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Plant-Derived Bioactive Compounds as Antidiabetic Agents: Therapeutic Mechanisms and Prospects

Mansa Shrivastava[1], Anju Daharia[1*]

[1]Kamla Institute of Pharmaceutical Sciences, Bhilai, 490020, India

***Corresponding Author E-mail: anjudaharia055@gmail.com**

Abstract:

Diabetes mellitus (DM) is a chronic metabolic disorder characterized by persistent hyperglycaemia, which leads to severe complications such as nephropathy, neuropathy, retinopathy, and cardiovascular diseases. Among various therapeutic approaches, inhibition of carbohydrate-hydrolyzing enzymes, particularly α-amylase and α-glucosidase, has emerged as an effective strategy to delay glucose absorption and control postprandial hyperglycaemia in non-insulin-dependent diabetes mellitus (NIDDM). In recent years, increasing attention has been directed toward natural sources for identifying potent enzyme inhibitors, with phytoconstituents such as alkaloids, flavonoids, terpenoids, glycosides, anthocyanins, and phenolic compounds showing significant promise. These bioactive plant-derived compounds not only act as α-amylase and α-glucosidase inhibitors but also exhibit multifaceted mechanisms, including stimulation of insulin secretion, improvement of insulin sensitivity, and regulation of glucose homeostasis. This review highlights the therapeutic potential of medicinal plants and their phytoconstituents as promising alternatives or complementary strategies for the management of diabetes mellitus.

Keywords: Diabetes mellitus, Phytoconstituents, Insulin, Hyperglycaemia.

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1. Introduction

Diabetes mellitus is a chronic condition associated with hyperglycaemia, or elevated blood glucose levels. The number of cases of diabetes is increasing worldwide because of unhealthy lifestyle choices. According to the International Diabetes Federation (IDF) Atlas 9th edition, in 2019, a total of 463 million people were estimated to be living with diabetes, and this number

is expected to increase to 578 million (10.2%) in 2030 and 700 million (10.9%) in 2045 [1]. It is a disease caused by abnormalities in the metabolism of carbohydrates, which is primarily associated with low blood insulin levels or insensitivity of target organs to insulin [2]. Insulin is a peptide hormone produced by the β-cells of the pancreas, and it plays an important role in the regulation of blood glucose and energy metabolism. Insulin resistance or insufficient insulin production impairs the normal glucose homeostasis, which ultimately results in hyperglycaemia [3]. Type 1 and type 2 diabetes are the two main classifications of diabetes. Type 1 diabetes, which is also known as insulin-dependent diabetes, is one of the most common metabolic disorders occurring in childhood [4]. The pathogenesis of type 1 diabetes includes T-cell-mediated autoimmune destruction of pancreatic beta-cells that produce insulin. Subsequently, this causes a deficiency of insulin secretion in the body, resulting in the onset of the disease [5]. Whereas type 2 diabetes is the most common type and comprises 90–95% of all forms of diabetes [6]. It is caused by a combination of impaired insulin secretion and insulin resistance [7]. The development of type 2 diabetes is significantly impacted by postprandial hyperglycaemia [8]. One of the effective approaches to managing diabetes mellitus, especially non-insulin-dependent diabetes mellitus (NIDDM), is the inhibition of carbohydrate-hydrolysing enzymes, such as α-glucosidase and α-amylase, to delay glucose absorption and reduce postprandial hyperglycaemia. Serious long-term consequences such as kidney failure, nerve damage, and cardiovascular disease can arise from chronic hyperglycaemia [9]. The synthetic oral hypoglycaemic medications and insulin are the primary methods of managing diabetes; however, these medications cannot totally reverse the progression of its problems rather worsen it due to their significant adverse effects. This forms the main reason behind discovering alternative sources of antidiabetic agents [10].

Natural products, especially those derived from plants, are the primary source for discovering promising lead candidates and are essential for the upcoming drug development programs [11-13]. In most indigenous communities, medicinal plants are sources of crude herbal medicines that are utilized to prevent, treat, or manage diseases. Traditional medicines play a most important role in the management of diabetes mellitus. Ease of availability, least side effects, and low cost make plant-based preparations the main key player of all available medications, especially in rural areas [14]. Compared to synthetic medications, medicinal herbs have fewer side effects and reduce drug toxicity because of their antioxidant qualities. Despite the availability of antidiabetic medications on the pharmaceutical market, treating diabetes using medicinal plants is frequently successful. Although various herbal medications are available to treat diabetes, only a small number of these plants have been evaluated recommended to use medicinal plants to treat illnesses like diabetes since they contain a variety of phytoconstituents that may have antidiabetic effects, including alkaloids, terpenoids, saponins, flavonoids, carotenoids, and glycosides [8,15]. This review article enumerates some medicinal plants possessing antidiabetic activity.

1.1 Mechanisms of anti-diabetic action in medicinal plants

Medicinal plants have been utilized for a long time in traditional medicine to treat diabetes, and new research has confirmed that they have anti-diabetic effects. These plants work therapeutically through a variety of pharmacological mechanisms, including insulin secretion and sensitivity, glucose metabolism, inflammation, and oxidative stress. The various functions

that medicinal plants play in controlling blood glucose levels and enhancing general metabolic health are highlighted by the following mechanisms [15].

1.1.1 Inhibiting α-glucosidase and α-amylase

α-Amylase and α-glucosidase inhibitors reduce postprandial hyperglycaemia by slowing the digestion of carbohydrates and subsequent intestinal absorption of glucose. Under normal conditions, α-amylase hydrolyses complex polysaccharides such as starch and glycogen into smaller oligosaccharides and disaccharides. These are then further broken down by α-glucosidase, an enzyme located in the brush border of the intestinal epithelium, into monosaccharides like glucose that can be readily absorbed (Figure 1).

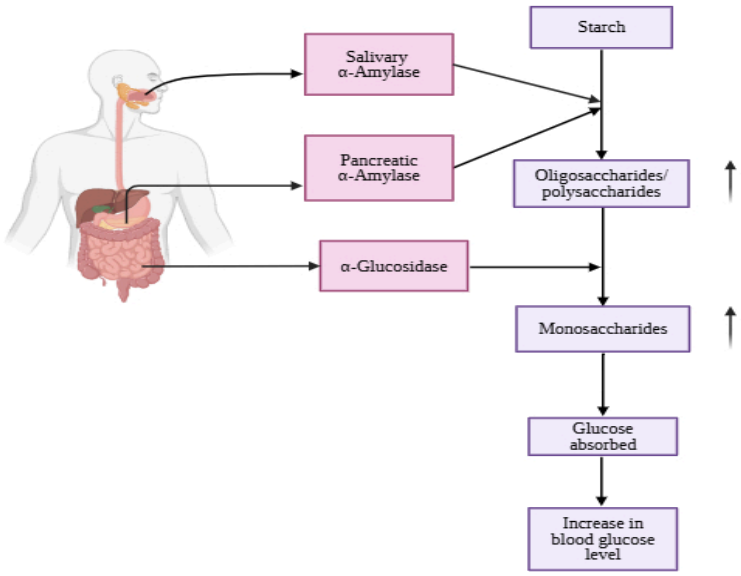

Figure 1. Enzymatic Hydrolysis of Polysaccharides by α-amylase and α-glucosidase

1.1.2 Stimulating Insulin Secretion

The stimulation of insulin secretion in pancreatic β-cells primarily involves the regulation of ion channels that mediate insulin granule exocytosis. Drugs such as meglitinides and sulfonylureas bind to the sulfonylurea receptor (SUR1), a subunit of ATP-sensitive potassium (K^+ATP) channels on the β-cell membrane. This interaction blocks potassium efflux, resulting in membrane depolarization. The depolarization, in turn, opens voltage-gated calcium channels, permitting calcium influx. The rise in intracellular calcium triggers the fusion of secretory granules with the plasma membrane, leading to insulin exocytosis and release into the bloodstream. The secreted insulin subsequently reduces blood glucose levels by enhancing glucose uptake in peripheral tissues, particularly muscle and adipose tissue, and by suppressing hepatic glucose production (Figure 2).

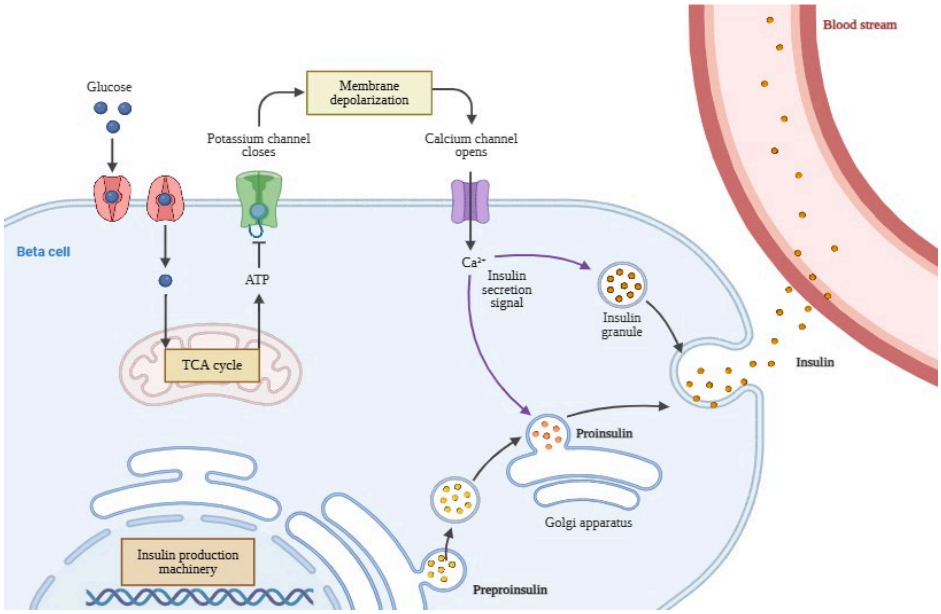

Figure 2. Overview of Insulin Biosynthesis and Secretion

1.1.3 Enhancing Insulin Sensitivity

Enhancing insulin sensitivity involves reducing insulin resistance in key tissues such as the liver, skeletal muscle, and adipose tissue, thereby improving their ability to respond to circulating insulin. Thiazolidinediones (TZDs) act by activating PPAR-γ receptors in adipose tissue, which regulate the expression of genes involved in lipid and carbohydrate metabolism. As a result, hepatic gluconeogenesis is suppressed, glycogen synthesis is promoted, and glucose uptake is increased through GLUT-4 transporters in muscle and fat. Moreover, TZDs modulate inflammatory responses, regulate adipokines such as adiponectin, and decrease circulating free fatty acid levels, collectively enhancing insulin signalling via the IRS-1/PI3K/Akt pathway. These combined effects contribute to maintaining normal blood glucose levels, improving glucose utilization, and restoring insulin responsiveness.

1.1.4 Modulating Glucose Uptake

Modulation of glucose uptake refers to enhancing the transport of glucose from the bloodstream into cells, particularly skeletal muscle and adipose tissue. This process occurs when insulin activates its signalling cascade via the IRS-1/PI3K/Akt pathway, leading to the translocation of GLUT-4 transporters to the cell membrane. The increased presence of GLUT-4 on the cell surface facilitates greater glucose entry, which is subsequently utilized for energy production or stored, thereby reducing blood glucose levels.

2. Antidiabetic effect of traditional medicinal plants

Herbal treatments have been used for centuries in various traditional systems to control hyperglycaemia, improve digestion, and support overall metabolic health. Modern scientific research has gradually validated many of these plant-based medicines, with numerous studies identifying bioactive phytochemicals that show significant anti-diabetic effects. These plants are gaining scientific recognition for their ability to control blood sugar levels and provide

supplementary therapeutic benefits for the treatment of diabetes. Studies have shown that plants with anti-diabetic properties often contain a variety of bioactive compounds, such as flavonoids, alkaloids, saponins, terpenoids, and phenolic acids (Table 1). These substances have several different pharmacological effects that work synergistically to treat various aspects of diabetes. Certain phytochemicals stimulate insulin production from the pancreatic β-cells, all of which contribute to improved glucose utilization, and others increase insulin sensitivity in tissues like the liver, muscles, and adipose tissue. Some phytochemicals also act by inhibiting enzymes like α-amylase and α-glucosidase, which slow down glucose absorption, thereby lowering postprandial blood glucose levels [16].

Table 1. Antidiabetic potential of selected medicinal plants.

S. N.	Plant name	Family	Plant part used	Type of extract	Animal model	Activity	References
1.	*Albizia odoratissima*	Mimosaceae	Bark	Methanol	Albino mice	Antidiabetic	[17]
2.	*Aloe vera*	Asphodelaceae	Leaves	Ethanolic	Male albino Wistar rats	Antidiabetic	[18]
3.	*Amaranthus tricolor*	Amaranthaceae	Whole plant	Methanolic	Male Swiss albino mice	hyperglycaemia	[19]
4.	*Axonopus compressus*	Poaceae	Leaves	Methanolic	Male Wistar rats	Antidiabetic	[20]
5.	*Azadirachta indica*	Meliaceae	Leaves	Ethanolic	Adult rabbits	Hypoglycaemic	[21]
6.	*Barleria prionitis*	Acanthaceae	Leaves and roots	Ethanolic	Adult albino rats	Antidiabetic	[22]
7.	*Berberis vulgaris*	Berberidaceae	Root	Aqueous	Adult male Wistar rats	Hypoglycaemic	[23]
8.	*Brassica juncea*	Cruciferae	Seed	Aqueous	Adult male Swiss albino rats	Hypoglycaemic	[24]
9.	*Alangium lamarckii*	Alangiaceae	Leaves	Alcoholic	Male albino rats of the Charles	Antidiabetic	[25]

					Foster strain		
10.	*Catharanthus roseus*	Apocynaceae	Leaf	Methanol	Mice and albino rats	Hypoglycaemic	[26]
11.	*Centaurium erythrea*	Gentianaceae	Leaf	Aqueous	Rat	Antidiabetic	[27]
12.	*Chaenomeles sinensis*	Rosaceae	Fruits	Ethyl acetate	Male Sprague-Dawley rats	Antidiabetic	[28]
13.	*Cinnamomum cassia*	Lauraceae	Bark	Ethanolic	Male Kunming mice	Hypoglycaemic	[29]
14.	*Costus speciosus*	Costaceae	Rhizome	Hexane	Male Wistar rats	Antidiabetic	[30]
15.	*Dillenia indica*	Dilleniaceae	Leaves	Methanolic	Wistar rat	Antidiabetic	[31]
16.	*Eucalyptus citriodora*	Myrtaceae	Leaves	Aqueous	Albino rats	Antidiabetic	[32]
17.	*Gymnema sylvestre*	Apocynaceae	Leaves	Ethanolic	Male Sprague–Dawley rats	Hypoglycaemic	[33]
18.	*Heinsia crinata*	Rubiaceae	Leaves	Ethanolic	Rats	Antidiabetic	[34]
19.	*Helicteres isora*	Sterculiaceae	Roots	Butanol and aqueous ethanol	Male Wistar rats	Antihyperglycemic and hypolipidemic	[35]
20.	*Hybanthus enneaspermus*	Violaceae	Whole plant	Alcholic	Rats	Antidiabetic	[36]
21.	*Lippa nodiflora*	Verbenaceae	Whole plant	Methanol	Adult Wistar male albino rats	Antidiabetic and Hypolipidemic	[37]
22.	*Lithocarpus polystachyus*	Fagaceae	Leaves	Ethanol & Aqueous	Rats	Hypoglycaemic	[38]

23.	*Marrubium vulgare*	Lamiaceae	Aerial part	Methanolic	Male Wistar rats	Antidiabetic and anticycloni c-emic	[39]
24.	*Moringa oleifera*	Moringaceae	Pod	Methanolic	Wistar albino rats	Antidiabetic and antioxidant	[40]
25.	*Moringa oleifera*	Moringaceae	Leaves	Methanolic	Male Sprague–Dawley rats	Antidiabetic and antioxidant	[68]
26.	*Ocimum sanctum*	Lamiaceae	Aerial part	Hydroalcoholic	Male albino rats	Antidiabetic	[42]
27.	*Opuntia streptacantha*	Cactaceae	Leaves	Ethanol	Wistar rats	Antihyperglycemic	[43]
28.	*Origanum vulgare*	Lamiaceae	Leaves	Methanolic	Male C57BL/6 mice	Antidiabetic	[44]
29.	*Passiflora nitida*	Passifloraceae	Leaves	Hydroethanolic	Female Wistar rats	Antihyperglycemic	[45]
30.	*Paspalum scrobiculatum*	Poaceae	Grains	Aqueous and ethanolic	Male Wistar albino rats	Antidiabetic	[46]
31.	*Persea americana*	Lauraceae	Leaves	Hydroalcoholic	Male Wistar rats	Antidiabetic	[47]
32.	*Phoenix dactylifera*	Arecaceae	Leaves	Ethanolic	Male Wistar rats	Antidiabetic	[48]
33.	*Phyllanthus niruri*	Phyllanthaceae	Leaves	Aqueous	Male Wistar rats	Antidiabetic	[49]
34.	*Piper longum*	Piperaceae	Root	Aqueous	Male Wistar albino rats	Antidiabetic and antihyperlipidemic	[50]
35.	*Solanum torvum*	Solanaceae	Fruit	Methanolic	Male albino Wistar rats	Antihyperglycemic	[51]

36.	*Sonchus oleraceus*	Asteraceae	Whole plant	Hydroalcoholic	Wistar rats	Antioxidant and antidiabetic	[52]
37.	*Symplocos cochinchinensis*	Symplocaceae	Leaves	Hexane	Male albino Wistar rats	Antidiabetic	[53]
38.	*Syzygium jambolana*	Myrtaceae	Seed	Ethanolic	Adult rabbits	Hypoglycaemic	[54]
39.	*Tamarindus indica*	Fabaceae or Leguminosae	Stem bark	Ethanolic	Wistar rats	Hypoglycaemic	[55]
40.	*Symplocos indica*	Fabaceae or Leguminosae	Seed coat	Ethanolic	Wistar albino rats	Antidiabetic	[56]
41.	*Terminalia chebula*	Combretaceae	Seed	Chloroform	Male Sprague–Dawley rats	Antidiabetic	[57]
42.	*Terminalia catappa*	Combretaceae	Fruit	Petroleum ether, methanol, and aqueous	Wistar albino rats and mice	Antidiabetic	[58]
43.	*Vaccinium arctostaphylos*	Ericaceae	Fruit	Ethanolic	Male Wistar rats	Antidiabetic	[59]
44.	*Vernonia amygdalina*	Asteraceae	Leaves	Aqueous	Wistar albino rats	Antidiabetic	[60]
45.	*Viscum schimperi*	Viscaceae	Aerial parts	Methanolic	Male Wistar rats	Antihyperglycemic & hypolipidemic	[61]
46.	*Witheringia solanacea*	Solanaceae	Leaves	Aqueous	Male Sprague–Dawley rats	Hypoglycaemic and antihyperglycemic	[62]
47.	*Zaleya decandra*	Aizoaceae	Roots	Ethanolic	Wistar albino rats	Antidiabetic	[63]

48.	*Zizyphus mauritiana*	Rhamnaceae	Fruit	Petroleum ether, chloroform, acetone, ethanol and aqueous	Female Wistar rats	Antidiabetic	[64]
49.	*Zygophyllum album*	Zygophyllaceae	Whole plant	Ethanol	Adult Swiss albino mice	Antidiabetic	[65]

2.1.Alangium lamarckii

Alangium lamarckii exhibits significant antidiabetic activity in STZ-nicotinamide-induced diabetic rats. The alcoholic leaf extract was administered at doses of 250 and 500 mg/kg body weight for the study [25].

2.2.Albizia odoratissima

Antidiabetic effect of methanolic bark extract of doses 250 and 500 mg/kg body weight of Albizia odoratissima in alloxan-induced diabetic mice. There was a significant reduction in the levels of alkaline phosphatase, serum cholesterol, triglycerides, SGOT, SGPT, and a decrease in total proteins in alloxan-induced albino mice [17].

2.3.Aloe vera

Aloe vera extract was evaluated in STZ-induced diabetic mice and in mouse embryonic NIH/3T3 cells. Aloe extract shows antidiabetic effects by improving pancreatic β-cell function and insulin secretion by restoring pancreatic islet mass in streptozotocin-induced diabetic rats [18].

2.4.Amaranthus tricolor

The methanolic extract of *Amaranthus tricolor* whole plant was administered at doses of 50, 100, 200, and 400 mg/kg, one hour prior to glucose administration in an oral glucose tolerance test (GTT). The extract exhibited significant antihyperglycemic activity at all tested doses, with the maximum effect observed at 400 mg/kg, comparable to that of glibenclamide (10 mg/kg) [19].

2.5.Barleria prionitis

Antidiabetic activity of alcoholic extracts of leaf and root of Barleria prionitis plant (200 mg/kg, p.o. for 14 days) was tested in alloxan-induced diabetic rats [66]. Animals treated with leaf extract significantly decreased blood glucose and glycosylated hemoglobin levels. And those which are treated with the root extract showed a moderate but non-significant antidiabetic activity.

2.6.Berberis vulgaris

Hypoglycaemic effect of Berberis vulgaris in streptozotocin-induced diabetic rats. The results showed that water extract and saponins show a significant hypoglycemic effect. The serum cholesterol and serum triglyceride levels were increased significantly [23].

2.7.Catharanthus roseus

Hypoglycemic effect of methanolic extract of the leaf of the plant Catharanthus roseus (C. roseus) in alloxan-induced diabetic rats. The levels of blood glucose were significantly decreased when compared with the Control rat [26].

2.8.Chaenomeles sinensis

Ethyl acetate fraction of Chaenomeles sinensis (C. sinensis) (Thouin) Koehne fruits has a significant Antidiabetic effect. Doses at which it shows antidiabetic activity were reported as 50 and 100 mg/kg body weight [28].

2.9.Eucalyptus citriodora

Aqueous extract of Eucalyptus citriodora leaves in alloxan-induced diabetic rats (250 and 500 mg/kg, p.o.) for 21 consecutive days significantly reduces blood glucose levels [32].

2.10. Gymnema sylvestre

Gymnema sylvestre, commonly referred to as the "sugar destroyer," is known to enhance insulin secretion. In STZ-induced diabetic rats, oral administration of ethanolic leaf extract at a dose of 100 mg/kg for four weeks demonstrated significant antidiabetic and antioxidant effects. The extract also exhibited in vitro antioxidant activity, as confirmed through ABTS, thiobarbituric acid (TBA), and superoxide dismutase (SOD) assays [33].

2.11. Heinsia crinata

The ethanolic leaf extract of *Heinsia crinata*, administered orally at doses of 450–1350 mg/kg for two weeks in alloxan-induced diabetic rats, demonstrated antidiabetic potential as evidenced by a significant reduction in fasting blood glucose (FBG) levels [34].

2.12. Moringa oleifera

The methanolic extract of *Moringa oleifera* pods (150 and 300 mg/kg, p.o. for 21 days) in streptozotocin-induced diabetic rats exhibited notable antidiabetic and antioxidant activities [41]. Both doses significantly lowered serum glucose and nitric oxide levels while enhancing serum insulin and protein concentrations. Furthermore, studies have shown that consumption of *Moringa oleifera* leaves exerts a hypoglycaemic effect and prevents body weight loss in alloxan-induced diabetic rats [67].

2.13. Origanum vulgare

An in vivo study in streptozotocin-induced diabetic mice revealed that the methanolic extract of *Origanum vulgare* reduced diabetes incidence and preserved normal insulin secretion. Phytochemical analysis indicated a high content of biophenols, and the extract demonstrated significant in vitro antioxidant activity in DPPH assays. In contrast, the aqueous extract showed

no notable effect on diabetes induction. Moreover, the methanolic extract exhibited cytoprotective properties, suppressed pro-inflammatory activity, and enhanced antioxidant defence by increasing the activities of SOD, CAT, glutathione reductase, and peroxidase [44].

2.14. Paspalum scrobiculatum

An aqueous and ethanolic extract of grains of Paspalum scrobiculatum Linn. was evaluated in alloxan-induced diabetic rats, possessing antidiabetic activity. The extracts at 250 and 500 mg/kg, p.o. for 15 days treatment, significantly reduced the blood glucose level and lipid parameters in a dose-related manner [46].

2.15. Persea americana

The hydroalcoholic extract of the leaves of Persea americana (0.15 and 0.3 g/kg, p.o. daily for 4 weeks) reduced blood glucose levels in STZ-induced diabetic rats [47]. The extract did not influence the plasma insulin level, suggesting that the hypoglycemic effect was due to extrapancreatic activity, independent of insulin secretion. The extract also improved the metabolic state of diabetic animals and increased their body weight. In another study, Persea americana seeds aqueous extract significantly decreased glucose levels and reversed the histopathological damage that occurred in alloxan-induced diabetic rats, comparable to the effects of glibenclamide [68].

2.16. Piper longum

The aqueous root extract of *Piper longum*, administered at 200 mg/kg in male albino rats with streptozotocin-induced diabetes, exhibited significant antidiabetic activity within 6 hours of treatment, surpassing the effectiveness of glibenclamide. Prolonged administration of the same dose for 30 days further resulted in a marked reduction in blood glucose levels and improvement of diabetic dyslipidemia compared with untreated diabetic rats. These findings suggest that the plant extract possesses strong potential for managing hyperglycemia and reducing diabetic complications in STZ-induced diabetic models [50].

2.17. Sonchus oleraceus

The hydroethanolic extract of *Sonchus oleraceus* was evaluated for its antidiabetic properties in streptozotocin-induced diabetic mice. In vitro analysis of the whole plant extract using the DPPH assay revealed notable antioxidant activity, with an IC_{50} of 0.19 mg/mL. In vivo, the extract demonstrated strong antidiabetic effects, supported by improved oxidative stress markers in the kidneys, liver, and plasma. These effects are likely associated with its significant hypoglycemic activity, free radical–scavenging potential, and ability to prevent oxidative stress, as evidenced by reduced MDA and H_2O_2 levels along with increased CAT activity in diabetic rats [52].

2.18. Syzygium jambolana

A combination of Syzygium jambolana extract obtained from the seeds, fruits of Momordica charantia, and leaves of Azadirachta indica (200 mg/kg) showed a hypoglycemic effect in rabbits. Treatment of diabetic rabbits with plant extracts was started 8 days after inducing

alloxan injection. In many of the rabbit groups, an antidiabetic effect was produced after 72 hours [54].

2.19. Tamarindus indica

In vitro assays of the alcoholic extract of *Tamarindus indica* stem bark demonstrated significant antioxidant activity against DPPH, nitric oxide, and hydroxyl radicals [55]. In alloxan-induced diabetic rats, oral administration of the alcoholic extract at doses of 250 and 500 mg/kg for 21 days produced a marked reduction in blood glucose levels. Similarly, a hydroethanolic extract of the seed coat of *Tamarindus indica* significantly lowered blood glucose in glucose-loaded, normoglycemic, and alloxan-induced diabetic rats [56].

2.20. Terminalia chebula

The chloroform extract of *Terminalia chebula* seed powder, administered at 100, 200, and 300 mg/kg in STZ-induced diabetic rats, produced a significant, dose-dependent reduction in blood glucose levels and exhibited notable renoprotective effects [57].

2.21. Terminalia catappa

The methanolic, aqueous, and petroleum ether extracts of *Terminalia catappa* fruits were evaluated in alloxan-induced diabetic rats, and all extracts produced a significant reduction in fasting blood glucose (FBG) levels [58].

2.22. Vaccinium Arctostaphylos

The ethanolic extract of *Vaccinium arctostaphylos* fruit was evaluated in alloxan-induced diabetic rats over three weeks. Treatment significantly reduced blood glucose and triglyceride levels while enhancing erythrocyte antioxidant defenses (SOD, CAT, and glutathione peroxidase) and upregulating the expression of GLUT-4 and insulin genes [59].

2.23. Witheringia solanaceae

Normal rats treated with an aqueous extract of *Witheringia solanacea* leaves at doses of 250, 500, and 1000 mg/kg showed a significant reduction in blood glucose levels after 1 hour of a glucose tolerance test (GTT) at the two higher doses. Additionally, a 500 mg/kg dose significantly lowered blood glucose levels in alloxan-induced hyperglycaemic rats at 4- 5 hours post-treatment [62].

2.24. Zaleya decandra

Oral administration of an ethanolic extract of *Zaleya decandra* roots (200 mg/kg for 15 days) significantly restored blood glucose, antioxidant enzyme levels, lipid peroxidation, total cholesterol, triglycerides, total proteins, urea, and creatinine in alloxan-induced diabetic rats [63].

2.25. Zizyphus mauritiana

Petroleum ether and aqueous extracts of *Zizyphus mauritiana* (200 and 400 mg/kg, p.o. for seven days) significantly improved glucose levels and other biochemical parameters, including total cholesterol (TC), triglycerides (TG), HDL, LDL, urea, creatinine, hemoglobin, and glycosylated hemoglobin, in alloxan-induced diabetic rats [64].

2.26. Zygophyllum album

The ethanolic extract of *Zygophyllum album* demonstrates significant antihyperglycemic and antioxidant effects in experimental mice. Oral administration of the extract reduced blood glucose levels and improved antioxidant status in STZ-induced diabetic mice. The treatment significantly increased nonenzymatic antioxidants, including GSH and ascorbic acid, while reducing vitamin E levels, indicating a protective effect. Additionally, key enzymatic antioxidants-catalase (CAT), superoxide dismutase (SOD), and glutathione peroxidase (GPx), which are crucial for reactive oxygen species (ROS) removal and H_2O_2 reduction, showed significant activity restoration in diabetic tissues following extract administration [65].

3. Conclusion

This review highlights the potential of phytoconstituents derived from traditional medicinal plants as promising candidates for the management of diabetes mellitus. Owing to their abundance, accessibility, and diverse bioactive properties, plant-based compounds offer a sustainable and effective alternative to synthetic drugs. The evidence discussed underscores their ability to modulate key metabolic pathways, inhibit carbohydrate-hydrolysing enzymes, and improve glycaemic control. These findings not only validate traditional knowledge but also provide a scientific basis for the development of novel antidiabetic therapeutics. Future research focusing on isolation, structural optimization, and clinical evaluation of these phytoconstituents will be instrumental in translating them into safe and effective antidiabetic agents.

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