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REVIEW ARTICLE

Role of medicinal plants in the management of diabetes mellitus: a review

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Abstract
Medicinal plants have a vast potential in the treatment of various ailments due to the presence of therapeutically important phytochemicals. Diabetes is a serious metabolic disorder and several marketed medications are available to alleviate the symptoms of diabetes. However, these over the counter drugs are expensive and associated with several complications. Herbal medicines are gaining importance as they are cost-effective and also display improved therapeutic effects with lesser side effects. The present review includes the reports available on medicinal plants used for treating diabetes complications. The aim of the review is to categorize and summarize the available information on medicinal plants with anti-diabetic properties and suggesting outlooks for future research. A systematic search was performed on medicinal plants with anti-diabetic properties using several search engines such as Google Scholar, PubMed, Science Direct and other online journals and books. All the plants listed in this review are native to Asian countries and are routinely used by the traditional practitioners for the treatment of various ailments. Based on the literature data available, a total of 81 medicinal plants with anti-diabetic, anti-hyperglycemic, hypoglycemic, anti-lipidemic and insulin mimetic properties have been compiled in this review. This review provides useful information about the different medicinal plants for treating diabetes-associated complications. Further research can be carried out to study the active constituents and mechanism of these plants.

Keywords Diabetes · Medicinal plants · Antidiabetic · Antihyperglycemic · Hypoglycemic

Introduction

Medicinal plants play a significant role in the treatment of diabetes mellitus which is a serious metabolic disorder. Traditional plants are reported to have significant anti-diabetic properties with no harmful side effects. They are rich sources of anti-diabetic compounds such as flavonoids, alkaloids, phenolic and tannins that improve the efficiency of pancreatic tissues by increasing the insulin secretion or decreasing the intestinal absorption of glucose (Kooti et al. 2016). Literature suggests that there are approximately 410 experimentally proven medicinal plants with anti-diabetic properties out of which the complete mechanism has been studied only for 109 plants. Several medicinal plant extracts have been shown to modulate the metabolic pathways such as glycolysis, gluconeogenesis, Krebs cycle, glycogen synthesis and their degradation, synthesis and release of insulin, cholesterol synthesis, carbohydrate metabolism and absorption (Prabhakar and Doble 2008). Diabetes mellitus (DM) is a chronic endocrine disorder which is characterized by high blood glucose levels that can interfere with carbohydrate, protein, and fat metabolism (Bastaki 2005). It is caused due to the deficit production of insulin by the β-Langerhans islet cells of the pancreas or due to defective insulin uptake in the peripheral tissues (Al-Goblan et al. 2014). An increase in the blood glucose level immediately after a meal triggers the release of insulin hormone from the pancreas. Insulin stimulates the liver to metabolize glucose and also stimulates the fat and muscle cells to remove glucose from the blood which results in a drop of blood sugar level to normal levels. If a person is diabetic, the blood sugar level remains high due to nil or ineffective production of insulin by the pancreas

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(Dean and McEntyre 2004). India has more than 61 million people living with diabetes and hence is considered to be the "capital of diabetes". Effective treatment of diabetes and its associated complications still remains a major challenge for India due to several issues such as inadequate health care system, lack of proper facilities, etc. (Viswanathan and Rao 2013). Herbal formulations are favored over synthetic drugs to reduce the ill-effects of diabetes and its secondary complications due to lesser side effects and also being cost-effective (Modak et al. 2007). The present review aims to summarize some of the important Indian medicinal plants with anti-diabetic activities based on the electronic literature data available online.

Medicinal plants with anti-diabetic activities

Aegle marmelos (L.) Corrêa (Wood apple)

Aegle marmelos (L.) Corrêa (Rutaceae), commonly known as Bael or wood apple, is an important medicinal tree native to Northern India. The fruits of this tree are being routinely used for the treatment of dysentery, peptic ulcers, chronic diarrhea and as a laxative in various folk medicine (Baliga et al. 2011). Juice of this fruit is consumed on an empty stomach everyday by the Tripuri tribe in North East India for treating gastric problems. Leaf paste is used for high fever during malaria (Debbarma et al. 2017). The fresh leaf decoction is consumed twice a day for the treatment of a cough, eye problems, breast inflammation and as body coolant by the tribes of Theni district, Tamil Nadu, India (Jeyaprakash et al. 2011). Oral administration of aqueous extract of *A. marmelos* fruit (twice a day for 4 weeks) at a dosage of 250 mg/kg body weight resulted in significant reduction of blood sugar levels in streptozotocin-induced diabetic Wistar rats. This dosage showed effective results over the standard drug glibenclamide (Kamalakkannan and Prince 2003). In a similar study conducted by Kamalakkannan and Prince (2005), the aqueous fruit extract showed protective effects on the pancreas by partially reversing the damage induced by streptozotocin to the pancreatic islets. The methanolic extract of the powdered callus of *A. marmelos* is found to have analogous anti-diabetic potential as its leaf extract (Arumugam et al. 2008). Regular administration of the aqueous seed extract of *A. marmelos* at a dosage of 250 mg/kg for 14 days resulted in substantial reduction of blood glucose level and stabilization of lipid profile in normal and severely diabetic rats. The glucose tolerance was also found to be enhanced in the sub-diabetic and mild diabetic rats (Kesari et al. 2006). Ethanolic extract (150 mg/kg for 30 days) of *A. marmelos* modulates the antioxidant status in the diabetic rats thereby providing a strong defense against the damage caused due to reactive oxygen species in streptozotocin-induced diabetic rats (Narendhirakannan and Subramanian 2010). Treatment with aqueous fruit and leaf extract of *A. marmelos* (450 mg/kg for 21 days) resulted in significant lowering of blood glucose and insulin levels accompanied with enhanced insulin sensitivity in neonatal type 2 diabetic model rats (Mudi et al. 2017). A compound (3,3-dimethylallyl) halfordinol isolated from the leaves of *A. marmelos* exhibited anti-diabetogenic and lipolytic activities as well as decreased insulin resistance in treated mice models (Saravanan et al. 2014). Limonene, a terpene isolated from the chloroform extract of *A. marmelos* demonstrated potent anti-glycative properties at a 20-fold lower concentration than commonly used inhibitor aminoguanidine (Panaskar et al. 2013). The methanolic extract of the bark of *A. marmelos* demonstrated hypoglycemic effect which can be attributed to the presence of antihyperglycemic constituents—aegelin and lupeol. The study also further demonstrated the regenerative effects of the bark extract on the pancreatic beta cells in diabetic rats (Gandhi et al. 2012). The aqueous fruit extract of *A. marmelos* has shown to salvage the pancreatic beta cell function and improve insulin sensitivity by increasing the peroxisome proliferator-activated receptor-γ (PPARγ) expression (Sharma et al. 2011). A series of phenylethyl cinnamides including two novel α-glucosidase inhibitors namely anhydromarmeline and aegelinosides have been isolated from the leaves of *A. marmelos* of which anhydroaegeline demonstrated high inhibitory activity against α-glucosidase (Phuwapraisirisan et al. 2008).

Coriandrum sativum L. (Coriander)

Coriandrum sativum L., a member of the Apiaceae family, is a commonly used food ingredient possessing medicinal as well as nutritional properties (Laribi et al. 2015). Administration of ethanolic stem and leaves extract of coriander to alloxan-induced diabetic Wistar rats at a dosage of 200 mg/kg/b.w. resulted in hepatoprotective, hypoglycemic, hypolipidemic activities with improved antioxidant potential (Sreelatha and Inbavalli 2012). Sub-chronic administration of aqueous extract of coriander seeds to hyper-caloric diet fed Meriones shawi rats resulted in normalization of blood glucose levels with improved insulin resistance and decreased levels of total cholesterol and triglycerides (Aissaoui et al. 2011). Treatment of streptozotocin-induced diabetic rats with ethanol extract of coriander seeds (200 mg/kg body weight) resulted in decreased serum glucose and increased the insulin releasing capacity of beta cells of pancreatic islets (Eidi et al. 2009).

Zingiber officinale Roscoe (Ginger)

Zingiber officinale Roscoe, commonly known as ginger, belongs to the family of Zingiberaceae and is considered to be an important spice with innumerable health benefits. The rhizomes of ginger have been used traditionally for the treatment of hypertension, diabetes, arthritis, sprain, muscular aches, sore throats, fever, cramps, gingivitis, toothache, asthma and infectious diseases (Haniadka et al. 2013). Dietary ginger has been studied to exhibit hypoglycemic, anti-diabetic, anti-oxidant, hypocholesterolemic and hypolipidemic potential (Al-amin et al. 2006; Iranloye et al. 2008; Rani et al. 2012) Supplementation of powdered ginger (3 g/day) for 3 months in type 2 diabetic patients resulted in improved glycemic index and antioxidant status (Shidfar et al. 2015). In a similar study conducted on type 2 diabetic patients, oral ginger supplementation (2 g/day) was found to decrease the insulin levels with no significant changes observed in the fasting plasma glucose and glycated hemoglobin levels (Mahluji et al. 2013). Hydroalcoholic extract of ginger has found to significantly reduce the heart structural abnormalities in STZ-induced diabetic rats with improvement in serum leptin, apoproteins, cathepsin G and homocysteine levels (Ilkhanizadeh et al. 2016). Treatment of diabetic mice with gingerol, an active component of *Z. officinale*, at a dosage of 200 mg/kg/b.w. enhanced the secretion of insulin and also facilitated the uptake of glucose in skeletal muscles through cell surface presentation of GLUT4 transporters and augmentation of glycogen synthase 1 activity (Li et al. 2012b; Samad et al. 2017). Oral administration of ginger extract (500 mg/kg/b.w.) to diabetic rats facilitated the peripheral uptake of glucose and also corrected the impaired glycolytic process of kidney and liver by limiting the gluconeogenic formation (Abdulrazaq et al. 2012).

Syzygium cumini (L.) Skeels (Black plum)

Syzygium cumini (L.) Skeels, commonly known as Jamun in India, belongs to the family of Myrtaceae and has a wide distribution in the Indian sub-continent, eastern Africa and Southeast Asian countries (Srivastava and Chandra 2013). Stem bark decoction is being consumed by the tribes of Sikkim and Darjeeling Himalaya, India, for the treatment of diabetes mellitus (Chhetri et al. 2005). Oral administration of ethanolic and aqueous extracts of the bark of *S. cumini* (500 mg/kg for 21 days) showed significant blood glucose lowering effects in diabetic Wistar rats (Tripathi and Kohli 2014). Crude hydroalcoholic leaf extract of *S. cumini* has shown to exhibit hypolipidemic and hypoglycemic properties rendering a defensive mechanism against DNA damage and damage caused due to oxidative stress. These properties can be attributed to the phenolic and myricetin content of the leaf (Baldissera et al. 2016). Vitalboside A, an insulin sensitizer isolated from the methanolic seed extract of *S. cumini* has shown to augment glucose transportation through IRb-triggered PI3K/Akt activation and allosteric inhibition of PTP1B in 3T3-L1 adipocytes and L6 myotubes (Thiyagarajan et al. 2016). Administration of aqueous extract of *S. cumini* seeds in high-fat-diet–streptozotocin-induced type 2 diabetic rats exhibited significant insulin sensitizing, anti-oxidant, anti-dyslipidemic, anti-inflammatory and β-cell protective effects by overexpression of PPARα and PPARγ activity (Sharma et al. 2017). Oral administration of ethyl acetate fractions significantly modulated the serum glucose level, glucose tolerance, lipid profile, muscle and hepatic glycogen contents, hepatic hexokinase and glucose-6-phosphatase activities. An increase in the volume and size of the pancreatic islets was observed in the treated diabetic rats (Panda et al. 2009). The flavonoid-rich extract obtained from the seeds of *S. cumini* showed to increase the release of insulin from the pancreatic islets as well as decreased the levels of triglycerides and LDL in treated diabetic rats. These activities are a result of the dual upregulation of both the peroxisome proliferators-activated receptors (PPARa and PPARc) (Sharma et al. 2008). Administration of ethanolic extract of the seeds of *S. cumini* significantly decreased the blood sugar level accompanied by an increased body weight in alloxan-induced diabetic rats (Singh and Gupta 2007). The aqueous seed extract of *S. cumini* (100 mg/kg for 21 days) exerts a modulatory effect on the hyperglycemic and inflammatory conditions observed in diabetes mellitus. It also exerts a protective effect against the pathophysiological manifestations triggered by the early stages of diabetes mellitus (Bitencourt et al. 2015). The presence of inorganic constituents such as chromium, potassium, sodium, vanadium in the seeds of *S. cumini* have also been studied to possess hypoglycemic and hypolipidemic activity (Ravi et al. 2004a, 2005). Oral administration of *S. cumini* kernel extract exhibited better hypoglycemic activity as compared to the whole seed extract in diabetic rats (Ravi et al. 2004b). Biosynthesized silver nano-particles from the seeds of *S. cumini* exhibited higher antioxidant activities as compared to the seed extract (Banerjee and Narendhirakannan 2011).

Murraya koenigii (L.) Spreng. (Curry tree)

Murraya koenigii (L.) Spreng., a member of Rutaceae family, commonly known as curry leaf is an important medicinal plant native to India exhibiting diverse biological activities. Leaf decoction mixed with rice flour is used a treatment for indigestion and eye problems by the tribes of Theni district, Tamil Nadu, India (Jeyaprakash et al. 2011). Koenidine, a metabolically stable carbazole alkaloid isolated from the leaves of *M. koenigii* demonstrated a considerable reduction in the postprandial blood glucose level and improved insulin sensitivity in streptozotocin-induced diabetic rats

(Patel et al. 2016). Administration of ethanolic leaf extract of *M. koenigii* ameliorated the insulin sensitivity and glucose tolerance in dexamethasone-induced insulin-resistant mice. The glucose uptake and GLUT-4 translocation was augmented by the stimulatory effect of *M. koenigii* via insulin-mediated phosphorylation of AKT (Pandey et al. 2014). Oral administration of ethanolic extract of the leaves of *M. koenigii* significantly decreased the blood sugar levels in diabetic rats and also rendered protective effects against development of diabetic neuropathy (Tembhurne and Sakarkar 2010). Administration of aqueous extract of the leaves of *M. koenigii* (200 and 400 mg/kg for 30 days) considerably enhanced the antioxidant status and renal function in diabetic rats and also exhibited strong hypolipidemic and hypoglycemic action (Kesari et al. 2007; Yankuzo et al. 2011). Aqueous leaf extract of *M. koenigii* demonstrated better antihyperglycemic activity over the methanolic extract in treated alloxan-induced diabetes mice. Both the extracts are capable of regulating inflammatory cytokines, oxidative stress and prevention of the pancreatic islet damage in diabetic mice. The hypoglycemic property of the *M. koenigii* aqueous extract is based on its ability to elevate PON1 (paraoxonase 1 antioxidant enzyme) activity and subsequently decreasing hyperlipidemia. (Paul et al. 2011; Saha and Mazumder 2013). The extract of *M. koenigii* has been studied to exhibit cytoprotective effects on the pancreatic beta cell production. The effect of this extract on insulin secretion and islet protection was found to persist even after the discontinuation of treatment in diabetic mice (Dusane and Joshi 2012). Oral administration of ethanolic extract of *M. koenigii* (150 mg/kg b.w.) for 30 days in male albino rats resulted in increased levels of insulin, C-peptide, hemoglobin and protein with concomitant decrease in the levels of glycosylated hemoglobin and blood glucose. The presence of inorganic trace elements such as zinc, copper, chromium vanadium, nickel, iron, sodium and potassium in the leaves of *M. koenigii* could be responsible for improvement in managing impaired glucose tolerance and their indirect role in management in diabetes mellitus (Narendhirakannan et al. 2005, 2006).

Gymnema sylvestre (Retz.) R.Br. ex Sm.

Gymnema sylvestre belonging to the family of Apocynaceae is an important medicinal plant with several pharmacological properties such as antidiabetic, anticarcinogenic and neuroprotective effects (Fabio et al. 2014). The leaves of this plant are dried and powdered and consumed orally with milk by the tribals in southern Western Ghats of Tamil Nadu, India, for alleviating the symptoms of diabetes mellitus (Ayyanar et al. 2008). *G. sylvestre* is popularly known as gurmar, exhibits sweet destroying property which is attributed to its phytoconstituents such as gymnemic acids, triterpenes, gymnema saponins, gurmarin (Tiwari et al. 2014). The active constituent of this plant includes gymnemic acid, gurmarin, tartaric acid, stigmasterol, betaine, glucose, calcium oxalate and choline which are responsible for the anti-obesity, anti-inflammatory and anti-diabetic properties of *G. sylvestre*. The possible mechanism for its hypoglycemic effects can be attributed to its ability to regenerate islet cells and inhibit glucose absorption from the intestine. It also acts by increasing the glucose utilization in the body and by increasing the activities of enzymes (phosphorylase enzyme) that are responsible for utilization of glucose (Kanetkar et al. 2007). Literature reports suggest that the leaves of *G. sylvestre* stimulates the pancreas due to which an increased insulin release is observed (Kanetkar et al. 2004).

Phyllanthus emblica L. (Indian gooseberry)

Phyllanthus emblica L. (synonym: *Emblica officinalis* Gaertn.), commonly known as Amla belonging to the family of Euphorbiaceae is considered as a highly important medicinal plant in Ayurvedic medicine. The major bioactivities of this plant are attributed to its rich polyphenol content comprising mainly tannins and flavonoids. *E. officinalis* (*P. emblica*) exhibits anti-inflammatory, anti-cancer, immunomodulatory, anti-hyperglycemic properties and is also known to maintain glucose homeostasis and improve glucose metabolism (Yadav et al. 2017). It also aids in stimulating pancreatic insulin secretion and regeneration of beta cells (D'souza et al. 2014). Administration of aqueous extract of *E. officinalis* (*P. emblica*) in type 2 diabetic rats (1.25 g/10 mL/kg body weight) for 8 weeks significantly reduced the fasting serum glucose levels with improved oral glucose tolerance (Ansari et al. 2014). In a study conducted by Akhtar et al. (2011), diabetic volunteers treated with *E. officinalis* (*P. emblica*) powder at a dosage of 3 g/day exhibited a significant decrease in the total lipids with improved HDL cholesterol and lowered LDL cholesterol levels. Treatment with *E. officinalis* (*P. emblica*) fruit juice at a dosage of 1 mL/kg/b.w. orally for 8 weeks in type 1 diabetes-induced Wistar rats resulted in improved hyperglycemia, oxidative stress, hyperlipidemia and also augmented the myocardial antioxidant defense mechanisms thereby improving myocardial function in STZ-induced diabetic Wistar rats (Patel and Goyal 2011). Oral administration of a polyphenol-rich ethyl acetate extract fraction of *E. officinalis* (*P. emblica*) at a dosage of 10 or 20 mg/kg of b.w./day to streptozotocin-induced diabetic rats resulted in strong inhibition of glycosylated end products with increased body weight (Rao et al. 2005).

Cinnamomum verum J. Presl (Cinnamon tree)

Cinnamomum verum J. Presl, belonging to the Lauraceae family is one of the most commonly consumed spices all

over the world. Cinnamon contains vital oils as well as active constituents such as cinnamic acid, cinnamaldehyde, cinnamate that are associated with several health benefits. Cinnamon exhibits a wide range of therapeutic effects such as antioxidant, anti-inflammatory, anti-cancer, anti-diabetic, anti-microbial and also known to have activities against neurological disorders (Rao and Gan 2014). Several polyphenols have been isolated from cinnamon that include rutin (90.06%), catechin (1.90%), quercetin (0.17%), kaempferol (0.02%), and isorhamnetin (0.10%) (Li et al. 2008; Yang et al. 2012). In a comparative study, the insulin potentiating effect of cinnamon was found to be 20-fold higher than many other spices (Broadhurst et al. 2000). Several literature reports reveal that cinnamon has blood glucose and cholesterol lowering activities (Mang et al. 2006; Crawford 2009). Cinnamon has been studied to induce GLUT4 translocation via the AMPK signaling pathway in 3T3-L1 adipocytes and C2C12 myotubes thus establishing its significant role in ameliorating the complications associated with type 2 diabetes mellitus (Shen et al. 2014). Cinnamon polyphenols have been reported to exhibit anti-diabetic activity by its mechanism that includes regulation of glucose levels, lipid metabolism, repair of pancreatic beta cells in STZ-induced high-fat diabetic mice and inhibition of iNOS, NF-κB activation (Li et al. 2013).

Momordica charantia L. (Bitter melon)

Momordica charantia L., belonging to the family of Cucurbitaceae has been used as a herbal medicine for several years due to its biological properties such as immunomodulation, hepatoprotection, anti-diabetes, anti-tumor and antioxidant (Zhang et al. 2016). A comparative study about the effect of charantin-rich extract (CEMC) of *M. charantia* on type 1 and type 2 diabetic animal models revealed that CEMC at a dosage of 200 mg/kg/day caused a significant decline in the body weight and non-fasting blood glucose level with decreased insulin resistance in high-fat-diet-induced diabetic KK/40HIJ mice. It also caused an increase in the plasma glucose tolerance, but no significant effect was observed on the insulin sensitivity of STZ-induced type 1 ICR 48 mice thus suggesting that CEMC has the potential of improving insulin sensitivity in T2D patients rather than protecting T1D patients against β-cell dysfunction (Wang et al. 2014). Oral administration of 3% bitter melon supplementation to high-fat-diet-induced male OLETF rats resulted in improved glucose tolerance and insulin sensitivity with significant down regulation of phospho-NF-κB (p65) (Ser536) and phospho-c-Jun N-terminal kinase (JNK) (Thr183/Tyr185) in liver, muscle and epididymal fats. It also significantly increased the levels of phospho-insulin receptor substrate-1 (Tyr612) and phospho-Akt (Ser473) and decreased activation of nuclear factor-κB (NF-κB) (Yang et al. 2015). Oral administration of *Momordica* fruit extract (1.5 g/kg b.w.) for 28 days in STZ-induced Sprague Dawley rats resulted in increased bodyweight and elevated levels of superoxide dismutase, glutathione and catalase in the cardiac tissues thereby establishing its anti-hyperglycemic, cardio-protective and anti-oxidative properties (Abas et al. 2014). Oral administration of *M. charantia* juice to STZ-induced diabetic rats was found to regulate the uptake of glucose into the brush border vesicles of jejunum and also stimulated the uptake of glucose into muscle cells, a response similar to that of insulin (Ahmed et al. 2004).

Ocimum tenuiflorum L. (Holy basil)

Ocimum tenuiflorum L. (synonym: *Ocimum sanctum* L.), commonly known as tulsi or holy basil belongs to the family of Lamiaceae and is considered as a sacred and important medicinal herb in India. Oral administration of ethanolic leaf extract of *O. sanctum* (*O. tenuiflorum*) (500 mg/kg b.w.) for 15 days resulted in decreased levels of blood glucose, glycosylated hemoglobin, free fatty acids, lipid peroxide and low density lipoproteins and had significantly beneficial effects on HDL synthesis. The mechanism behind the lipid-lowering action of *O. sanctum* (*O. tenuiflorum*) can be attributed to its ability to reactivate lecithin cholesterol acyl transferase, hepatic lipoprotein lipase enzymes and post-heparin lipolytic enzymes (Husain et al. 2015). A tetracyclic terpenoid [16-hydroxy-4,4,10,13-tetramethyl-17-(4-methyl-pentyl)-hexadecahydro-cyclopenta[a]phenanthren-3-one] isolated from the hydro alcoholic extract of the aerial parts of *O. sanctum* (*O. tenuiflorum*) exhibited potential anti-diabetic properties by ameliorating glucose levels, total cholesterol, low and high density lipoprotein cholesterol and triglycerides parameters (Patil et al. 2011). Fixed oil extracted from the leaves of *O. sanctum* (*O. tenuiflorum*) significantly lowered the blood glucose and lipid parameters while increasing serum insulin levels. It also exhibited nephro-protective activity by suppression of high TBARs level and enhancement of various antioxidative enzymes present in the renal tissues of diabetic Wistar rats. This property may be attributed to α linolenic acid present in the fixed oil (Suanarunsawat et al. 2016). Oral administration of aqueous extract of *O. sanctum* (*O. tenuiflorum*) mixed with diet for 8 weeks showed a significant reduction in fasting blood glucose, lipid peroxidation products, serum lipid profile and improvement in glucose tolerance (Hussain et al. 2001). In a study carried out by Hannan et al. 2006, ethanol, butanol, aqueous and ethylacetate fractions of *O. sanctum* (*O. tenuiflorum*) leaves stimulated insulin secretion from the damaged rat pancreas, isolated rat islets and in clonal pancreatic β-cells. Administration of *O. sanctum* (*O. tenuiflorum*) seed oil (0.8 g/day b.w.) for 4 weeks demonstrated hypocholesterolemic and

Table 1 Medicinal plants with anti-diabetic properties

S. no.	Botanical name	Common name(s)	Family	Part(s) used for the study	Activities	References
1	*Abelmoschus esculentus* (L.) Moench	Lady's finger	Malvaceae	Seeds, fruit	Antidiabetic, antioxidant and antihyperlipidemic	Sabitha et al. (2011) and Mishra et al. (2016)
2	*Acacia nilotica* (L.) Delile	Gum arabic tree	Leguminosae	Leaves	Antioxidant, antidiabetic, antihyperlipidemic	Hegazy et al. (2013)
3	*Allium cepa* L.	Onion	Amaryllidaceae	Bulb	Hypoglycemic, anti-diabetic, anti-hyperlipidemic	Eldin et al. (2010) and Ikechukwu and Ifeanyi (2016)
4	*Aloe vera* (L.) Burm.f.	Aloe	Asphodelaceae	Leaves	Anti-hyperglycemic. anti-hypercholesterolemic, hypoglycemic, hypolipidemic	Huseini et al. (2012) and Kim et al. (2009)
5	*Annona squamosa* L.	Sugar apple	Annonaceae	Leaves, fruit pulp	Hypoglycemic, anti-diabetic, anti-lipidemic	Shirwaikar et al. (2004), Gupta et al. (2005) and Gupta et al. (2008)
6	*Artemisia pallens* Wall. ex DC.	Artemisia	Asteraceae	Aerial parts	Hypoglycemic	Subramoniam et al. (1996), Ruikar et al. (2011)
7	*Averrhoa bilimbi* L.	Bilimbi	Oxalidaceae	Leaves, roots, fruit	Anti-hyperglycemic, anti-hyperlipidemic, hypoglycemic, anti-diabetic	Tan et al. (2005), Xu et al. (2014) and Kurup and Mini (2017)
8	*Azadirachta indica* A. Juss	Neem tree	Meliaceae	Leaves, seeds	Hypoglycemic, β-cell regeneration	McCalla et al. (2016) and Khosla et al. (2000)
9	*Berberis vulgaris* L.	Barberry	Berberidaceae	Root, fruit	Hypoglycemic, anti-diabetic	Meliani et al. (2011)
10	*Beta vulgaris* L.	Beet	Amaranthaceae	Leaves, fruit	Anti-hyperglycemic, hypoglycemic	Bolkent et al. (2000) and Kabir et al. (2015)
11	*Biophytum sensitivum* (L.) DC.	Little tree plant	Oxalidaceae	Leaves	Hypoglycemic	Puri (2001) and Ananda et al. (2012)
12	*Brassica juncea* (L.) Czern.	Brown mustard	Brassicaceae	Seeds	Hypoglycemic	Yadav et al. (2004) and Thirumalai et al. (2011)
13	*Bryophyllum pinnatum* (Lam.) Oken	Life plant, miracle leaf	Crassulaceae	Leaves	Antidiabetic, hypoglycemic	Ojewole (2005)
14	*Boerhavia diffusa* L.	Spreading hogweed	Nyctaginaceae	Leaves	Anti-diabetic	Pari and Satheesh (2004) and Singh et al. (2011)
15	*Bombax ceiba* L	Cotton tree	Bombacaceae	Leaves	Antihyperglycemic, antihyperlipidemic	Guang-Kai et al. (2017)
16	*Caesalpinia bonduc* (L.) Roxb	Fever nut	Caesalpiniaceae	Seeds, root bark	Hypoglycemic, antihyperglycemic, antihypercholesterolemic, antihypertriglyceridemic hypolipidemic	Sharma et al. (1997), Chakrabarti et al. (2005) and Sayyed and Wadkar (2018)
17	*Cajanus cajan* (L.) Millsp.	Pigeon pea	Fabaceae	Leaves, seeds	Hypoglycemic	Jaiswal et al. (2008) and Uchegbu and Ishiwu (2016)

Table 1 (continued)

S. no.	Botanical name	Common name(s)	Family	Part(s) used for the study	Activities	References
18	*Camellia sinensis* (L.) Kuntze	Tea plant	Theaceae	Leaves	Anti-hyperglycemic, antihyperglycemic and antidiabetic	Ankolekar et al. (2011) and Abeywickrama et al. (2011) and Satoh et al. (2015)
19	*Capparis decidua* (Forssk.) Edgew.	Karira	Capparidaceae	Fruit, flowers, bark	Anti-diabetic, hypolipidemic	Chahlia (2009) and Sharma et al. (2010)
20	*Capsicum annuum* L.	Capsicum	Solanaceae	Fruit	Insulinotropic	Islam and Choi (2008)
21	*Centaurium erythraea* Rafn	Common centaury	Gentianaceae	Leaves	Antihyperglycemic	Stefkov et al. (2014)
22	*Catharanthus roseus* (L.) G.Don	Madagascar periwinkle	Apocynaceae	Leaves	Anti-diabetic, hyperlipidemic, anti-hyperglycemic	Rasineni et al. (2010) and Al-Shaqha et al. (2015)
23	*Citrullus colocynthis* (L.) Schrad.	Bitter apple, wild gourd	Cucurbitaceae	Fruit, seeds, root	Hypoglycemic, antihyperglycemic	Abdel-Hassan (2000), Barghamdi et al. (2016), Hussain et al. (2014)
24	*Clausena anisata* (Willd.) Hook.f. ex Benth.	Horsewood	Rutaceae	Root	Hypoglycemic	Ojewole (2002)
25	*Cocos nucifera* L.	Coconut	Arecaceae	Spadix, drupe, coconut water	Anti-hyperglycemic, antiglycation, hypoglycemic	Naskar et al. (2011) and Pinto et al. (2015)
26	*Cheilocostus speciosus* (J.Koenig) C.D.Specht	Cane-reed	Costaceae	Root, leaves	Antihyperglycemic, hypoglycemic, hypolipidemic	Bavarva and Narasimhacharya (2008) and Eliza et al. (2009)
27	*Curcuma longa* L.	Turmeric	Zingiberaceae	Rhizome	Antioxidant, antidiabetic, hepatoprotective	Ahmad et al. (2014)
28	*Cyclocarya paliurus* (Batalin) Iljinsk.	Wheel wingnut	Juglandaceae	Bark	Hypoglycemic, anti-ti-hyperglycemic, anti-hyperlipidemic	Li et al. (2011), Xiao et al. (2017) and Wang et al. (2013)
29	*Dillenia indica* L.	Elephant apple	Dilleniaceae	Leaves	Antidiabetic, hypolipidemic	Kumar et al. (2011)
30	*Eucalyptus globulus* Labill.	Blue-gum	Myrtaceae	Leaves	Anti-hyperglycemic	Ahlem et al. (2009)
31	*Embelia ribes* Burm.f.	False black pepper	Myrsinaceae	Berries	Anti-hyperglycemic, antidiabetic	Bhandari and Ansari (2008) and Durg et al. (2017)
32	*Eugenia uniflora* L.	Brazilian cherry	Myrtaceae	Fruit	Antihyperglycemic, antidyslipidemic	de Souza Cardoso et al. (2017)
33	*Ficus benghalensis* L.	Banyan tree	Moraceae	Bark, aerial roots	Anti-diabetic	Singh et al. (2009)
34	*Ficus religiosa* L.	Sacred fig	Moraceae	Bark	Anti-diabetic	Pandit et al. (2010)
35	*Helicteres isora* L.	Indian screw tree	Sterculiaceae	Root	Antidiabetic, hypolipidemic, antihyperglycemic	Chakrabarti et al. (2002) and Venkatesh et al. (2004)
36	*Hibiscus rosa-sinensis* L.	Chinese hibiscus, shoe black plant	Malvaceae	Flower, leaves	Hypoglycemic, antidyslipidemic	Sachdewa and Khemani (2003) and Kumar et al. (2013)
37	*Ipomoea batatas* (L.) Lam	Sweet potato	Convolvulaceae	Leaves, root	Hypoglycemic	Oki et al. (2011), Mohanraj and Sivasankar (2014)
38	*Juniperus communis* L.	Common juniper	Cupressaceae	Berries	Hypoglycemic	de Medina et al. (1994), Gordien et al. (2009)

Table 1 (continued)

S. no.	Botanical name	Common name(s)	Family	Part(s) used for the study	Activities	References
39	*Lantana camara* L.	Big-sage, wild-sage	Verbenaceae	Fruits	Anti-hyperglycemic, anti-diabetic	Venkatachalam et al. (2011)
40	*Lithocarpus polystachyus* (Wall. ex A.DC.) Rehder	Sweet tea	Fagaceae	Leaves	Hypoglycemic	Hou et al. (2011)
41	*Phyla nodiflora* (L.) Greene	Capeweed	Verbenaceae	Whole plant	Anti-hyperlipidemic, anti-hyperglycemic	Balamurugan et al. (2011)
42	*Mangifera indica* L.	Mango	Anacardiaceae	Leaves, fruit	Anti-diabetic, hypoglycemic	Gondi et al. (2015) and Ganog-pichayagrai et al. (2017)
43	*Memecylon umbellatum* Burm. f.	Iron wood	Melastomataceae	Leaves	Anti-diabetic	Sunil et al. (2017)
44	*Morus alba* L.	White mulberry	Moraceae	Fruit, leaves	Anti-hyperglycemic, anti-hyperlipidemic, anti-glycemic	Naowaboot et al. (2009) and Jiao et al. (2017)
45	*Mucuna pruriens* (L.) DC.	Velvet bean	Fabaceae	Seeds	Anti-diabetic	Majekodunmi et al. (2011)
46	*Musa* × *paradisiaca* L.	Plantain	Musaceae	Stem, leaves, infructescence stalks, fruit	Antidiabetic, antihyperlipidemic, anti-hyperglycemic	Dikshit et al. (2012) and Jaber et al. (2013)
47	*Nelumbo nucifera* Gaertn.	Indian lotus	Nelumbonacea	Seeds, leaves	Hypoglycemic, antihyperlipidemic	Mani et al. (2010) and Liu et al. (2013)
48	*Olea europaea* L.	Wild olive	Oleaceae	Leaves	Antihyperglycemic, hypolipidemic, hypoglycemic	Wainstein et al. (2012)
49	*Ophiopogon japonicus* (Thunb.) Ker Gawl.	Dwarf lilyturf	Asparagaceae	Root	Anti-diabetic, hypoglycemic	Li et al. (2012a)
50	*Opuntia streptacantha* Lem.	Prickly pear cactus	Cactaceae	Leaves (cladode)	Anti-hyperglycemic	Andrade-Cetto and Wiedenfeld (2011)
51	*Phyllanthus niruri* L.	Stonebreaker	Phyllanthaceae	Aerial parts	Anti-diabetic	Beidokhti et al. (2017)
52	*Picrorhiza kurroa* Royle ex Benth.	Yellow gentian	Plantaginaceae	Rhizome	Anti-diabetic	Chauhan et al. (2008)
53	*Piper nigrum* L.	Black pepper	Piperaceae	Fruit	Anti-hyperglycemic	Atal et al. (2012)
54	*Prosopis glandulosa* Torr.	Honey mesquite	Fabaceae	Pods	Anti-diabetic	George et al. (2011)
55	*Psidium guajava* L.	Guava	Myrtaceae	Fruit, leaves	Anti-hyperglycemic, anti-hyperlipidemic	Deguchi and Miyazaki (2010) and Huang et al. (2011)
56	*Pterocarpus marsupium* Roxb.	Indian kino tree	Fabaceae	Bark	Hypoglycemic, anti-hyperglycemic, inhibition of aldose reductase activity	Dhanabal et al. (2006), Mishra et al. (2013) and Xu et al. (2018)
57	*Punica granatum* L.	Pomegranate	Punicaceae	Leaves, fruit	Anti-diabetic, anti-hyperlipidemic, anti-glycation	Das and Barman (2012) and Kumagai et al. (2015)
58	*Salacia reticulata* Wight	Marking nut tree, kotalahimbatu	Celastraceae	Root, stem, leaves	Anti-diabetic, anti-hyperlipidemic	Stohs and Ray (2015)
59	*Semecarpus anacardium* L.f.	Marking nut	Anacardiaceae	Nut	Anti-hyperlipidemic, hypoglycemic and antihyperglycemic	Arul et al. (2004) and Khan et al. (2013)

Table 1 (continued)

S. no.	Botanical name	Common name(s)	Family	Part(s) used for the study	Activities	References
60	*Senna auriculata* (L.) Roxb.	Avaram senna, styptic weed, Matara tea	Fabaceae	Leaves, flower	Antihyperglycemic, hypolipidemic, antihyperlipidemic	Gupta et al. (2009) and Rajendran et al. (2017)
61	*Solanum virginianum* L.	Yellow-fruit nightshade	Solanaceae	Leaves	Anti-hyperglycemic	Poongothai et al. (2011)
62	*Swertia chirayita* (Roxb.) Buch.-Ham. ex C.B.Clarke	Clearing nut tree, bitter stick	Gentianaceae	Whole plant	Anti-diabetic	Phoboo et al. (2013)
63	*Symplocos cochinchinensis* (Lour.) S. Moore	Laurel sapphire berry	Symplocaceae	Leaves	Anti-diabetic, anti-lipidemic	Sunil et al. (2011) and Sunil et al. (2012)
64	*Tetraena alba* (L.f.) Beier & Thulin	White bean-caper	Zygophyllaceae	Whole plant	Antihyperglycemic and antihyperlipidemic	Ghoul et al. (2013)
65	*Tinospora sinensis* (Lour.) Merr.	Malabar gulbel, Chinese tinospora	Menispermaceae	Root	Hypoglycemic and hypolipidemic	Stanely Mainzen Prince and Menon (2003)
66	*Trigonella foenum-graecum* L.	Fenugreek	Fabaceae	Seeds	Hypoglycemic, hypocholesterolemic, anti-hyperglycemic	Xue et al. (2007) and Kumar et al. (2012)
67	*Urtica dioica* L	Stinging nettle	Urticaceae	Aerial parts	Anti-hyperglycemic	Bnouham et al. (2003)
68	*Vitex negundo* L.	Chinese chastetree, horseshoe vitex	Lamiaceae	Leaves	Anti-hyperglycemic	Sundaram et al. (2012)
69	*Viscum album* L.	Mistletoe	Viscaceae	Leaves	Antihyperglycemic, insulinotropic	Eno et al. (2008)

antioxidant effects in cholesterol-fed rabbits (Gupta et al. 2006).

Allium sativum L. (Garlic)

Allium sativum L., commonly known as garlic, belongs to the *Allium* genus in the family Alliaceae that are known to contain a high concentration of non-protein sulfur amino acids that are responsible for their medicinal features (Ovesná et al. 2015). Administration of *A. sativum* extract along with the commercially available drug glibenclamide resulted in increased weight and exhibited better hypoglycemic effect in streptozotocin-induced diabetic rats (Poonam et al. 2013). Similar results were observed in a study where diabetic patients when treated with combination of commercially available drug metformin and garlic supplementation exhibited improved glycemic control in addition to antihyperlipidemic activity (Ashraf et al. 2011). Treatment with fresh garlic homogenate (250 mg/kg b.w.) for 6 weeks resulted in better modulation of antioxidant status in blood and cardiac tissues of streptozotocin-induced diabetic-induced Wistar rats (Naderi et al. 2015) Administration of garlic extract resulted in reduction of blood glucose concentration accompanied by downregulation of the adrenal and renal expression of angiotensin AT1 receptor in STZ-induced diabetic rats which explains its potential in reversing the harmful consequences of excessive Ang II signaling, manifested by the development of hypertension and nephropathy (Mansour et al. 2013). The anti-diabetic effect of garlic extract has been reported to be more effective than the standard drug glibenclamide (Eidi et al. 2006).

Coccinia grandis (L.) Voigt (Ivy gourd)

Coccinia grandis (L.) Voigt (synonym: *Coccinia indica* Wight & Arn.) belonging to the family of Cucurbitaceae is an important medicinal plant known for its anti-diabetic and hypoglycemic properties. *C. indica* (*C. grandis*) fruits have been studied to exhibit renoprotective effect as it has been reported to ameliorate glucose tolerance, urine sugar, albumin excretion, kidney index, and glomerular filtration rate as well as exhibited beneficial effects on the antioxidant enzymes of the kidney in diabetic rats (Gurukar et al. 2013). *C. indica* (*C. grandis*) leaf extract possesses anti-ureogenic, anti-hyperglycemic (Baizid Alam Shibib et al. 2012), antioxidant (Venkateswaran and Pari 2003), hypoglycemic and hypolipidemic (Pari and Venkateswaran 2003) effects as reported by several studies carried out on diabetic rats. In a study carried out on diabetic patients *C. indica* (*C. grandis*) dried extract was found to exhibit insulin mimicking activity by correcting the elevated enzymes (G-6-p (ase) and LDH) in the glycolytic pathway and by restoring the LPL activity in lipolytic pathway (Kamble et al. 1998). Methanolic extract of *C. grandis* fruit exhibited 96.6% in vitro aldose reductase inhibitory activity against partially purified bovine lens aldose reductase with an IC_{50} value of 6.12 µg/mL. This activity can be attributed to the high percentage of phenolic and flavonoid content of the fruit (Kondhare and Lade 2017).

Few medicinal plants with anti-diabetic potential are tabulated in Table 1.

Conclusion

Diabetes is the most common endocrine disorder that affects nearly 100 million people worldwide. India, also known as the diabetes capital of the world has witnessed an alarming increase in the number of diabetics over the past decade. Advancement in modern medicine has resulted in the development of several pharmaceutical drugs such as biguanides, thiazolidinediones, biguanides, and insulin. Even though these drugs show hypoglycemic activities, they are often associated with several complications such as nephrological disorders, fatigue, upset stomach, diarrhea, etc. All these reasons have stimulated the rework on herbal medicine to fine suitable alternatives that will have lesser side effects and improved therapeutic effects. The present review has summarized the list of medicinal plants of Asian countries that are known to possess anti-diabetic properties. These plants are traditionally used by various tribal people for the treatment of several ailments. Pharmacological studies have reported their hypoglycemic, anti-hyperglycemic, insulin mimicking, anti-lipidemic properties and hence when administered in proper dosages can be beneficial for ameliorating the various complications associated with diabetes mellitus. This review provides the scope for the readers to further explore the active constituents of anti-diabetic plants and its possible mechanisms for future research.

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Compliance with ethical standards

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References

Abas R, Othman F, Thent ZC (2014) Protective effect of *Momordica charantia* fruit extract on hyperglycaemia-induced cardiac fibrosis. Oxid Med Cell Longev. https://doi.org/10.1155/2014/429060

Abdel-Hassan IA, Abdel-Barry JA, Tariq Mohammeda S (2000) The hypoglycaemic and antihyperglycaemic effect of *Citrullus colocynthis* fruit aqueous extract in normal and alloxan diabetic rabbits. J Ethnopharmacol 71:1–2. https://doi.org/10.1016/S0378-8741(99)00215-9 325–330.

Abdulrazaq NB, Cho MM, Win NN, Zaman R, Rahman MT (2012) Beneficial effects of ginger (*Zingiber officinale*) on carbohydrate metabolism in streptozotocin-induced diabetic rats. Br J Nutr 108:1194–1201. https://doi.org/10.1017/S0007114511006635

Abeywickrama KRW, Ratnasooriya WD, Amarakoon AM (2011) Oral hypoglycaemic, antihyperglycaemic and antidiabetic activities of Sri Lankan Broken Orange Pekoe Fannings (BOPF) grade black tea (*Camellia sinensis* L.) in rats. J Ethnopharmacol 135:2:278–286. https://doi.org/10.1016/j.jep.2011.02.035

Ahlem S, Khaled H, Wafa M, Sofiane B, Mohamed D, Jean-Claude M, Abdelfattah el F (2009) Oral administration of *Eucalyptus globulus* extract reduces the alloxan-induced oxidative stress in rats. Chem Biol Interact 181(1):71–76. https://doi.org/10.1016/j.cbi.2009.06.006

Ahmad M, Kamran SH, Mobasher A (2014) Protective effect of crude *Curcuma longa* and its methanolic extract in alloxanized rabbits. Pak J Pharm Sci 27:1121–1128

Ahmed I, Adeghate E, Cummings E, Sharma AK, Singh J (2004) Beneficial effects and mechanism of action of *Momordica charantia* juice in the treatment of streptozotocin-induced diabetes mellitus in rat. Mol Cell Biochem 261:63–70. https://doi.org/10.1023/B:MCBI.0000028738.95518.90

Aissaoui A, Zizi S, Israili ZH, Lyoussi B (2011) Hypoglycemic and hypolipidemic effects of *Coriandrum sativum* L. in Meriones shawi rats. J Ethnopharmacol 137:652–661. https://doi.org/10.1016/j.jep.2011.06.019

Akhtar MS, Ramzan A, Ali A, Ahmad M (2011) Effect of Amla fruit (*Emblica officinalis* Gaertn.) on blood glucose and lipid profile of normal subjects and type 2 diabetic patients. Int J Food Sci Nutr 62(6):609–616. https://doi.org/10.3109/09637486.2011.560565

Al-amin ZM, Thomson M, Al-qattan KK, Peltonen-shalaby R, Ali M (2006) Anti-diabetic and hypolipidaemic properties of ginger (*Zingiber officinale*) in streptozotocin-induced diabetic rats. Br J Nutr 96(4):660–666. https://doi.org/10.1079/BJN20061849

Al-Goblan AS, Al-Alfi MA, Khan MZ (2014) Mechanism linking diabetes mellitus and obesity. Diabetes Metab Syndr Obes 7:587–591. https://doi.org/10.2147/DMSO.S67400

Al-Shaqha WM, Khan M, Salam N, Azzi A, Chaudhary AA (2015) Anti-diabetic potential of *Catharanthus roseus* Linn. and its effect on the glucose transport gene (GLUT-2 and GLUT-4) in streptozotocin induced diabetic wistar rats. BMC Complement Altern Med 15(1):379. https://doi.org/10.1186/s12906-015-0899-6

Ananda PK, Kumarappan CT, Christudas S, Kalaichelvan VK (2012) Effect of *Biophytum sensitivum* on streptozotocin and nicotinamide-induced diabetic rats. Asian Pac J Trop Biomed 2:1:31–35. https://doi.org/10.1016/S2221-1691(11)60185-8

Andrade-Cetto A, Wiedenfeld H (2011) Anti-hyperglycemic effect of *Opuntia streptacantha* Lem. J Ethnopharmacol 133:2, 940–943. https://doi.org/10.1016/j.jep.2010.11.022

Ankolekar C, Terry T, Johnson K, Johnson D, Barbosa AC, Shetty K (2011) Anti-hyperglycemia properties of Tea (*Camellia sinensis*) bioactives using in vitro assay models and influence of extraction time. J Med Food 14(10):1190–1197. https://doi.org/10.1089/jmf.2010.0291

Ansari A, Shahriar MSZ, Hassan MM, Das SR, Rokeya B, Haque MA, Biswas N, Sarkar T (2014) *Emblica officinalis* improves glycemic status and oxidative stress in STZ induced type 2 diabetic model rats. Asian Pac J Trop Med 7(1):21–25. https://doi.org/10.1016/S1995-7645(13)60185-6

Arul B, Kothai R, Christina AJ (2004) Hypoglycemic and antihyperglycemic effect of *Semecarpus anacardium* Linn in normal and streptozotocin-induced diabetic rats. Methods Find Exp Clin Pharmacol 26:10:759–762. https://doi.org/10.1358/mf.2004.26.10.872556

Arumugam S, Kavimani S, Kadalmani B, Ahmed ABA, Akbarsha MA, Rao MV (2008) Antidiabetic activity of leaf and callus extracts of *Aegle marmelos* in rabbit. Sci Asia 34:317–321. https://doi.org/10.2306/scienceasia1513-1874.2008.34.317

Ashraf R, Khan RA, Ashraf I (2011) Garlic (*Allium sativum*) supplementation with standard antidiabetic agent provides better diabetic control in type 2 diabetes patients. Pak J Pharm Sci. 24(4):565–570

Atal S, Agrawal RP, Vyas S, Phadnis P, Rai N (2012) Evaluation of the effect of piperine per se on blood glucose level in alloxan-induced diabetic mice. Acta Pol Pharm 69(5):965–969

Ayyanar M, Sankarasivaraman K, Ignacimuthu S (2008) Traditional herbal medicines used for the treatment of diabetes among two major tribal groups in South Tamil Nadu, India. Ethnobot Leaf 12:276–280

Baizid Alam Shibib MAA, Hasan AM, Rahman R (2012) A creeper, *Coccinia indica*, has anti-hyperglycaemic and anti-ureogenic effects in diabetic rats. JPMA 62:1145

Balamurugan R, Duraipandiyan V, Ignacimuthu S (2011) Antidiabetic activity of γ-sitosterol isolated from *Lippia nodiflora* L. in streptozotocin induced diabetic rats. Eur J Pharmacol 667(1–3):410–418. https://doi.org/10.1016/j.ejphar.2011.05.025.

Baldissera G, Sperotto NDM, Rosa HT, Henn JG, Peres VF, Moura DJ, Roehrs R, Denardin ELG, Dal Lago P, Nunes RB, Saffi J (2016) Effects of crude hydroalcoholic extract of *Syzygium cumini* (L.) Skeels leaves and continuous aerobic training in rats with diabetes induced by a high-fat diet and low doses of streptozotocin. J Ethnopharmacol 194:1012–1021. https://doi.org/10.1016/j.jep.2016.10.056

Baliga MS, Bhat HP, Joseph N, Fazal F (2011) Phytochemistry and medicinal uses of the bael fruit (*Aegle marmelos* Correa): a concise review. Food Res Int 44:7:1768–1775. https://doi.org/10.1016/j.foodres.2011.02.008

Banerjee J, Narendhirakannan RT (2011) Biosynthesis of silver nanoparticles from *Syzygium cumini* (L.) seed extract and evaluation of their in vitro antioxidant activities. Dig J Nanomater Biostruct 6:961–968

Barghamdi B, Ghorat F, Asadollahi K, Sayehmiri K, Peyghambari R, Abangah G (2016) Therapeutic effects of *Citrullus colocynthis* fruit in patients with type II diabetes: a clinical trial study. J Pharm Bioallied Sci 8(2):130–134. https://doi.org/10.4103/0975-7406.171702

Bastaki S (2005) Diabetes mellitus and its treatment. Int J Diabetes Metab 13:111–134

Bavarva JH, Narasimhacharya AV (2008) Antihyperglycemic and hypolipidemic effects of *Costus speciosus* in alloxan induced diabetic rats. Phytother Res 22(5):620–626. https://doi.org/10.1002/ptr.2302

Beidokhti MN, Andersen MV, Eid HM, Villavicencio MLS, Staerk D, Haddad PS, Jäger AK (2017) Investigation of antidiabetic potential of *Phyllanthus niruri* L. using assays for α-glucosidase, muscle glucose transport, liver glucose production, and adipogenesis. Biochem Biophys Res Commun 493(1):869–874. https://doi.org/10.1016/j.bbrc.2017.09.080

Bhandari U, Ansari MN (2008) Antihyperglycaemic activity of aqueous extract of *Embelia ribes* Burm in streptozotocin-induced diabetic rats. Indian J Exp Biol 46:8:607–613. http://nopr.niscair.res.in/handle/123456789/4570

Bitencourt PER, Bona KS, De Cargnelutti LO, Bonfanti G, Pigatto A, Boligon A, Athayde ML, Pierezan F, Zanette RA, Moretto MB (2015) *Syzygium cumini* seed extract ameliorates adenosine

deaminase activity and biochemical parameters but does not alter insulin sensitivity and pancreas architecture in a short-term model of diabetes. J Complement Integr Med 12:187–193. https://doi.org/10.1515/jcim-2015-0008

Bnouham M, Merhfour FZ, Ziyyat A, Mekhfi H, Aziz M, Legssyer A (2003) Antihyperglycemic activity of the aqueous extract of *Urtica dioica*. Fitoterapia 74(7):677–681. https://doi.org/10.1016/S0367-326X(03)00182-5

Bolkent Ş, Yanardağ R, Tabakoğlu-Oğuz A, Özsoy-Saçan Ö (2000) Effects of chard (*Beta vulgaris* L. var. cicla) extract on pancreatic B cells in streptozotocin-diabetic rats: a morphological and biochemical study. J Ethnopharmacol 73(1):251–259. https://doi.org/10.1016/S0378-8741(00)00328-7

Broadhurst CL, Polansky MM, Anderson RA (2000) Insulin like biological activity of culinary and medicinal plant aqueous extracts in vitro. J Agric Food Chem 48(3):849–852. https://doi.org/10.1021/jf9904517

Chahlia N (2009) Evaluation of Hypolipidaemic Activity of *Capparis decidua*. Int J Biomed Sci 5(1):70–73

Chakrabarti R, Vikramadithyan RK, Mullangi R, Sharma VM, Jagadheshan H, Rao YN, Sairam P, Rajagopalan R (2002) Antidiabetic and hypolipidemic activity of *Helicteres isora* in animal models. J Ethnopharmacol 81(3):343–349. https://doi.org/10.1016/S0378-8741(02)00120-4

Chakrabarti S, Biswas TK, Seal T, Rokeya B, Ali L, Khan AA, Nahar N, Mosihuzzaman M, Mukherjee B (2005) Antidiabetic activity of *Caesalpinia bonducella* F. in chronic type 2 diabetic model in Long-Evans rats and evaluation of insulin secretagogue property of its fractions on isolated islets. J Ethnopharmacopol 97(1):117–122. https://doi.org/10.1016/j.jep.2004.10.025

Chauhan S, Nath N, Tule V (2008) Antidiabetic and antioxidant effects of *Picrorhiza kurrooa* rhizome extracts in diabetic rats. Indian J Clin Biochem 23(3):238–242. https://doi.org/10.1007/s12291-008-0053-z

Chhetri DR, Parajuli P, Subba GC (2005) Antidiabetic plants used by Sikkim and Darjeeling Himalayan tribes, India. J Ethnopharmacol 99(2):199–202. https://doi.org/10.1016/j.jep.2005.01.058

Crawford P (2009) Effectiveness of cinnamon for lowering hemoglobin A1C in patients with type 2 diabetes: a randomized, controlled trial. J Am Board Fam Med 22:507–512. https://doi.org/10.3122/jabfm.2009.05.080093

D'souza JJ. D'souza PP, Fazal F, Kumar A, Bhat HP, Baliga MS (2014) Anti-diabetic effects of the Indian indigenous fruit *Emblica officinalis* Gaertn: active constituents and modes of action. Food Funct 5:635. https://doi.org/10.1039/c3fo60366k

Das S, Barman S (2012) Antidiabetic and antihyperlipidemic effects of ethanolic extract of leaves of *Punica granatum* in alloxan-induced non-insulin-dependent diabetes mellitus albino rats. Indian J Pharmacol 44(2):219–224. https://doi.org/10.4103/0253-7613.93853

de Medina FS, Gamez MJ, Jimenez I, Jimenez J, Osuna JI, Zarzuelo A (1994) Hypoglycemic activity of juniper "berries". Planta Med 60(03):197–200. https://doi.org/10.1055/s-2006-959457

de Souza Cardoso J, Oliveira PS, Bona NP, Vasconcellos FA, Baldissarelli J, Vizzotto M, Soares MSP, Ramos VP, Spanevello RM, Lencina CL, Tavares RG (2017) Antioxidant, antihyperglycemic, and antidyslipidemic effects of Brazilian-native fruit extracts in an animal model of insulin resistance. Redox Rep. https://doi.org/10.1080/13510002.2017.1375709

Dean L, McEntyre J (2004) The genetic landscape of diabetes [Internet]. National Center for Biotechnology Information (US), Bethesda

Debbarma M, Pala NA, Kumar M, Bussmann RW (2017) Traditional knowledge of medicinal plants in tribes of Tripura in northeast, India. Afr J Tradit Complement Altern Med 14(4):156. https://doi.org/10.21010/ajtcam.v14i4.18

Deguchi Y, Miyazaki K (2010) Anti-hyperglycemic and anti-hyperlipidemic effects of guava leaf extract. Nutr Metab (Lond) 7(1):9. https://doi.org/10.1186/1743-7075-7-9

Dhanabal SP, Kokate CK, Ramanathan M, Kumar EP, Suresh B (2006) Hypoglycaemic activity of *Pterocarpus marsupium* Roxb. Phytother Res 20(1):4–8. https://doi.org/10.1002/ptr.1819

Dikshit P, Shukla K, Tyagi MK, Garg P, Gambhir JK, Shukla R (2012) Antidiabetic and antihyperlipidemic effects of the stem of *Musa sapientum* Linn. in streptozotocin-induced diabetic rats. J Diabetes 4(4):378–385. https://doi.org/10.1111/j.1753-0407.2012.00198

Durg S, Veerapur VP, Neelima S, Dhadde SB (2017) Antidiabetic activity of *Embelia ribes*, embelin and its derivatives: a systematic review and meta-analysis. Biomed Pharmacother 86:195–204. https://doi.org/10.1016/j.biopha.2016.12.001

Dusane MB, Joshi BN (2012) Islet protective and insulin secretion property of *Murraya koenigii* and *Ocimum tenuflorum* in streptozotocin-induced diabetic mice. Can J Physiol Pharmacol 90:371–378. https://doi.org/10.1139/y11-133

Eidi A, Eidi M, Esmaeili E (2006) Antidiabetic effect of garlic (*Allium sativum* L.) in normal and streptozotocin-induced diabetic rats. Phytomedicine 13(9–10):624–629. https://doi.org/10.1016/j.phymed.2005.09.010

Eidi M, Eidi A, Saeidi A, Molanaei S, Sadeghipour A, Bahar M, Bahar K (2009) Effect of coriander seed (*Coriandrum sativum* L.) ethanol extract on insulin release from pancreatic beta cells in streptozotocin-induced diabetic rats. Phytother Res 23(3):404–406. https://doi.org/10.1002/ptr.2642

Eldin IM, Ahmed EM, Abd EH (2010) Preliminary study of the clinical hypoglycemic effects of *Allium cepa* (red onion) in type 1 and type 2 diabetic patients. Environ Health Insights 4:71. https://doi.org/10.4137/EHI.S5540

Eliza J, Daisy P, Ignacimuthu S, Duraipandiyan V (2009) Antidiabetic and antilipidemic effect of eremanthin from *Costus speciosus* (Koen.)Sm., in STZ-induced diabetic rats. Chem Biol Interact 182(1):67–72. https://doi.org/10.1016/j.cbi.2009.08.012

Eno AE, Ofem OE, Nku CO, Ani EJ, Itam EH (2008) Stimulation of insulin secretion by *Viscum album* (mistletoe) leaf extract in streptozotocin-induced diabetic rats. Afr J Med Med Sci 37(2):141–147

Fabio GD, Romanucci V, De Marco A, Zarrelli A (2014) Triterpenoids from *Gymnema sylvestre* and their pharmacological activities. Molecules 19(8):10956–10981. https://doi.org/10.3390/molecules190810956

Gandhi GR, Ignacimuthu S, Paulraj MG (2012) Hypoglycemic and β-cells regenerative effects of *Aegle marmelos* (L.) Corr. bark extract in streptozotocin-induced diabetic rats. Food Chem Toxicol 50:1667–1674. https://doi.org/10.1016/j.fct.2012.01.030

Ganogpichayagrai A, Palanuvej C, Ruangrungsi N (2017) Antidiabetic and anticancer activities of *Mangifera indica* cv. Okrong leaves. J Adv Pharm Technol Res 8(1):19–24. https://doi.org/10.4103/2231-4040.197371

George C, Lochner A, Huisamen B (2011) The efficacy of *Prosopis glandulosa* as antidiabetic treatment in rat models of diabetes and insulin resistance. J Ethnopharmacol 137(1):298–304. https://doi.org/10.1016/j.jep.2011.05.023

Ghoul JE, Boughattas NA, Ben-Attia M (2013) Antihyperglycemic and antihyperlipidemic activities of ethanolic extract of *Zygophyllum album* in streptozotocin-induced diabetic mice. Toxicol Ind Health 29(1):43–51. https://doi.org/10.1177/0748233712442706

Gondi M, Basha SA, Bhaskar JJ, Salimath PV, Rao UJ (2015) Antidiabetic effect of dietary mango (*Mangifera indica* L.) peel in streptozotocin-induced diabetic rats. J Sci Food Agric 95(5):991–999. https://doi.org/10.1002/jsfa.6778

Gordien AY, Gray AI, Franzblau SG, Seidel V (2009) Antimycobacterial terpenoids from *Juniperus communis* L.(Cuppressaceae). J Ethnopharmacol 126(3):500–505

Guang-Kai XU, Xiao-Ying QI, Guo-Kai WA, Guo-Yong XI, Xu-Sen LI, Chen-Yu SU, Bao-Lin LI, Min-Jian QI (2017) Antihyperglycemic, antihyperlipidemic and antioxidant effects of standard ethanol extract of *Bombax ceiba* leaves in high-fat-diet-and streptozotocin-induced type 2 diabetic rats. Chin J Nat Med 15(3):168–177. https://doi.org/10.1016/S1875-5364(17)30033-X

Gupta RK, Kesari AN, Murthy PS, Chandra R, Tandon V, Watal G (2005) Hypoglycemic and antidiabetic effect of ethanolic extract of leaves of *Annona squamosa* L. in experimental animals. J Ethnopharmacol 99(1):75–81. https://doi.org/10.1016/j.jep.2005.01.048

Gupta S, Mediratta PK, Singh S, Sharma KK, Shukla R (2006) Antidiabetic, antihypercholesterolaemic and antioxidant effect of *Ocimum sanctum* (Linn) seed oil. Indian J Exp Biol 44(4):300–304

Gupta RK, Kesari AN, Diwakar S, Tyagi A, Tandon V, Chandra R, Wata G (2008) In vivo evaluation of anti-oxidant and anti-lipidemic potential of *Annona squamosa* aqueous extract in type 2 diabetic models. J Ethnopharmacol 118(1):21–25. https://doi.org/10.1016/j.jep.2008.03.008

Gupta S, Sharma SB, Bansal SK, Prabhu KM (2009) Antihyperglycemic and hypolipidemic activity of aqueous extract of *Cassia auriculata* L. leaves in experimental diabetes. J Ethnopharmacol 123(3):499–503. https://doi.org/10.1016/j.jep.2009.02.019

Gurukar MSA, Mahadevamma S, Chilkunda ND (2013) Renoprotective effect of *Coccinia indica* fruits and leaves in experimentally induced diabetic rats. J Med Food 16:9:839–846. https://doi.org/10.1089/jmf.2012.2689

Haniadka R, Saldanha E, Sunita V, Palatty PL, Fayad R, Baliga MS (2013) A review of the gastroprotective effects of ginger (*Zingiber officinale* Roscoe). Food Funct 4(6):845–855. https://doi.org/10.1039/C3FO30337C

Hannan JM, Marenah L, Ali L, Rokeya B, Flatt PR, Abdel-Wahab YH (2006) *Ocimum sanctum* leaf extracts stimulate insulin secretion from perfused pancreas, isolated islets and clonal pancreatic beta-cells. J Endocrinol 189(1):127–136. https://doi.org/10.1677/joe.1.06615

Hegazy GA, Alnoury AM, Gad HG (2013) The role of *Acacia arabica* extract as an antidiabetic, antihyperlipidemic, and antioxidant in streptozotocin-induced diabetic rats. Saudi Med J 34(7):727–733

Hou SZ, Chen SX, Huang S, Jiang DX, Zhou CJ, Chen CQ, Liang YM, Lai XP (2011) The hypoglycemic activity of *Lithocarpus polystachyus* Rehd. leaves in the experimental hyperglycemic rats. J Ethnopharmacol 138(1):142–149. https://doi.org/10.1016/j.jep.2011.08.067

Huang CS, Yin MC, Chiu LC (2011) Antihyperglycemic and antioxidative potential of *Psidium guajava* fruit in streptozotocin-induced diabetic rats. Food Chem Toxicol 49(9):2189–2195. https://doi.org/10.1016/j.fct.2011.05.032

Husain I, Chander R, Saxena JK, Mahdi AA, Mahdi F (2015) Antidyslipidemic effect of *Ocimum sanctum* leaf extract in streptozotocin induced diabetic rats. Indian J Clin Biochem 30:72–77. https://doi.org/10.1007/s12291-013-0404-2

Huseini HF, Kianbakht S, Hajiaghaee R, Dabaghian FH (2012) Antihyperglycemic and anti-hypercholesterolemic effects of *Aloe vera* leaf gel in hyperlipidemic type 2 diabetic patients: a randomized double-blind placebo-controlled clinical trial. Planta Med 78(04):311–316. https://doi.org/10.1055/s-0031-1280474

Hussain EHMA, Jamil K, Rao M (2001) Hypoglycaemic, hypolipidemic and antioxidant properties of tulsi (*Ocimum sanctum* Linn) on streptozotocin induced diabetes in rats. Indian J Clin Biochem 16:190–194. https://doi.org/10.1007/BF02864859

Hussain AI, Rathore HA, Sattar MZ, Chatha SA, Sarker SD, Gilani AH (2014) *Citrullus colocynthis* (L.) Schrad (bitter apple fruit): a review of its phytochemistry, pharmacology, traditional uses and nutritional potential. J Ethnopharmacol 155(1):54–66

Ikechukwu JO, Ifeanyi SO (2016) The antidiabetic effects of the bioactive flavonoid (kaempferol-3-O-β-D-6 {P-Coumaroyl} glucopyranoside) isolated from *Allium cepa*. Recent Pat Antiinfect Drug Discov 11(1):44–52

Ilkhanizadeh B, Shirpoor A, Ansari M, Nemati K, Rasmi S Y (2016) Protective effects of ginger (*Zingiber officinale*) extract against diabetes-induced heart abnormality in rats. Diabetes Metab J 40:46–53. https://doi.org/10.4093/dmj.2016.40.1.46

Iranloye BO, Arikawe AP, Rotimi G, Sogbade AO (2008) Anti-diabetic and anti-oxidant effects of *Zingiber officinale* on alloxan-induced and insulin-resistant diabetic male rats. Niger J Physiol Sci 26(1):89–96

Islam MS, Choi H (2008) Dietary red chilli (*Capsicum frutescens* L.) is insulinotropic rather than hypoglycemic in type 2 diabetes model of rats. Phytother Res 22(8):1025–1029. https://doi.org/10.1002/ptr.2417

Jaber H, Baydoun E, EL-Zein O, Kreydiyyeh SI (2013) Anti-hyperglycemic effect of the aqueous extract of banana infructescence stalks in streptozotocin-induced diabetic rats. Plant Foods Hum Nutr 68(1):83–89. https://doi.org/10.1007/s11130-013-0341-5

Jaiswal D, Rai PK, Kumar A, Watal G (2008) Study of glycemic profile of *Cajanus cajan* leaves in experimental rats. Indian J Clin Biochem 23(2):167–170. https://doi.org/10.1007/s12291-008-0037-z

Jeyaprakash K, Ayyanar M, Geetha KN, Sekar T (2011) Traditional uses of medicinal plants among the tribal people in Theni District (Western Ghats), Southern India. Asian Pac J Trop Biomed 1:S20–S25. https://doi.org/10.1016/S2221-1691(11)60115-9

Jiao Y, Wang X, Jiang X, Kong F, Wang S, Yan C (2017) Antidiabetic effects of *Morus alba* fruit polysaccharides on high-fat diet- and streptozotocin-induced type 2 diabetes in rats. J Ethnopharmacol 199:119–127. https://doi.org/10.1016/j.jep.2017.02.003

Kabir AU, Samad MB, Ahmed A, Jahan MR, Akhter F, Tasnim J, Hasan SN, Sayfe SS, Hannan JM (2015) Aqueous fraction of *Beta vulgaris* ameliorates hyperglycemia in diabetic mice due to enhanced glucose stimulated insulin secretion, mediated by acetylcholine and GLP-1, and elevated glucose uptake via increased membrane bound GLUT4 transporters. PloS One 10(2):e0116546. https://doi.org/10.1371/journal.pone.0116546

Kamalakkannan N, Prince PSM (2003) Hypoglycaemic effect of water extracts of *Aegle marmelos* fruits in streptozotocin diabetic rats. J Ethnopharmacol 87(2–3):207–210. https://doi.org/10.1016/S0378-8741(03)00148-X

Kamalakkannan N, Prince PSM (2005) The effect of *Aegle marmelos* fruit extract in streptozotocin diabetes: a histopathological study. J Herb Pharmacother 5(3):87–96. https://doi.org/10.1080/J157v05n03_08

Kamble SM, Kamlakar PL, Vaidya S, Bambole VD (1998) Influence of *Coccinia indica* on certain enzymes in glycolytic and lipolytic pathway in human diabetes. Indian J Med Sci 52:143–146

Kanetkar PV, Laddha KS, Kamat MY (2004) Gymnemic acids: a molecular perspective of its action on carbohydrate metabolism. Proceedings of the 16th ICFOST meet organized by CFTRI and DFRL, Mysore, India

Kanetkar P, Singhal R, Kamat M (2007) *Gymnema sylvestre*: a memoir. J Clin Biochem Nutr 41(2):77–81

Kesari NA, Gupta KR, Singh KS, Diwakarr S, Watal G (2006) Hypoglycemic and antihyperglycemic activity of *Aegle marmelos* seed extract in normal and diabetic rats. J Ethnopharmacol 107:374–379. https://doi.org/10.1016/j.jep.2006.03.042

Kesari AN, Kesari S, Singh SK, Gupta RK, Watal G (2007) Studies on the glycemic and lipidemic effect of *Murraya koenigii* in experimental animals. J Ethnopharmacol 112:305–311. https://doi.org/10.1016/j.jep.2007.03.023

Khan HB, Vinayagam KS, Moorthy BT, Palanivelu S, Panchanatham S (2013) Anti-inflammatory and anti-hyperlipidemic effect of *Semecarpus anacardium* in a high fat diet: STZ-induced type 2 diabetic rat model. Inflammopharmacol 21(1):37–46. https://doi.org/10.1007/s10787-011-0109-1

Khosla P, Bhanwra S, Singh J, Seth S, Srivastava RK (2000) A study of hypoglycaemic effects of *Azadirachta indica* (Neem) in normal and alloxan diabetic rabbits. Indian J Physiol Pharmacol 44(1):69–74

Kim K, Kim H, Kwon J, Lee S, Kong H, Im SA, Lee YH, Lee YR, Oh ST, Jo TH, Park YI (2009) Hypoglycemic and hypolipidemic effects of processed *Aloe vera* gel in a mouse model of non-insulin-dependent diabetes mellitus. Phytomedicine 16(9):856–863. https://doi.org/10.1016/j.phymed.2009.02.014

Kondhare D, Lade H (2017) Phytochemical profile, aldose reductase inhibitory, and antioxidant activities of Indian traditional medicinal *Coccinia grandis* (L.) fruit extract. 3 Biotech 7(6):378

Kooti W, Farokhipour M, Asadzadeh Z, Ashtary-Larky D, Asadi-Samani M (2016) The role of medicinal plants in the treatment of diabetes: a systematic review. Electron Physician 8(1):1832–1842. https://doi.org/10.19082/1832

Kumagai Y, Nakatani S, Onodera H, Nagatomo A, Nishida N, Matsuura Y, Kobata K, Wada M (2015) Anti-glycation effects of pomegranate (*Punica granatum* L.) fruit extract and its components in vivo and in vitro. J Agric Food Chem 63(35):7760–7764. https://doi.org/10.1021/acs.jafc.5b02766

Kumar S, Kumar V, Prakash O (2011) Antidiabetic, hypolipidemic and histopathological analysis of *Dillenia indica* (L.) leaves extract on alloxan induced diabetic rats. Asian Pac J Trop Med 4(5):347–352. https://doi.org/10.1016/S1995-7645(11)60101-6

Kumar P, Kale RK, Baquer NZ (2012) Antihyperglycemic and protective effects of *Trigonella foenum graecum* seed powder on biochemical alterations in alloxan diabetic rats. Eur Rev Med Pharmacol Sci 16:18–27

Kumar V, Mahdi F, Khanna AK, Singh R, Chander R, Saxena JK, Mahdi AA, Singh RK (2013) Antidyslipidemic and antioxidant activities of *Hibiscus rosa sinensis* root extract in alloxan induced diabetic rats. Indian J Clin Biochem 28(1):46–50. https://doi.org/10.1007/s12291-012-0223-x

Kurup SB. Mini S (2017) *Averrhoa bilimbi* fruits attenuate hyperglycemia-mediated oxidative stress in streptozotocin-induced diabetic rats. J Food Drug Anal 25(2):360–368. https://doi.org/10.1016/j.jfda.2016.06.007

Laribi B. Kouki K, M'Hamdi M, Bettaieb T (2015) Coriander (*Coriandrum sativum* L.) and its bioactive constituents. Fitoterapia 103:9–26. https://doi.org/10.1016/j.fitote.2015.03.012

Li HB, Wong CC, Cheng KW, Chen F (2008) Antioxidant properties in vitro and total phenolic contents in methanol extracts from medicinal plants. LWT Food Sci Technol 41(3):385–390. https://doi.org/10.1016/j.lwt.2007.03.011

Li S, Li J, Guan XL, Li J, Deng SP, Li LQ, Tang MT, Huang JG, Chen ZZ, Yang RY (2011) Hypoglycemic effects and constituents of the barks of *Cyclocarya paliurus* and their inhibiting activities to glucosidase and glycogen phosphorylase. Fitoterapia 82(7):1081–1085. https://doi.org/10.1016/j.fitote.2011.07.002

Li PB, Lin WL, Wang YG, Peng W, Cai XY, Su WW (2012a) Antidiabetic activities of oligosaccharides of *Ophiopogonis japonicus* in experimental type 2 diabetic rats. Int J Biol Macromol 51(5):749–755. https://doi.org/10.1016/j.ijbiomac.2012.07.007

Li Y, Tran VH, Duke CC, Roufogalis BD (2012b) Gingerols of *Zingiber officinale* enhance glucose uptake by increasing cell surface GLUT4 in cultured L6 myotubes. Planta Medica 78(14):1549–1555. https://doi.org/10.1055/s-0032-1315041

Li R, Liang T, Xu L, Li Y, Zhang S, Duan X (2013) Protective effect of cinnamon polyphenols against STZ-diabetic mice fed high-sugar, high-fat diet and its underlying mechanism. Food Chem Toxicol 51:419–425. https://doi.org/10.1016/j.fct.2012.10.024

Liu S, Li D, Huang B, Chen Y, Lu X, Wang Y (2013) Inhibition of pancreatic lipase, α-glucosidase, α-amylase, and hypolipidemic effects of the total flavonoids from *Nelumbo nucifera* leaves. J Ethnopharmacol 149(1):263–269. https://doi.org/10.1016/j.jep.2013.06.034

Mahluji S, Attari VE, Mobasseri M, Payahoo L, Ostadrahimi A, Golzari SE (2013) Effects of ginger (*Zingiber officinale*) on plasma glucose level, HbA1c and insulin sensitivity in type 2 diabetic patients. Int J Food Sci Nutr 64:963–7486. https://doi.org/10.3109/09637486.2013.775223

Majekodunmi SO, Oyagbemi AA, Umukoro S, Odeku OA (2011) Evaluation of the anti-diabetic properties of *Mucuna pruriens* seed extract. Asian Pac J Trop Med 4(8):632–636. https://doi.org/10.1016/S1995-7645(11)60161-2

Mang B, Wolters M, Schmitt B, Kelb K, Lichtinghagen R, Stichtenoth DO, Hahn A (2006) Effects of a cinnamon extract on plasma glucose, HbA1c, and serum lipids in diabetes mellitus type 2. Eur J Clin Investig 36(5):340–344. https://doi.org/10.1111/j.1365-2362.2006.01629.x

Mani SS, Subramanian IP, Pillai SS, Muthusamy K (2010) Evaluation of hypoglycemic activity of inorganic constituents in *Nelumbo nucifera* seeds on streptozotocin-induced diabetes in rats. Biol Trace Elem Res 138(1–3):226–237. https://doi.org/10.1007/s12011-010-8614-4

Mansour MH, Al-Qattan K, Thomson M, Ali M (2013) Garlic (*Allium sativum*) down-regulates the expression of angiotensin II AT1 receptor in adrenal and renal tissues of streptozotocin-induced diabetic rats. Inflammopharmacology 21:147–159. https://doi.org/10.1007/s10787-012-0139-3

McCalla G, Parshad O, Brown PD, Gardner MT (2016) Beta cell regenerating potential of *Azadirachta indica* (neem) extract in diabetic rats. West Indian Med J. https://doi.org/10.7727/wimj.2014.224

Meliani N, Dib MEA, Allali H, Tabti B (2011) Hypoglycaemic effect of *Berberis vulgaris* L. in normal and streptozotocin-induced diabetic rats. Asian Pac J Trop Biomed 1(6):468–471. https://doi.org/10.1016/S2221-1691(11)60102-0

Mishra A, Srivastava R, Srivastava S, Gautam S, Tamrakar AK, Maurya R, Srivastava AK (2013) Antidiabetic activity of heart wood of *Pterocarpus marsupium* Roxb. and analysis of phytoconstituents. Indian J Exp Biol 51(5):363–374

Mishra N, Kumar D, Rizvi SI (2016) Protective effect of *Abelmoschus esculentus* against alloxan-induced diabetes in Wistar strain rats. J Diet Suppl 13(6):634–646. https://doi.org/10.3109/19390211.2016.1164787

Modak M, Dixit P, Londhe J, Ghaskadbi S, Paul A, Devasagayam T (2007) Indian herbs and herbal drugs used for the treatment of diabetes. J Clin Biochem Nutr 40(3):163–173. https://doi.org/10.3164/jcbn.40.163

Mohanraj R, Sivasankar S (2014) Sweet potato (*Ipomoea batatas* [L.] Lam)—a valuable medicinal food: a review. J Med food 17(7):733–741

Mudi SR, Akhter M, Biswas SK, Muttalib MA, Choudhury S, Rokeya B, Ali L (2017) Effect of aqueous extract of *Aegle marmelos* fruit and leaf on glycemic, insulinemic and lipidemic status of type 2 diabetic model rats. J Complement Integr Med. https://doi.org/10.1515/jcim-2016-0111

Naderi R, Mohaddes G, Mohammadi M, Alihemmati A, Badalzadeh R, Ghaznavi R, Ghyasi R, Mohammadi S (2015) Preventive effects of garlic (*Allium sativum*) on oxidative stress and histopathology of cardiac tissue in streptozotocin-induced diabetic rats. Acta Physiol Hung 102:380–390. https://doi.org/10.1556/036.102.2015.4.5

Naowaboot J, Pannangpetch P, Kukongviriyapan V, Kongyingyoes B (2009) Antihyperglycemic, antioxidant and antiglycation

activities of mulberry leaf extract in streptozotocin-induced chronic diabetic rats. Plant Foods Hum Nutr 64(2):116–121. https://doi.org/10.1007/s11130-009-0112-5

Narendhirakannan RT, Subramanian S (2010) Biochemical evaluation of the protective effect of *Aegle marmelos* (L.), Corr. leaf extract on tissue antioxidant defense system and histological changes of pancreatic beta-cells in streptozotocin-induced diabetic rats. Drug Chem Toxicol 33:120–130. https://doi.org/10.3109/01480540903203984

Narendhirakannan RT, Subramanian S, Kandaswamy M (2005) Mineral content of some medicinal plants used in the treatment of diabetes mellitus. Biol Trace Elem Res 103(2):109–115. https://doi.org/10.1385/BTER:103:2:109

Narendhirakannan RT, Subramanian S, Kandaswamy M (2006) Biochemical evaluation of antidiabetogenic properties of some commonly used Indian plants on streptozotocin-induced diabetes in experimental rats. Clin Exp Pharmacol Physiol 33(12):1150–1157. https://doi.org/10.1111/j.1440-1681.2006.04507.x

Naskar S, Mazumder UK, Pramanik G, Gupta M, Kumar RB, Bala A, Islam A (2011) Evaluation of antihyperglycemic activity of *Cocos nucifera* Linn. on streptozotocin induced type 2 diabetic rats. J Ethnopharmacol 138(3):769–773. https://doi.org/10.1016/j.jep.2011.10.021

Ojewole JA (2002) Hypoglycaemic effect of *Clausena anisata* (Willd) Hook methanolic root extract in rats. J Ethnopharmacol 81(2):231–237. https://doi.org/10.1016/S0378-8741(02)00085-5

Ojewole JA (2005) Antinociceptive, anti-inflammatory and antidiabetic effects of *Bryophyllum pinnatum* (Crassulaceae) leaf aqueous extract. J Ethnopharmacol 99(1):13–19. https://doi.org/10.1016/j.jep.2005.01.025

Oki N, Nonaka S, Ozaki S (2011) The effects of an arabinogalactan-protein from the white-skinned sweet potato (*Ipomoea batatas* L.) on blood glucose in spontaneous diabetic mice. Biosci Biotechnol Biochem 75(3):596–598. https://doi.org/10.1271/bbb.100711

Ovesná J, Mitrová K, Kučera L (2015) Garlic (*A. sativum* L.) alliinase gene family polymorphism reflects bolting types and cysteine sulphoxides content. BMC Genet 16:53. https://doi.org/10.1186/s12863-015-0214-z

Panaskar SN, Joglekar MM, Taklikar SS, Haldavnekar VS, Arvindekar AU (2013) *Aegle marmelos* Correa leaf extract prevents secondary complications in streptozotocin-induced diabetic rats and demonstration of limonene as a potent antiglycating agent. J Pharm Pharmacol 65:884–894. https://doi.org/10.1111/jphp.12044

Panda DK, Ghosh D, Bhat B, Talwar SK, Jaggi M, Mukherjee R (2009) Diabetic therapeutic effects of ethyl acetate fraction from the roots of *Musa paradisiaca* and seeds of *Eugenia jambolana* in streptozotocin-induced male diabetic rats. Methods Find Exp Clin Pharmacol 31(9):571–584. https://doi.org/10.1358/mf.2009.31.9.1435645

Pandey J, Maurya R, Raykhera R, Srivastava MN, Yadav PP, Tamrakar AK (2014) *Murraya koenigii* (L.) Spreng. ameliorates insulin resistance in dexamethasone-treated mice by enhancing peripheral insulin sensitivity. J Sci Food Agric 94:2282–2288. https://doi.org/10.1002/jsfa.6555

Pandit R, Phadke A, Jagtap A (2010) Antidiabetic effect of *Ficus religiosa* extract in streptozotocin-induced diabetic rats. J Ethnopharmacol 128(2):46462–46466. https://doi.org/10.1016/j.jep.2010.01.025

Pari L, Satheesh MA (2004) Antidiabetic activity of *Boerhaavia diffusa* L.: effect on hepatic key enzymes in experimental diabetes. J Ethnopharmacol 91(1):109–113. https://doi.org/10.1016/j.jep.2003.12.013

Pari L, Venkateswaran S (2003) Protective effect of *Coccinia indica* on changes in the fatty acid composition in streptozotocin induced diabetic rats. Die Pharmazie Int J Pharm Sci 58(6):409–412

Patel SS, Goyal RK (2011) Prevention of diabetes-induced myocardial dysfunction in rats using the juice of the *Emblica officinalis* fruit. Exp Clin Cardiol 16:87–91

Patel OP, Mishra A, Maurya R, Saini D, Pandey J, Taneja I, Raju KS, Kanojiya S, Shukla SK, Srivastava MN, Wahajuddin M (2016) Naturally occurring carbazole alkaloids from *Murraya koenigii* as potential antidiabetic agents. J Nat Prod 79:1276–1284. https://doi.org/10.1021/acs.jnatprod.5b00883

Patil R, Patil R, Ahirwar B, Ahirwar D (2011) Isolation and characterization of anti-diabetic component (bioactivity-guided fractionation) from *Ocimum sanctum* L. (Lamiaceae) aerial part. Asian Pac J Trop Med 4:278–282. https://doi.org/10.1016/S1995-7645(11)60086-2

Paul S, Bandyopadhyay TK, Bhattacharyya A (2011) Immunomodulatory effect of leaf extract of *Murraya koenigii* in diabetic mice. Immunopharmacol Immunotoxicol 33:691–699. https://doi.org/10.3109/08923973.2011.561354

Phoboo S. Pinto MD, Barbosa ACL, Sarkar D, Bhowmik PC, Jha PK, Shetty K (2013) Phenolic-linked biochemical rationale for the anti-diabetic properties of *Swertia chirayita* (Roxb. ex Flem.) Karst. Phytother Res 27(2):227–235. https://doi.org/10.1002/ptr.4714

Phuwapraisirisan P, Puksasook T, Jong-aramruang J, Kokpol U (2008) Phenylethyl cinnamides: a new series of alpha-glucosidase inhibitors from the leaves of *Aegle marmelos*. Bioorg Med Chem Lett 18:4956–4958. https://doi.org/10.1016/j.bmcl.2008.08.024

Pinto IF, Silva RP, Filho AD, Dantas LS, Bispo VS, Matos IA, Otsuka FA, Santos AC, Matos HR (2015) Study of antiglycation, hypoglycemic, and nephroprotective activities of the green dwarf variety coconut water (*Cocos nucifera* L.) in alloxan-induced diabetic rats. J Med Food 18(7):802–809. https://doi.org/10.1089/jmf.2014.0046

Poonam T, Prakash GP, Kumar LV (2013) Influence of *Allium sativum* extract on the hypoglycemic activity of glibenclamide: an approach to possible herb-drug interaction. Drug Metab Drug Interact 28:225–230. https://doi.org/10.1515/dmdi-2013-0031

Poongothai K, Ponmurugan P, Ahmed KS, Kumar BS, Sheriff SA (2011) Antihyperglycemic and antioxidant effects of *Solanum xanthocarpum* leaves (field grown & in vitro raised) extracts on alloxan induced diabetic rats. Asian Pac J Trop Med 4(10):778–785. https://doi.org/10.1016/S1995-7645(11)60193-4

Prabhakar PK, Doble M (2008) A target based therapeutic approach towards diabetes mellitus using medicinal plants. Curr Diabetes Rev 4(4):291–308

Puri D (2001) The insulinotropic activity of a Nepalese medicinal plant *Biophytum sensitivum*: preliminary experimental study. J Ethnopharmacol 78(1):89–93. https://doi.org/10.1016/S0378-8741(01)00306-3

Rajendran V, Krishnegowda A, Nachiappan V (2017) Antihyperlipidemic activity of *Cassia auriculata* flower extract in oleic acid induced hyperlipidemia in Saccharomyces cerevisiae. J Food Sci Technol 54(9):2965–2972. https://doi.org/10.1007/s13197-017-2735-0

Rani MP, Krishna MS, Padmakumari KP, Raghu KG, Sundaresan A (2012) *Zingiber officinale* extract exhibits antidiabetic potential via modulating glucose uptake, protein glycation and inhibiting adipocyte differentiation: an in vitro study. J Sci Food Agric 92(9):1948–1955. https://doi.org/10.1002/jsfa.5567

Rao PV, Gan SH (2014) Cinnamon: a multifaceted medicinal plant. Evid Based Complement Altern Med. https://doi.org/10.1155/2014/642942

Rao TP, Sakaguchi N, Juneja LR, Wada E, Yokozawa T (2005) Amla (*Emblica officinalis* Gaertn.) extracts reduce oxidative stress

in streptozotocin-induced diabetic rats. J Med Food 8(3):362–368. https://doi.org/10.1089/jmf.2005.8.362

Rasineni K, Bellamkonda R, Singareddy SR, Desireddy S (2010) Antihyperglycemic activity of *Catharanthus roseus* leaf powder in streptozotocin-induced diabetic rats. Pharmacogn Res 2(3):195–201. https://doi.org/10.4103/0974-8490.65523

Ravi K, Sekar DS, Subramanian S (2004a) Hypoglycemic activity of inorganic constituents in *Eugenia jambolana* seed on streptozotocin-induced diabetes in rats. Biol Trace Elem Res 99(1–3):145–155. https://doi.org/10.1385/BTER:99:1-3:145

Ravi K, Sivagnanam K, Subramanian S (2004b) Anti-diabetic activity of *Eugenia jambolana* seed kernels on streptozotocin-induced diabetic rats. J Med Food Summer 7(2):187–191. https://doi.org/10.1089/1096620041224067

Ravi K, Rajasekaran S, Subramanian S (2005) Antihyperlipidemic effect of *Eugenia jambolana* seed kernel on streptozotocin-induced diabetes in rats. Food Chem Toxicol 43(9):1433–1439. https://doi.org/10.1016/j.fct.2005.04.004

Ruikar AD, Khatiwora E, Ghayal NA, Misar AV, Mujumdar AM, Puranik VG, Deshpande NR (2011) Studies on aerial parts of *Artemisia pallens* wall for phenol, flavonoid and evaluation of antioxidant activity. J Pharm Bioallied Sci 3(2):302–305. https://doi.org/10.4103/0975-7406.80768

Sabitha V, Ramachandran S, Naveen KR, Panneerselvam K (2011) Antidiabetic and antihyperlipidemic potential of *Abelmoschus esculentus* (L.) Moench. in streptozotocin-induced diabetic rats. J Pharm Bioallied Sci 3(3):397–402. https://doi.org/10.4103/0975-7406.84447

Sachdewa A, Khemani LD (2003) Effect of *Hibiscus rosa sinensis* Linn. ethanol flower extract on blood glucose and lipid profile in streptozotocin induced diabetes in rats. J Ethnopharmacol 89(1):61–66. https://doi.org/10.1016/S0378-8741(03)00230-7

Saha A, Mazumder S (2013) An aqueous extract of *Murraya koenigii* leaves induces paraoxonase 1 activity in streptozotocin induced diabetic mice. Food Funct 4:420–425. https://doi.org/10.1039/C2FO30193H

Samad MB, Mohsin MN, Razu BA, Hossain MT, Mahzabeen S, Unnoor N, Muna IA, Akhter F, Kabir AU, Hannan JM (2017) [6]-Gingerol, from *Zingiber officinale*, potentiates GLP-1 mediated glucose-stimulated insulin secretion pathway in pancreatic β-cells and increases RAB8/RAB10-regulated membrane presentation of GLUT4 transporters in skeletal muscle to improve hyperglycemia in Leprdb/db type 2 diabetic mice. BMC Complement Altern Med 17:395. https://doi.org/10.1186/s12906-017-1903-0

Saravanan M, Pandikumar P, Saravanan S, Toppo E, Pazhanivel N, Ignacimuthu S (2014) Lipolytic and antiadipogenic effects of (3,3-dimethylallyl) halfordinol on 3T3-L1 adipocytes and high fat and fructose diet induced obese C57/BL6J mice. Eur J Pharmacol 740:714–721. https://doi.org/10.1016/j.ejphar.2014.06.004

Satoh T, Igarashi M, Yamada S, Takahashi N, Watanabe K (2015) Inhibitory effect of black tea and its combination with acarbose on small intestinal α-glucosidase activity. J Ethnopharmacol 161:147–155. https://doi.org/10.1016/j.jep.2014.12.009

Sayyed FJ, Wadkar GH (2018) Studies on in-vitro hypoglycemic effects of root bark of *Caesalpinia bonducella*. Ann Pharm Fr 76(1):44–49. https://doi.org/10.1016/j.pharma.2017.09.004

Sharma SR, Dwivedi SK, Swarup D (1997) Hypoglycaemic, antihyperglycaemic and hypolipidemic activities of *Caesalpinia bonducella* seeds in rats. J Ethnopharmacol 58(1):39–44. https://doi.org/10.1016/S0378-8741(97)00079-2

Sharma B, Balomajumder C, Roy P (2008) Hypoglycemic and hypolipidemic effects of flavonoid rich extract from *Eugenia jambolana* seeds on streptozotocin induced diabetic rats 46:2376–2383. https://doi.org/10.1016/j.fct.2008.03.020

Sharma B, Salunke R, Balomajumder C, Daniel S, Roy P (2010) Antidiabetic potential of alkaloid rich fraction from *Capparis decidua* on diabetic mice. J Ethnopharmacol 127(2):457–462. https://doi.org/10.1016/j.jep.2009.10.013

Sharma AK, Bharti S, Goyal S, Arora S, Nepal S, Kishore K, Joshi S, Kumari S, Arya DS (2011) Upregulation of PPARγ by *Aegle marmelos* ameliorates insulin resistance and β-cell dysfunction in high fat diet fed-streptozotocin induced type 2 diabetic rats. Phytother Res 25:1457–1465. https://doi.org/10.1002/ptr.3442

Sharma S, Pathak S, Gupta G, Kumar S (2017) Pharmacological evaluation of aqueous extract of *Syzigium cumini* for its antihyperglycemic and antidyslipidemic properties in diabetic rats fed a high cholesterol diet—role of PPAR g and PPAR a. Biomed Pharmacother 89:447–453. https://doi.org/10.1016/j.biopha.2017.02.048

Shen Y, Honma N, Kobayashi K, Jia LN, Hosono T, Shindo K, Ariga T, Seki T (2014) Cinnamon extract enhances glucose uptake in 3T3-L1 adipocytes and C2C12 myocytes by inducing LKB1-AMP-activated protein kinase signaling. PLoS One 9(2):e87894. https://doi.org/10.1371/journal.pone.0087894

Shidfar F, Rajab A, Rahideh T, Khandouzi N, Hosseini S, Shidfar S (2015) The effect of ginger (*Zingiber officinale*) on glycemic markers in patients with type 2 diabetes. J Complement Integr Med 12:165–170. https://doi.org/10.1515/jcim-2014-0021

Shirwaikar A, Rajendran K, Kumar CD, Bodla R (2004) Antidiabetic activity of aqueous leaf extract of *Annona squamosa* in streptozotocin–nicotinamide type 2 diabetic rats. J Ethnopharmacol 91(1):171–175. https://doi.org/10.1016/j.jep.2003.12.017

Singh N, Gupta M (2007) Effects of ethanolic extract of *Syzygium cumini* (Linn) seed powder on pancreatic islets of alloxan diabetic rats. Indian J Exp Biol 45(10):861–867

Singh RK, Mehta S, Jaiswal D, Rai PK, Watal G (2009) Antidiabetic effect of *Ficus bengalensis* aerial roots in experimental animals. J Ethnopharmacol 123(1):110–114. https://doi.org/10.1016/j.jep.2009.02.017

Singh PK, Baxi D, Doshi A, AV R (2011) Antihyperglycaemic and renoprotective effect of *Boerhaavia diffusa* L. in experimental diabetic rats. J Complement Integr Med. https://doi.org/10.2202/1553-3840.1533

Sreelatha S, Inbavalli R (2012) Antioxidant, antihyperglycemic, and antihyperlipidemic effects of *Coriandrum sativum* leaf and stem in alloxan-induced diabetic rats. J Food Sci. https://doi.org/10.1111/j.1750-3841.2012.02755.x

Srivastava S, Chandra D (2013) Pharmacological potentials of *Syzygium cumini*: a review. J Sci Food Agric 93(9):2084–2093. https://doi.org/10.1002/jsfa.6111

Stanely Mainzen Prince P, Menon VP (2003) Hypoglycaemic and hypolipidaemic action of alcohol extract of *Tinospora cordifolia* roots in chemical induced diabetes in rats. Phytother Res 17(4):410–413. https://doi.org/10.1002/ptr.1130

Stefkov G, Miova B, Dinevska-Kjovkarovska S, Stanoeva JP, Stefova M, Petrusevska G, Kulevanova S (2014) Chemical characterization of *Centaurium erythrea* L. and its effects on carbohydrate and lipid metabolism in experimental diabetes. J Ethnopharmacol 152(1):71–77. https://doi.org/10.1016/j.jep.2013.11.047

Stohs SJ, Ray S (2015) Anti-diabetic and anti-hyperlipidemic effects and safety of *Salacia reticulata* and related species. Phytother Res 29(7):986–995. https://doi.org/10.1002/ptr.5382

Suanarunsawat T, Anantasomboon G, Piewbang C (2016) Anti-diabetic and anti-oxidative activity of fixed oil extracted from *Ocimum sanctum* L. leaves in diabetic rats. Exp Ther Med 11:832–840. https://doi.org/10.3892/etm.2016.2991

Subramoniam A, Pushpangadan P, Rajasekharan S, Evans DA, Latha PG, Valsaraj R (1996) Effects of *Artemisia pallens* Wall. on blood glucose levels in normal and alloxan-induced diabetic rats. J Ethnopharmacol 50(1):13–17. https://doi.org/10.1016/0378-8741(95)01329-6

Sundaram R, Naresh R, Shanthi P, Sachdanandam P (2012) Antihyperglycemic effect of iridoid glucoside, isolated from the leaves of *Vitex negundo* in streptozotocin-induced diabetic rats with special reference to glycoprotein components. Phytomedicine 19(3–4):211–216. https://doi.org/10.1016/j.phymed.2011.10.006

Sunil C, Ignacimuthu S, Agastian P (2011) Antidiabetic effect of *Symplocos cochinchinensis* (Lour.) S. Moore. in type 2 diabetic rats. J Ethnopharmacol 134(2):298–304. https://doi.org/10.1016/j.jep.2010.12.018

Sunil C, Agastian P, Kumarappan C, Ignacimuthu S (2012) In vitro antioxidant, antidiabetic and antilipidemic activities of *Symplocos cochinchinensis* (Lour.) S. Moore bark. Food Chem Toxicol 50(5):1547–1553. https://doi.org/10.1016/j.fct.2012.01.029

Sunil V, Shree N, Venkataranganna MV, Bhonde RR, Majumdar M (2017) The anti-diabetic and antiobesity effect of *Memecylon umbellatum* extract in high fat diet induced obese mice. Biomed Pharmacother 89:880–886. https://doi.org/10.1016/j.biopha.2017.01.182

Tan BKH, Tan CH, Pushparaj PN (2005) Anti–diabetic activity of the semi-purified fractions *of Averrhoa bilimbi* in high fat diet fed–streptozotocin-induced diabetic rats. Life Sci 76(24):2827–2839. https://doi.org/10.1016/j.lfs.2004.10.051

Tembhurne SV, Sakarkar DM (2010) Influence of *Murraya koenigii* on experimental model of diabetes and progression of neuropathic pain. Res Pharm Sci 5(1):41–47

Thirumalai T, Therasa SV, Elumalai EK, David E (2011) Hypoglycemic effect of *Brassica juncea* (seeds) on streptozotocin induced diabetic male albino rat. Asian Pac J Trop Biomed 1(4):323–325. https://doi.org/10.1016/S2221-1691(11)60052-X

Thiyagarajan G, Muthukumaran P, Sarath Kumar B, Muthusamy VS, Lakshmi BS (2016) Selective inhibition of PTP1B by vitalboside A from *syzygium cumini* enhances insulin sensitivity and attenuates lipid accumulation via partial agonism to PPARγ. *In vitro* and *in silico* investigation. Chem Biol Drug Des 88(2):302–312

Tiwari P, Mishra BN, Sangwan NS (2014) Phytochemical and pharmacological properties of *Gymnema sylvestre*: an important medicinal plant. Biomed Res Int 2014:830295. https://doi.org/10.1155/2014/830285

Tripathi AK, Kohli S (2014) Pharmacognostical standardization and antidiabetic activity of *Syzygium cumini* (Linn) barks (Myrtaceae) on streptozotocin-induced diabetic rats. J Complement Integr Med 11(2):71–81. https://doi.org/10.1515/jcim-2014-0011

Uchegbu NN, Ishiwu CN (2016) Germinated Pigeon Pea (*Cajanus cajan*): a novel diet for lowering oxidative stress and hyperglycemia. Food Sci Nutr 4(5):772–777. https://doi.org/10.1002/fsn3.343

Venkatachalam T, Kumar VK, Selvi PK, Maske AO, Anbarasan V, Kumar PS (2011) Antidiabetic activity of *Lantana camara* Linn fruits in normal and streptozotocin-induced diabetic rats. J Pharm Res 4(5):1550–1552

Venkatesh S, Reddy GD, Reddy YSR, Sathyavathy D, Reddy BM (2004) Effect of *Helicteres isora* root extracts on glucose tolerance in glucose-induced hyperglycemic rats. Fitoterapia 75(3):364–367. https://doi.org/10.1016/j.fitote.2003.12.025

Venkateswaran S, Pari L (2003) Effect of *Coccinia indica* leaf extract on plasma antioxidants in Streptozotocin-induced experimental diabetes in rats. Phyther Res 17:605–608. https://doi.org/10.1002/ptr.1195

Viswanathan V, Rao VN (2013) Problems associated with diabetes care in India. Diabetes Manag 3(1):31–40

Wainstein J, Ganz T, Boaz M, Bar Dayan Y, Dolev E, Kerem Z, Madar Z (2012) Olive leaf extract as a hypoglycemic agent in both human diabetic subjects and in rats. J Med Food 15(7):605–610. https://doi.org/10.1089/jmf.2011.0243

Wang Q, Jiang C, Fang S, Wang J, Ji Y, Shang X, Ni Y, Yin Z, Zhang J (2013) Antihyperglycemic, antihyperlipidemic and antioxidant effects of ethanol and aqueous extracts of *Cyclocarya paliurus* leaves in type 2 diabetic rats. J Ethnopharmacol 150(3):1119–1127. https://doi.org/10.1016/j.jep.2013.10.040

Wang HY, Kan WC, Cheng TJ, Yu SH, Chang LH, Chuu JJ (2014) Differential anti-diabetic effects and mechanism of action of charantin-rich extract of Taiwanese *Momordica charantia* between type 1 and type 2 diabetic mice. Food Chem Toxicol 69:347–356. https://doi.org/10.1016/j.fct.2014.04.008

Xiao HT, Wen B, Ning ZW, Zhai LX, Liao CH, Lin CY, Mu HX, Bian ZX (2017) *Cyclocarya paliurus* tea leaves enhances pancreatic β cell preservation through inhibition of apoptosis. Sci Rep 7(1):9155

Xu X, Liang T, Wen Q, Lin X, Tang J, Zuo Q, Tao L, Xuan F, Huang R (2014) Protective effects of total extracts of *Averrhoa carambola* L. (Oxalidaceae) roots on streptozotocin-induced diabetic mice. Cell Physiol Biochem 33(5):1272–1282. https://doi.org/10.1159/000358695

Xu Y, Zhao Y, Sui Y, Lei X (2018) Protective effect of *Pterocarpus marsupium* bark extracts against cataract through the inhibition of aldose reductase activity in streptozotocin-induced diabetic male albino rats. 3 Biotech 8(4):188. https://doi.org/10.1007/s13205-018-1210-6

Xue WL, Li XS, Zhang J, Liu YH, Wang ZL, Zhang RJ (2007) Effect of *Trigonella foenum-graecum* (fenugreek) extract on blood glucose, blood lipid and hemorheological properties in streptozotocin-induced diabetic rats. Asia Pac J Clin Nutr 16(S1):422–426. https://doi.org/10.6133/apjcn.2007.16.s1.77

Yadav SP, Vats V, Ammini AC, Grover JK (2004) *Brassica juncea* (Rai) significantly prevented the development of insulin resistance in rats fed fructose-enriched diet. J Ethnopharmacol 93(1):113–116. https://doi.org/10.1016/j.jep.2004.03.034

Yadav SS, Singh MK, Singh PK, Kumar V (2017) Traditional knowledge to clinical trials: a review on therapeutic actions of *Emblica officinalis*. Biomed Pharmacother 93:1292–1302. https://doi.org/10.1016/j.biopha.2017.07.065

Yang CH, Li RX, Chuang LY (2012) Antioxidant activity of various parts of *Cinnamomum cassia* extracted with different extraction methods. Molecules 17(6):7294–7304. https://doi.org/10.1016/j.biopha.2017.07.065

Yang SJ, Choi JM, Park SE, Rhee EJ, Lee WY, Oh KW, Park SW, Park CY (2015) Preventive effects of bitter melon (*Momordica charantia*) against insulin resistance and diabetes are associated with the inhibition of NF-κB and JNK pathways in high-fat-fed OLETF rats. J Nutr Biochem 26:234–240. https://doi.org/10.1016/j.jnutbio.2014.10.010

Yankuzo H, Ahmed QU, Santosa RI, Akter SF, Talib NA (2011) Beneficial effect of the leaves of *Murraya koenigii* (Linn.) Spreng (Rutaceae) on diabetes-induced renal damage in vivo. J Ethnopharmacol 135:88–94. https://doi.org/10.1016/j.jep.2011.02.020

Zhang F, Lin L, Xie J (2016) A mini-review of chemical and biological properties of polysaccharides from *Momordica charantia*. Int J Biol Macromol 92:246–253. https://doi.org/10.1016/j.ijbiomac.2016.06.101