

Antidiabetic potential of plant natural products: A review

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Abstract

The present review explains the use of natural plant products for therapeutics of diabetes. It is a serious metabolic disorder that imposes multiple effects on human health. Although diabetes is curable, an erratic lifestyle always make panic and causes disease severity if proper medication is not being made available. Several ethnomedicines have been used by local people in form of crude extracts prepared from flowers, fruits, and roots of endemic plant species for cure of diabetes. There is a common usage of herbal parts for preparation of concoctions, syrups, vegetables, juices, green tea, from leaves, and roots for therapeutic purposes. This article explains antidiabetic effects of various plant secondary metabolites such as anthraquinones, flavonoids, secoiridoids, iridoids, flavanones, biophenols, triterpenes, benzoic acid derivatives, isochromans, and phytosterols. Daily meals containing good nutraceuticals such as protein and fiber can replace carbohydrate food that is a main source of glucose. Mainly, herbal foods rich in flavanols and polyphenols show hypoglycemic effects and can be used in the prevention of diabetes-induced vascular dysfunctions. Antidiabetic plant natural products restore insulin level and increase utilization of external glucose. Herbal dietary supplementation having diverse antioxidants, fibers, minerals, and antiglycants show inhibitory activity against α -amylase and α -glucosidase can easily control carbohydrate metabolism in humans. No doubt plant origin natural products can be used as alternative medicine for treatment of diabetes, but they must need proper composition and formulation before being used.

Key words: α -glucosidase inhibitors, diabetes, hyperglycemia, natural plant products, phytomedicines

INTRODUCTION

Diabetes is one of the most frequent non-communicable lifestyle-related diseases in the world. There is permanent growth in the incidence of diabetes according to the International Diabetes Federation, and there is possibility that it will mark the increase in the number of diabetics to 439 million worldwide by the year 2030. Type 2 diabetes (T2D) accounts for about 90% of all diabetes incidences. Diabetes is a serious metabolic disorder affecting the metabolism of carbohydrate, protein, and fat. Diabetes has already become a threat to the large population of the world and the individual due to its high prevalence rates and high medical expenses. Among its two types, diabetes mellitus is a major metabolic disorder whose prevalence is increasing day by day. Diabetes is characterized by defects in insulin secretion, mainly related to action or both. Recent evidence indicates that loss of functional β -cell mass through apoptosis is main the cause of development of diabetes. In addition, advanced glycation endproducts after accumulation also cause

sustained hyperglycemia that contributes to the development of diabetic complications.^[1] Both genetic- and stress-induced diabetes exist that also cause multiple health-related abnormalities. There are so many antidiabetic plants whose natural products tackle with diabetes and directly affect on insulin secretion of the pancreas.^[2] The use of natural plant products as the alternative medicinal herb is increasingly gaining popularity with the sale of these products. *Ficus deltoidea* tea bags and capsules are available in the local market. There are several plant species which are screened for antidiabetic potential and its products inhibit α -glucosidase activity in animal models.^[3] These plant species belong to family Fabaceae (6 species), Crassulaceae (3 species), Hippocrateaceae (3 species), Lamiaceae (3 species), and Myrtaceae (3 species). Till date, most studied species being *Salacia reticulata* (Hippocrateaceae), Jamun, Maithi, and

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Morus alba (Moraceae) that could be used for traditional management of diabetes.

There should be a proper usage of plant natural products that could reduce gastrointestinal glucose production and its absorption in the human intestine through the inhibition of carbohydrate-digesting enzymes such as α -amylase and α -glucosidase.^[4] Disease is associated with oxidative stress, leading to an increased production of reactive oxygen species.^[5] Therefore, preventing diabetes at an earlier stage is very important. The management of diabetes without any side effects is still a challenge to the medical system. Today, there is an increasing interest of herbal medicine for care and management of diabetes due to their natural origin and fewer side effects. However, for the purpose of medication, various species have been extensively used by local people as folkloric medicine. In addition, many research laboratories have been searching for novel therapeutic targets in form of natural products to cure diabetic patients. The present review aims to discuss the usage and relevance of various natural products and its bioactive components in controlling diabetes and diabetes-associated pathologies. The present review also explains evidence-based therapeutic potency of the plants to facilitate their commercial exploitation for future drug development.

Therapeutic Approaches

For therapeutic purposes, solvent extracts from various plant species have been screened for potential antidiabetic components. There are extracts which show α -glucosidase inhibitory effects due to the presence of flavonoid glycosides.^[3] *Opuntia dillenii* polysaccharides (ODP-Ia) polysaccharides isolated from *O. dillenii* exerts an antihyperglycemic effect by protecting the liver from peroxidation damage and by maintaining tissue function, thereby improving the sensitivity and response of target cells in diabetic mice to insulin.^[6] However, ODP-Ia did not significantly increase insulin levels in the mice with streptozotocin (STZ)-induced diabetes. Similarly, aqueous infusions of the aerial parts of *Artemisia herba-alba* Asso and *Ajuga iva* Schreber are used to make local folk medicine for diabetes by using the traditional procedure. It was well confirmed after oral administration of *A. herba-alba* and *A. iva* infusions in normal and alloxan-induced diabetic rats.^[7] Similar antidiabetic activity was reported in *Alstonia scholaris* (L.) R. Br., *Blumea balsamifera* (L.) DC., *Cinnamomum burmanni* Nees ex Bl., and *Piper betle* L.^[8]

Although there are so many possibilities to control increasing glucose level, improvement of β -cell function and insulin secretion in pancreatic cells can induce utilization of external glucose. It protects the liver from peroxidation damage and assists in maintaining tissue function, thereby improving the sensitivity and response of target cells in a diabetic patient to insulin.^[6] *Scabiosa arenaria* Forssk a North African plant reduce gastrointestinal glucose production and

absorption through the inhibition of carbohydrate-digesting enzymes such as α -amylase and α -glucosidase. Its ethyl acetate (EtOAc), butanolic (n-BuOH) fractions of fruits, and the EtOAc fractions prepared from flowers inhibited α -glucosidase in a non-competitive manner with inhibitory concentration 50 values of 0.11 ± 0.09 , 0.28 ± 0.04 , and 0.221 ± 0.01 mg/ml, respectively.^[4] *Cudrania tricuspidata* also inhibit α -glucosidase activity.^[9] High inhibition of α -amylase activity (>50%) is also reported in extracts fresh root, bark, and leaves of *Salvadora persica* L. (Salvadoraceae).^[10] Major flavonoid glycosides found in *Microctis folium* showed α -glucosidase inhibitory effect.^[3] *Cassia alata* is by inhibiting carbohydrate digestion and act on α -glucosidase activity of kaempferol 3-O-gentiobioside.^[11] Similarly, various plant essential oils also contain active principles, which are used for antidiabetic drug development with numerous pharmacological activities. Few important active principles such as carthamin, carthamidin, isocarthamidin, hydroxysafflor yellow A, safflor yellow A, safflamin C and luteolin and caryophyllene, p-allyltoluene, 1-acetoxytetralin, and heneicosane were identified as the major components for *C. tinctorius* flower essential oil.^[12] Moreover, a combination of glucose uptake and antiadipogenesis activity is not found in the current insulin mimetic drugs and may indicate a great therapeutic potential of penta-O-galloyl-glucopyranose (PGG). These could be used for preparation of various drug formulations for control of diabetes.

Use of Plant Extracts

Many active components derived from edible natural resources such as plant extracts have recently attracted attention for their potential use as functional foods or drugs for preventing and treating metabolic diseases such as diabetes.

Aegle marmelos

Leaf extract (LE) of *A. marmelos* is an important medicine in Ayurveda for diabetes. It enhances the ability to utilize the external glucose in the body by stimulation of glucose uptake similar to insulin.^[13,14] Bel LE significantly cut down blood urea and cholesterol in experimental diabetic animals.^[15,16] It also decreases oxidative stress in experimental diabetic animals by making a significant reduction in lipid peroxidation, conjugated diene, and hydroperoxide level and increased levels of superoxide dismutase, catalase, glutathione peroxidase, and glutathione levels in serum as well as liver.^[17-23] Juice of bel leaves is employed as an antidiabetic drug in the Unani system of medicine also.^[24] It also shows antidiabetic and antihyperlipidemic effects in oral glucose tolerance test (OGTT) and STZ-induced diabetic rat model.^[25] It significantly enhances glycemic control, protects pancreas from degeneration, and shows antioxidant and hepatoprotective effects. It contains umbelliferon- α -D-glucopyranosyl-(2(I)→1(II))- α -D-glucopyranoside and cut down extra glucose level in STZ-induced diabetic

rats.^[26] UFG also possesses an antidiabetic, antioxidant, and antihyperlipidemic effect on the STZ-induced diabetic rat. *A. marmelos* (L.) Correa reduces alloxan induced early stage diabetic nephropathy and cardiomyopathy in rats.^[27]

A. marmelos extract does inhibition of aldose reductase and shows its protective role in diabetic cataract.^[28] It also shows *in vitro* inhibitory effects on intestinal α -glucosidase and pancreatic α -amylase.^[29] Its LE also prevents secondary complications in STZ-induced diabetic rats due to the presence of limonene as a potent antiglycating agent.^[30] Similarly, synthetic triterpenoid (lupeol) and their derivatives showed antihyperglycemic and antidyslipidemic activity *in vivo*.^[31] Plant shows hypoglycemic and antioxidant activity of *A. marmelos* in alloxan-induced diabetic rats.^[13] More specifically, upregulation of peroxisome proliferator-activated receptor gamma (PPAR γ) by *A. marmelos* ameliorates insulin resistance and β -cell dysfunction in high-fat diet fed-STZ-induced Type 2 diabetic rats.^[32] Hypoglycemic and β -cells regenerative effects of *A. marmelos* (L.) Corr. bark extract in STZ-induced diabetic rats.^[33] Moreover, overall hypoglycemic effects of some plant extracts are possibly mediated through inhibition in corticosteroid concentration.^[14]

A. marmelos (L.) Corr. LE shows improve and protect tissue antioxidant defense system and histological changes of pancreatic β -cells in STZ-induced diabetic rats.^[34] It does alterations in hippocampal serotonergic and INSR function in STZ-induced diabetic rats exposed to stress and enhance neuroprotective role of pyridoxine in experimental animals.^[35] Umbelliferone is the parent compound for a large number of natural products. *A. marmelos* (L.) Corr. LE contains umbelliferone which influence on membrane-bound ATPases in STZ-induced diabetic rats^[36] and increase functionality effect on tail tendon collagen and restore hemostatic function in STZ-diabetic rats.^[37] Herniarin is 7-*O*-methylumbelliferone or 7-methoxycoumarin that is found in the leaves of water hemp *Eupatorium ayapana* and Rupturewort (*Herniaria* sp). Its *O*-glycosylated derivatives such as skimmin (7-*O*- β -D-glucopyranosylumbelliferone) and isoprenylated derivatives, i.e., marmin and furocoumarins such as marmesin, angelicin, and psoralen are antidiabetic in nature. Umbelliferone 7-apiosylglycoside isolated from the root of *Gmelina arborea*^[38] work as an antihyperglycemic and antidyslipidemic agent.^[39]

Alcoholic LEs of *A. marmelos* restored enzymatic activities of diabetic rats.^[40] Both crude extracts and chemical constituents of Bel, *A. marmelos* (L.) Corr.^[41] is also an herbal drug to treat ischemic heart disease in patients with diabetes.^[42] Its green leafy porridges are used to control hypo- and hyperglycemic responses.^[43] Plant shows inhibitory potential of traditional herbs on α -amylase activity.^[44] It cut down level of aldose reductase, display anticataract and free radical scavenging activity, and shows amelioration of diabetes complications.^[45,46] Similarly, phenylethyl cinnamides: A new series of α -glucosidase inhibitors was isolated from

the leaves of *A. marmelos*.^[47] LE significantly decreased muscarinic M1 receptor gene expression in the cerebral cortex of STZ-induced diabetic rats and showed wider therapeutic function.^[48] *A. marmelos* seed extract shows hypoglycemic and antihyperglycemic activity in normal and diabetic rats.^[49] Plant shows antidiabetogenic properties and lower down diabetic effects in STZ-induced diabetes in experimental rats.^[18] Plant contains enough mineral content and is used in the treatment of diabetes mellitus.^[50] Similar effects of *A. marmelos* fruit extract in STZ diabetes were reported in rats histopathologically by Kamalakkannan.^[51] Plant extract also cut down the level of tissue antioxidants in STZ diabetic rats.^[17,52] Umbelliferone β -D-galactopyranoside isolated from *A. marmelos* shows antidiabetic, antihyperlipidemic, and antioxidative activity. Hence, the plant can be used for management of T2D.^[21]

A. marmelos seed extract showed hypoglycemic and antihyperglycemic activity in normal and diabetic rats.^[49] *A. marmelos* decreases glucose uptake *in vitro* by activation of glucose transporter Type 4 (GLUT4), phosphoinositide 3-kinase, and PPAR γ in L6 myotubes.^[53] Effect of Dianex, an herbal formulation on experimentally induced diabetes mellitus.^[54] Methanolic LE of *A. marmelos* was found to reduce blood sugar in alloxan diabetic rats.^[17] It shows both antidiabetic and antihyperlipidemic activities.^[24] Limonene isolated from *A. marmelos* possesses potent antiglycating activity and is non-toxic at higher concentration.^[30]

Fresh *Portulaca oleracea* L. (POL) has been used as a folk medicine for the treatment of diabetes mellitus.^[55] Both fresh and dried POL possesses antidiabetic activities. Similarly, *Momordica charantia* L. fruits (MC) methanolic and ethanolic extracts showed hypoglycemic, hypolipidaemic, and pancreatic β -cell regeneration activities in alloxan-induced diabetic rabbits.^[55] Similarly, *Artemisia pallens* Walls ex D.C. (Asteraceae) possesses various pharmacological properties such as antidiabetic, antioxidant, analgesic, and anti-inflammatory activity.^[56] Crude ethanolic extract of *Peucedanum japonicum* Thunb has been identified as an antiobesity and antidiabetic candidate.^[57] Leaves or whole aerial parts of wild bilberry (*Vaccinium myrtillus* L.) and northern highbush blueberry (*Vaccinium corymbosum* L.) cultivars^[58] have been used as antidiabetic drugs mainly polyphenols [Figure 1].^[59] *Cimicifuga racemosa* extract Ze 450^[60] is used for the treatment of T2D. In mice, Ze 450 (PO/IP) decreases significantly average daily and cumulative weight gain, average daily food, and water intake. Ze 450 also significantly reduced body weight, plasma glucose, improved glucose metabolism, and insulin sensitivity in diabetic ob/ob mice.

The administration of 1 and 2 (50 mg/kg b.w.) daily for 28 days in STZ-induced diabetic rats, resulted in a significant decrease in blood glucose, glycosylated hemoglobin, serum glutamic oxaloacetic transaminase, serum glutamic pyruvic transaminase, alkaline phosphatase serum urea, and

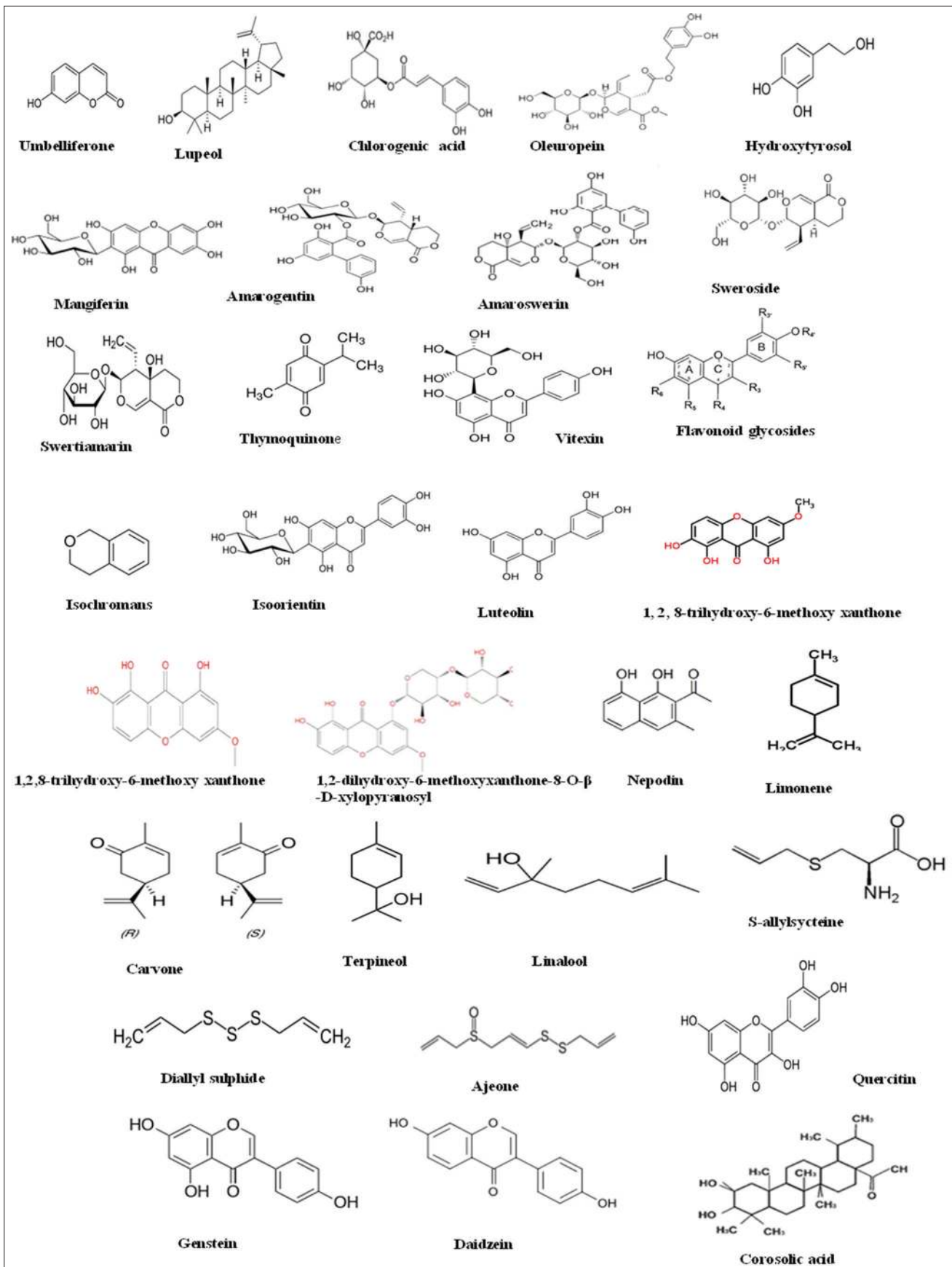


Figure 1: Anti-diabetic bio-organic compounds from different plant species

creatinine with significant rise in plasma insulin level. These compounds also protect tissues such as pancreas, liver, and kidney against peroxidation damage.^[61] In Iran, *Otostegia persica* (Burm.) Boiss. (Lamiaceae), Goldar is used for control of diabetes mellitus.^[62] Underutilized vegetable palm hearts from *Plectocomiopsis geminiflora* and *Eugeissona insignis* lalis (*P. geminiflora*) and pantu (*E. insignis*) possess antioxidative and antidiabetic properties. For the first time, the phenolic compounds and chlorogenic acid found vegetables showed high inhibition of α -amylase activity.^[10] Chlorogenic acid is the ester of caffeic acid and (-)-guinic acid. In plants, it is an important intermediate in lignin biosynthesis and is a strong antioxidant, which slows down the release of glucose into the blood stream after meal.

Fresh root, bark, and leaves of *S. persica* L. (Salvadoraceae) have been used in the folk medicine for the treatment of diabetic patients.^[63] Its root extract cut down hyperlipidemia and hyperglycemia in diabetic rats.^[63] *F. deltoidea* (var. *angustifolia* [SF] and var. *kunstleri* [BF]) possesses phenolic compounds which showed antihyperglycemic and antioxidant activities. It is used for treatment of diabetes mellitus.^[5] Similarly, *Gynura procumbens*,^[64] *Cinnamomum tamala*,^[65] *Acorus calamus* (Sweet flag),^[66] and *Gymnema sylvestre* contain antidiabetic principles and are used for traditional management of diabetes in Southern Asia. *G. procumbens* acute dose (1 g/kg) - of extracts significantly lowered fasting blood glucose (FBG) in STZ-induced diabetic rats $P < 0.05$ - has antiobesity and antidiabetic properties. It decreases body weight and inhibits glucose absorption. Several components extracted from *Gymnema* prevent the accumulation of triglycerides in muscle and liver and also decrease fatty acid accumulation in the circulation.^[67] *Populus balsamifera* extract and its active component salicortin reduce obesity and attenuate insulin resistance in a diet-induced obese mouse model.^[68] Methanolic extract (ME) of *Caralluma tuberculata* also shows similar antidiabetic activity in STZ-induced diabetic rats.^[69] Its physiological dose enhances skeletal muscle utilization of glucose, does inhibition of hepatic gluconeogenesis and stimulation of insulin secretion.^[69] Natural plant products mainly extracts contain antioxidant compounds which cut down oxidative stress in pathogenesis of β -cell dysfunction, could be helpful in management of diabetes and its complications. These also do suppression of oxidative stress, cytokine-induced impairment, suppression of nuclear factor κ B - a key regulator of endothelial activation, activation of uncoupling protein 2, insulin-like activity, and increasing intracellular calcium.^[70] Golden germander (*Teucrium polium* L.) is a Mediterranean shrub of the Labiatae family, shows antidiabetic effects.^[71] *Ageratum conyzoides* and *Commelina africana* showed hypoglycemic effect.^[72]

Aerial parts of *Phlomis anisodonta* ME (PAE) showed a significant reduction in FBG in STZ-induced diabetic rats. These also showed an increase in serum insulin levels in comparison with diabetic control group. PAE is beneficial

in the control of diabetes by reduction of blood glucose and increasing insulin levels and combating oxidative stress by activation of hepatic antioxidant enzymes.^[73] Extracts of the Canadian lowbush blueberry *Vaccinium angustifolium* contains active principles which are proved novel therapeutic agents against diabetes mellitus. *Desmodium gangeticum* (L.) DC. and *Desmodium adscendens* (Sw.) DC.^[74] and *Cleome droserifolia* (Forssk.) Del. showed antidiabetic effects.^[75] *Dodonaea viscosa* effects rendered insulin resistant by feeding 66% (w/w) fructose and 1.1% (v/w) coconut oil mixed with normal pellet diet.^[76] *Phyllanthus niruri* L. (Euphorbiaceae) is an antidiabetic herb inhibits glucose absorption and cut down its storage in diabetes. It shows blood glucose lowering and glycemic control in diabetes.^[77] Herb-derived components if used as dietary supplements can control diabetes [Figure 1].^[78]

ODP also showed antidiabetic effects.^[6] *A. conyzoides* reduce FBG of experimental animals by 39.1%.^[72] *C. alata* Linn. (syn. *Senna alata* (L.) Roxb.) (Caesalpiniaceae) is used for treating various diseases including diabetes. Regular consumption of its leaves inhibit carbohydrate digestion and absorption.^[11] Similarly, aqueous extract of *Enicostemma littorale* Blume in antidiabetic effect in STZ-induced Type 1 diabetic rats.^[79] Ethanolic extract of *Rhus coriaria* fruits shows alleviation of diabetes complications and inhibits intestinal α -glucosidases.^[80] *Vaccinium vitis-idaea* L. aqueous extract possesses flavonoid components, which are potent antiglycation agents.^[1] *Tecoma stans* (L.) Juss. ex Kunth (Bignoniaceae) and *Teucrium cubense* Jacq (Lamiaceae) are plants extensively used for the empirical treatment of diabetes mellitus.^[81] These plant species contain oleuropein and hydroxytyrosol which cut down serum glucose and cholesterol, hepatic glycogen level.^[82] Oleuropein is phenylethanoid mainly a phenolic bio-organic compound that occurs in olive leaves. There are other closely related compounds such as 10-hydroxyoleuropein, ligstroside, and 10-hydroxyligstroside. These are tyrosol esters of elenoic acid which get further glycosylated and hydroxylated. Oleuropein had activity as an agonist of the G-protein estrogen receptor and has multiple pharmacological properties.

Psidium guajava unripe fruit peel cut down blood glucose level (BGL) in STZ-induced diabetic rats.^[83] *Croton klotzianus* extract caused a significant concentration-dependent increase in insulin secretion 8-fold at 2 mg/mL for cells challenged with 20 mM glucose from MIN6 cells grown as monolayers and as pseudoislets. It shows that the antidiabetic activity may be as a result of increased insulin secretion.^[84] Silver nanoparticles of *Bauhinia variegata* LE of *B. variegata* L. display strong antidiabetic properties.^[85] *Salacia oblonga* extract is mediated not only by inhibiting intestinal α -glycosidases but also by enhancing glucose transport in muscle and adipose cells. *S. oblonga* extract and mangiferin exert their antidiabetic effect by increasing GLUT4 expression and translocation in muscle cells [Table 1]. Mangiferin is found in mangoes,^[86] *Iris unguicularis*,^[87] *Anemarrhena asphodeloides* rhizomes,^[88] and in *Bombax*

Table 1: Important anti-diabetic ingredients isolated from various plant species

Plant	Part	Active ingredients	Chemical group	Biological activity
<i>Olea europaea</i>	Olive leaf Privet leaf	Oleuropein 10-hydroxyoleuropein, ligstroside, and 10-hydroxyligstroside	Phenolic compound, tyrosol esters of enolic acid	Anti-oxidant and antidiabetic
Rutaceae plants oranges, lemons, grapefruit, and limes	Citrus peels	D- <i>limonene</i> is an oral dietary supplement containing a natural cyclic monoterpene	Colorless liquid hydrocarbon classified as a cyclic terpene	Strong anti-oxidant and antidiabetic
Plants of family Lamiaceae		Linalool naturally occurring terpene alcohol	Flowers and spiceplants	Anti-oxidant, antidiabetic, repellent products
<i>Carum carvi</i> and Spearmint (<i>Mentha spicata</i>) and Dill	Seeds	Carvone is a member of a family of chemicals called terpinoids	Carvone is found naturally in many essential oils	Anti-oxidant and antidiabetic
Cajuput oil, pine oil, petitgrain oil	Leaves	Terpineol mainly monoterpene alcohol Terpineol is usually a mixture of these isomers with alpha-terpineol as the major constituents	Four isomers, α -, β -, γ -terpineol, and terpinen-4-ol. β - and γ -terpineol differ only by the location of the double bond	Anti-oxidant and antidiabetic
<i>Allium sativum</i>	Bulbs	SAC is an organic compound and a natural constituent of fresh garlic	It is a derivative of the amino acid cysteine in which an allyl group has been added to the sulfur atom	Anti-oxidant and antidiabetic
<i>Allium sativum</i>	Leaves and bulbs	DATS, also known as allitridin, is an organosulfur compound	Derived from the hydrolysis of alliin, garlic contains many polysulfides, including diallyl disulfide and diallyl tetrasulfide	Most potent anti-diabetic agent
<i>Allium sativum</i>	Leaves and bulbs	Contains a mixture of up to four isomers, which differ in terms of the stereochemistry of central alkene (E- vs. Z-) and the chirality of the sulfoxide	Organosulfur compound, colorless liquid that contains sulfoxide and disulfide functional groups	Most potent antioxidant and antidiabetic agent, potentially reducing the risk of heart disease, virucidal
Fruits, vegetables, leaves and grains	Aerial parts and seeds	Quercetin physiological effect in human health	Quercetin supplements have been promoted for prevention and treatment of cancer	It can be used as an ingredient in supplements, beverages, or foods. Nutrient nor an antioxidant
<i>Genista tinctoria</i>	Genistein	Genistein is a phytoestrogen and belongs to the category of isoflavones	Antioxidant and anthelmintic	Angiogenesis inhibitor
<i>Opuntia dillenii</i>	Leaves and roots	Polysaccharides	By protecting the liver from peroxidation damage	Antihyperglycemic effect by protecting the liver from peroxidation damage
<i>Cudrania tricuspidata</i>	Leaves and flowers	Cudraflavanone A	2S-2',5,7-trihydroxy-4',5' -(2,2-dimethylchromeno)-6 -prenyl flavanone	Inhibit α -glucosidase activity
<i>Cassia alata</i>	Leaves and flowers	Kaempferol 3-O- gentiobioside	Phytosterols	Antidiabetic

(Contd...)

Table 1: (Continued)

Plant	Part	Active ingredients	Chemical group	Biological activity
<i>Carthamus tinctorius</i>	Seed	Allyltoluene, 1-acetoxytetralin and heneicosane	Antioxidant, analgesic, anti-inflammatory and antidiabetic activities	Antidiabetic and cardiovascular
<i>Microctis folium</i>	Leaves and stem	flavonoid glycosides	α -glucosidase inhibitory effect	Antidiabetic
<i>Aegle marmelos</i>	Fruit	Limonene	Liquid hydrocarbon classified as a cyclic terpene	A potent antiglycating agent
<i>Vaccinium myrtillus L.</i>	Aerial parts, wild bilberry	Anthocyanins	Including delphinidin and cyanidin glycosides	Antidiabetic and improvement of night vision
<i>Vaccinium corymbosum</i>	Leaves and stem	And linalool, antioxidant butylated hydroxytoluene	Citral, 1,8-cineole	Antidiabetic
<i>Cimicifuga racemosa</i>	Leaves and stem	Triterpene glycosides	Cycloartanes	Analgesic, sedative, and anti-inflammatory properties
<i>Populus balsamifera</i>	Leaves and stem	Salicortin, sesquiterpenes and n-alkanes	Aliphatic acids and hydroxyacids, phenolcarboxylic acids, substituted cinnamic acids, and their esters	Attenuate insulin resistance
<i>Cleome droserifolia</i>	Leaves	Flavonol glycosides	Artemetin and bonanzin	Attribute insulin-like effects
<i>Tecoma stans</i> (L.) Juss. ex Kunth	Leaves and roots	Monoterpenes	Isoacteoside	Empirical treatment of diabetes mellitus
<i>Teucrium cubense</i> Jacq	Flowers	3-O - glucoside of β -sitosterol and cryptoxanthin I	Kaempferitrin, and kaempferol trirhamnoside	Empirical treatment of diabetes mellitus
<i>Salacia oblonga</i>	Root	Salalcinol and kotalanol, along with several phenolic compounds		α -glucosidase inhibitory potential
<i>Mangifera indica</i>	Leaves	Mangiferin	A xanthone glycoside	Antidiabetic and antioxidant
<i>Berberis lycium</i> Royle	Root, leaves, and fruits	Palmitine (3.1%) and berberine, vasicine and vasicinone	Palmatine, and berberine, (alkaloids)	Febrifuge, and piles, antihistaminic, stomachic
<i>Cuminum cyminum</i>	Seeds	Thymoquinone, cuminoids	Antiglycative effects	Antidiabetic
<i>Oroxylum indicum</i>	Leaves	Flavonoids	Terpenoids, phenols and glycosides	Antidiabetic
<i>Scutellaria lateriflora</i>	Leaves	Apigenin, luteolin, 6-methoxyluteolin 4'-methyl ether, isoscutellarin 8-O- β -D-glucuronide, naringenin, jionoside D	Terpenoids, phenols, leucosceptoside A, and (+)-syringaresinol 4'-O- β -D-glucopyranoside	Antidiabetic
<i>Swertia chirata</i>	Leaves and stem	Flavonoids and secoiridoids	Flavonoids	Antidiabetics and antioxidant activity
<i>Ananas comosus</i>	Leaves	Alcoholic extract	Flavonoids	Antidiabetic
<i>Zingiber officinale</i>		Roscoe contain gingerol and shoagol as major constituents	Phenolic components	Antidiabetic
<i>Vitex negundo</i>		Antihyperglycemic		
<i>Cinnamomum zeylanicum</i>	Leaf oil	Contains a major component called eugenol, and cinnamaldehyde, and camphor	Cinnamon	Anti-diabetic activities

(Contd...)

Table 1: (Continued)

Plant	Part	Active ingredients	Chemical group	Biological activity
<i>Marrubium vulgare</i>	Leaves	5-caffeoylquinic (chlorogenic)	Flavonoids	Strong anti-diabetic activity
<i>Casearia esculenta</i> (Roxb.)	Root	3-hydroxymethyl xylitol	Flavonoids, alcohols	A novel anti-diabetic compound is isolated from
<i>Carissa carandas</i> Linn.	Unripe fruit extract	Polyphenolic and flavonoid contents	Polyphenolic and flavonoid	And show anti-hyperglycemic effect
<i>Phellodendron lavalei</i>	Bark	Berberins	Polyphenolic and flavonoid	Anti-diabetic activity
<i>Ficus religiosa</i> L	Leaves	Phytosterols, amino acids, furanocoumarins, phenolic components, hydrocarbons, aliphatic alcohols, volatile components	Phytosterols, phenolic components	Anti-diabetic activity
<i>Fagopyrum tataricum</i>	Leaves	Rutin and quercetin, which had notable	Flavonoids	Antioxidant, antidiabetic, hypocholesterolemic and antitumor activities
<i>Swertia corymbosa</i>	Leaves	1, 2, 8-trihydroxy-6-methoxy xanthone (1) and 1, 2-dihydroxy-6-methoxyxanthone-8-O- β -D-xylopyranosyl	Flavonoids	Indian traditional system for the treatment of diabetes
Leguminous plants	Leaves	Genistein and daidzein as alpha-amylase inhibitors and alpha-glucosidase inhibitors	Enzyme and glucosidase inhibitors	Anti-diabetic activity
<i>Lavandula stoechas</i>	Essential oil	Contains D-Fenchone, α -pinene, Camphor, Camphene, Eucapur	Limonene, linalool, endobornyl acetate	Anti-diabetic activity
<i>Carthamus tinctorius</i>	Leaves	Carthamin, safflower yellow carthamidin, isocarthamidin, hydroxysafflor yellow A, safflor yellow A, 1-acetoxytetralin and heneicosane	Safflamin C and luteolin as main constituents. caryophyllene, p-allyltoluene	Anti-diabetic activity
<i>Pelargonium graveolens</i>	Essential oil	Glibenclamide	Amide	Anti-diabetic activity
<i>Psidium guajava</i>	Leaves	Flavonoids	Flavonoids and other phenolic	Restore the activities of carbohydrate metabolizing enzymes
<i>Phlomis linearis</i> Boiss	Leaf essential oil	Monoterpenes (alpha-pinene, limonene and linalool), sesquiterpenes (germacrene D and β -caryophyllene)	Terpenes and flavonoids	Anti-angiogenic and anti-inflammatory activity

SAC: S-allyl cysteine, DATS: Diallyl trisulfide

ceida.^[89] It is also found in the genera *Salacia* and *Cyclopia*. These effects are probably mediated through two independent pathways that are related to 5'-AMP-activated protein kinase and PPAR γ .^[90] *Borreria hispida* (BHE), a weed of Rubiaceae family, BHE enhanced the protein expression of PPAR γ , PPAR-delta, and GLUT4, probably revealing the antiobese and antidiabetic potential of BHE.^[91] *Swertia chirata* (Gentianaceae) is known for its multifarious medicinal value in the Indian system of medicine (Ayurveda). Its methanol

extracts having antidiabetic activity contains mangiferin, amarogentin, amaroswerin, sweroside, and swertiamarin as active constituents.^[92] Berberine *Berberis lyceum* root produces high concentrations of berberine that show hypoglycemic activity in several *in vitro* and *in vivo* models [Table 1].^[93] MCE exhibited significant antihyperglycemic effect and protected β -cells in STZ-diabetic rats, in a dose-dependent manner, and diminished the hyperglycemia-related oxidative stress.^[94]

Plant Natural Products

Natural plant products also act as hypoglycemic agents. Few plant species, i.e., *Opuntia streptacantha* Lem, *Trigonella foenum graecum* L., MC, *Ficus bengalensis* L., *Polygala senega* L., *G. sylvestre* R., *Allium sativum*, *Citrullus colocynthis*, *Aloe vera*, *Occimum sanctum*, and *Artemisia absinthum* possess antidiabetic activity [Table 1].^[95-100] These plants possess bioactive components and are used as folk medicine.^[101-104] However, a large number of medicinal plants possess some degree of toxicity to human when used for diabetes.^[105] However, oral administration of *Asteracantha longifolia* Nees. (20 g/kg) significantly increases glucose tolerance in healthy human subjects and diabetic patients. Its oral administration of 2, 3, and 4 g/kg of *Achyranthes aspera* L. produced a significant dose-related hypoglycemic effect in man. This hypoglycemic action of *A. longifolia* may be due to a reduction in the intestinal absorption of glucose.^[106] Similarly, *Daucus carota* L. extract has shown improved glucose tolerance in swiss mouce. Similar antidiabetic activity was reported in *Coriandrum sativum* L. (Coriander), *Cuminum cyminum*, *C. niger*, *Vinca rosa*, *Catharanthus roseus*, and *Rhazya stricta* when administered with diet.^[107-111] Moreover, ginseng polypeptides (GPP) isolated from the root of *Panax ginseng* Mey. (Asiatic ginseng) cut down the level of blood sugar and liver glycogen at 50-200 mg/kg dose.^[112,113] Similarly, the oral administration of *Ginseng radix* water extract to normal and adrenaline-induced hyperglycemic mice caused a significant decrease in BGL 4 h after its administration.^[114] Moreover, saponins isolated from the leaves of *Acanthopanax senticosus* have been found decrease the blood sugar in hyperglycemic mice.^[115] Besides this, *Cleome droserifolia* Delile significantly suppressed the glycemia, both in the basal (fasting) state and after glucose intake.^[116]

Moreover, GPP isolated from the root of *P. ginseng* Mey. (Asiatic ginseng) cut down the level of blood sugar and liver glycogen at 50-200 mg/kg dose.^[112,113] Oral administration of *Convolvulus althaeoides* (Linn.) extract to normoglycemic rats produced a persistent hypoglycemic effect.^[117] Similarly, oral administration of *Ipomea batatas* L. (white-skinned sweet potato) produced a reduction in hyperinsulinemia in Zucker fatty rats. Its boiled extract has significantly decreased glucose level in healthy Wistar rats.^[118] Healthy mice when treated with MC (Karela) have shown strong antiglycemic glycemc response to both oral and intraperitoneal glucose, without altering the insulin level.^[119] Similarly, oral administration of an alcoholic extract of leaves of *Ocimum sanctum*, *Ocimum album*, and *T. cubense* reduced glycemia in normoglycemic, glucose-fed hyperglycemic, and STZ-induced diabetic rats.^[120-123]

BIO-ORGANIC COMPOUNDS

Thymoquinone (TQ)

The bioactive natural products (plant secondary metabolites) are widely known to possess therapeutic value for the

prevention and treatment of various chronic diseases including cancer. 2-methyl-5-isopropyl-1,4-benzoquinone (TQ), a monoterpene present in black cumin seeds, exhibits pleiotropic pharmacological activities including antioxidant, anti-inflammatory, antidiabetic, and antitumor effects [Table 1].^[124] TQ inhibits experimental carcinogenesis in a wide range of animal models and has been shown to arrest the growth of various cancer cells in culture as well as xenograft tumors *in vivo*. At the molecular level, TQ targets various components of intracellular signaling pathways, particularly a variety of upstream kinases and transcription factors, which are aberrantly activated during the course of tumorigenesis.^[124] Anthraquinones found in *A. conyzoides* showed hypoglycemic effects [Figure 1].^[72]

Flavonoids

Oroxylum indicum (L.) Kurz contains flavonoids as major constituents in all parts [Figure 1]. This plant is used for centuries as a traditional medicine in Asia in ethnomedicinal systems for the prevention and treatment diabetes. Many commercial ayurvedic medicines and other ethnomedicinal preparations in human subjects are based on this plant.^[125] Phytochemicals such as flavonoids, secoiridoids, iridoids, flavanones, biophenols, triterpenes, benzoic acid derivatives, isochromans, and other classes of secondary metabolites isolated from *O. europaea* have shown a wide spectrum of *in vitro* and *in vivo* pharmacological activities against diabetes.^[126] Flavonoids, iridoids, and phenylethyl alcohol constitute the main compounds isolated from phlomis extracts good antidiabetic agents.^[127] *M. folium* contain vitexin, isovitexin, isorhamnetin 3-O- β -D-rutinoside, and flavonoid glycosides which showed antidiabetic potential. Isoorientin (ISO) is a plant C-glycosyl flavonoid which shows purported antidiabetic effects.^[128] The leaves of *Lagerstroemia speciosa* (Lythraceae), gallotannin and PGG, corosolic acid which stimulate the glucose uptake in adipocytes.^[129] Flavonoids and secoiridoids isolated from *S. chirata* (family Gentianaceae) have antidiabetics and antioxidant activity.^[130] *Scutellaria lateriflora* contains many active ingredients such as apigenin, luteolin, 6-methoxyluteolin 4'-methyl ether, isoscutellarin 8-O- β -D-glucuronide, luteolin 7-O- β -D-glucuronide, wogonin 7-O- β -D-glucuronide methyl ester, eriodictyol, naringenin, naringenin 7-O- β -D-glucuronide, jionoside D, leucosceptoside A, and (+)-syringaresinol 4'-O- β -D-glucopyranoside. Due to presence of these components, *S. lateriflora* extract shows inhibitory properties against α -glucosidase provide a good antidiabetic usage.^[131] Similarly, phytochemical constituents, i.e. hydroxycinnamic acids, three hydroxycinnamoyl quinic acids, four phenylpropane monoglycerides, three flavones, and six phenylpropanoid glycosides found in ethanolic extract of *Ananas comosus* L. leaves were found antidiabetic, antihyperlipidemic, and antioxidative agents [Table 1].^[132]

EtOAc extract of rhizome of *Zingiber officinale* Roscoe contains phenolic components such as gingerol and shoagal as

major constituents. These enhance glucose uptake in cell lines (Zingiberaceae).^[133] Similarly, iridoid glucoside isolated from the leaves of *Vitex negundo* showed antihyperglycemic^[134] effects on dearrangement in plasma and tissue glycoprotein components in STZ-induced diabetic rats. In treatments levels of blood glucose, plasma and tissues glycoproteins such as hexose, hexosamine, fucose, and sialic acid were significantly increased, whereas plasma insulin levels were significantly decreased in diabetic rats. *Marrubium vulgare* (Lamiaceae) contains seven flavonoids with 5-caffeoylquinic (chlorogenic) show strong antidiabetic activity.^[135] Similar activity is also reported in polyphenols.^[135] *Angelica keiskei* (Ashitaba) exhibits antitumor, antioxidant, and antidiabetic activities.^[136] Cinnamon (*Cinnamomum zeylanicum*) leaf oil contains a major component called eugenol, and cinnamaldehyde and camphor that showed antidiabetic activities.^[75] Cinnamon contains trans-cinnamyl acetate as a major compound in fruits, flowers, and fruit stalks, whereas bark and fruits were found to contain proanthocyanidins with doubly linked bis-flavan-3-ol units in the molecule.^[75] *Casearia esculenta* root (Roxb.) is widely used in the traditional system of medicine to treat diabetes in India. 3-hydroxymethyl xylitol, a novel antidiabetic compound, is isolated from *C. esculenta* (Roxb.) root which act on glycoprotein components in STZ-diabetic rats [Table 1].^[137] Dry extracts of *T. polium* L. ssp. *capitatum* (L.) Arcangeli (Lamiaceae) effects on blood glucose, lipids, and carbohydrate-related enzymes in normal- and STZ-hyperglycemic rats. Plant extracts also contain flavonoids such as luteolin, apigenin, cirsiol, diosmetin, cirsimaritin, and cirsilinoneol as both free aglycons and glycosides which showed insulinotropic and antihyperglycemic effects.^[138] *Carissa carandas* Linn. unripe fruit extract contains polyphenolic and flavonoid contents which show antihyperglycemic effect.^[139] Berberines isolated from bark of *Phellodendron lavalei* show antidiabetic activity and are effectively used against metabolic syndrome and prevention of diabetes Type 2.^[140] *Ficus religiosa* L. (Moraceae) contains phytosterols, amino acids, furanocoumarins, phenolic components, hydrocarbons, aliphatic alcohols, volatile components, and few other classes of secondary metabolites, which are strong antidiabetic in nature.^[141] ISO is a plant C-glycosyl flavonoid which shows strong antidiabetic effects but its mechanisms of action is unknown [Table 1].^[128] Similarly, ethanol extract of *Melothria heterophylla* (EEMH) contains rutin (RU) and gallic acid (GA) EEMH, GA which demonstrated remarkable antidiabetic activity in STZ-induced diabetic rats.^[142]

Monoterpenes

Monoterpenes are major components of essential oils [Figure 1]. These belong to the group of isoprenoids which contain 10 carbon atoms. Being widely distributed in the plant kingdom, they are extensively used in cuisine and human health-care products. Both natural monoterpenes and their synthetic derivatives are endowed with various pharmacological properties including antifungal, antibacterial, antioxidant, anticancer, antiarrhythmic, antiaggregating, local anesthetic,

antinociceptive, anti-inflammatory, antihistaminic, and antispasmodic activities. Monoterpenes act as regulators of growth, heat, transpiration, tumor inhibitors, inhibitors of oxidative phosphorylation, insect repellants, feline and canine attractants, and antidiabetics.^[143] The major functional components of *Fagopyrum tataricum* have been demonstrated to be flavonoids (i.e., rutin and quercetin), which had notable antioxidant, antidiabetic, hypocholesterolemic, and antitumor activities. *F. tataricum* hairy root culture is an effective source of rutin and quercetin production that showed antidiabetic activity.^[144] Petroleum ether and EtOAc extracts of *Swertia corymbosa* (Gentianaceae) contain 1, 2, 8-trihydroxy-6-methoxy xanthone (1) and 1, 2-dihydroxy-6-methoxyxanthone-8-O- β -D-xylopyranosyl (2) as main constituents, and the plant is used in the Indian traditional system for the treatment of diabetes [Table 1]. *G. sylvestre* R. Br. contains phytosterols β -sitosterol, campesterol, and stigmasterol which are antidiabetic in nature.^[145]

Nepodin

Leguminous plants mainly beans contain bioactive compounds displaying antidiabetic activity. These contain genistein and daidzein as α -amylase inhibitors and α -glucosidase inhibitors [Table 1]. Leguminous plants possess important dietary nutrients and promote healthy lifestyles in terms of functional food.^[146] Nepodin has an antidiabetic effect, which is at least partly mediated by stimulation of GLUT4 translocation via adenosine monophosphate-activated protein kinase (AMPK) activation [Figure 1].^[147] It rescued the impaired phosphorylation of AMPK in the skeletal muscle of db/db mice.

Essential Oils

Lavandula stoechas essential oil contains D-Fenchone (29.28%), α -pinene (23.18%), camphor (15.97%), camphene (7.83%), eucapur (3.29%), limonene (2.71%), linalool (2.01%), and endobornyl acetate (1.03%). The essential oils also contain smaller percentages of tricyclene, Cymene, Delta-Cadinene, and Selina-3,7(11)-diene. *L. stoechas* essential oil significantly protects against the increase of blood glucose as well as the decrease of antioxidant enzyme activities induced by alloxan treatment.^[148] Essential oils of *A. calamus* have been isolated and characterized by α - and β -asarone as predominant bioactive components [Table 1].^[66] Flowers of *C. tinctorius* contain carthamin, safflower yellow carthamidin, isocarthamidin, hydroxysafflor yellow A, safflor yellow A, safflamin C, and luteolin as main constituents. Caryophyllene, p-allyltoluene, 1-acetoxytetralin, and heneicosane were identified as the major components of *C. tinctorius* flower essential oil. Its essential oil is used in drug development with numerous pharmacological activities in the world [Table 1].^[12]

Essential oil of *Pelargonium graveolens* L'Hér. together with glibenclamide shows hypoglycemic effect. Essential

oil of *P. graveolens* may be helpful in the prevention of diabetic complications associated with oxidative stress.^[149] The essential oil of *Phomis* is composed of four chemotypes dominated by monoterpenes (α -pinene, limonene, and linalool), sesquiterpenes (germacrene D and β -caryophyllene), aliphatic compounds (9,12,15-octadecatrienoic acid methyl ester), fatty acids (hexadecanoic acid), and other components (trans-phytol, 9,12,15-octadecatrien-1-ol) [Figure 1]. Argan oil is principally composed of monounsaturated (up to 80%) and saturated (up to 20%) fatty acids. As minor components, it contains polyphenols, tocopherols, sterols, squalene, and triterpene alcohols.^[150] *Tetraena gaetula* (Emb. and Maire) Beier and Thulin (*Zygophyllum gaetulum* Emb. and Maire, Zygophyllaceae) showed antidiabetic activity.^[151] Aerial parts of *Zygophyllum album* L. essential oils are used in folk medicine as an antidiabetic agent. It contains mainly oxygenated monoterpenes with major constituents: Carvone and α -terpineol. However, the most of the compounds present in the hydro-distilled volatile fraction were not terpene species, with β -damascenone as a major constituent.^[152] Cinnamon oil may be useful in the treatment of T2D mellitus.^[153] Flavonoids, iridoids, and phenylethyl alcohol constitute the main compounds isolated from phlomis extracts [Table 1].^[127]

S-allylcysteine (SAC)

Oral administration of SAC to diabetic rats cut down glycoprotein levels in the STZ-induced diabetic model.^[154] SAC possesses a significantly beneficial effect on the glycoprotein moiety in addition to its antidiabetic effect.^[154] Alkaloids, stilbenoids (polyphenol), triterpene, acids (chlorogenic acid, betulinic acid, syringic acid, vanillic acid, bartogenic acid, oleanolic acid, dehydrotrametenolic acid, corosolic acid, ellagic acid, ursolic acid, GA), phytosterol, myoinositol, flavonoids, flavonolignans, anthraquinones, anthrones, and xanthenes, feruloylglucosides, flavanone glucosides, acetophenone glucosides, glucopyranoside derivatives, genine derivatives, flavonol, anthocyanin, and others showed antiglycemic effect and inhibit α -glucosidase activity.^[155] Onion and garlic contain SAC sulfoxide, S-methylcysteine sulfoxide, and diallyl trisulfide which are strong antidiabetic agents [Figure 1].^[156]

USE OF PROPER NUTRACEUTICALS

Hydrolyzable tannins are among the major bioactive components of the fruits. Mucic acid gallate, mucic acid lactone gallate, monogalloylglucose, GA, digalloylglucose, putranjivain A, galloyl-HHDP-glucose, elaeocarpusin, and chebulagic acid are the most abundant hydrolyzable tannins. Fruits of emblic leafflower have been used as food and traditional medicine in Asia. Based on scientific researches, fruits are best kind healthy foods and good source of bioactive ingredients which possess wide range of biological activities [Table 1].^[157] *Artemisia* species have

been extensively used for the management of diabetes in folkloric medicine. According to the results, *Artemisia indica* possesses hypoglycemic, antihyperlipidemic, and valuable effects on liver and renal functions in diabetic rats, which seems to validate its traditional usage.^[158]

P. guajava is an important plant of high medicinal value and has been used in traditional systems of medicine against various ailments. Its ethanolic extract of leaves protective effect on altered glucose metabolism in STZ-induced diabetic rats. Treatment with *P. guajava* extract showed a significant reduction in blood glucose and HbA1c levels and a significant increase in plasma insulin levels. *P. guajava* leaves contain flavonoids and other phenolic components which significantly restore the activities of carbohydrate metabolizing enzymes [Table 1].^[159] *Antidesma bunius* Spreng. (Phyllanthaceae), *Averrhoa bilimbi* L. (Oxalidaceae), *Biophytum sensitivum* (L.) DC. (Oxalidaceae), *Ceriops tagal* (Perr.) C.B. Rob. (Rhizophoraceae), *Kyllinga monocephala* Rottb. (Cyperaceae), and *Rhizophora mucronata* Lam. (Rhizophoraceae) are used as remedies to control diabetes. The 80% aqueous ethanolic extracts were screened for their α -glucosidase enzyme inhibitory activity using yeast α -glucosidase enzyme.^[160] Huanglian Wan is prescribed for the treatment of diabetes mellitus in the traditional Chinese medicine. Its extract contains components such as berberine and catalpol which control body weight, increase food intake, urine volume, urine sugars, fasting plasma glucose, and fasting plasma insulin in diabetic rats [Table 1].^[161]

Mainly herbal foods rich in flavanols^[162] and polyphenols^[163] show hypoglycemic effects and can be used in the prevention of diabetes-induced vascular dysfunction. Herbal dietary supplementation having diverse antioxidants, fibers, minerals,^[164] antiglycant, which show inhibitory activity against α -amylase and α -glucosidase^[165] can easily control carbohydrate metabolism in humans.^[166] Further, inclusion of white vegetables such as garlic (*Allium sativum*) provides^[167,168] in daily diet provides better diabetic control in T2D patients.^[169] Natural components found in garlic oil^[170] and its ingredients^[171] found more beneficial to control T2D mellitus^[172] because they possess antihyperglycemic, antihyperlipidemic, anti-inflammatory, and adenosine deaminase-lowering effects in patients and cut down obesity.^[173] Bitter melon MC lowers serum insulin and normalizes glucose tolerance.^[174]

CONCLUSION

There is a common usage of herbal preparations in form of concoctions, syrups, vegetables, juices, green tea, from leaves, and roots for diabetic therapeutics. Leguminous plants mainly pulses or soybeans should be made the main source of dietary needs in the promotion of healthy lifestyles in terms of functional food. Legumes are protein rich containing large amounts of soluble alimentary fiber, polyunsaturated

fatty acids, vitamins and minerals, and bioactive substances which possess antioxidant, anti-inflammatory, and anticancer activity. These possess α -glucosidase inhibitors which can easily cut down glucose utilization if added to the daily meals. Leguminous plants possess genistein and daidzein, α -amylase inhibitors, and α -glucosidase inhibitors which have shown very high antidiabetic properties. Their high amount of bioactive compounds interferes with the metabolism of glucose. The most significant consumption of vegetables and legumes is inversely associated with the risk of T2D. Garlic and garlic extracts have been shown to be effective in reducing insulin resistance. Daily usage of garlic helps in controlling diabetes and diabetes-associated pathologies. The beneficial effects of garlic are mainly attributed due to the presence of volatile sulfur compounds such as alliin, allicin, diallyl disulfide, diallyl trisulfide, diallyl sulfide, S-allyl cysteine, ajoene, and allyl mercaptan. Phytochemicals, nutritional, and mineral constituents of different plant species will definitely assist clinicians and pharmacists to prepare antidiabetic drug formulation with an establishment of non-toxic herbal drugs. These could be used as sources of nutrients and as replacements for synthetic antidiabetic drugs. No doubt indigenous medicinal plants can be used to maximize the production of economically feasible drugs as an alternative of synthetic drugs to treat diabetes. There is a need of natural plant products that can be used for preparation of antidiabetic formulations which could do a significant reduction in BGL in comparison to existing standard antidiabetic drugs. Various herbal preparations are also used as ethnomedicines by local people in form of crude extracts prepared from flowers, fruits, and roots of endemic plant species.

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