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The Role of Medicinal Plants in Supporting Gut Health in Diabetic Patients

Nalongo Bina K.

Faculty of Medicine Kampala International University Uganda

ABSTRACT

Type 2 diabetes mellitus (T2DM), a metabolic disorder marked by insulin resistance and progressive β-cell dysfunction, is on the rise globally and is often accompanied by chronic complications. Recent scientific interest has shifted toward the gut microbiota's role in the development and management of T2DM. Dysbiosis an imbalance in gut microbial communities has been strongly linked to impaired gut barrier function, systemic inflammation, and metabolic dysfunctions that exacerbate hyperglycemia. Medicinal plants, especially those used in traditional systems like Chinese herbal medicine, present a promising avenue for restoring gut homeostasis and modulating metabolic pathways. This paper explores the potential of bioactive components in medicinal plants, such as polysaccharides, flavonoids, and saponins, to regulate gut microbiota and support glycemic control. Focusing on *Astragalus membranaceus* and other synergistic herbs, we analyze the mechanisms by which these natural compounds enhance intestinal integrity, reduce inflammation, and stimulate beneficial microbial growth. Understanding the gut–diabetes axis and identifying efficacious plant-based interventions may revolutionize integrative and preventive approaches to diabetes care.

Keywords: Type 2 Diabetes Mellitus (T2DM), Gut Microbiota, Medicinal Plants, Astragalus membranaceus, Dysbiosis, Phytochemicals, Insulin Resistance, Traditional Chinese Medicine.

INTRODUCTION

Diabetes mellitus (DM) is a chronic metabolic disorder globally affecting 422 million people. Type 2 diabetes mellitus (T2DM) is a combination of insulin resistance and progressive pancreatic islet dysfunction. It is one of the biggest drivers of morbidity and mortality and can lead to severe complications such as cardiovascular disease, blindness, and kidney failure. New approaches to T2DM treatment are urgently required due to concerns over the effect of long-term use of T2DM drugs and their side effects. Current T2DM medications treat high glucose levels. Recent research indicates the gut microbiota considerably contributes to the development and management of T2DM. Diabetes susceptibility is determined by complex interactions between hereditary factors, environmental exposures, and gut microbiota. The gut microbiota participates in regulating metabolic homeostasis. A Western-style diet, which has high-calorie fat and protein content and low fiber, results in gut dysbiosis, which causes abnormal propagation of antibiotics and pathogenic bacteria. In turn, gut dysbiosis leads to functions of mucosa barrier disruption, low-grade inflammation, and increased short-chain fatty acids, contributing to glucose and lipid metabolism disorder and hepatic steatosis, thus causing T2DM. Therefore, restoring a balanced composition of the gut microbiota or improving gut barrier function is viewed to be the new direction for T2DM prevention and intervention. Astragalus membracnaceus, a traditional Chinese herb, is used as an adjuvant therapy for diabetes. Previous research indicates its bioactive constituents have therapeutic effects on diabetes. Astragalus polysaccharides enhance glucose utilization in the liver and skeletal muscle in vitro and in T2DM rat models. Astragalus total flavonoids lower glucose tolerance and drive abnormal gut microbiota back to normal in T2DM mice. Astragaloside

IV reduces intestinal barrier permeability by enhancing immune function in high-fat diet-fed mice. Astragalus total saponins regulate the gut microbiota to maintain the stability of xylanase producers [1, 2].

Understanding Gut Health

Gut health is important to maintain overall health; a healthy gut means a healthier person. Digestive health is an integral part of gut health, which includes gut luminal contents, gut epithelium cells, and gut-associated lymphoid tissue. Digestive health is defined as the ability to process food, absorb nutrition, eliminate waste, and regulate immune functions. The gastrointestinal tract is not only responsible for the digestion and absorption of food but it also has an immune function to regulate glucose metabolism, water balance, and production of biologically active molecules. Concentration of short chain fatty acids, diversity of gut microbiome, and an intact mucosal barrier are key aspects that need to be maintained for good digestive health. A reduction in gut microbe diversity or an increase in the Firmicute/Bacteroidete ratio is associated with various diseases for example; increased concentration of Bacteroides is linked to over intake of fat and monosaccharides, which lead to obesity and hyperglycemia state and decreased Lactobacilli and bifidobacterial strains, which are involved in prevention of non-alcoholic fatty liver disease. At the individual level, a shift away from a high-fiber and low-fat intake is linked to a reduction in gut microbe diversity. The gut microbiome has also been suggested as a third friend or organ alongside of the liver and pancreas in the regulation of glucose metabolism. A diet rich in dietary fibber results in reduced concentration of acetate, propionate, and butyrate compared to a low-fiber diet. A high-fat diet also reduces the abundance of Lactobacillus, which leads to an impaired intestinal barrier and glucose tolerance. Dietary components from various plant sources such as fruits, vegetables, whole grains, fermented foods, and tea play an important role in the prevention and management of gut health [3, 4].

Definition of Gut Health

Gut health is essential for human well-being, providing an ideal environment for the colonization of various native microorganisms. The gut microbiota provides beneficial effects on human health through diverse metabolic and biological activities that miraculously protect the human body against infection by pathogenic microbes, facilitate digestion and absorption of nutrients, maintain gut integrity, and modulate the development and maturation of the immune system. Any disruption to these homeostatic conditions might result in gut dysbiosis that is characterized by reduced diversity and composition of gut microbiota, altered metabolic activity of gut microbes, and abnormalities in gut physiology or immune function. Gut dysbiosis has been causally linked to the development of a plethora of diseases, including metabolic disorders such as diabetes mellitus (DM), obesity, and metabolic syndrome. DM is a heterogeneous disorder characterized by hyperglycemia due to defects in insulin secretion or action or both. According to the global diabetes statistics, about 537 million adults in the age range of 20–79 years had diabetes in 2021. The majority of diabetes cases were type 2 diabetes (T2DM), accounting for nearly 90% of all DM cases and affecting 483 million adults across the globe. T2DM has a progressive nature that is initially characterized by insulin resistance (IR). Later on, the IR condition worsens, and pancreatic β-cell insulin secretion begins to fall. Apart from T2DM, type 1 diabetes (T1DM) is the second most common type of diabetes, accounting for about 5%–10% of all DM cases. T1DM is caused by the autoimmune loss of insulin-producing pancreatic β-cells, leading to absolute insulin deficiency and resulting in hyperglycemia and ketogenesis [5, 6].

Importance of Gut Microbiota

The human gut microbiota, consisting of approximately 10^13–10^14 microbial cells, plays a vital role in maintaining human health. Gut health is regarded as important to the overall health of an individual, influencing immune function and resistance to diseases. Although considerable research has indicated that gut microbiota and the gut microbiome are implicated in the initiation and/or progression of various diseases, little data is available on the composition and activity of gut microbiota in adults with T2DM. This immense community of gut microbial cells is thought to affect human health and diseases via their metabolism of dietary compounds or host biochemicals, thereby impacting metabolism, immunity, inflammation, and obesity. Nevertheless, it remains to be explored how the composition and activity of gut microbiota are modulated by plant-derived bioactive components or other natural products. Integrative pharmacology has become an important approach for dissecting the mechanism of bioactivities of traditional Chinese herbs. Because gut microbiota is a newly identified drug target for the treatment of common metabolic diseases, such as obesity and T2DM, traditional Chinese herbs that may modulate gut microbiota deserve further investigation. The gut microbiota is an assemblage of trillions of

microbes (bacteria, archaea, viruses, and fungi) residing in the gastrointestinal tract of an individual. There are both inter-individual and intra-individual variations in gut microbial composition, but their richness or diversity is quite constant throughout the human population. Gut microbiota composition is associated with certain diseases, ethnicities, environments, and dietary habits. Studies have demonstrated that the human gut microbiota exerts considerable impact on the metabolism, bioavailability, activity, and toxicity of dietary bioactive components, drugs, and intestinal toxins, and this can, in turn, affect host health [7, 8].

Gut Health and Diabetes Connection

The gut plays a crucial role in health and disease, hosting a complex microbial community that affects human well-being. Various factors like diet, age, genetics, and fitness influence the microbiome. Dysbiosis, an imbalance in gut microbiota, is linked to numerous conditions, including obesity, diabetes, and depression. The global rise in diabetes mellitus (DM) threatens healthcare systems, with dysbiosis particularly affecting type 2 diabetes (T2DM). Human gut microbiota primarily consists of bacteria, and dysbiosis shows reduced diversity, which has been associated with several diseases. Factors like lifestyle, age, and medications shape the gut microbiota's composition. For instance, T2DM patients exhibit a reduction in beneficial gut bacteria, leading to increased intestinal permeability and metabolic inflammation. The gut microbiota is essential in T2DM pathogenesis, and strategies targeting gut dysbiosis could improve T2DM management. Dietary interventions, including fibers, polyphenols, probiotics, and anti-diabetic herbs, along with physical activity, have shown potential in modulating gut microbiota to confer anti-diabetic effects [9, 10].

Diabetes Overview

Diabetes is a type of endocrine disorder characterized by hyperglycemia due to insufficient insulin secretion, insulin resistance, or a combination of these factors. Diabetes is essentially the same as hyperglycemia, which is the accepted universal terminology for higher blood glucose levels. With this characterization, separate disease classifications can be made: type 1 diabetes is described as autoimmune type diabetes due to a selective deficiency of insulin secretion; type 2 diabetes is otherwise expressed as type 2 diabetes mellitus or non–insulin-dependent diabetes due to insulin resistance and a relative deficiency of insulin secretion; and gestational diabetes is referred to as glucose intolerance during pregnancy and is less considered a stereotyped type of disease. With advancing age, the incidence of type 2 diabetes markedly increases and accounts for the majority of diabetes cases worldwide. The need for treatment of diabetes becomes more pressing with the increasing incidence. Current treatments include lifestyle changes, oral medicine, and insulin injections, all of which have undesirable side effects along with efficacy. Among them, medicinal plants may provide more suitable alternatives. A herbal remedy can alleviate disease symptoms, whereas tinctures from herbal substances already separated may have wider uses. Considerable numbers of plants are used for diabetes treatment in folk medicine across the world, some of which have been pharmacologically and clinically confirmed to alleviate insulin resistance and lower blood glucose. Large-scale bioassay-guided chemiscreened or primary activity screening trials have identified these plants for further investigation of the active principles [11, 12].

Medicinal Plants: An Overview

Medicinal plants play a vital role in diabetes treatment, offering various antihyperglycemic benefits. Their key actions include enhancing insulin secretion, glucose uptake, improving insulin sensitivity, and delaying carbohydrate absorption. Effective diabetes management is crucial to avoid complications associated with this chronic condition, which is characterized by high blood glucose levels due to insufficient insulin or insulin resistance. In 2021, approximately 537 million individuals were affected by diabetes, and the number is expected to rise to 783 million by 2045. Persistent hyperglycemia can lead to severe complications like nephropathy, neuropathy, retinopathy, and atherosclerosis, caused by the nonenzymatic glycation of biomolecules. Thus, early detection and effective blood glucose control are essential and can be achieved through lifestyle changes, medications, or both. The treatment plan typically includes two classes of oral hypoglycemic agents: insulin secretagogues, which promote insulin release from β cells, and insulin sensitizers. Over 500 plant species have been identified for diabetes treatment, with many gaining acceptance in clinical settings due to their beneficial effects. Although numerous medicinal plant extracts show promise in regulating blood glucose levels based on experimental findings, few have undergone rigorous pharmacological evaluation and clinical trials. These plants have historically contributed to diabetes management through traditional medicine practices worldwide [13, 14].

Mechanisms of Action of Medicinal Plants

The use of medicinal plants for gut health and diabetes treatment is fundamental in traditional medicine, where herbs, powders, tinctures, juices, and teas are applied. The DOC method avoids tools or chemicals, making it economical and secure. Antidiabetic plants and phyto-nutraceuticals, which are secondary metabolites, possess pharmacological effects on diabetes mellitus. Nanocaloric herbal medicines and bioactive components may reduce blood glucose through the gut-brain axis and neuro-hormonal signaling, with flavonoids and phenolics identified as significant phyto-comparable molecules. The mechanism of transcriptional control can be disrupted by the electrophilic substitution in 8-prenyl quercetin, impacting the interaction between various proteins that subsequently regulates glucose production and testosterone concentration. Additionally, a structural basis exists for phenols targeting CK2, hinting at their potential in anti-cancer pathways. Medicinal plants act on multiple physiological processes by interacting with cellular proteins. The antidiabetic effectiveness of these plants relies on phytochemicals, such as flavonoids and terpenoids, to lower blood sugar via various mechanisms. Phytochemicals can influence insulin secretion and action pathways, leading to improved glucose transport and reduced insulin resistance. Numerous medicinal plants and their active compounds can enhance glucose uptake, thereby lowering serum glucose levels in diabetic individuals, through mechanisms like activating insulin-like signaling and enhancing transporter expression in target tissues [15, 16].

Key Medicinal Plants for Gut Health

Herbal medicine research has provided a wide variety of herbs with optimal effects and safety for treating gut health disorders. Therefore, herbs that have been well-studied and have been used to promote gut health are listed here. Recent studies have reported that 179 types of herbs exert their effects on gut health disorders, accounting for 44.37% of the total herbs collected. However, one herb was selected for its heavy emphasis on gut health disorders or medications in the literature, which is the main source of medicinal plants for gut health disorder treatments in this system as shown in the figure. Astragalus (Huangqi) is a herb that is widely used in traditional Chinese medicine and has also been used in Western countries as an herbal remedy. Astragalus contains antioxidants, anti-inflammatory agents, and polysaccharides that have important functions in regulating gut immunity and inflammation and promoting the growth of bacteria beneficial to human health. Datong Jiangjun addition selected Honey Gum, Bai Wood and Earth, Panax Ginseng, and Saposhnikovia Divaricata to Astragalus as the pilot herbal Teas in 12 Series that makes gut healthier. These herbs have been used in traditional Chinese medicine therapy for nearly 2000 years either singly or in combinations, and their actions, composing components, possible biliary mechanism, and action targets has been extensively studied. Herbal Family Co., Ltd called this pilot tea as "Tea Everytime" [17, 18].

Research Studies and Findings

Numerous studies have explored gut health's impact on diabetes. This includes research on medicinal plants' effects on gut health and glycaemic control. Systematic reviews and meta-analyses have also investigated these plants. One notable study analyzed the gut health benefits of medicinal plants for diabetic patients in a double-blind, placebo-controlled trial involving 70 participants. They were divided into treatment and placebo groups, with the former receiving a herbal mix of 17 plants over 8 weeks, while the latter received a control treatment. Participants' dietary habits and physical activity were monitored throughout. A comprehensive questionnaire assessed demographics, dietary intake, physical activity, quality of life, and gastrointestinal symptoms, while faecal samples aided microbiome analysis. Biochemical assessments evaluated glycaemic control post-intervention. Results showed the treatment group had significant glycaemic improvements, linked to increased beneficial gut microbes and reduced harmful ones, as analyzed via next-generation sequencing. Linear regression indicated that dietary intake of Matahonda herb, Indian glycyrrhiza, and Abu Shahar may enhance glycaemic control and alleviate gut dysbiosis and gastrointestinal symptoms, positively affecting quality of life. Despite these findings, the study faced limitations, such as a small sample size, indicating a need for larger, multi-center trials to confirm results [19, 20].

Integrating Medicinal Plants into Dietary Practices

Promoting gut health in diabetic patients using medicinal plants requires integrating them into dietary practices. These dietary supplements can be consumed in various forms, such as teas, powders, or capsules. The choice of dietary supplement form often depends on local customs, personal preferences, and convenience. In some cases, medicinal plants are mixed with various foodstuffs to enhance flavor or

nutrient density. Traditional practices surrounding medicinal plant use are often lost in younger generations; thus, it is essential to pass along knowledge of local practices and plant taxonomy, as it relates to their beneficial use. Traditional food preparations have long been a prime approach to incorporate medicinal plants into the diet . With proper drying and cooking methods, several medicinal plant materials can be formulated into dried food products. Fermentation methods offer a unique way to modify sensory attributes, improve the shelf life of products, and increase their health-promoting properties. In addition, smoothies have become popular while maintaining quality nutrition, as they are a convenient way of consuming various fruits and vegetables. Climate-smart activities can introduce traditional crops, which are water- and nutrient-efficient, drought-resistant, and resilient to climate change. Dietary practices can mediate the efficiency of prebiotics and probiotics, also referred to as synbiotics. These dietary practices are either direct, where dietary ingredients elicit a gut microbiome alteration, or indirect, whereby a dietary ingredient alters the host metabolism to change microbiome composition. Many of the above-highlighted dietary practices fall within the latter category. Both approaches may enhance microbial survival in harsh gastrointestinal conditions and improve their effectiveness. More rigorous studies are warranted to explore these knowledge gaps, as multiple plant options are traditionally used as food supplements or functional foods [21, 22].

Future Directions in Research

A systematic inquiry on newly discovered antidiabetic plants and their bioactive compounds in Tamil Nadu, India, is essential. Researchers conducted a literature survey on Palani hills medicinal plants due to the need for science-based validation and bioactive compound profiling. Herbs not only treat diseases but also promote metabolic homeostasis, gut well-being, and functional balance. Gut health is crucial for blood glucose metabolism; however, diabetes complicates this, making gut pathogens a concern. Diabetic patients may experience increased colonic PO4 concentration and gut microbiota dysfunction. Reduced gut well-being arises from low-grade inflammation affecting metabolic activity. Psyllium provides insoluble fiber and mucilage that may lower diabetes risk. Future studies should focus on profiling bioactive compounds in konjac and psyllium, exploring the metabolic mechanisms, and assessing gut health in preclinical models. Aloe vera is known to improve gut health and may protect against diabetes by modifying gut microflora. Aloe barbadensis is an antidiabetic functional food supporting gut health, with protective phytochemicals like β-sitosterol, aloin, and aloe-emodin. Further studies should explore additional bioactive compounds and β-sitosterol's preventive role in diabetes within experimental models. Curcumin from Curcuma longa is safe for diabetic patients and alleviates diabetic pathophysiology through various organs, also helping gut health. Longitudinal studies are needed to evaluate pharmacokinetics, dynamics, and curcumin-like compounds for glucose-lowering effects. A rarer bioactive compound, 18β-glycyrrhetinic acid, is safe and has potential for gut modulation in GI ailments, though anti-diabetic studies on it are lacking [23, 24].

CONCLUSION

The integration of medicinal plants into diabetes management represents a novel, holistic approach to tackling the complex pathophysiology of T2DM. As the gut microbiota emerges as a central player in metabolic regulation, restoring microbial diversity and gut barrier integrity through plant-based compounds offers significant therapeutic promise. Herbs such as *Astragalus membranaceus* have demonstrated multifaceted effects ranging from anti-inflammatory and immunomodulatory to microbiota-regulating and glucose-lowering actions. These plants may act synergistically with dietary fibers and probiotics to reestablish gut homeostasis, thereby enhancing insulin sensitivity and controlling blood glucose levels. While traditional medicine has long acknowledged these benefits, modern pharmacological and clinical validations are essential for integrating these practices into mainstream healthcare. Future research should emphasize well-designed clinical trials, mechanistic studies, and integrative pharmacology to fully harness the potential of medicinal plants as safe, effective, and sustainable interventions in the management of T2DM through gut health modulation.

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