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Abstract

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ANTIDIABETIC EFFECTS OF MEDICINAL PLANTS

Diabetes is a chronic disorder that is characterized by an increase in blood glucose (hyperglycemia) with alteration of protein, carbohydrates, and fat metabolism. Consequently, it can lead to renal failure, atherosclerosis, nerve damage, blindness, and coronary heart disease. It is also known as the 5th leading cause of death. Although, there are numerous types of glucose-lowering drugs that exhibit anti-diabetic effects but results of treatment in patients are still not so perfect. Therefore, many treatments that include the use of medicinal plants are suggested and encouraged. Medical plants are believed to contain chemical substances with potential curative effects and can often have anti-diabetic effects. This study introduced about 23 effective medicinal plants reported by various experimental researchers with the curative potential to treat diabetes. Although, most of the research used animal models, there is a clear indication that medicinal plants with anti-diabetic potentials are being investigated by several researchers. However, there is a need for further research to be conducted with isolated bioactive ingredients present in these plants in order to have potential ingredients that could be used as a pharmacological agent in the treatment of diabetes mellitus with fewer adverse effects. Again, the mechanisms of action of these medicinal plants in ameliorating diabetes need to be investigated.

Keywords: diabetes mellitus, antidiabetic plants, medicinal plants, hyperglycemia, hypoglycemia, insulin, antioxidants.

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Introduction

Diabetes is a chronic disorder characterized by an increase in blood glucose (hyperglycemia) with alteration of protein, carbohydrates and fat metabolism [1, 2]. It is caused by either insulin deficiency or malfunction [2]. Diabetes mellitus leads to high blood glucose level, which causes acute complications such as hyperglycemia and hypoglycemia accompanied with long-term complications in many organs of the body, which may result to increased tendency of renal failure, atherosclerosis, nerve damage, blindness and coronary heart disease resulting in increasing disability [3].

However, it can be classified as either Type I diabetes, Type II diabetes or gestational diabetes mellitus on the basis of clinical representation of the disorder [4]. According to statistics, in 2012, diabetes mellitus affects about 200 million people in the world [5], and it is estimated to rise to over 366 million in the year 2030 [6]. It is also known as the 5th leading cause of death [7]. Oxidative stress (OS) plays a major role in the pathogenesis of micro-vascular and macro-vascular diabetic

complications. Hyperglycemia, insulin resistance (IR), and dyslipidemia are present in diabetic patients due to increased OS [8]. Recently, there are different treatments available to control diabetes which includes insulin therapy, diet and pharmacotherapy. Additionally, there are numerous types of glucose-lowering drugs that exhibit anti-diabetic effects via diverse mechanisms of action [9]. But, inspect of the progress significantly made in the treatment of diabetes, the results of treatment in patients is still not so perfect. These treatments are known to have disadvantages which include side effects, drug resistance (reduction of efficiency), and even toxicity [9]. For instance, glucose-lowering drugs are not able to control presence of excess lipids in the blood (hyperlipidemia) [10].

Recently, many treatments that include the use of medicinal plants are suggested and encouraged [11, 12, 13]. Medical plants are believed to contain chemical substances such as flavonoids, carotenoids, terpenoids, glycosides, alkaloids with potential curative effects and can often have anti-diabetic effects [14, 15]. The anti-hyperglycemic effects that occur from treatment with plants are most times due to the ability of the plants to improve the action of pancreatic tissue, which is carried out by either increased insulin secretions or reduced intestinal absorption of glucose [9]. The increasing number of people with diabetes has raised a concern for the medical community and the public at large. The aim of this study is to introduce a number of effective medicinal plants with curative potential to treat diabetes and to present other mechanisms of plant compounds used to reduce blood glucose levels. This study will help the medical community and the world at large to find and use a suitable pharmacological agent to treat diabetes with less adverse effects.

Acacia nilotica

Acacia nilotica belong to the family Mimosaceae. In a study that was carried out to evaluate the efficiency of *Acacia nilotica* leaf to ameliorate diabetic complications, oral administration of 50 mg/kg and 200 mg/kg of *Acacia nilotica* leaf extract to alloxanized mice for 20 days significantly lowered systemic glucose load and insulin resistance without showing any significant effects on insulin sensitivity. Additionally, lowered level of HbA1c and improved glucose utilization supported the anti-hyperglycemic properties of *Acacia nilotica* leaf. Renal (creatinine, blood urea nitrogen (BUN)) and hepatic (AST, ALT) and injury markers were lowered and there was normalization of dyslipidemia. Furthermore, peroxidase and catalase (CAT) activities in liver, skeletal muscle and kidney increased. It was reported that the plant contains phenolic, flavonoid, catechol, tocopherol and β-sitosterol [16]. In another experiment to determine the effect of *Acacia nilotica* leaves extract in reducing the high level of glucose and lipid in the blood in alloxanized diabetic rats. Oral administration of *Acacia nilotica* aqueous methanol leaves extract for 1–3 weeks significantly decreased fasting blood glucose (FBG), low density lipoprotein (LDL), phospholipids, triglyceride (TG), total cholesterol (TC), and very low density lipoprotein (VLDL). In addition, the level of high density lipoprotein (HDL) and the level of serum insulin increased. The duration of these effects was noted after 2 weeks of treatment [8]. Also, 200 mg/kg of *Acacia nilotica* fruit extract orally administered for 5 weeks to alloxan-induced diabetic rats significantly decreased serum level of LDL and TG, although, there was no significant change in the serum glucose concentrations of diabetic rats [17]. Another study used the *Acacia nilotica* pods extract to determine its therapeutic effect on streptozotocin (STZ) induced diabetic nephropathy in rat. In this experiment, 150 and 300 mg/kg administration of the extract for 60 days decreased the blood glucose level, and restored creatinine, and serum urea. The normal histopathological architecture of kidney was restored, glomerular size and damaged area were ameliorated, and the adverse effect of diabetes on lipid peroxidation (LPO), superoxide dismutase (SOD) and glutathione (GSH) activity was attenuated [18]. Oral administration of *Acacia nilotica* leaves extract (300 mg/kg b.w), in comparison to glyburide (900 microgm/kg b.w) for 3 weeks significantly decreased fasting blood glucose FBG and increased insulin level in STZ-induced diabetic rats [19]. Also, administration of *Acacia nilotica* leaves extract resulted into hypoglycemic and anti-platelet aggregation in STZ induced diabetic rats [20]. In summary, aqueous methanol extract from *Acacia nilotica* (AN) fruits, bark, pods and seeds have been reported to be used traditionally for the treatment of diabetes [19, 33].

Adonsonia digitata

Adonsonia digitata of the family Malvaceae have been reported to be traditionally used for the treatment of diabetes mellitus in Nigeria. The oral administration of the seed prepared by infusion was

reported to be used. Also the infusion of the powered fruit of *Adonsonia digitata* and cow milk was also reported in the study [21]. Traditionally, various parts of the *Adonsonia digitata* tree have been used to cure many clinical illnesses such as dysentery and diarrhea. Phytochemical screening has indicated that the leaf extract of *Adonsonia digitata* contains saponins, flavonoids, mucilage, alkaloids and steroids [22]. In an experimental research to determine and evaluate the hypolipidaemic and hyperglycaemic effects of methanolic extract of *Adonsonia digitata* leaves, oral administration of 200 mg/kg and 400 mg/kg of the extract for 6 weeks to STZ induced diabetic rats significantly decreased the blood glucose, TG, cholesterol, glycosylated hemoglobin, LDL, tumor necrosis factor-alpha (TNF-α), interleukin 6 (IL-6), and malondialdehyde (MDA) levels by 46.7%, 43%, 48.91%, 46.15%, 60%, 45.45%, 66% and 30.4%, respectively, in comparison to the diabetic control group. Also, the decline of red blood cell (RBC) count, packed cell volume (PCV), hemoglobin level, HDL and erythropoietin concentration was mitigated. While the level of antioxidant enzymes, SOD and CAT were maintained with reduction in GSH and reduction of elevated white blood corpuscles (WBC) count [22].

Allium cepa

Allium cepa (onions) belonging to the family Amaryllidaceae have been reported to have anti-diabetic effects in different experimental researches. A study carried out to evaluate the effects of onion (*Allium cepa*) dried by heat treatment on FBG level and plasma lipid profile in STZ induced diabetic rats showed a significant lower level of FBG, TG, LDL and TC after 5% onion powered dried at -70°c in a lyophilizator was administered to the diabetic rats. In this experiment HDL level increased [23]. The fasting serum HDL was increased in an experiment carried out to determine the antioxidant activity and hypoglycemic effects of *Allium cepa* in STZ induced diabetic rats. In this experiment, lipoperoxide concentration and lipid hydroperoxide were not increased after administration of *Allium cepa* [24]. However, in a clinical study with type 1 and type 2 diabetic patients, oral ingestion of crude *Allium cepa* (100g) by the diabetic patients caused a significant decrease in FBG level in type 1 diabetic patient by about 89 mg/dl in comparison to insulin (145 mg/dl), while in the type 2 diabetic patients, significant decrease in FBG level by 40 mg/dl was observed in relation to glibenclamide (81 mg/dl). In this same study, after 4 hours, induced hyperglycemia was significantly reduced by about 120 mg/dl in patients with type 1 diabetes, in comparison to water (77 mg/dl) and insulin (153 mg/dl) with same dose of crude *Allium cepa,* while in type 2 diabetic patient, a significant reduction of about 159 mg/dl compared to water (55 mg/dl) and glibenclamide (114 mg/dl) was observed [25]. Onions is believed to contain flavonoids like quercetin and quercetrin. It also contains sulphur compounds like allyl propyl disulphide and cysteine [25]. These compounds are believed to have antibiotic, anticancer, hypocholesterolaemic, antithrombotic, antioxidant, antibacterial, antidiabetic and fibrinolytic effects [26, 27, 28, 29, 34, 35, 36, 37]. A bioactive flavonoid (Kaempferol-3-O-β-D-6{P- Coumaroyl} Glucopyranoside) that was isolated from *Allium cepa* was used to determine its antidiabetic effect on alloxan-induced diabetic male rate. The isolated compound administered at 25 mg/kg to the diabetic rats significantly decreased blood glucose in diabetic rats in a manner comparable to the effects obtained with 2 mg/kg of glibenclamide [30]. Also, supplementation of onion powder (7% w/w) administered to STZ-induced diabetic rat for 5 weeks caused reduced level of blood glucose, triglyceride, total serum lipid, renal oxidative stress, and atherogenic index in comparison to the control groups. In this experiment, high density lipoprotein cholesterol/total cholesterol ratio increased [31]. Aqueous extract of onion exhibited an antithrombotic effect in STZ-induced diabetic rats [32].

Anacardium occidentalis

Anacardium occidentalis (cashew) belongs to the family Anacardiaceae. The root, bark, stem and leaves of *Anacardium occidentalis* have been experimentally researched for their antidiabetic effects. For instance, in an experimental study, 2 mg/100g-body weight of crude ethanolic extract of cashew root orally administered to adult guinea pigs and albino rats 3 times daily for 7 days significantly decreased plasma glucose level, cholesterol, liver glycogen and total lipid in guinea pig and albino rats after increased postprandial glucose level, although, plasma protein was not affected [38]. In essence, it could be concluded that ethanolic extract of cashew root can be used as a treatment and for the management of diabetes mellitus. Furthermore, isolated and characterized compounds (stigmast-4-en-3-ol and stigmast-4-en-3-one) gotten from the hexane extract of the bark of

Anacardium occidentalis were used in an experiment to determine their hypoglycemic effects. In this experiment, intravenous administration of these compounds at 1.3 mg/kg b.w significantly reduced blood glucose level in normal, healthy dogs. It was hypothesized that these compounds presence in cashew bark could be responsible for its hypoglycemic effects [39]. Also, 100 mg/kg of *Anacardium occidentalis* administered to alloxan-induced diabetic rats showed a significant increase in SOD activity [40]. In another experiment, when graded doses (100-800 mg/kg p.o.) of aqueous and methanolic stem-bark extracts of *A. occidentale* was administered to STZ induced diabetic rat, there was dose-dependent, significant decrease in the blood glucose level of fasted normal and fasted diabetic rats. In the same study, a single dose of 800 mg/kg p.o., of *Anacardium occidentalis* stem-bark aqueous and methanolic extracts significantly decreased mean basal blood glucose level of fasted normal and fasted diabetic rats, although, it was reported that these extract is less potent in comparison to insulin. The authors concluded that the presence of terpenoid and/or coumarin in the extract could have caused the hypoglycemic effects but the mechanism is not yet fully understood [41]. In another study, administration of methanolic leaves extract of *Anacardium occidentalis* to alloxan-induced diabetic rat caused 79.2% change compared to Tolbutamide (63.1%) over 4 hours for moderately diabetic rat. In the experiment, when diabetes became severe, the extract reduced blood glucose level by 20.8% compared to Tolbutamide (47.63%) over 4 hours, although, the values were not considered to be significant. So, *Anacardium occidentalis* is believed to have similar ability in lowering blood glucose concentration compared to Tolbutamide (a reference drug) [42]. Injection of 100 mg/kg of *Anacardium occidentalis* plant extract to neonatal STZ diabetic rats for 30 days caused a significant decrease in FBG level. The effects gotten are similar to the treatment with Pioglitazone (a standard drug). It was reported that, for future purpose, specific compound(s) responsible for the antidiabetic effects of *Anacardium occidentalis* is needed to be investigated [49].

Azadirachta indica

Neem (*A. indica)* belongs to the family Meliaceae. Traditionally, maceration of *Azadirachta indica* leaves and *Vernonia amygdalina* (bitter leaf) has been reported to be orally used to treat diabetes in Nigeria [21]. *Azadirachta indica* is known to have hypoglycemic, hypolipidemic, hepatoprotective and immunostimulant properties [43, 44]. Some chemical compounds such as nimolinone, nimbocinone, kulactone, isonimocinolide, nimocinolides, nimbin, azadirachtin, salanin, flavonoids, meldenindiol, myricetin, isomargosinolide, margosinolide, desacetyldihydro-nimbic acid and vilasinin have been isolated from *A. indica* leaves [45, 46, 47]. In an experimentally study, ethanolic extract of *Vernonia amygdalina* (VA) and *Azadirachta indicia* (AI) co-administered at 200 mg/kg, 50:50 to STZ-induced diabetic rats for 28 days reduced blood glucose, T3 and T4. Decreased glutathione peroxidase (GPx) and CAT activities were ameliorated and SOD activities increased. It was reported that the antidiabetic synergistic action of VA/AI could be due to insulin mimetic action, oxidative stress attenuation and β-cell regeneration [48]. In another study, intraperitoneal injection of chloroform plant extract of *Azadirachta indicia* to STZ induced diabetic mice for 21 days regenerated insulin-producing cells with increase in plasma insulin and c-peptide levels. In the experiment, intestinal glucosidase activity reduced, glucose-6-phosphate dehydrogenase activity and hepatic, skeletal muscle glycogen content increased, and oral glucose was well tolerated [50]. *A. indicia* is reported to have bioactive compounds such as rutin, quercetin and nimbidin, which is said to be responsible for its hypoglycemic effects [51]. The hypoglycemic effect of combination of *Azadirachta indicia* and *Gynura procumbens* was carried out by Sunarwidhi *et al.* In the experiment, the macerated extracts administered to alloxan-induced diabetic rats for 15 days significantly improved the morphology of β-cells and the islets of Langerhans. Also, insulin expression increased and elevated-glucose concentration decreased [51]. Furthermore, in a randomized, double-blind, placebo-controlled clinical study, subjects with type 2 diabetes already placed on standard metformin therapy received different doses of neem for 12 weeks. In this experiment, neem at 125, 250, and 500mg doses significantly decreased postprandial blood sugar level, FBG, HbA1C and IR compared to the placebo group. Endothelial function improved OS and systemic inflammation decreased but there was no effects on lipid profile or platelet aggregation. It was suggested by the authors that neem may cure hyperglycemia, systemic inflammation and endothelial dysfunction in patients with type 2

diabetes in comparison to the effects of metformin [52]. In another study, butanol fraction of *Azadirachta indica* ethanol stem bark extract showed DDPH scavenging activity, FRAP activity, ameliorated oxidative injury in hepatic tissue by reducing malondialdehyde (MDA) concentration significantly, improved the activities of SOD and CAT, improved glucose uptake in psoas muscle with or without insulin, and inhibited activities of α-glucosidase and α-amylase. Sistosterol, campestrol, stigmasterol, squalene and nimbiol are reported to be present in *Azadirachta indica*. It was suggested that butanol and ethyl acetate fractions of *A. indica* may possibly have bioactive compounds with potentials to cure diabetes [53]. Impaired nerve functions and delayed nerve recovery occurring due to hyperglycemia-induced OS was ameliorated in STZ-induced diabetic rats by the action of *A. indica* flower extract at a dose of 250, 500 or 750 mg/kg. In this experiment, functional recovery (motor and sensory functions) improved significantly, MDA levels significantly decreased, while SOD activity and axon density significantly increased. It was suggested by the authors that *A. indica* flower extract may have antioxidative effect [54]. In another study, combination of (1:1) aqueous extract of dried powder of *Azadirachta indica* (leaves) and *Abroma augusta* (root) orally administered to alloxan-induced diabetic rats once a day for 8 weeks significantly decrease blood sugar, serum lipids, formation of lipid peroxides and LPO with increased antioxidants (SOD, CAT, glutathione transferase and glutathione peroxidase). Decrease in body weight was also prevented by the extract [55]. Also, chloroform leaf extract of *Azadirachta indica* increased GSH, SOD, CAT and oxidized glutathione (GSSG), hepatic glycogen content, insulin plasma and glucose-6-phosphatase in STZ-induced diabetic rats after chronic oral administration of the extract for 28 days. Meanwhile, IR, lipid peroxidation and glucokinase (GK) decreased. It was reported that *A. indica* can be considered to be a potential antidiabetic-safe agent [56]. Absence of marked hyperglycemia, absence of diabetic nephropathy, absence of nodular glomerulosclerosis and absence of vacuolation of proximal tubule cells was observed in an experiment carried out to determine the ameliorative effects of ethanolic leaf extract of *Azadirachta indica* (500 mg/kg b.w) for 50 days on renal histological alterations in STZ-induced diabetic rats. It was stated that leaf extract of *Azadirachta indica* ameliorates hyperglycemia and diabetic nephropathy in rats [57].

Balanites aegyptiaca

Balanites aegyptiaca commonly known as desert date tree belongs to the family Balanitiaceae. The kernel fruit was reported to contain polyphenols [58] and saponins [59]. Other bioactive compounds like flavonoids, alkaloids, tannins and vitamins have been reported in the fruit as well as the branches, leaves and roots of *Balanites aegyptiaca* [60, 61, 62]. In a study, 50 mg/kg b.w of crude extract, butanol or dichloromethane fraction of *Balanites aegyptiaca* administered to diabetic rats produced a decrease in plasma glucose, lactic acid, HbA1c, lipid profile, MDA, GSH levels, CAT and SOD activities with an increase in insulin and insulin receptor substrate 1 in rat pancreas. In essence, it was suggested by the authors that the hypoglycemic effect of *Balanites aegyptiaca* is due to the inhibition of the SAPK-JNK pathway [63]. In another study, *B. aegyptia* significantly decreased mean plasma glucose and MDA levels and significantly increased mean plasma insulin, total antioxidant capacity (TAC) levels, and liver-pyruvate kinase (L-PK) in STZ-induced diabetic rats after oral administration of *Balanites aegyptiaca* fruits aqueous extract (1.5 g/kg b.w) daily for 45 days. Size of the islets of Langerhans and weight of the pancreas increased and histoarchitecture also improved [64]. In a randomized double-blinded pilot clinical study to determine the antidiabetic efficacy of 70% ethanol extract of the pericarps of *B. aegyptiaca* on type 2 diabetic patients, *B. aegyptiaca* incorporation in hard gelatine capsules and administration at 400 mg/day for 8 weeks decreased postprandial plasma glucose, FBG, TG, LDL, TC, AST, ALT significantly. In the experiment, HDL increased. Administration of *B. aegyptiaca* capsules to type 2 diabetic patients caused significant improvements in glycaemic markers and lipid profile, without adverse effects or hypoglycemia [65]. Ethyl acetate extract from *Balanites aegyptiaca* administered at 10, 20 or 50 mg/kg b.w to experimental diabetic rats for 8 weeks lowered blood glucose level, HbA1c, MDA and vascular endothelial growth factor (VEGF) in diabetic retina. Tumor necrosis factor alpha (TNF-α) and interleukin (IL-1β) significantly decreased in diabetic rats treated with the extract and β-sistosterol was present in the extract [66].

Brassica oleracea

Brassica oleracea (broccoli) belongs to the family Brassicaceae. It is said to contain

components like minerals, vitamins, dietary fiber, hydroxycinnamic acids, flavonol glycosides and glucosinolates [67]. In an experimental study, when STZ-induced diabetic rats were administered polyphenols (5 mL/week) gotten from aqueous broccoli extract for 8 weeks, DNA damage reduced significantly, GSH and TAC values were significantly conserved, and pancreatic histopathological changes were attenuated. The author concluded that *B. oleracea* reduced the STZ mediated hyperglycemia and the STZ-induced oxidative injury to pancreas tissue [67]. In a recent study, a single oral administration of aqueous extract of *B. oleracea* at a dose of 60 mg/kg significantly decreased blood glucose at the 6^{th} hour in STZ-induced diabetic rats. In the study, repeated administration of the same dose for 7 days significantly decreased the blood glucose to the normal level. The author revealed that *B. oleracea* aqueous extract is rich in numerous phytochemical compounds and can exert antioxidant activity [68]. In another study, 500 mg/kg b.w of *B. oleracea* methanol extract administered to alloxan-induced diabetic rats significantly lowered FBG, TC, and LDL, whereas the HDL increased in comparison to the diabetic control group. The changes were said to be similar in comparison to glibenclamide (a reference drug) [69]. However, the antioxidant activity *B. oleracea* edible sprouts [70], it phytochemical components [71], and amino acid compositions [72] have been reported. Furthermore, 800 mg/kg b.w of *B. oleracea* aqueous extract administered to STZ-induced diabetic rats for 28 days significantly decreased FBG by about 64% within 7 days of treatment. Additionally, HbA1c and lipid profile normalized. The authors also declared that BUN, Serum glutamic oxaloacetic transaminase (SGOT) and Serum glutamic pyruvic transaminase (SGPT) significantly decreased, meanwhile, activities of CAT and SOD significantly increased. However, chlorogenic acid, sinapic acid and rutin were present in the extract [73].

Table 1 – Other medicinal plants with investigated antidiabetic effects

No.	Botanical name	Family	Common name	Part(s) used	Significant antidiabetic activities
1	*Carica papaya*	Caricaceae	Pawpaw	Leaves, fruits	Preserved integrity of pancreatic islets, improved basal insulin secretion and protected cultured call from adverse effects of STZ [74]. Exhibited hypoglycemic and antioxidant effects and improved lipid profile [75]. Improved platelet function and increased total antioxidant capacity (TAC) and SOD in type 2 diabetic patients [76]. Decreased blood glucose and serum lipid levels [77, 78, 79, 38].
2	*Eugenia caryophyllus*	Myrtaceae	Clove	Bud	Inhibited α-amylase and α-glucosidase activities and exhibited antioxidants activities [80].
3	*Ficus carica*	Moraceae	Fig	Fruit	Improved cholesterolaemic status [81]. Regulated blood glucose and lipids parameters [82]. Lowered blood glucose, TC, and TG to normal [83].
4	*Ficus deltoidea*	Moraceae	Fig	Leaf	Stimulated insulin secretion and blocked the production of hepatic glucose [84]. Suppressed hepatic glucose output, improved insulin sensitivity and enhanced glucose uptake in type 2 diabetes mellitus [85]. Decreased total and LDL-c concentration [86]. Decreased blood glucose to near normal [100, 101]. Promoted regeneration of islet, increased antioxidant enzymes of pancreas and increased insulin secretion [101].
5	*Ficus racemosa*	Moraceae	Cluster fig, redwood fig	Bark, stem, leaves, root	Decreased blood glucose [87, 88, 92, 93, 94 95], serum lipid, and lipoprotein [89], serum cholesterol, serum triglycerides and serum urea [90]. Exhibited increased in plasma insulin level [91] and inhibited the activity of hexokinase and glucose 6-phosphatase [89].

No.	Botanical name	Family	Common name	Part(s) used	Significant antidiabetic activities
6	*Ficus thonningii*	Moraceae	Wild fig	Stem bark	Exhibited hypoglycemic effects [96, 97, 98], and hypolipidaemic effects [99]. Increased glucose uptake in primary hepatocytes [99].
7	*Gossypium herbaceum*	Malvaceae	Cotton	Seed	Reduced serum level of glucose, TG, cholesterol, urea and creatinine [102].
8	*Guiera senegalensis*	Combretaceae	Sabara	Leaves and root	Increased body weight and HDL-c, and decreased glycaemia, insulin, LDL-c, TG, TC creatinine and urea [103].
9	*Khaya senegalensis*	Meliaceae	Mahogany	Root, stem, bark	Reduced the level of blood glucose, stimulated synthesis of hepatic glycogen, improved tolerance of oral glucose and function of β-cell, decreased insulin resistance, ameliorated alterations of serum lipids and prevented renal and hepatic damages [104]. Inhibited α-glucosidase and α-amylase activities [105, 106].
10	*Lawsonia inermis*	Lythraceae	Egyptian priest, henna	Leaves	Decreased glucose, cholesterol, and TG concentration to normal [107]. Improved plasma albumin, lipid profile, serum creatinine and total plasma protein [108].
11	*Mangifera indica*	Anacardiaceae	Mango	Leaves, kernel flour.	Exhibited dose-dependent inhibition against α-glucosidase activities [109, 110] and α-amylase [110]. Decreased blood glucose level beyond glibenclamide effects with increase in the sensitivity of insulin and plasma insulin levels [111]. Prevented the decline in body weight and decrease in β-cell mass [112]. Improved FBG, HbA1c, hepatic glycogen, plasma electrolytes, lipid profile, pancreatic and hepatic MDA, and the markers of liver function [113].
12	*Moringa oleifera*	Moringaceae	Drumstick	Leaf, seed, fruit	Significantly decreased blood glucose in diabetic rats and mice [114-130]. Reduced triglycerides levels [115]. Increased CAT [116, 119, 130], increased SOD [118. 119. 130] and decreased MDA [116, 118, 119]. Increased HDL [120, 121, 122], decreased cholesterol, LDL, VLDL and triglycerides [120, 121, 122, 125]. Decreased HbA1c level [126, 129].
13	*Parkia biglobosa*	Fabaceae	Locust bean	Seed	Decreased FBG [132, 133] cholesterol, serum triglyceride, LDL-c, VLDL cholesterol and LPO with increase in HDL-c and restoration of biomarkers of OS [131]. Improvement of glucose tolerance and pancreatic β-cell function with stimulation of insulin secretion, decrease in insulin resistance, restoration of liver glycogen amelioration of serum dyslipidaemia and prevention of renal and hepatic damages in comparison to the untreated diabetic rats [132].
14	*Psidium guajava*	Myrtaceae	Guava	Leaves	Decreased TC [134, 135 137, 140], LDL [134, 135, 137, 140], glucose level [134, 136-141], and TG [135, 137, 140]. Increased plasma insulin level [138], HDL [135, 137, 140], SOD and CAT activity [141].
15	*Solanum incanum*	Solanaceae	Bitter apple	Fruit	Reduced blood glucose concentration [142].

No.	Botanical name	Family	Common name	Part(s) used	Significant antidiabetic activities
16	*Vernonia amygdalina*	Asteraceae	Bitter leaf	Leaves	Exhibited antihyperglycemic effects, decreased LDL-c, VLDL cholesterol and increased HDL-c in diabetic rats [143]. Improved glucose tolerance, decreased FBG, TG and TC, protected β-cells and increased insulin in diabetic rats [144]. Decreased TG and MDA levels and normalized cholesterol concentration [145].
17	*Ziziphus mucronata*	Rhamnaceae	Buffalo thorn	Root,	Lowered blood glucose, improved glucose tolerance, and increased serum insulin and liver glycogen [146].

Abbreviations: streptozotocin (STZ); total cholesterol (TC); triglycerides (TG); low density lipoprotein cholesterol (LDL-c); high density lipoprotein (HDL); low density lipoprotein (LDL), very low density lipoprotein (VLDL); superoxide dismutase (SOD); catalase (CAT); malondialdehyde (MDA); glycosylated hemoglobin (HbA1c); high density lipoprotein cholesterol (HDL-c); oxidative stress (OS); lipid peroxidation (LPO); fasting blood glucose (FBG)

Conclusions

In summary, this present study has listed some medicinal plants with reported and potential antidiabetic effects. Although, most of the research used animal models, there is a clear indication that medicinal plants with anti-diabetic potentials are being investigated by several researchers. Unfortunately, most of the investigations are preliminary in nature. However, there is a need for further research to be conducted with isolated bioactive ingredients present in these plants in order to have potential compounds that could be used as a pharmacological agent in the treatment of diabetes mellitus. Again, the mechanisms of action of these medicinal plants in ameliorating diabetes need to be investigated. Moreover, pharmaceutical industries need to support more research activities in this area in order to produce and commercially utilize antidiabetic product from medicinal plants with less disadvantages/adverse effects.

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The author declares no conflict of interest.

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