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ANTIDIABETIC POTENTIAL OF MEDICINAL PLANTS

Miss: Pradnya Gokul Babar, Dr.Naziya Tamboli
Sahyadri College Of Pharmacy Methwade, Sangola

Abstract:
Diabetes mellitus is a chronic metabolic disorder characterized by persistent hyperglycemia resulting from defects in insulin secretion, insulin action, or both. The global prevalence of diabetes is increasing rapidly, leading to serious health and economic burdens. Although several synthetic antidiabetic drugs are available, their long-term use is often associated with adverse effects and high cost. Medicinal plants have been traditionally used in the management of diabetes due to their safety, affordability, and therapeutic efficacy. Various medicinal plants exhibit antidiabetic activity through multiple mechanisms such as stimulation of insulin secretion, enhancement of glucose uptake, inhibition of carbohydratedigesting enzymes, and antioxidant effects. This review highlights commonly used medicinal plants with antidiabetic potential, their active constituents, mechanisms of action, advantages, limitations, and future prospects in diabetes management. Traditional systems of medicine such as Ayurveda, Siddha, Unani, and folk medicine have long utilized medicinal plants for the treatment of diabetes. Numerous medicinal plants, including Gymnema sylvestre, Momordica charantia, Syzygium cumini, Trigonella foenum-graecum, Salacia reticulata, and Tinospora cordifolia, have demonstrated significant antidiabetic activity in in vitro and in vivo experimental models. These plants exert their effects through multiple mechanisms, such as stimulation of insulin secretion, enhancement of insulin sensitivity, inhibition of carbohydrate-digesting enzymes, reduction of oxidative stress, and protection of pancreatic β-cells.
***Keywords**: Antidiabetic activity, Medicinal plants, Diabetes mellitus, Herbal drugs, Phytochemicals*

Corresponding author:
Pradnya Gokul Babar,
Sahyadri College Of Pharmacy Methwade, Sangola

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INTRODUCTION:

Diabetes mellitus is a complex, chronic metabolic disorder characterized by elevated blood glucose levels due to impaired insulin secretion, insulin resistance, or a combination of both[1].It affects carbohydrate, fat, and protein metabolism and leads to severe long-term complications if not properly controlled[2].The incidence of diabetes has increased dramatically over the past few decades, making it one of the most challenging global health problems of the 21st century[3].According to the International Diabetes Federation, India is among the top countries with the highest number of diabetic patients and is often referred to as the "diabetes capital of the world"[4].Rapid urbanization, sedentary lifestyle, unhealthy dietary habits, obesity, and genetic predisposition are the major contributing factors to the increasing prevalence of diabetes mellitus[5].The disease not only affects the quality of life of patients but also places a significant economic burden on healthcare systems worldwide[6].Currently available antidiabetic therapies include insulin and various classes of oral hypoglycemic agents such as sulfonylureas, biguanides, thiazolidinediones, α-glucosidase inhibitors, and DPP-4 inhibitors[7].Although these drugs are effective in controlling blood glucose levels, they are often associated with undesirable side effects such as hypoglycemia, weight gain, gastrointestinal disturbances, and liver toxicity[8].Moreover, long-term use of synthetic antidiabetic drugs may lead to reduced efficacy and poor patient compliance[9].Due to these limitations, there is growing interest in the exploration of alternative and complementary therapies derived from natural sources[10].Medicinal plants have been used since ancient times in traditional systems of medicine such as Ayurveda, Unani, Siddha, and Traditional Chinese Medicine for the treatment of diabetes[11]. The World Health Organization has also emphasized the importance of traditional medicinal plants in the management of chronic diseases, including diabetes mellitus[12].India possesses a rich biodiversity of medicinal plants, and more than 800 plant species have been reported to exhibit antidiabetic activity[13].Commonly used antidiabetic plants include *Gymnema sylvestre*, *Momordica charantia*, *Azadirachta indica*, *Trigonella foenum graecum*, and *Ocimum sanctum*[14].These plants have shown promising results in experimental and clinical studies by improving glucose homeostasis and insulin sensitivity[15].The antidiabetic potential of medicinal plants is attributed to the presence of bioactive phytoconstituents such as flavonoids, alkaloids, glycosides, terpenoids, phenolic compounds, and saponins[16].Thesephyto chemicals exert their effects through multiple mechanisms, including stimulation of insulin secretion from pancreatic β-cells, enhancement of peripheral glucoseuptake, inhibition of intestinal glucose absorption, suppression of hepatic gluconeogenesis, and antioxidant activity[17].Oxidative stress plays a crucial role in the pathogenesis of diabetes and its associated complications[18].Many medicinal plants possess strong antioxidant properties that help reduce oxidative damage and protect pancreatic β-cells from destruction[19].Thus, plant-based antidiabetic therapies offer dual benefits of glycemic control and prevention of diabetic complications[20].Despite extensive traditional use, scientific validation, standardization, and clinical evaluation of medicinal plants are essential to ensure their safety, efficacy, and quality[21].Recent advancements in pharmacological and phytochemical research have facilitated the identification of active compounds responsible for antidiabetic activity[22].Therefre, systematic investigation of medicinal plants may lead to the development of novel, safe, and effective antidiabetic agents[23].The present study aims to review and highlight the antidiabetic potential of medicinal plants, their mechanisms of action, and their role as a complementary or alternative approach in the management of diabetes mellitus[24].

TYPE 1 AND TYPE 2 DIABETES AND ANTIDIABETIC MEDICINAL PLANTS

Diabetes mellitus is broadly classified into Type 1 diabetes mellitus (T1DM) and Type 2 diabetes mellitus (T2DM) based on etiology and pathophysiology[1].Type 1 diabetes is an autoimmune disorder characterized by the destruction of pancreatic β-cells, leading to absolute insulin deficiency[25].Type 2 diabetes is characterized by insulin resistance combined with relative insulin deficiency and accounts for more than 90% of diabetes cases worldwid[26].

Medicinal Plants Used in Type 1 Diabetes Mellitus

In Type 1 diabetes, medicinal plants mainly act by protecting pancreatic βcells, stimulating residual insulin secretion, and reducing oxidative stress[27].Several plants have shown β-cell regenerative and immunomodulatory effects in experimental studies[28].*Gymnema sylvestre* has been reported to promote regeneration of pancreatic β-cells and increase insulin secretion in insulindeficient diabetic models[29].Experimental studies have shown that *Gymnema sylvestre* leaf extract significantly reduces blood glucose levels in Type 1 diabetic animals [30].Panax ginseng exhibits antidiabetic activity by improving insulin secretion and protecting β-cells from oxidative damage[31].It has been reported to enhance glucose uptake and improve glycemic control in insulin-deficient conditions[32].Tinospora cordifolia has demonstrated immunomodulatory and antioxidant properties that help in reducing β-cell damage in Type 1 diabetes[33].Its ethanolic extract significantly lowers fasting blood glucose levels in streptozotocininduced diabetic rats [34].

Medicinal Plants Used in Type 2 Diabetes Mellitus

In Type 2 diabetes, medicinal plants exert antidiabetic effects mainly by improving insulin sensitivity, enhancing peripheral glucose uptake, inhibiting carbohydratedigesting enzymes, and reducing insulin resistance[35].Most herbal antidiabetic therapies are found to be more effective in Type 2 diabetes mellitus[36].*Momordica charantia* (bitter gourd) has shown insulin-like activity and improves glucose utilization in peripheral tissues[37].It significantly reduces postprandial blood glucose levels by inhibiting intestinal glucose absorption [38].*Trigonella foenumgraecum* (fenugreek) seeds contain soluble fiber and alkaloids that improve insulin sensitivity and delay glucose absorption [39].Clinical studies have reported significant reduction in fasting and postprandial blood glucose levels in Type 2 diabetic patients[40].*Azadirachta indica* (neem) exhibits hypoglycemic activity by enhancing glucose uptake and reducing insulin resistance[41].Neem leaf extract has been shown to reduce blood glucose and improve lipid profiles in Type 2 diabetes[42].*Ocimum sanctum* (*holy basil*) improves insulin secretion and decreases insulin resistance in Type 2 diabetic models[43].Its antidiabetic effect is attributed to flavonoids and phenolic compounds with antioxidant activity [44].

Dual Action Plants (Effective in Both Type 1 and Type 2 Diabetes)

Some medicinal plants exhibit antidiabetic activity in both Type 1 and Type 2 diabetes due to their multiple mechanisms of action[45].*Allium sativum* (garlic) reduces blood glucose levels by enhancing insulin secretion and improving insulin sensitivity[46].*Aloe vera* improves glucose tolerance, protects β-cells, and reduces insulin resistance[47].Thus, medicinal plants provide a multifaceted approach in the management of diabetes mellitus and may serve as potential complementary therapies for both Type 1 and Type 2 diabetes[48].

In *Vitro* and In *Vivo* Studies of Antidiabetic Medicinal Plants

In *Vitro* Studies

In *vitro* studies play a crucial role in the preliminary screening of medicinal plants for antidiabetic activity by evaluating their effects on key enzymes and cellular pathways involved in glucose metabolism[52].Several medicinal plant extracts have demonstrated significant α-amylase and α-glucosidase inhibitory activity, which helps in reducing post-prandial hyperglycemia [32].Extracts of Salacia reticulata showed potent α-glucosidase inhibition due to the presence of salacinol and kotalanol, validating its traditional use in diabetes management[51].

Cell-based in *vitro* assays using pancreatic β-cell lines (INS-1, MIN6) have shown that *Gymnema sylvestre* leaf extract enhances insulin secretion and protects βcells from glucose-induced toxicity[29].Similarly, flavonoid-rich extracts of *Syzygium cumini* seeds improved glucose uptake in L6 myotubes and 3T3-L1 adipocyte cell lines, indicating improved insulin sensitivity [22].Antioxidant-based in *vitro* studies have revealed that plants such as Tinospora cordifolia and Curcuma longa reduce oxidative stress by scavenging free radicals and inhibiting lipid peroxidation, which is essential for preventing β-cell damage[33].

In *Vivo* Studies

In *vivo* studies using experimental animal models provide strong evidence for the antidiabetic potential of medicinal plants[53].Streptozotocin (STZ)- and alloxaninduced diabetic rat models are commonly used to evaluate the hypoglycemic and antihyperglycemic effects of plant extracts[54].

Administration of *Momordica charantia* fruit extract significantly reduced fasting blood glucose levels and improved insulin sensitivity in STZ-induced diabetic rats[37].In *vivo* studies on *Gymnema sylvestre* demonstrated regeneration of pancreatic β-cells and increased plasma insulin level following long-term treatment in diabetic animals[55]. *Trigonella foenum-graecum* seed extract showed significant reduction in blood glucose, cholesterol, and triglyceride levels in diabetic rats, indicating its dual antidiabetic and hypolipidemic activity[39].Animal studies on *Azadirachta indica* leaf extract revealed improvement in glucose tolerance and enhancement of hepatic glycogen content, suggesting modulation of glucose metabolism [42].Chronic in *vivo* administration of Tinospora cordifolia extract significantly reduced oxidative stress markers and prevented diabetic complications such as nephropathy and neuropathy in experimental models[11].

Significance of In *Vitro* and In *Vivo* Studies

In *vitro* studies help identify potential mechanisms of action, while in *vivo* studies confirm the efficacy, safety, and pharmacological relevance of medicinal plants under physiological conditions[56].
Together, these studies provide a scientific basis for the traditional use of medicinal plants and support their further development into standardized antidiabetic formulations[50]

Medicinal Plants with Antidiabetic Potential
Diabetes mellitus is a chronic metabolic disorder characterized by persistent hyperglycemia resulting from defects in insulin secretion, insulin action, or both. The increasing prevalence of diabetes and limitations associated with synthetic antidiabetic drugs have stimulated interest in medicinal plants as alternative or complementary therapeutic agents. Traditional systems of medicine, particularly Ayurveda, Siddha, and Unani, have long utilized medicinal plants for the management of diabetes mellitus.A number of medicinal plants have been scientifically evaluated for antidiabetic activity through in *vitro*, in *vivo*, and clinical studies. Table 1 summarizes major plants along with their botanical family, active constituents, mechanisms, and reported results

Table number 1

Sr No	**Plant name**	***Botanical name***	***Family***	**Active consituent**	**Mechanisms of action**
1	Gurmar	*Gymnema sylvestre*	*Apocynaceae*	Gymnemic acids, saponins	Stimulates insulin secretion; partial β-cell regeneration; inhibits intestinal glucose absorption
2	Bitter gourd	*Momordica charantia*	*Cucurbitaceae*	Charantin, polypeptide-P	Insulin-like activity; increases peripheral glucose uptake; reduces postprandial hyperglycemia
3	Fenugreek	*Trigonella foenum graecum*	*Fabaceae*	4-Hydroxyisoleucine, saponins, fiber	Improves insulin sensitivity; delays carbohydrate absorption
4	Neem	*Azadirachta indica*	*Meliaceae*	Nimbin, nimbidin, flavonoids	Enhances glucose uptake; reduces insulin resistance
5	Tulsi	*Ocimum sanctum*	*Lamiaceae*	Eugenol, flavonoids	Stimulates insulin secretion; antioxidant protection of β-cells
6	Garlic	*Allium sativum*	*Amaryllidaceae*	Allicin, sulfur compounds	Increases insulin secretion; improves insulin sensitivity

7	Aloe	*Aloe vera*	*Asphodelaceae*	Polysaccharides, phytosterols	Improves glucose tolerance; protects β-cells; reduces insulin resistance
8	Guduchi	*Tinospora cordifolia*	*Menispermaceae*	Alkaloids, diterpenoids	Antioxidant activity; β-cell protection; immunomodulation
9	Jamun	*Syzygium cumini*	*Myrtaceae*	Jamboline, ellagic acid	Inhibits α-amylase & α-glucosidase; enhances insulin activity
10	Indian kino	*Pterocarpus marsupium*	*Fabaceae*	Epicatechin	Regeneration of β-cells; increases insulin secretion
11	Cinnamon	*Cinnamomum verum*	*Lauraceae*	Polyphenols	Enhances insulin receptor signaling; improves insulin sensitivity
12	Daruharidra	*Berberis aristata*	*Berberidaceae*	Berberine	Activates AMPK; reduces hepatic gluconeogenesis; improves insulin sensitivity
13	Mango (leaves)	*Mangifera indica*	*Anacardiaceae*	Mangiferin	Inhibits intestinal glucose absorption; antioxidant effect
14	Curry leaf	*Murraya koenigii*	*Rutaceae*	Alkaloids, carbazole	Stimulates insulin secretion; improves glucose tolerance
15	Ashwagandha	*Withania somnifera*	*Solanaceae*	Withanolides	Antioxidant; insulin-sensitizing; protects pancreatic tissue

16	Periwinkle	*Catharanthus roseus*	*Apocynaceae*	Vindoline, catharanthine	Enhances insulin secretion; increases glucose uptake
17	Banyan	*Ficus benghalensis*	*Moraceae*	Flavonoids, tannins	Improves insulin secretion; antioxidant protection
18	Ginger	*Zingiber officinale*	*Zingiberaceae*	Gingerols, shogaols	Improves insulin sensitivity; suppresses hepatic gluconeogenesis
19	Ginseng	*Panax ginseng*	*Araliaceae*	Ginsenosides	Enhances insulin secretion; improves glucose uptake

Mechanisms of Antidiabetic Action of Medicinal Plants

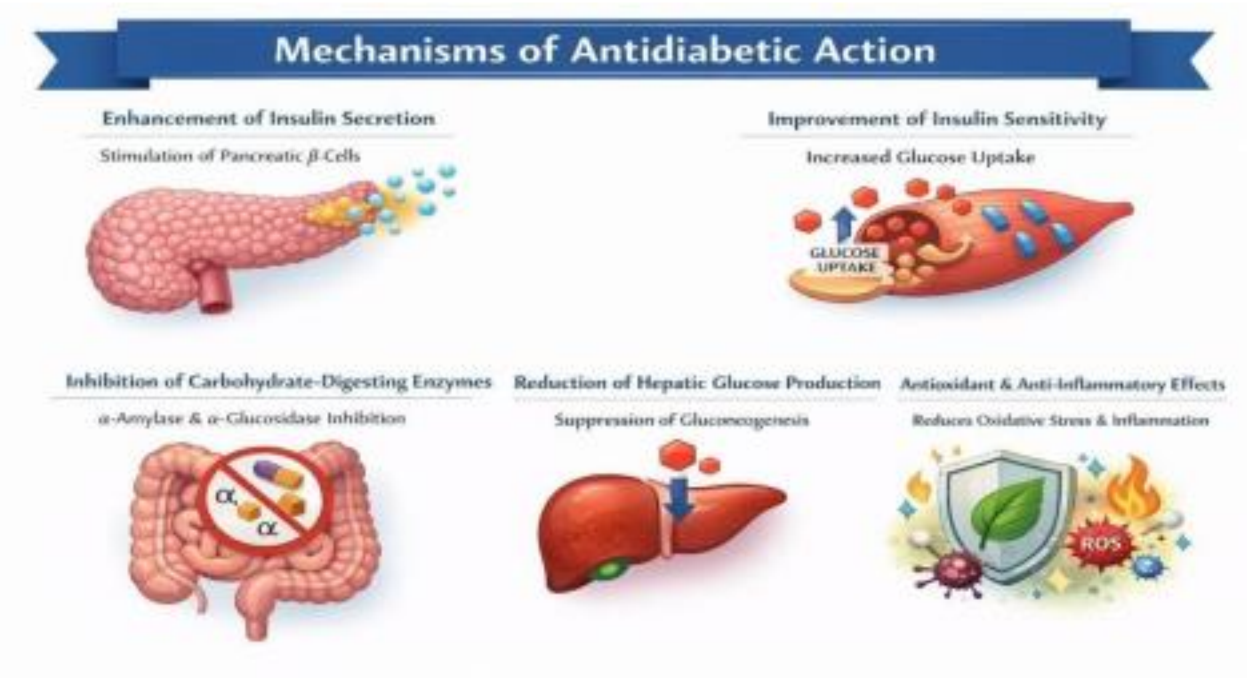

Fig No.1

Medicinal plants exhibit antidiabetic activity through diverse and complementary mechanisms that target multiple pathophysiological defects of diabetes mellitus. One of the most important mechanisms is the stimulation of insulin secretion from pancreatic β-cells. Plants such as *Gymnema sylvestre*, *Ocimum sanctum*, and *Allium sativum* have been reported to enhance insulin release, thereby improving glycemic control in diabetic conditions[8,49]. *Gymnemic acids* present in *Gymnema sylvestre* not only stimulate insulin secretion but also contribute to partial regeneration of damaged pancreatic β-cells [29].

Protection and regeneration of pancreatic β-cells is another significant mechanism by which medicinal plants exert antidiabetic effects. Oxidative stress– induced β-cell damage plays a crucial role in the progression of diabetes mellitus. Plants like *Tinospora cordifolia* and *Aloe vera* possess strong antioxidant and cytoprotective properties that help preserve β-cell integrity and function[33,47]. These effects contribute to improved endogenous insulin availability and longterm glycemic regulation.Several medicinal plants act by improving insulin sensitivity and reducing insulin resistance, which is particularly relevant in Type 2 diabetes mellitus. *Trigonella foenumgraecumenhances* insulin sensitivity through the action of 4hydroxyisoleucine, while *Azadirachta indica* improves peripheral glucose utilization in muscle and adipose tissues[39,42]. Such mechanisms help restore normal glucose uptake and utilization in insulin resistant states.Another important mechanism involves the inhibition of carbohydrate-digesting enzymes, such as α amylase and α-glucosidase, resulting in delayed glucose absorption from the gastrointestinal tract. *Syzygium cumini* and *Momordica charantia* have been shown to suppress these enzymes, thereby reducing postprandial hyperglycemia[37,11]. This mechanism is comparable to that of synthetic αglucosidase inhibitors used clinically.In addition, many medicinal plants exert insulin-like effects by mimicking the action of insulin at peripheral tissues. *Momordica charantia* contains polypeptide-P, which exhibits insulinlike activity and enhances glucose uptake in skeletal muscle and adipose tissue[37]. Similarly, *Panax ginseng* improves glucose metabolism by enhancing insulin signaling pathways through its active constituents, ginsenosides[31].

Role of Medicinal Plants in Diabetes Management

Diabetes mellitus is a chronic metabolic disorder characterized by hyperglycemia due to impaired insulin secretion, insulin action, or both. The increasing global and Indian prevalence of diabetes has created a demand for safer, affordable, and long-term therapeutic options. In this context, medicinal plants play a significant role in diabetes management, particularly in traditional systems of medicine such as Ayurveda, Siddha, Unani, and folk medicine.Medicinal plants contribute to diabetes management through multifactorial mechanisms. Many plants stimulate insulin secretion from pancreatic β-cells, enhance insulin sensitivity in peripheral tissues, inhibit intestinal glucose absorption, and suppress hepatic glucose production. For example, *Gymnema sylvestre* enhances insulin secretion and promotes regeneration of pancreatic β-cells, while Momordica charantia improves glucose utilization and reduces insulin resistance[17,29].Another important role of medicinal plants is the inhibition of carbohydrate-digesting enzymes such as αamylase and α-glucosidase. Plants like *Salacia reticulata* and *Syzygium cumini* delay glucose absorption from the intestine, thereby preventing postprandial hyperglycemia[51]. This mechanism is particularly beneficial in type 2 diabetes mellitus.

Medicinal plants also play a protective role by reducing oxidative stress and inflammation, which are major contributors to diabetic complications. *Plants* rich in flavonoids and phenolic compounds, such as *Tinospora* cordifolia, *Curcuma* longa, and *Ocimum sanctum*, exhibit strong antioxidant activity, helping to protect pancreatic cells and reduce complications like neuropathy, nephropathy, and cardiovascular disorders[18,33].In India, ethnobotanical surveys have documented extensive use of medicinal plants for diabetes management. Rural and tribal communities rely on plants such as *Azadirachta indica*, *Coccinia grandis*, *Moringa oleifera*, and *Trigonella foenum-graecum* due to their accessibility, low cost, and perceived safety[18]. These plants are often used as primary healthcare remedies or as dietary supplements for long-term glycemic control.Medicinal plants are increasingly used as adjunct therapy along with conventional antidiabetic drugs. Their combined use can improve glycemic control, reduce drug dosage, and minimize adverse effects associated with synthetic drugs[10]. Additionally, many antidiabetic plants function as nutraceuticals, contributing to prevention and early management of diabetes.

Advantages of Antidiabetic Medicinal Plants

1. One of the major advantages of medicinal plants in the management of diabetes mellitus is their multitargeted mechanism of action. Unlike synthetic antidiabetic drugs that usually act through a single biochemical pathway, medicinal plants simultaneously improve insulin secretion, insulin sensitivity, glucose uptake, and antioxidant defense, leading to better overall glycemic control[17].

2. Medicinal plants are generally considered to have fewer side effects compared to synthetic antidiabetic agents. Long-term use of oral hypoglycemic drugs is often associated with adverse effects such as hypoglycemia, weight gain, and gastrointestinal disturbances, whereas plant-based therapies are better tolerated when used appropriately[8].

3. Another important advantage is their cost-effectiveness and easy availability, especially

in developing countries like India. Many antidiabetic medicinal plants are locally available and have been used traditionally, making them accessible to rural populations[14].

4. Medicinal plants also possess significant antioxidant and anti-inflammatory properties, which help in preventing or delaying diabetic complications such as neuropathy, nephropathy, and cardiovascular disorders[18]. Plants like Tinospora cordifolia, *Withania somnifera*, and *Ocimum sanctum* reduce oxidative stress and protect pancreatic β cells[33].

5. In addition, medicinal plants can be used as adjunct therapy along with conventional antidiabetic drugs to enhance therapeutic efficacy and reduce required drug dosage, thereby minimizing side effects[10].

Limitations of Antidiabetic Medicinal Plants

- Despite their advantages, medicinal plants also have several limitations that restrict their widespread clinical use. One of the major limitations is the lack of standardization and quality control. Variations in plant species, geographical origin, harvesting time, and extraction methods can lead to inconsistent therapeutic outcomes[14].

- Another limitation is the insufficient clinical evidence. Although many medicinal plants have demonstrated antidiabetic activity in experimental animal models, well-designed large-scale clinical trials in humans are still limited[23].

- The delayed onset of action is another drawback of herbal antidiabetic therapy. Unlike synthetic drugs that provide rapid glycemic control, medicinal plants often require prolonged use to produce significant therapeutic effects[45].

- Herbal medicines may also cause drug–herb interactions when used concomitantly with conventional antidiabetic drugs, potentially leading to hypoglycemia or reduced drug efficacy[50].

- Additionally, safety and toxicity concerns remain due to the presence of bioactive compounds that may cause adverse effects at higher doses or during long-term use. The misconception that herbal medicines are completely safe can result in inappropriate usage [24].

Future Prospects and Research Directions

- Isolation and characterization of active compounds.
- Standardization and quality assurance using modern analytical techniques.
- Conducting well-designed randomized clinical trials.
- Development of novel delivery systems including nanoformulations.
- Using systems biology and omics approaches to understand multitarget mechanisms.

DISCUSSION:

Medicinal plants such as *Momordica charantia*, *Gymnema* sylvestre, *Trigonella foenum-graecum*, *Azadirachta indica*, *Ocimum sanctum*, Syzygium cumini, *Cinnamomum verum*, and Emblica officinalis demonstrate significant antidiabetic activity through multiple mechanisms. They effectively reduce fasting and postprandial blood glucose, improve insulin secretion and sensitivity, and decrease oxidative stress. These multitarget effects make them promising alternatives or adjuncts to conventional therapy. However, further large-scale clinical trials are needed to confirm efficacy and safety.

CONCLUSION:

Medicinal plants have shown considerable antidiabetic potential and can be considered safe, cost-effective alternatives for diabetes management. Their use in combination with conventional therapy may provide improved glycemic control and reduced complications. Scientific validation, standardization, and clinical evaluation are essential to establish their role in evidence-based modern therapeutics.

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