistic pathways. Many types of herbal plants and their phytochemicals have gained immense popularity over the years, having

been widely investigated in the pharmaceutical, chemical, and health-care industries. Comprehensive phytochemical and pharmacological research on natural products opened up broad prospects for discovering multi-potent drug models necessary in current medicine. Several undiscovered active biophytomolecules from plants are still periodically being documented and evaluated for their biological properties. To evaluate the anti-diabetic effects of newly discovered herbal plants and biocompounds, various pharmacological protocols have been developed in laboratories around the world. The extraction and bioactivity evaluation protocols are individualized based on the resources available in the laboratories. A detailed methodology of extraction, biophytocompound isolation, utilization, and bioactivity evaluation methodologies after conducting extensive literature research is presented here [23, 24].

Future Directions in Research

Future work will focus on isolating, purifying, and identifying bioactive substances from plants, enhancing understanding of anti-diabetic functional foods, and drug development. Scientists continue their efforts globally to extract bioactive compounds from edible plants for treating and preventing diabetes. While in vitro and in vivo results are promising, challenges remain in extracting phytochemicals from natural sources and integrating herbal therapy into daily life. Certain compounds like naringenin, curcumin, and berberine show anti-diabetic activity in models and trials, but their poor solubility limits absorption and bioavailability. Lack of knowledge on how to consume plants in various forms, such as tea or capsules, is another barrier. Stakeholders agriculturalists, chemists, pharmacists, community health workers, and policymakers, need to address these issues and promote herbal therapies in diets. Traditional medicinal plants, proven effective over centuries in folk medicine, require comprehensive research, particularly on those showing potent anti-diabetic effects in type 2 diabetes models and lesser-known ethnomedical herbs. Moreover, medicinal plants studied less extensively also need systematic research for their potential as clinical therapeutic agents or functional food ingredients. Advances in phytochemical studies could lead to active principles with improved solubility and efficacy, enhancing biological activity via potent β-glucosidase and α-amylase inhibitors. Leveraging bioactive compounds from traditional anti-diabetic and other medicinal plants may enhance efficacy and safety in treatments [25-32].

CONCLUSION

Medicinal plants represent a valuable, multifaceted resource in the management of diabetes mellitus, offering both therapeutic and nutritional benefits. Their rich composition of bioactive compounds, ranging from flavonoids and alkaloids to polyphenols and essential minerals, supports glucose regulation, enhances insulin activity, and reduces oxidative stress. Unlike many synthetic drugs, plant-based interventions are generally more affordable, accessible, and culturally accepted, especially in low- and middle-income regions. While traditional knowledge provides a strong foundation, the integration of medicinal plants into modern therapeutic frameworks requires rigorous scientific validation, standardization of dosages, and evaluation of long-term safety. With growing evidence of efficacy from both preclinical and clinical studies, medicinal plants hold significant promise as adjunctive or alternative treatments for diabetes, potentially reshaping strategies for sustainable and holistic healthcare.

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