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REVIEW

Commonly consumed Indian plant food materials in the management of diabetes mellitus

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KEYWORDS
Diabetes mellitus;
Oral hypoglycemic agents;
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Review

Summary Diabetes mellitus is a common disease affecting several million individuals worldwide. Over the last century changes in human behavior and lifestyle have resulted in a dramatic increase in the incidence of diabetes world over. Though oral hypoglycemic agents and insulin is the mainstay of treatment of diabetes, they have prominent side effects and fail to significantly alter the course of diabetic complications. Lifestyle modifications including appropriate diet and exercise programs have been found to be greatly effective in the management of the disease. Diet therapy especially is showing a bright future in the therapy of diabetes mellitus. In this regard this paper reviews 27 common Indian plant food materials that have been reported to possess anti-diabetic properties. The food materials reviewed in relation to diabetes and its complications are: *Cajanus cajan, Cicer arietinum, Phaseolus mungo, Phaseolus vulgaris, Aegle marmelose, Mangifera indica, Morus alba, Musa sapientum, Psidium guajava, Punica granatum, Syzigium cumini, Vitis vinifera, Allium cepa, Annona squamosa, Beta vulgaris, Cucurbita pepo, Ipomoea batatus, Momordica charantia, Allium sativum, Brassica juncea, Cuminum cyminum, Curcuma, Murraya koeingii* and *Trigonella foenum graecum*. In addition to these food materials black tea, green tea and red wine have also been reviewed. All these plant food materials have been reported to have varying degree of hypoglycemic and anti-hyperglycemic activity. It is concluded that the various plant foods which which form an important part of our diet not only possess blood glucose lowering properties but are also beneficial in decreasing the risk factors for cardiovascular and renal diseases through various mechanisms including free radicals.

Abbreviations: ADA, American Diabetes Association; T2DM, Type 2 diabetes mellitus; GI, glycemic index; OGTT, oral glucose tolerance test; LDL, low density lipoprotein; VLDL, very low density lipoprotein; HDL, high density lipoprotein; STZ, streptozotocin; SC, subcutaneous; IP, intraperitoneal; BP, blood pressure; FBG, fasting blood glucose.

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Contents

Introduction

Diabetes mellitus (DM), a global public health problem, is now emerging as an epidemic world over. According to a widely accepted estimation, the number of diabetic patients would reach 366 million by the year 2030 [1]. The situation is particularly grim in developing countries like India where unprecedented economic growth has been accompanied with an unfortunate byproduct of that prosperity in the form of diabetes. India now has the world's largest diabetic population, encompassing an estimated 35 million people out of an overall population of 1 billion. Another 79 million people have impaired glucose tolerance. In just over 20 years (i.e. 2025) the country will have almost 200 million people (approximately 15% of the population) affected by diabetes or its precursor [2].

Emergence of diabetes mellitus and implications of conventional management practices

Diabetes is a metabolic disease which affects not only the glucose metabolism but also lipid and protein metabolism. There are mainly two types of diabetes—Type 1 and Type 2. In Type 1 diabetes, in the absence of pancreatic β-cells the hormone insulin is not produced while Type 2 diabetes mellitus (T2DM), is characterized by a progressive impair-

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Table 1 Common Indian plant food materials with antidiabetic activity

Sr. no.	Food material	Part/form in which administered	Organism	Activity	Reference	Mode of action
1.	Legumes: Pigeon pea	Globulin fraction	Hypercholesterolemic rats	Hypolipidemic effect	Prema and Kurup [17]	Lowers plasma glucose level (Amalraj and Ignacimuthu [21])
		Aqueous fraction of leaves and stems	Mice	Glucose tolerance enhancing activity	Esposito Avella [18]	
		Cooked diet	Healthy human volunteers	Hypoglycemic effect	Panlasigui et al. [19]	
2.	Bengal gram	Isoflavones given as crude extract/ individual compounds	Triton WR-1339-Hyperlipidemic rats	Hypolipidemic effect	Siddiqui and Siddiqi [22]	Chickpea constituents protein, fat, fibre, saponins, isoflavones were believed to be involved in the normalization of the lipid metabolism (Alzorriz and Hernandez [28])
		Lipid fraction (ungerminated chick pea). Carbohydrate fraction (both germinated and ungerminated chick pea)	Hypercholesterolemic rats	Hypocholesterolemic effect	Jaya and Venkatraman [23]	
		Proteins and lipid constituents	Hypercholesterolemic rats	Hypocholesterolemic effect	Murthy and Urs [25]	
		Protein, lipid and carbohydrate fraction	Hyperlipidemic rats	Hypolipidemic effect	Malik et al. [26]	
		Feeding chick peas	Hypercholesterolemic rats	Hypocholesterolemic effect	Sharma [24], Zulet and Martinez [27]	
3.	Black gram	Whole seed diet	Guinea pigs	Hypoglycemic, hypocholesterolemic, hypolipidemic	Srivastava and Joshi [29]	Lowering of blood glucose, total lipids and cholesterol
4.	Kidney beans	Diet containing baked beans	Hypercholesterolemic pigs	Hypocholesterolemic	Costa et al. [30]	Lowering of blood glucose, total lipids and cholesterol triglycerides, plasma thiobarbituric acid reactive substances (TBARS)
		Aqueous extract of pods	Diabetic rats	Hypoglycemic, hypocholesterolemic, antioxidant; retoration of normal levels of HDL cholesterol plasma insulin and vitamin C	Venkateswaran et al. [31]	
5.	Fruits: Holy fruit tree (Bael)	Aqueous decoction of plant root bark	Normal fasted rats	Hypoglycemic effect	Karunanayake et al. [32]	Increases utilization of glucose; either by direct simulation of glucose uptake or via the mediation of enhanced insulin secretion (Sachdewa et al. [36]) and also decreases the elevated glucose and glycosylated haemoglobin levels (Kamalakkanan et al. [39])
		Aqueous leaf extract	Alloxanized rats	Antihyperglycemic	Ponnachan et al. [33]	
		Aqueous leaf extract	STZ-induced diabetic rats	Antihyperglycemic	Das et al. [34], Seema et al. [35]	
		Leaves	Hyperglycemic rats	Antihyperglycemic	Sachdewa et al. [36]	
		Aqueous fruit extract	Diabetic rats	Antihyperglycemic	Kamalakkanan et al. [39]	
		Water extract of fruits	Diabetic rats	Hypoglycemic	Kamalakkanan and Prince [40]	
		Aqueous extract of fruits	Diabetic rats	Antioxidant	Kamalakkanan and Stanley [41]	
		Plant	Alloxanized rats	Antihyperglycemic, antioxidant	Sabu and Kuttan [37]	
		Leaves	Diabetic rats	Hypoglycemic, antioxidant	Upadhya et al. [38]	

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Table 1 (*Continued*)

Sr. no.	Food material	Part/form in which administered	Organism	Activity	Reference	Mode of action
6.	Onion	Ethyl ether extract	Normal fasted rats	Hypoglycemic	Augusti [84]	Lowers blood glucose level and has potent antioxidant activity, which may account for the hypoglycemic potential (Augusti [84])
		Organic solvent extracts powder dried onion	Alloxanized diabetic rabbits	Hypoglycemic	Jain and Vyas [85]	
		Juice	Diabetic patients	Hypoglycemic	Mathew and Augusti [86]	
		Petroleum ether insoluble fraction of ether extract of dried onion powder	Alloxanized diabetic rabbits	Antihyperglycemic	Mathew and Augusti [86]	
		Petroleum ether and chloroform extracts	Rabbits	Lowered blood sugar in OGTT	Gupta et al. [87]	
		Aqueous onion extract	Fasted healthy volunteers	Increased glucose tolerance comparable to tolbutamide	Sharma et al. [88]	
		Fresh onion diet	Diabetic patients	Decreased/maintained blood sugar levels	Tjokroprawiro et al. [93]	
		S containing amino acid (SMCS)	Alloxanized rats	Hypoglycemic, hypolipidemic	Kumari et al. [89]	
		Bulb decoction	Rabbits	Decreased hypoglycemic peak and area under glucose tolerance curve	Roman-Ramos et al. [90]	
		SMCS and SACS	Alloxanized diabetic rats	Beneficial effect on glucose intolerance, weight loss and liver glycogen	Sheela et al. [91]	
		Freeze-dried onion powder	STZ-diabetic rats	Hypoglycemic, hypocholesterolemic, antioxidant	Babu and Srinivasan [94]	
		SMCS	Alloxanized diabetic rats	Antidiabetic, antioxidant	Kumari and Augusti [92]	
		Solution	STZ-diabetic rats	Hypoglycemic, hypolipidemic, antioxidant	Campos et al. [95]	
7.	Mango	Aqueous extract of leaves	Normoglycemic or STZ-diabetic rats	Antidiabetic	Aderibigbe et al. [43]	Action attributed to reduction in intestinal absorption of glucose (Aderibigbe et al. [43]). Pancreatic and extra pancreatic mechanisms involved (Muruganandan et al. [47]). Different chemical constituents of plant, i.e. the polyphenolics, flavonoids, triterpenoids, mangiferin are involved in the hypoglycemic effects of the extract (Ojewole [46])
		Aqueous extract of leaves	Normoglycemic and glucose-induced hyperglycemic mice	Hypoglycemic	Aderibigbe et al. [45]	
		Mangiferin	STZ-diabetic rats and normoglycemic rats	Hypoglycemic	Muruganandan et al. [47]	
		Stem bark aqueous extract	STZ-diabetic rats	Hypoglycemic	Ojewole [46]	
8.	Mulberry	Leaf extract	Rabbits	Degranulation of pancreatic β-cells	Gulubova and Boiadzhiev [48]	Degranulation of pancreatic β-cells (Gulubova and Boiadzhiev [48]). Alkaloids possess glycosidase inhibitory activity (Asano et al. [49]). Increase in glucose uptake (Chen et al. [50])
		Ethanol insoluble fraction of hot water extract of leaves	Fasted and non-fasted STZ diabetic mice	Hypoglycemic	Chen et al. [50]	
		Mulberry therapy	Diabetic patients	Hypocholesterolemic, hypotriglyceridemic, antioxidant	Andallu et al. [51]	

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		Dry leaf powder	STZ-diabetic rats	Hypoglycemic, antioxidant	Andallu and Varadacharyulu [52]	
		Root bark extract	STZ-diabetic rats	Hypoglycemic, antiperoxidative, stimulation of insulin	Singab et al. [53]	
9.	Banana	Isolated dietary fibre	Rats	Hypoglycemic, glycogenesis	Usha et al. [54]	Hypocholesterolemic effect of pulp attributed to soluble and insoluble components of dietary fibre (Horigome et al. [55])
		Freeze-dried banana pulp	Hypercholesterolemic rats	Hypocholesterolemic	Horigome et al. [55]	
		Fresh flower decoction	Hyperglycemic rabbits	Hypoglycemic	Alarcon-Aguilara et al. [56]	
		Chloroform extract of flowers	Alloxanized rats	Hypoglycemic	Pari and Maheshwari [57]	
10.	Pomegranate	Aqueous ethanolic extract male abortive flowers	Alloxanized diabetic rats	Hypoglycemic	Jafri et al. [64]	Blood glucose lowering effect (Jafri et al. [64])
		Methanol extract of seed	STZ-diabetic rats	Hypoglycemic	Das et al. [65]	
		Juice	NIDDM patients	Hypocholesterolemic	Esmaillzadeh et al. [66]	
11.	Grape	Extract of grape seed derived procyanidins	STZ-diabetic rats	Antihyperglycemic	Pinent et al. [82]	Antihyperglycemic effect attributed to insulinomimetic activity of procyanidins on insulin sensitive cell lines (Pinent et al. [82])
		Grape seed proanthocyanidins	Alloxan-diabetic rats	Antihyperglycemic; inhibition of lipid peroxidation; insulin stimulation	El-Alfy et al. [83]	
12.	Guava	Juice	Normal and alloxan diabetic mice	Hypoglycemic	Cheng and Yang [59]	Antidiabetic effect in part mediated via inhibition of protein tyrosine phosphatase 1B (Oh et al. [62]) Numerous tannins, polyphenolic compound guiajaverin and other chemical compounds responsible for Hypoglycemic and Hypotensive effects (Ojewole [46])
		Aqueous methanol/water extract of fruits	Normal and Alloxan Hyperglycemic rabbits	Hypoglycemic	El-Badrawy [60]	
		Juice	NIDDM rats	Insulin stimulation	Sunagawa et al. [61]	
		Leaf extract	NIDDM mice	Hypoglycemic	Oh et al. [62]	
		Aqueous leaf extract	Normal and STZ-diabetic rats	Hypoglycemic, hypotensive	Ojewole [63]	
13.	Black berry	Plant extract	Normal rats	Hypoglycemic; insulin stimulation	Bansal et al. [68]	Hypoglycemic action mediated by insulin secretion (Achrekar et al. [75]) or due to alteration in hepatic and skeletal muscle
		Pulp extract of fruit	Normoglycemic or STZ-diabetic rats	Hypoglycemic	Achrekar et al. [75]	
		Aqueous extract of seeds	Alloxan-diabetic rats	Hypoglycemic, antioxidant	Prince et al. [79]	
		Lyophilized plant powder	Diabetic rats	Hypoglycemic	Grover et al. [70]	Glycogen content and hepatic glucokinase, hexokinase, glucose-6-phosphate and phosphofructokinase levels in diabetic rats (Grover et al. [70]). It also enhances serum insulin activity (Sharma et al. [81]) and exhibits normoglycemia and better glucose tolerance (Ravi et al. [74])
		Aqueous extract	STZ-diabetic rats	Antihyperglycemic; prevented polyuria and renal hypertrophy	Grover et al. [71]	
		Extract	STZ diabetic mice	Hypoglycemic	Grover et al. [72]	
		Ethanolic extract of seeds	Alloxan diabetic rabbits	Hypoglycemic, hypolipidemic	Sharma et al. [81]	

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Table 1 (*Continued*)

Sr. no.	Food material	Part/form in which administered	Organism	Activity	Reference	Mode of action
		Alcoholic extract	Diabetic rats	Hypoglycemic, prevented polyuria	Prince et al. [73]	Mechanism of action of Hypoglycemic extract appeared to be both pancreatic by stimulating release of insulin and extra pancreatic by directly acting on the tissues (Sharma et al. [76])
		Ethanolic whole seeds, kernel and seed coat extracts	STZ-diabetic rats	Hypoglycemic	Ravi et al. [74]	
		Seed powder	STZ-diabetic rats	Hypoglycemic	Sridhar et al. [80]	
		Hypoglycemic fraction of water extract of fruit pulp	Alloxan-diabetic rats	Hypoglycemic, insulin stimulation	Sharma et al. [76]	
14.	Garlic	Allicin	Normal rats	Hypolipidemic	Augusti and Mathew [133]	Hypolipidemic and Hypoglycemic effect on account of decreased activities of serum enzymes Alkaline phosphatase, acid phosphatase and lactate dehydrogenase and liver glucose-6-phosphatase. Increased liver and intestinal HMG CoA reductase activity and liver hexokinase activity (Sheela and Augusti [147])
		Allicin	Diabetic rabbits	Hypoglycemic	Mathew and Augusti [134]	
		Ethanol, petroleum ether, ethyl ether extract	Alloxan diabetic rabbits	Hypoglycemic	Jain and Vyas [137]	
		Aqueous homogenate	Hyperglycemic rabbits	Glycogenesis, hypoglycemic, hypotriglyceridemic	Zacharias et al. [138]	
		Freeze-dried garlic powder	Hyperlipidemic rats	Hypolipidemic	Kamanna and Chandrasekhara [144]	
		SACS	Alloxan-diabetic rats	Hypolipidemic, hypoglycemic	Sheela and Augusti [147]	
		Standardized garlic	Healthy adults	Hypocholesterolemic	Jain et al. [145]	
		SACS	Alloxan-diabetic rats	Glycemic control	Sheela et al. [91]	
		SACS	Diabetic rats	Antidiabetic	Augusti and Sheela [148]	
		Aged garlic extract	Stress-induced hyperglycemia model of mice	Antihyperglycemic; prevention of adrenal hypertrophy and elevation of cortisone	Kasuga et al. [139]	
		Ethanolic extract	Alloxanized diabetic mice	Hypoglycemic with anti-nociceptive effects in tail-flick, hotplate, allodynia and formalin tests	Kumar and Reddy [140]	
		Extract	STZ-diabetic rats	Improved lipid profile; enhancement of plasma insulin; hypoglycemic, anti-atherosclerotic	Patumraj et al. [141]	
		Allicin	Hyperlipidemic, hyperinsulinemic, hypertensive rats	Antihyperlipidemic, antihyperinsulinemic, antihpertensive	Elkayam et al. [135]	
		Garlic oil	Diabetic rats	Antioxidant, antihyperglycemic, antihypertriglyceridemic	Anwar and Meki [136]	
		Juice	Alloxan-diabetic rats	Antioxidant; antihyperglycemic; restoration liver and renal damage	El-Demerdash et al. [146]	

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		Ethanolic extract	STZ-diabetic rats	Hypoglycemic; hypocholesterolemic; hypotriglyceridemic; enhancement of serum insulin	Eidi et al. [142]	
15.	Beet root	Root extract	Rats	Hypoglycemic	Yoshikawa et al. [98]	Lowers blood glucose level (Yoshikawa et al. [98])
		Root extract	STZ-diabetic rats	Inhibited non-enzymatic glycosylation of skin proteins	Tunali et al. [99]	
16.	Sweet potato	Plant	Diabetic Zucker rats	Antihyperinsulinemic, antihyperglycemic, improved lipid metabolism	Kusano and Abe [101]	Reduces insulin resistance (Kusano and Abe [101]; Ludvik et al. [102]) and possibly acts by maltase inhibition, not by sucrase or glucose transport inhibition at intestinal membrane (Matsui et al. [103])
		Anthocyanin Peonidin isolated from storage roots	Sprague Dawley rats	Hypoglycemic	Matsui et al. [103]	
		Nutraceutical Caiapo	NIDDM patients	Improved metabolic control	Ludvik et al. [102]	
17.	Pumpkin	Protein bound polysaccharide	Alloxan-diabetic rats	Hypoglycemic, enhancement of serum insulin	Li et al. [100]	Increased levels of serum insulin and improved glucose tolerance (Li et al. [100])
18.	Custard apple	Aqueous leaf extracts	Diabetic rats	Hypoglycemic	Shirwaikar et al. [96]	Lowers blood glucose level (Shirwaikar et al. [96])
		Ethanolic extract of Annona leaves	STZ rats and alloxan-diabetic rabbits	Hypoglycemic, hypocholesterolemic, antiglucosuria	Gupta et al. [97]	
19.	Bitter gourd	Charantin	Rabbits	Hypoglycemic	Lolitkar and Rao [130]	Hypoglycemic effect of extracts in STZ diabetic mice suggests mechanism of action independent of intestinal glucose absorption and probably involves an extra-pancreatic effect (Day et al. [105]; Welihinda and Karunanayake [123]; Day et al. [106])
		Fried fruits	NIDDM patients	Hypoglycemic	Leatherdale et al. [121]	
		Polypeptide-p from fruit, seeds and tissue	Gerbils, langurs, humans	Hypoglycemic	Khanna et al. [131]	
		Aqueous extract of unripe fruits	Obese, hyperglycemic mice	Stimulation of insulin release	Welihinda et al. [110]	Hypoglycemic effect of ethanolic extract possibly due to inhibition of key gluconeogenic enzymes glucose-6-phosphatase and fructose-1,6-biphosphatase in liver and through stimulation of red cell and hepatic glucose-6-phosphate dehydrogenase activities
		Aqueous decoction	Laboratory animals	Hypoglycemic	Karunanayake et al. [32]	
		Aqueous extracts	STZ diabetic mice	Antihyperglycemic	Bailey et al. [107]	
		Juice	Normal rats	Glycogenesis	Welihinda and Karunanayake [123]	
		Juice	Diabetic patients	Improved glucose tolerance	Welihinda et al. [124]	
		Extract	Alloxanized diabetic rats	Prevented cataract development	Srivastava et al. [111]	
		Ethanolic extract	Rats	Hypoglycemic	Chandrasekar et al. [108]	
		Acetone extract of fruit powder	Alloxan-diabetic rats	Hypoglycemic, hypocholesterolemic	Singh et al. [112]	

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Table 1 (*Continued*)

Sr. no.	Food material	Part/form in which administered	Organism	Activity	Reference	Mode of action
		Saponin free methanol extract of juice	NIDDM model rats	Hypoglycemic	Ali et al. [126]	Antihyperglycemic effect of glucuronide and momordin by inhibiting glucose transport at the brush border of intestine (Matsuda et al. [132]). Antidiabetic effect of aqueous extract of fruit derived in part from a decrease in insulin resistance due to increase of GLUT 4 protein content in plasma membrane of muscle (Miura et al. [118])
		Diet containing *M. charantia*	Normal adult rats	Hypocholesterolemic	Platel et al. [127]	
		Ethanolic extract	Normal and STZ-diabetic rats	Hypoglycemic	Shibib et al. [109]	
		Aqueous extract of fruits	Alloxan-diabetic rats	Hypoglycemic	Srivastava et al. [113]	
		Aqueous extract of fruits	Hyperglycemic and normoglcemic mice	Hypoglycemic	Cakici et al. [114]	
		Fruit juice	STZ-diabetic rats	Renewal of β cells	Ahmed et al. [115]	
		Constituents (-Oleanolic acid 3-*O* -glucuronide and momordin Ic)	Rats	Antihyperglycemic	Matsuda et al. [132]	
		Homogenized suspension of vegetable pulp	NIDDM subjects	Hypoglycemic	Ahmad et al. [115]	
		Freeze-dried powder with cholesterol and bile acid	Normal rats	Hypoglycemic, anti-atherogenic	Jayasooriya et al. [122]	
		Aqueous juice of fruit	STZ diabetic mice	Hypoglycemic, decrease in lipid peroxidation in pancreas of mice	Sitasawad et al. [129]	
		Fruit extract	STZ-diabetic rats	Hypolipidemic, hypoglycemic	Ahmed et al. [128]	
		Aqueous extract of fruit	KK-Ay mice	Hypoglycemic, decrease in serum insulin	Miura et al. [118]	
		Aqueous extract powder of fresh unripe whole fruits		Hypoglycemic	Virdi et al. [119]	
		Methanol extract of fruit	Diabetic rats	Improved glucose tolerance, hypotriglyceridemic	Chaturvedi et al. [120]	
20.	Mustard	Diet	Normal rats	Hypoglycemic	Khan et al. [149]	Hypoglycemic action on account of stimulation of glycogen synthetase and suppression of glycogen phosphorylase and other gluconeogenic enzymes
		Seed supplementation to laboratory diet	Rats	Hypocholesterolemic, increase in HDL	Khan et al. [151]	
		Diet	Diabetic rats	Antihyperglycemic	Grover et al. [72]	
21.	Cumin	Dietary regime containing powder	STZ-diabetic rats	Antihyperglycemic; antiglycosuric; countered other metabolic alterations caused by diabetes	Willatgamuwa et al. [152]	Lowers blood glucose and lowered excretions of urea, glucose and creatinine (Willatgamuwa et al. [152])
22.	Turmeric	Curcumin	Rat liver microsomes	Inhibited lipid peroxidation	Reddy and Lokesh [153]	The underlying mechanism involved hypocholestrolemic, antioxidant nature and free radical scavenging property (Babu and Srinivasan [155])
		Curcumin diet	STZ-diabetic rats	Lowered Lipid peroxidation	Babu and Srinivasan [155]	
23.	Curry leaves	Powder supplementation	NIIDM patients	Hypoglycemic	Iyer and Mani [156]	Hypoglycemic action associated with increased hepatic glycogen content owing to increased glycogenesis and decreased glycogenolysis and gluconeogenesis (Khan et al. [149])
		Leaves diet	Normal rats	Hypoglycemic	Khan et al. [149]	
		Leaves	Rats	Hypolipidemic	Khan et al. [151]	

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		Leaves	Diabetic rats	Hypoglycemic	Yadav et al. [157]	
		Aqueous extract of leaves	Diabetic rabbits	Hypoglycemic	Kesari et al. [158]	
24.	Fenugreek	Defatted fraction of seeds	Diabetic dogs	Antidiabetic	Ribes et al. [159]	Fenugreek may exert its hypoglycemic effect by acting at insulin receptors as well as at the gastrointestinal level (Raghuram et al. [175])
		Defatted fraction of seeds	Dogs	Hypocholesterolemic	Valette et al. [160]	
		Defatted seed material	Alloxan diabetic dogs	Antihyperglycemic, antiglycosuric	Ribes et al. [161]	
		Decoction	Normal and alloxanized mice	Hypoglycemic	Ajabnoor and Tilmisany [163]	
		Powdered seed	NIIDM patients	Hypoglycemic	Madar et al. [166]	
		Defatted seed powder	NIIDM patients	Hypoglycemic	Sharma and Raghuram [167]	
		Seed powder	IIDM patients	Hypoglycemic, antiglycosuric, hypolipidemic	Sharma et al. [168]	
		Defatted ethanolic extract of seeds	Rats	Hypocholesterolemic	Stark and Madar [162]	
		Diets with seeds	NIIDM patients	Hypoglycemic	Raghuram et al. [175]	
		Plant extract	Normal and diabetic rats	Hypoglycemic	Khosla et al. [164]	
		Ethanolic leaf extract	Normal and alloxanized diabetic rats	Hypoglycemic	Abdel-Barry et al. [165]	
		4-Hydroxyisoleucine extracted from seeds	Rats and humans	Increased glucose-induced insulin release	Sauvaire et al. [178]	
		Seed powder	Diabetic rats	Antioxidant	Genet et al. [169]	
		Seed supplementation in diet	Diabetic rats	Antioxidant	Ravikumar and Anuradha [171]	
		Hydroalcoholic extract of seeds	NIDDM patients	Glycemic control; decreased insulin resistance	Gupta et al. [172]	
		Alcoholic extract of seeds	Alloxan-diabetic rats	Hypoglycemic	Vats et al. [173]	
		Seed mucilage	STZ-diabetic rats	Hypoglycemic, antiglycosuric	Kumar et al. [174]	
25.	Black tea	Hot water extract	STZ-diabetic rats	Hypoglycemic	Gomes et al. [179]	Hot water extract reduced blood glucose and had both preventive and curative effects on STZ-induced diabetes in rats (Gomes et al. [179])
26.	Green tea	Supplementation of casein diet containing cholesterol with crude tea catechins	Hypercholesterolemic rats	Hypocholesterolemic	Muramatsu et al. [180]	Hypocholesterolemic effect exerted through increase in fecal excretion of total lipids and cholesterol (Muramatsu et al. [180]). Tea catechins possibly control dietary glucose uptake at the intestinal tract contributing to blood glucose homeostatsis (Shimizu et al. [182]). Dietary gallate esters of tea catechins fed to rats reduced activities of enzymes involved in hepatic fatty acid synthesis Reducing hepatic triacylglycerol and possibly of visceral fat deposition (Ikeda et al. [185])
		Epigallocatechin gallate (polyphenols)	Rats	Hypoglycemic, hypocholesterolemic, hypotriglyceridemic, hypoinsulinomic	Kao et al. [181]	
		Epicatechin gallate	Human intestinal epithelial caco-2-cells	Hypoglycemic	Shimizu et al. [182]	
		Aqueous solution of green tea polyphenols	Alloxan-diabetic rats	Hypoglycemic, antioxidant	Sabu et al. [183]	
		Epicatechin	STZ-diabetic rats	Antihyperglycemic Well preserved islet morphology	Kim et al. [184]	
		Green tea extract	Diabetic rats	Hypoglycemic	Quan et al. [186]	
27.	Red wine	Consumption with meal	NIDDM patients	Antioxidant	Ceriello et al. [187]	Red wine preserved plasma antioxidant defenses and reduction of LDL oxidation (Ceriello et al. [187]) Reduced glycemia, food intake and body growth (Al-Awwadi et al. [188])

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ment of insulin secretion by pancreatic β-cells and by a relative decreased sensitivity of target tissues to the action of this hormone [3].

DM is a major worldwide health problem predisposing to markedly increased cardiovascular mortality. Other serious morbidities and mortalities are related to development of nephropathy (kidney damage), neuropathy (nerve damage), and retinopathy (blindness) [4–6] due to diabetes. Increased oxidation stress has been implicated in the pathogenesis of DM. Hyperglycemia-induced protein glycation generates superoxide free radicals [4–8]. The generation of active oxygen species may lead to lipid peroxidation and formation of reactive products, which may be involved in severe damage of cell molecules and structures. As a result of these the chances of cardiovascular and cerebral morbidities become manifold.

As the prevalence of T2DM continues to increase worldwide, there is an enhanced need for effective disease management. T2DM is managed through a stepwise program of intensive therapy that consists of lifestyle modification including appropriate diet and exercise programs and sequential addition of oral antihyperglycemic agents (OHAs) and insulin as necessary. Improvement in blood glucose control through a combination of lifestyle modifications and oral modifications may slow the rate of this progression and enhance the quality of life for people with T2DM [9].

About one third of Type II diabetic patients are treated with oral hypoglycemic agents to stimulate insulin secretion. These drugs however risk inducing hypoglycemia and, over time, lose their efficacy [3]. Although, oral hypoglycemic agents/insulin are the mainstay of treatment of diabetes and are effective in controlling hyperglycemia, they have prominent side effects and fail to significantly alter the course of diabetic complications. The common side effects associated with the main classes of drugs used for the treatment of T2DM are hypoglycemia, weight gain, gastrointestinal disorders, peripheral edema and liver disease [10].

The overall management of diabetes not only enthrusts upon achieving normoglycemic states ($HbA_{1c} \leq 6.5$ mg/100 ml, FPG ≤ 110 mg/100 ml) but also reducing risks for other metabolic diseases, viz. serum cholesterol $\leq$150 mg/100 ml, serum triglyceride $\leq$140 mg/100 ml, $LDL_c \leq 70$ mg/100 ml and high density lipoprotein (HDL) ≥ 60 mg/100 ml. While the pharmacological therapies are in use for management, the diabetes prevention trials in China [11–13] remind us that nutrition and lifestyle approaches can be more effective in delaying the onset of the disease.

Dietary therapy for DM management

Dietary therapy especially is showing a bright future in the management of T2DM. In this background this paper reviews the common Indian plant food materials which form the various components of a balanced diet (includes cereals, legumes, fruits, vegetables, spices and flavoring agents and beverages) which have been shown to possess antidiabetic properties. Currently the ADA recommends the use of diabetes food pyramid for the T2DM patients. The food pyramid divides food into six groups, which vary in size. The largest group comprising of grains, beans and starchy vegetables is on the bottom. This implies that eating more of these as compared to other foods is beneficial for diabetic patients. The next group is that of the vegetables and fruits followed by milk and meat products. The smallest group — fats, sweets, and alcohol — is at the top of the pyramid. This implies that it is advisable to eat very few servings from these food groups [14]. The use of low-glycemic index (GI) diets (comprising of whole grain cereals and legumes) in the management of diabetes have been recommended around the world [15], European Association for the study of diabetes [16]. Since diet forms the mainstay in the management of diabetes mellitus, there is an urgent need to exploit plant food materials possessing hypoglycemic activity for a possible beneficial use.

Plant food materials

A major portion of the Indian diet comprises of plant materials like cereals, legumes, fruits, vegetables and beverages like tea, coffee and wine. Since time immemorial the use of plants and plant based food materials in the management of diabetes has been prevalent in the Indian society. Several medicinal plants have been reported to possess potential hypoglycemic activity in Indian system of medicine. However, it is important to note that many of these are not edible and with an explosion in the number of diabetic patients especially in developing countries it is of importance to focus on plant food materials with hypoglycemic properties that are easily available, culturally acceptable, and economical and are absolutely free from side effects when compared with the drugs for managing diabetes (Table 1).

Legumes

The legumes commonly consumed in the Indian subcontinent include red gram, Bengal gram, green

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gram, black gram and kidney beans. Generally the legume seeds have been tried for bioefficacy studies conducted mostly in rat and mice. Among these the Bengal gram has been extensively studied for its effect in diabetes management.

***Cajanus cajan*: pigeon pea**

Globulin fraction from red gram when administered to rats fed on high-fat-high-cholesterol diet showed prominent hypolipidemic effect [17]. Aqueous fraction of the leaves and stems of *C. cajan* (500 and 1000 mg/kg) lacked hypoglycemic effect in normoglycemic mice. However, it significantly increased glucose tolerance at 1 and 2 h in OGTT [18].

Cooked diet of *C. cajan* has also shown significant hypoglycemic effect in healthy human volunteers [19]. Single doses of unroasted seeds of *C. cajan* (60 and 80%) administered to normal and alloxanized mice caused a significant reduction in the serum glucose levels after 1—2 h and a significant rise at 3 h. While, in case of roasted seeds there was a significant increase in the serum glucose levels during the 3 h experimental period. Roasting of seeds at high temperature for 30 min resulted in the total loss of hypoglycemic principle but not the hyperglycemic principle present in the seeds [21].

***Cicer arietinum*: Bengal gram**

Two isoflavones, biochanin-A and formononetin, isolated from gram when administered as a crude extract or as individual compounds to Triton WR-1339-induced hyperlipidemia in male albino rats exhibited hypolipidemic properties [22]. Germinated chickpea was more effective in lowering the cholesterol levels of hypercholesterolemic rats as compared to the ungerminated ones. The lipid fraction (from ungerminated chickpea) and the carbohydrate fractions (both germinated and ungerminated chickpea) fed rats showed lower cholesterol levels compared to those fed whole legumes [23].

Bengal gram effectively controlled hypercholesterolemia in rats when compared to tannin, phytate and pectin given individually to those rats [24]. Both proteins and lipid constituents of Bengal gram flour lowered serum cholesterol in rats whereas liver cholesterol was lowered by proteins and not by the lipid fraction [25]. Four active fractions of gram, i.e. total lipid, fatty acid, globulin and insoluble carbohydrate fractions effectively controlled fructose-induced hyperlipidemia in rats [26].

Supplementation of diet with chickpea significantly decreased the concentrations of total cholesterol (54%), triacylglyerols (70%) as well as the levels of low density lipoprotein (LDL) (54%) and VLDL (70%) in hypercholesterolemic rats [27]. Feeding chickpea or casein as protein sources to hypercholesterolemic rats for 16 days improved the lipid disturbances, with the legume being more effective than casein in decreasing the total and LDL cholesterol. The chickpea constituents (protein, fat, fiber, saponins, isoflavones) were believed to be involved in the normalization of the lipid metabolism [28].

***Phaseolus mungo*: black gram**

Normal and alloxan-induced diabetic guineapigs given whole seed diet of black gram for 4 weeks showed appreciable lowering of blood glucose, serum total lipids, triglycerides and esterified portion of cholesterol. Total cholesterol/phospholipid ratio also decreased indicating the atherogenic nature of *P. mungo* [29].

***Phaseolus vulgaris*: kidney beans**

Hypercholesterolemic pigs fed diets containing baked beans at 300 g/kg for 28 days showed reduction in the plasma total cholesterol by 35.5% while the level of LDL cholesterol was reduced by 48%. A significant lowering of about 50% in cholesterol deposition in the liver was observed compared with the controls [30]. Oral administration of aqueous extract of *P. vulgaris* pods (200 mg/kg body weight (bw)) for 45 days to diabetic rats significantly reduced the elevated blood glucose, serum triglycerides, free fatty acids, phospholipids, total cholesterol, VLDL cholesterol and LDL cholesterol. The extract also decreased the plasma thiobarbituric acid-reactive substances (TBARS) and hyroperoxides. The decreased serum levels of HDL cholesterol, plasma insulin and vitamin C were restored to normal levels [31].

The legumes have been found to have potent anti-diabetic effect (hypocholesterolemic and hypoglycemic effect) on account of their various constituents that comprise of protein, fat, fibre and isoflavones.

Fruits

There are various fruits which are popular in the country however; the ones selected for this review include holy fruit, mango, mulberry, banana, pomegranate, grape, guava and black berry. It is of importance to note that not only the fruits and the fruit extract but also the plant root bark extracts, leaf extracts, juice and active ingredients like mangiferin, allicin and charantin have also been reported to possess antihyperglycemic activity.

***Aegle marmelose:* holy fruit tree**

Root bark extract. Oral administration of aqueous decoction of *A. marmelose* root bark (1 ml/100 gm) exhibited hypoglycemic effect which was maximum

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(44%) at 3 h in normal fasted rats. Also, the same extract completely prevented peak rise of blood sugar at 1 h in OGTT [20,32].

Leaf extract. Aqueous extract of the leaves (1 gm/kg for 30 days) significantly controlled blood glucose, urea, body weight, liver glycogen and serum cholesterol of alloxanized (60 mg/kg IV) rats as compared to controls and this effect was similar to insulin treatment [20,33]. Aqueous leaf extract administered orally for 28 days also normalized STZ (45 mg/kg body weight) induced histo-pathological alterations in the pancreatic, liver and the kidney tissues of rats indicating the potential hypoglycemic nature of the extract [34]. When fed as aqueous leaf extract (1 gm/kg/day) to STZ (45 mg/kg IV) diabetic rats for 2 weeks, the extract was equally effective in comparison to insulin in restoring blood glucose and body weight to normal levels [35]. The leaves exhibited antihyperglycemic activity in glucose-induced hyperglycemic rats at oral dose equivalent to 250 mg/kg [36].

While A methanolic extract of leaf effectively reduced the oxidative stress induced by alloxan in diabetic rats and produced a reduction in blood sugar (a 54% reduction on 12th day) [37]. Hypoglycemic and antioxidant activity of leaves was seen in diabetic male albino rats [38].

Fruit extract. Aqueous fruit extract (250 mg/kg) fed to STZ-induced female albino Wistar diabetic rats twice daily for 1 month reduced the blood glucose significantly [39]. Similarly the hypoglycemic activity of water extract of fruits was observed in STZ-induced diabetic Wistar rats (125 and 250 mg/kg) given orally twice a day for 4 weeks [40]. However, the same extract at the same dose in STZ rats revealed antioxidant effect [41]. Oral administration of fruit extract at doses of 125 and 250 mg/kg twice daily to diabetic rats for a period of 30 days resulted in a significant increase in body weight, weight of the pancreas and insulin levels associated with a significant decrease in fasting glucose levels. The fruit extract treated groups showed improved functional state of pancreatic β-cells and partially reversed the damage caused by streptozotocin to pancreatic islets. The effects observed in fruit treated animals were better than those treated with 300 mg/kg glibenclamide [42].

Mangifera indica: mango

Leaf extract. Oral administration of aqueous extract of the leaves (1 gm/kg) failed to alter the blood glucose levels in normoglycemic or STZ-induced diabetic rats. However, the extract exhibited anti-diabetic activity when given 60 min before or concurrently with glucose and this action could be attributed to the reduction in intestinal absorption of glucose [43]. However, possibility of other mechanism cannot be excluded [20]. *M. indica* has also been shown to exert powerful antioxidant activity in vitro [20,44]. The aqueous extract of leaves of *Mangifera* produced a reduction in blood glucose level in normoglycemic and glucose-induced hyperglycemia but was ineffective on streptozotocin-induced diabetic mice [45].

Stem bark extract. Stem bark aqueous extract (50—800 mg/kg intraperitoneal) caused significant hypoglycemic effects in STZ diabetic rats. The different chemical constituents of the plant especially the polyphenolics, flavonoids, triterpenoids, mangiferin may be involved in the hypoglycemic effects of the extract [46]. Mangiferin (10 and 20 mg/kg), intraperitoneal administered once daily for 28 days to STZ-induced diabetic rats caused lowering of blood glucose and improved oral glucose tolerance in glucose loaded normal rats upon chronic administration (10 and 20 mg/kg) intraperitoneal for 14 days. Probably the pancreatic and extra pancreatic mechanisms were involved in the effect [47].

Morus alba: white mulberry

Leaf extract. Chronic subcutaneous administration of the extract of the leaves of *M. alba* to rabbits led to degranulation of beta-cells of the Langerhans islets [20,48]. Alkaloids of this plant are known to possess glycosidase inhibitory activity [20,49]. Single intra-peritoneal dose of 200 mg/kg of ethanol insoluble fraction of hot water extract of *M. alba* leaves exhibited a potent hypoglycemic activity in fasted and non-fasted STZ (150 mg/kg IV) diabetic mice and the glucose level fell by 24.6 ± 6 and $81.4 \pm 7.9\%$, respectively. Increase in glucose uptake was postulated as the mechanism of hypoglycemic action [20,50].

In 12 diabetics mulberry therapy for 30 days significantly decreased the concentration of serum total cholesterol (12%), triglycerides (16%), plasma free fatty acids (12%), LDL-cholesterol (23%), VLDL-cholesterol (17%), plasma peroxides (25%), urinary peroxides (55%), while increasing the HDL-cholesterol (18%) [51]. In clinical trials on STZ-diabetic rats 25% dry mulberry leaf powder mixed with standard diet was given as an intervention for 8 weeks. In addition to glycemic control the increased lipid peroxidation and the activity of catalase in erythrocytes in diabetic controls was significantly decreased by mulberry leaves (48 and 33%, respectively). Even the activity of antioxidant enzymes was improved very efficiently by mulberry treatment [52].

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Stem bark extract. Further, the oral administration of the root bark extract to STZ diabetic rats for 10 days (600 mg/kg/day) reduced the amount of glucose from control (379 ± 9 mg/dl) to a lower level (155 ± 8 mg/dl) and significantly increased the insulin level from control (10.8 ± 0.3 μU/ml) to a high level (15.6 ± 0.3 μU/ml). In addition potent antioxidant activity was observed [53].

***Musa sapientum*: banana**

Dietary fibre. Feeding of isolated dietary fibre from Musa to rats showed significantly lower levels of fasting blood glucose and higher concentration of liver glycogen. The activities of some glycolysis cycle enzymes were also inhibited [54]. Freeze-dried banana pulp showed a marked cholesterol-lowering effect when incorporated into a diet at the level of 300 or 500 g/kg. The soluble and insoluble components of dietary fiber were believed to be involved in the hypo-cholesterolemic effect of banana pulp in rat fed on a cholesterol-containing diet [55].

Flower. Intra-gastric administration of fresh flower decoction (4 ml/kg) to hyperglycemic rabbits significantly decreased the hyperglycemic peak and/or the area under the glucose tolerance curve [20,56]. Oral administration of various doses (150, 200 and 250 mg/kg) of chloroform extract of *M. sapientum* flowers for 30 days significantly reduced blood glucose and glycosylated hemoglobin and increased total hemoglobin in alloxanized rats (150 mg/kg, IP). The effect was highly significant at the dose of 250 mg/kg [20,57]. Antioxidant activity [20,58] has also been described in the literature.

***Psidium guajava*: guava**

Fruit. Acute intraperitoneal treatment with 1 g/kg guava juice produced a marked hypoglycemic action in normal and alloxan-diabetic mice. However, the effective duration of guava was more transient and was less potent than chlorpropamide and metformin [59]. The aqueous methanol/water of the fruits markedly reduced the blood sugar level on IP injection to normal and alloxan-produced hyperglycemia in rabbits [60]. The plasma insulin concentration was increased by long term ingestion of guava juice in spontaneous non-insulin-dependent diabetes mellitus (NIDDM) rats while the blood glucose levels remain unchanged [61].

Leaf extract. An extract from the leaves significantly lowered the blood glucose in $Lepr^{db}/Lepr^{db}$ mice after an intraperitoneal injection of the extract at a dose of 10 mg/kg in both 1- and 3-month-old mice. It was suggested that the extract possessed anti-diabetic effect in Type 2 diabetic mice model and these effect were at least in part, mediated via the inhibition of the protein tyrosine phosphatase 1B (PTP1B) [62]. Acute oral administration of the plant leaf aqueous extract (50–800 mg/kg, PO) caused dose-related, significant hypoglycemia in normal and STZ diabetic rats. The extract also produced dose-dependent, significant reductions in systemic arterial blood pressures and heart rates of hypertensive, Dahl salt-sensitive rats. The numerous tannins, polyphenolic compound, guiajaverin and other chemical compounds present in plant are speculated to account for the observed hypoglycemic and hypotensive effects of the extract [63].

***Punica granatum*: pomegranate**

Oral administration of aqueous–ethanolic extract (50%, v/v) of male abortive flowers of *Punica* led to significant blood glucose lowering effect in glucose fed hyperglycemic and alloxanized diabetic rats with the maximum effect at the dose of 400 mg/kg body weight [64]. The methanol extract of the seed at doses of 300 and 600 mg/kg administered orally caused a significant reduction of blood glucose levels by 47 and 52%, respectively in STZ diabetic rats at the end of 12 h [65].

Consumption of concentrated pomegranate juice (40 g/day) by 22 Type 2 diabetic patients for 8 weeks lead to significant reduction in total cholesterol, LDL-cholesterol, LDL-cholesterol/HDL-cholesterol and total cholesterol/HDL-cholesterol. However, no significant changes were observed in serum triacyl-glycerol and HDL-cholesterol concentrations [66]. In addition to hypoglycemic and hypo-cholesterolemic activities, antioxidant activity has also been observed [67].

***Syzigium cumini* (*Eugenia jambolana*): black berry**

Extract. Oral feeding of *E. jambolana* (170, 240 and 510 mg/rat for 15 days) caused 50% reduction in blood glucose of normal fasted rats while chlorpropamide showed 52% reduction. In addition, there was a 2.4–6.8-fold and 9.2-fold increase in cathepsin B activity (proteolytic conversion of proinsulin to insulin) by plant extract and chlorpropamide, respectively [20,68]. Decoction of dry leaves of *S. cumini* has shown hypoglycemic effect [20,69].

Daily administration of lyophilized powder of *E. jambolana* (200 mg/kg) showed maximum reduction of 73.51, 55.62 and 48.81 as compared to their basal values in mild (plasma sugar >180 mg/dl, duration 21 days), moderate (plasma sugar >280 mg/dl, duration 120 days) and severe (plasma sugar >400 mg/dl, duration 60 days) diabetic rats. In

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addition, the treatment also partially restored altered hepatic and skeletal muscle glycogen content and hepatic glucokinase, hexokinase, glucose-6-phosphate and phosphofructokinase levels [20,70].

Oral feeding of Eugenia extracts (200 mg/kg) daily for 40 days to STZ-diabetic rats reduced the plasma glucose concentrations by 20.84%, prevented polyuria and partially but significantly prevented renal hypertrophy [71]. The plant extract at 200 mg/kg upon administration for 50 days in STZ-induced diabetic mice caused considerable reduction in the plasma glucose concentration [72]. Oral administration of alcoholic *S. cumini* extract to diabetic rats at a dose of 100 mg/kg body weight resulted in a significant reduction in blood glucose and urine sugar and lipids in serum and tissues. The extract also increased the total hemoglobin [73]. Ethanolic whole seeds, kernel (100 mg/kg of body weight) and seed coat extracts fed to STZ-diabetic rats displayed prominent hypoglycemic effect [74].

Fruit. Oral administration of pulp extract of the fruit of *S. cumini* to normoglycemic and STZ-induced diabetic rats showed hypoglycemic activity in 30 min while the seeds of the same fruit required 24 h. The action was possibly mediated by insulin secretion [75]. Treatment of alloxan diabetic and severely diabetic rabbits daily once with 25 mg/kg, body weight with F-III (hypoglycemic fraction) of water extract of fruit pulp of Eugenia for 7 and 15 days reduced the fasting glucose (38% diabetic; 48% severely diabetic). Further there was increase in the plasma insulin levels in both diabetic (24.4%) and severely diabetic rabbits (26.3%). The mechanism of action of F-III appeared to be both pancreatic by stimulating release of insulin and extra pancreatic by directly acting on the tissues [76].

Seeds. Preliminary studies on *S. cumini* seeds have also shown hypoglycemic effect [20,77]. Oral administration of dried alcoholic extract of the seeds caused hypoglycemia and reduced glycosuria [20,78]. Oral administration of the aqueous extract of seeds of *S. cumini* (2.5 and 5.0 g/kg body weight for 6 weeks) to alloxan-diabetic rats exhibited hypoglycemic (>glibenclamide) and antioxidant activity. The hypoglycemic effect was most prominent at the dose of 5.0 g/kg while no significant effect was observed at 7.5 g/kg dose [20,79]. Blood glucose lowering response of seed powder in STZ female albino Wistar rats was observed at oral doses of 250, 500 or 100 mg/kg [80]. Oral feeding of ethanolic extract (100 mg/kg body weight) of seeds of Eugenia to alloxan-diabetic rabbits showed hypoglycaemic and hypolipidemic effect along with normal histopathological parameters [81].

Vitis vinifera: grape

Oral administration of extract of grape seed derived procyanidins to STZ-induced diabetic rats revealed an antihyperglycemic effect which was accounted to the insulinomimetic activity of procyanindins on insulin-sensitive cell lines [82]. Oral administration of 50 and 100 mg/kg of body weight of red grape seed proanthocyanidins (GSP) for 72 h significantly increased pancreatic glutathione levels and inhibited the increase in lipid peroxidation caused by alloxan. A significant reduction in pancreatic total nitrate/nitrite content was observed. Furthermore, GSP caused significant decline in the hyperglycemia-induced by alloxan and also resulted in a significant increase in serum insulin levels in diabetic rats [83].

Seasonal fruits on account of their taste are very popular among the Indians in addition to their taste they are nutritionally superior on account of various minerals, vitamins and fibre present in them. The various extracts from fruit trees possess anti-diabetic action which acts through pancreatic and extra pancreatic mechanisms. Among the fruits studied Black berry has been reported to have significant hypoglycemic, hypolipidemic and antioxidant effect.

Vegetables

Vegetables are taken along with the cereal grains and supplement the legumes. The vegetables selected for the purpose of review include onion, beet root, sweet potato, pumpkin, custard apple and bitter gourd. These are prepared in various forms all over India. Apart from the fruits even the various extracts prepared from them and the forms like juice, powder, active ingredient have been reported to possess anti-diabetic activity.

Allium cepa: onion

Extracts. Various ether soluble fractions of onion as a single oral dose (0.25 mg/kg) displayed significant hypoglycemic effect in normal fasted rabbits. The most potent hypoglycemic action was shown by ethyl ether extract [84]. Oral administration of 250 mg/kg of ethanol, petroleum, chloroform and acetone extract of powder dried onion showed maximal reduction of 18.57, 8.35, 3.0 and 3.20% in fasting blood glucose of alloxanized (150 mg/kg, IP) diabetic rabbit [20,85].

Petroleum ether insoluble fraction of the ether extract of dried onion powder (100 mg/kg) given orally for 7 days to alloxanized (180 mg/kg) diabetic rabbits caused a significant antihyperglycemic

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effect [20,86]. In a preliminary study of seven different fractions obtained from onion bulb, only petroleum ether and chloroform extracts significantly lowered blood sugar in OGTT (2 gm/kg) in rabbits [20,87]. Oral administration of 25, 50, 100 and 200 gm of aqueous onion extract to overnight fasted healthy volunteers ($n = 5$/group) 30 min before, after or simultaneously with oral glucose (50 gm) significantly and in a dose-dependent manner increased glucose tolerance and the effect was comparable to tolbutamide. In addition, adrenaline (0.5 ml of 1:1000, SC) induced hyperglycemia was also inhibited in these patients. In the same experiment, there was no difference in the antihyperglycemic effect of raw and boiled onion extract in these human volunteers [20,88].

Amino acids. Oral administration of a sulfur containing amino acid isolated from *A. cepa* Linn. called S-methyl cysteine sulfoxide (SMCS) (200 mg/kg for 45 days) to alloxanized rats significantly controlled blood glucose and lipids in serum and tissues and normalized the activities of liver hexokinase, glucose 6-phosphatase and HMG CoA reductase. The effect was comparable to that of glibenclamide and insulin [20,89]. It also significantly decreased hyperglycemic peak and the area under the glucose tolerance curve in subcutaneous glucose tolerance tests conducted in rabbits [90]. Beneficial effect of SMCS and S-allyl cysteine sulfoxide (SACS) was shown in alloxanized diabetic rats on glucose intolerance, weight loss and liver glycogen [20,91]. Similarly [92] concluded that in the amelioration of diabetes in alloxan-diabetic rats the standard drugs glibenclamide and insulin were more effective as compared to SMCS however SMCS proved to be a better antioxidant.

Diet. Beneficial effects of fresh onion (3 × 20 g) as a dietary aid has also been shown in a crossover designed clinical study. The onion diet decreased or maintained blood sugar levels [20,93]. Feeding of diet containing 3% freeze-dried onion powder for 8 weeks produced a significant hypoglycemia along with partial reversion of abnormal plasma albumin, urea, creatinine and inorganic phosphorus in STZ diabetic albino rats. Thus, onion feeding improved the metabolic status in diabetic condition probably because of hypoglycemic as well as hypercholesterolemic effect of onion [94].

Juice. Oral single dose of 50 gm of juice expressed onion residue to 3 diabetic patients significantly controlled post-prandial glucose levels [20,86]. Treatment of STZ diabetic rats daily with 1 ml *A. cepa* solution (0.4 g *A. cepa*/rat) demonstrated hypoglycaemic and hypolipidaemic actions of *A. cepa*. These effects were associated with antioxidant activity, since onion decreased superoxide dismutase activities while no increased lipid hydroperoxide and lipoperoxide concentrations were observed in diabetic rats treated with *A. cepa* [95].

***Annona squamosa*: custard apple**

Graded doses of aqueous leaf extracts of custard apple administered in drinking water to diabetic rats for 12 days exhibited considerable anti-diabetic activity [96].

The ethanolic extract (350 mg/kg bw) of Annona leaves was orally administered to STZ rats and alloxan-diabetic rabbits. A 10-day treatment of STZ diabetic rats produced 73.3% fall in fasting blood glucose (FBG) levels with inhibition of glucosuria. Treatment of severely diabetic rabbits for 15 days reduced (FBG) by 52.7% and urine sugar by 75%. There was fall in TC (total cholesterol) by 49.3% with increase of 30.3% in HDL and decrease of 71.9 and 28.7% in LDL and triglycerides levels, respectively [97].

***Beta vulgaris*: garden beet**

Various glycosides isolated from the root extract of *B. vulgaris* (e.g. beta vulgarosides II, III and IV) have been shown to increase glucose tolerance in OGTT conducted in rats [20,98]. In addition, the extract also inhibited non-enzymatic glycosylation of skin proteins in STZ diabetic rats [20,99].

***Cucurbita pepo*: pumpkin**

The protein bound polysaccharide isolated from pumpkin increased the levels of serum insulin, reduced the blood glucose levels and improved the glucose tolerance in alloxan-diabetic rats. It was noticed that the hypoglycemic effect of big dose (1000 mg/kg bw) excelled that of small dose group (500 mg/kg bw) and the anti-diabetic agent group [100].

***Ipomoea batatas*: sweet potato**

Oral administration of white skinned potato reduced hyperinsulinemia in diabetic Zucker fatty rats by 23, 26, 60 and 50% after 3, 4, 6 and 8 weeks, respectively. Seven weeks of treatment with the extract lead to inhibition of blood glucose level after glucose loading. At the end of 8 weeks of treatment remarkable regranulation of pancreatic β-cells along with improved lipid metabolism was observed [101]. Short-term treatment with 4 g/day of the nutraceutical Caiapo consistently improved the metabolic control in Type 2 diabetic patients by decreasing insulin resistance without affecting body

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weight, glucose effectiveness, or insulin dynamics [102].

Momordica charantia: bitter gourd

Diet. STZ (50 mg/kg, IP) diabetic rats fed 0.5% diet containing *M. charantia* for 6 weeks did not show beneficial hypoglycemic effect and neither prevented diabetes related abnormalities in the levels of protein, urea and creatinine [20,104].

Extract. In a scientific investigation, an aqueous decoction of *M. charantia* showed hypoglycemic as well as antihyperglycemic activity in laboratory animals. Aqueous extracts of *M. charantia* improved OGTT after 8 h in normal mice and reduced hyperglycemia by 50% after 5 h in STZ diabetic mice [20,32]. Oral administration of different *M. charantia* extracts showed a varying pattern of hypoglycaemic effect in STZ diabetic mice without altering the insulin response suggesting a mechanism of action which is independent of intestinal glucose absorption and probably involves an extra-pancreatic effect [105,106]. In addition, chronic oral administration of extract to normal mice for 13 days improved OGTT while no significant effect was seen on plasma insulin levels [20,107].

Ethanolic extract of *M. charantia* (250 mg/kg dose, PO) significantly lowered blood sugar in fasted as well as glucose loaded non-diabetic rats [20,108]. The ethanolic extract of *M. charantia* (200 mg/kg) showed an antihyperglycemic as well as hypoglycemic effect in normal and STZ-diabetic rats as evident by 23% ($P < 0.01$) and 27% ($P < 0.001$) decrease in blood sugar, respectively. This occurred possibly due to inhibition of key gluconeogenic enzymes glucose-6-phosphatase and fructose-1,6-bisphosphatase in the liver and through the stimulation of red-cell and hepatic glucose-6-phosphate dehydrogenase activities [109].

Fruit extract. Water-soluble extract of the fruits of *M. charantia* significantly reduced blood glucose concentrations in the 9 NIDDM diabetics on OGTT (50 gm) [20,121]. Aqueous extract of unripe fruits of *M. charantia* was found to partially stimulate insulin release from isolated beta-cell of obese–hyperglycemic mice which unlike D-glucose and other insulin secretagogues was not suppressed by L-epinephrine and was potentiated by the removal of Ca^{2+} suggesting that the insulin-releasing action is the result of perturbations of membrane functions [20,110]. Daily administration of extract of *M. charantia* fruit (4 gm/kg) for 2 months to alloxanized diabetic rats (120 mg/kg) delayed development of cataract. Respective blood sugar level in the two groups was 307 ± 81 and 66.37 mg% [20,111]. Oral administration of acetone extract of fruit powder of *M. charantia* for 15–30 days to alloxan-diabetic rats lowered the blood sugar and serum cholesterol levels to normal range and the blood sugar was found normal even after 15 days of discontinuation of the treatment [20,112]. A significant fall of blood sugar was observed after 3 weeks treatment of alloxan-diabetic rats with aqueous extract of fruits of *M. charantia*. The aqueous extract of fruit was more effective in diabetes (fall of blood sugar 54% after 3 weeks therapy) than the powder of the fried fruit (fall 25% nonsignificant) [113]. Oral feeding of aqueous extract of fruit of *M. charantia* demonstrated hypoglycemic effect in cyproheptadine-induced hyperglycemic and normoglycemic mice, respectively. However, the ethanolic extract did not show such an effect [114]. Homogenized suspension of the vegetable pulp of *M. charantia* given to 100 moderate NIDDM subjects resulted in a significant reduction ($P < 0.001$) of post-prandial serum glucose in 86% cases and fasting glucose in 5% cases [20,115]. Antioxidant activity has also been described [20,116]. Long term feeding (10 weeks) of *M. charantia* fruit extract to STZ-induced diabetic rats exhibited hypolipidemic as well as hypoglycemic effects in diabetic rats [117].

Oral administration of water extract of the fruit reduced the blood glucose and the serum insulin of KK-Ay mice in 3 weeks. Moreover, the muscle content of facilitative glucose transporter isoform 4 (GLUT4) protein content in the plasma membrane of muscle showed significant increase. It was suggested that the anti-diabetic action of the extract was derived in part from a decrease in insulin resistance because of the increase of GLUT 4 protein content in the plasma membrane of the muscle [118].

The aqueous extract powder of fresh unripe whole fruits at a dose of 20 mg/kg body weight was found to reduce fasting blood glucose by 48% an effect comparable to that of glibenclamide. In addition the extract did not show any signs of nephrotoxicity and hepatotoxicity [119]. Treatment of diabetic rats for 30 days with methanol extract of *M. charantia* fruit showed a significant decrease in triglyceride, low density lipoprotein and a significant increase in the high density lipoprotein level. Chronic administration showed an improvement in the oral glucose tolerance curve [120].

Fruit. Fried karela fruits consumed as a daily supplement to the diet produced a small but significant improvement in glucose tolerance in diabetic subjects without any increase in serum insulin levels [20,121].

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Oral supplementation (0.5, 1 and 3%) with freeze-dried powder of *M. charantia* for 14 days with and without 0.5% cholesterol and 0.15% bile acid in the diet resulted in a hypoglycemic effect in normal rats only in the former group. Anti-atherogenic activity was also noted [20,122].

Juice. Oral feeding of *M. charantia* juice to normal rats prior to glucose loading increased hepatic and muscle glycogen content while the triglyceride content was not effected. In vitro the fruit juice increased glucose uptake by tissues without concomitant increase in tissue respiration suggesting extra pancreatic effects of the extract [20,123]. The fruit juice of *M. charantia* was found to significantly improve the glucose tolerance of 73% of the patients investigated while the other 27% failed to respond [124]. Single or repeated oral administration of *M. charantia* juice (10 ml/kg for 30 days) did not affect the results of OGTT in STZ-diabetic rats. In addition, glycosylated hemoglobin concentration remained unchanged in treated and untreated diabetic rats. Results of this study were suggestive of the fact that viable beta cells are required to manifest the hypoglycemic activity of *M. charantia* [20,125]. In NIDDM model rats it was observed that the saponin-free methanol extract of juice produced a significant hypoglycemic effect both in fasting ($P < 0.05$ at 120 min) and in post prandial states (sum of percentage increments over basal value: 140 ± 26 in the control versus 71 ± 7 in the pulp juice group, $P < 0.05$) [126]. In other study, feeding of 0.02, 0.1 and 0.5% (w/w) diet containing *M. charantia* for 8 weeks did not affect blood sugar, food intake, growth, organ weights and hematological parameters of normal adult rats. However, 0.5% diet caused a significant hypo-cholestrolemic effect [20,127]. The fruit juice significantly increased the number of beta cells ($P < 0.004$) in STZ-diabetic rats suggesting possible role of the extract in the renewal of beta cells [128]. Aqueous juice of *M. charantia* fruit exerted hypoglycemic effect and reduced the STZ-induced lipid peroxidation in pancreas of STZ-diabetic mice [129].

Peptide. Charantin, a peptide resembling insulin isolated from *M. charantia* lowered fasting blood sugar in rabbits gradually beginning from 1st and lasting till the 4 h and slowly recovering to the initial level. Charantin (50 mg/kg) administered orally, lowered blood glucose by 42% at the 4 h with a mean fall of 28% during 5 h [20,130]. Polypeptide-p, isolated from fruit, seeds, and tissue of *M. charantia* showed potent hypoglycemic effect when administered subcutaneously to gerbils, langurs, and humans [20,131].

Experiments in rats showed that two important constituents of *M. charantia*, i.e. oleanolic acid 3-*O*-glucuronide and momordin Ic exert antihyperglycemic effect by inhibiting glucose transport at the brush border of the small intestine [20,132].

The common Indian vegetables possess hypoglycemic, hypocholesterolemic, antihyperinsulinemic, antihypertensive and antioxidant properties. Among the vegetables the antidiabetic effects of onion and bitter gourd are extensively studied.

Spices and condiments

India is known worldwide for its spices and condiments which add characteristic flavor and aroma to the various dishes in which they are used. The most common spices and condiments that form a part of the majority of the Indian dishes include garlic, mustard, cumin, turmeric, curry leaves and fenugreek.

Allium sativum: garlic

Allicin. Hypolipidemic effect of allicin (an active constituent of garlic) on long term feeding to normal rats has also been described [133]. Oral administration of 0.25 gm/kg allicin produced hypoglycemia comparable to tolbutamide in mildly diabetic rabbits (glucose levels ranging from 180 to 300 mg%) while it showed no such effect in severely diabetic animals (blood sugar >350 mg%) [20,134]. A synthetic preparation of allicin lowered the BP from the maximal level (after 3 weeks of fructose) of 153.4 ± 8 to 139.7 ± 12 mmHg after 2 weeks on allicin; insulin from 11.7 ± 3.7 ng/ml on fructose diet to 6.92 ± 3.3 ng/ml on allicin and triglycerides from 132.8 ± 18 mg/dl on fructose to 59.6 ± 27 mg/dl on allicin in hyperlipidemic hyperinsulinemic hypertensive rats [135]. Treatment of diabetic rats with garlic oil (10 mg/kg i.p.) for 15 days significantly decreased the lipid peroxides, blood glucose, total lipid, triglyceride and cholesterol [136].

Extract. Oral administration of 0.25 gm/kg of ethanol, petroleum ether, ethyl ether extract of *A. sativum* causes 18.9, 17.9, 26.2% reduction in blood sugar in alloxan-diabetic rabbits (150 mg/kg IV) [20,137]. Aqueous homogenate of garlic (10 ml/kg/day) administered orally to sucrose fed rabbits (10 gm/kg/day in water for 2 months) significantly increased hepatic glycogen and free amino acid contents, decreased fasting blood sugar, triglyceride levels in serum, liver and aorta and protein levels in serum and liver in comparison to sucrose controls [20,138]. Pretreatment with aged garlic extract (AGE) (5 and 10 ml/kg, PO) in stress-induced hyperglycemia model of mice (immobilization stress

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for 16 h/day for 2 consecutive days) significantly prevented adrenal hypertrophy, hyperglycemia and elevation of cortisone without altering serum insulin levels. The efficacy of AGE was the same as that of diazepam (5 mg/kg, PO). Thus, AGE may prevent stress-induced risk of DM and its progression [20,139].

Administration of ethanolic (95%) extract (45 mg/kg body weight/day for 28 days) of garlic to alloxanized diabetic mice resulted in significant lowering of serum glucose levels with simultaneous anti-nociceptive effects in tail-flick, hotplate, allodynia and formalin tests [140]. Daily oral feeding of garlic extract (100 mg/kg) increased cardiovascular functions in STZ rats, prevented abnormality in lipid profile and increased fibrinolytic activities with decreased platelet aggregation. Plasma insulin level increased with concomitant decrease in plasma glucose levels. In addition, daily oral feeding of the same dose for 16 weeks showed anti-atherosclerotic effects in STZ-diabetic rats. Thus, garlic may prevent diabetic cardiovascular complications [20,141]. Oral administration of ethanolic extract of garlic (0.1, 0.25 and 0.5 g/kg body weight) for 14 days to STZ-diabetic rats significantly decreased the serum glucose, total cholesterol and triglycerides while the serum insulin levels were increased. The antidiabetic effect of the extract was more effective than that of glibenclamide [142].

Powder. Chi et al. demonstrated the hypocholesterolemic effects of garlic in cholesterol fed rats [143]. The incorporation of freeze-dried garlic powder at 2% level in an atherogenic diet fed to rats partly reversed the increased levels of low density lipoproteins (LDL) and LDL cholesterol and enhanced the percentage of HDL whereas the levels of HDL cholesterol were unchanged [144]. Treatment with standardized garlic 900 mg/d reduced total serum cholesterol (TC) level of 262 $\pm$ 34 to 247 $\pm$ 40 mg/dl while the low density lipoprotein cholesterol was reduced by 11% after 12 weeks of garlic treatment in 42 healthy adults with TC greater than or equal to 220 mg/dl [145].

Juice. In subcutaneous glucose tolerance test in rabbits, garlic decreased hyperglycemic peak [20,90]. Oral administration of 1 ml dose of either onion or garlic juice (equivalent to 0.4 g/100 g bw) to alloxan-diabetic rats daily for 4 weeks exerted antioxidant and antihyperglycemic effects and could restore the liver and renal damage caused by alloxan-induced diabetes [146].

Amino acid. SACS, a sulfur containing amino acid is the precursor of allicin and garlic oil [147]. Various studies in experimental diabetes have shown beneficial effect of SACS. Administration of SACS (200 mg/kg) significantly decreased the concentration of serum lipids, blood glucose and activities of serum enzymes like alkaline phosphatase, acid phosphatase and lactate dehydrogenase and liver glucose-6-phosphatase. It also significantly increased liver and intestinal HMG CoA reductase activity and liver hexokinase activity in alloxan-diabetic rats [20,147].

In another study, oral administration of SACS to alloxan-diabetic rats for 1 month ameliorated glucose intolerance, weight loss, depletion of liver glycogen in diabetic rats in comparison to glibenclamide and insulin [20,91]. SACS also controlled lipid peroxidation better than that compared to glibenclamide and insulin and ameliorated diabetic condition almost to the same extent as they did. Furthermore, SACS significantly stimulated in vitro insulin secretion from β cells isolated from normal rats [20,148].

Brassica juncea: mustard

Oral feeding of *B. juncea* diet (10%, w/w) for 60 days to normal rats led to significant hypoglycemic effect. The probable mechanism involved was the stimulation of glycogen synthetase (leading to increase in hepatic glycogen content) and suppression of glycogen phosphorylase and other gluconeogenic enzymes [20,149]. *Brassica juncea* diet (10 and 15%) showed significant antihyperglycemic effect in alloxan (35 mg/kg) but not in STZ (60 mg/kg) rats. It also failed to modulate the hepatic glycogen content and enzyme activities [150].

Addition of 10% mustard seeds at a level of 10% body weight to standard laboratory diet of rats for 90 days resulted in a reduction in total serum cholesterol and LDL + VLDL, an increase in the HDL, lower release of lipoproteins into the circulation and an increase in the LCAT activity [151].

Cuminum cyminum: cumin

An 8 week dietary regime containing cumin powder (1.25%) was found to be beneficial in reduction of hyperglycemia and glucosuria. This was also accompanied by improvement in body weights of STZ-diabetic rats. Dietary cumin also countered other metabolic alterations as revealed by lowered blood urea level and reduced excretions of urea and creatinine by diabetic animals [152].

Curcuma: turmeric

The spice principle curcumin inhibited superoxide anion generation in xanthine-xanthine oxidase system to an extent of 40% at the concentration of

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75 μM and the generation of hydroxyl radicals (OH) to 76% as measured by deoxyribose degradation. The spice principle also prevented the oxidation of Fe^{2+} in Fentons reaction which generates OH radicals [153]. Curcumin (5—50 μM) inhibited ascorbate/Fe^{2+} induced lipid peroxidation in a dose-dependent manner in rat liver microsomes [154]. Feeding 0.5% curcumin diet to STZ-diabetic rats partially reversed the abnormalities in plasma albumin, urea, creatine and inorganic phosphorous. It also lowered lipid peroxidation in plasma and urine despite no effect on hyperglycemic status or body weights. The underlying mechanism involved was believed to be on account of its hypocholesterolemic influence, antioxidant nature and free radical scavenging property [155].

Murraya koeingii: curry leaves

Curry leaves powder supplementation (12 g providing 2.5 g fiber) for a period of 1 month in 30 NIDDM patients showed reduction in fasting and post-prandial blood sugar levels at 15-day period with no appreciable changes in serum glycosylated protein levels, glycosylated low density lipoprotein cholesterol fraction, serum lipids, lipoprotein cholesterol levels, uronic acid and total amino acids [20,156].

Oral feeding of *M. koeingii* leaves diet (10%, w/w) for 60 days to normal rats resulted in significant hypoglycemic action associated with increased hepatic glycogen content owing to increased glycogenesis and decreased glycogenolysis and gluconeogenesis [20,149]. Dietary supplementation with curry leaves has been shown to have a hypolipidemic effect in rats [151].

Diet containing various doses of curry leaves (5, 10 and 15%) was fed to normal rats for 7 days as well as mild diabetic (blood glucose levels>175 mg/dl) and moderate diabetic rats (>250 mg/dl) for 5 weeks. In normal rats reduction in blood glucose was almost negligible (~4% with 10 and 15% diet). In mild and moderate diabetic rats feeding of 5, 10 and 15% diet caused a maximal reduction in blood sugar by 13.1, 16.3 and 21.4% and 3.2, 5.58 and 8.21%, respectively [157].

A single oral administration of 300 mg/kg of aqueous extract of leaves led to 14.68% fall of blood glucose level in normal and 27.96% in mild diabetic after 4 h. The same dose also showed improvement in glucose tolerance of 46.25% in sub diabetic and 38.5% in mild diabetic rabbits in glucose tolerance test after 2 h [158].

Trigonella foenum graecum: fenugreek

Defatted seed fraction. Administration of defatted fraction (comprising mainly of the fibers) of fenugreek seeds to normal and diabetic dogs for 8 days exhibited prominent antidiabetic effect [159]. The hypocholesterolemic effect of defatted portion of fenugreek seeds in dogs has been investigated [160]. Defatted seed material of fenugreek which is rich in fibers, saponins and other proteins given with meals to alloxan-diabetic dogs for 21 days showed significant antihyperglycemic and anti-glycosuric effect along with reduction in high plasma glucagon and somatostatin [161]. Defatted ethanolic extract of fenugreek seeds fed to rats for a 4-week period showed hypocholesterolemic activity [162].

Extract. A single 0.5 ml oral dose of 40—80% decoctions to normal as well as alloxanized mice was followed by hypoglycemia developed over a 6-h period, which was maximum at 6 h and was dose-dependent. The hypoglycemia caused by the ethanol extract (200—400 mg/kg) in alloxanized mice was also dose-dependent and 200 mg/kg was comparable in effect to 200 mg/kg tolbutamide [163]. Oral administration of 2 and 8 g/kg of plant extract produced dose-dependent fall ($P < 0.05$) in blood glucose both in the normal as well as diabetic rats [20,164]. Oral administration of aqueous leaf extract (0.06, 0.2, 0.5, 1 g/kg, IP and 1, 2, 8 g/kg, PO) to normal and alloxanized diabetic rats showed significant hypoglycemic and antihyperglycemic effect while (50%) ethanolic extract significantly reduced blood glucose concentration ($P < 0.02$) at 2 and 24 h when given IP (0.8 g/kg) [20,165].

Seed powder. A similar glucose lowering effect of powdered fenugreek seed (15 g) soaked in water was observed in non-insulin dependent diabetics [166]. Fifteen non-insulin dependent diabetic patients given diets with 100 g defatted fenugreek seed powder for 10 days exhibited significant hypoglycaemic effect [167]. Administration of fenugreek seed powder (50 g given with the meals) to Type I diabetic patients for 10 days significantly reduced fasting blood sugar and improved OGTT along with 54% reduction in glycosuria. Significant hypolipidemic effect was also observed [20,168].

Seed powder normalized the altered creatinine kinase activity in heart, skeletal muscle and liver of diabetic rats to almost control values [20,169]. It also normalized alteration in hepatic and renal glucose-6-phosphatase and fructose-1,6-bisphosphatase activity [20,170]. Disrupted free radical metabolism in diabetic rats was found to be normalized by fenugreek seed supplementation in the diet [171].

Adjunct use of fenugreek seeds (1 g/day hydroalcoholic extract) for 2 months improved glycemic control and decreased the insulin resistance in mild

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12 type-2 diabetic patients. There was also a favorable effect on hypertriglyceridemia [172]. Alcoholic extract (1 g/kg, PO) of fenugreek seeds orally administered to normal and alloxan-diabetic rats for 21 days daily reduced the blood sugar levels from 74.33 ± 4.77 to 60.56 ± 1.9 in normal rats and 201.25 ± 7.69 to 121.25 ± 6.25 in diabetic rats [173]. A 26% improvement in fasting blood glucose and 30% improvement in glucosuria were observed in STZ-diabetic rats given fenugreek seed mucilage [174].

Diet. In a metabolic study diets with 25 g fenugreek given to 10 non-insulin dependent diabetics for 15 days significantly reduced the area under the plasma glucose curve, half-life and increased the metabolic clearance rate with an increase in the erythrocyte insulin receptors. Thus, fenugreek may exert its hypoglycemic effect by acting at the insulin receptors as well as at the gastrointestinal level [175]. Fenugreek given in a dose of 2.5 g twice daily for 3 months to coronary artery disease patients also with NIDDM, significantly decreased the blood lipids (total cholesterol and triglycerides) without affecting the HDL-c. When administered in the same daily dose to NIDDM (non-CAD) patients (mild cases), fenugreek reduced significantly the blood sugar (fasting and post prandial). However, in severe NIDDM cases no such effect was observed [176]. Ingestion of an experimental diet containing 25 g fenugreek seed powder resulted in a significant reduction of total cholesterol, LDL and VLDL cholesterol and triglyceride levels [177].

Amino acid. 4-hydroxyisoleucine, a novel amino acid has been extracted and purified from fenugreek seeds. It increased glucose-induced insulin release (ranging from 100 μmol/l to 1 mmol/l) through a direct effect on the isolated islets of Langerhans in both rats and humans. This pattern of insulin secretion was biphasic, glucose dependent, occurred in the absence of any change in pancreatic alpha and delta cell activity and without interaction with other agonists of insulin secretion (such as leucine, arginine, tolbutamide, glyceraldehyde) [20,178].

Beverages

Beverages though do not form a part of the diet but are equally important as they are taken at least two to three times a day by the people. These offer respite from stress, fatigue and enhance alertness. Tea is the most popular drink throughout the nation consumed by people in all walks of life and in all situations. Wine though not that common is increasing its hold especially among the elite classes.

Black tea

The hot water extract of black tea significantly reduced the blood glucose level and was found to possess both preventive and curative effects on STZ-induced diabetes in rats [179].

Green tea

The supplementation of a 25% casein diet containing 15% lard and 1% cholesterol for 28 days with 1 and 2% crude tea catechins prepared from green tea powder increased the fecal excretion of total lipids and cholesterol exerting a hypocholesterolemic effect in cholesterol-fed rats [180]. Green tea polyphenols especially epigallocatechin gallate injected IP into rats significantly reduced food intake, body weight, blood levels of insulin, glucose, cholesterol and triglyceride [181]. Epicatechin gallate showed the highest inhibition of glucose uptake by human intestinal epithelial Caco-2-cells suggesting tea catechins could play a role in controlling the dietary glucose uptake at the intestinal tract and possibly contribute to blood glucose homeostasis [182]. Daily administration of an aqueous solution of green tea polyphenols (GTP) at 50, 100 mg/kg bw for 15 days to alloxan-diabetic rats produced 29 and 44% reduction in the elevated serum glucose level. Significant increases in hepatic and renal enzymes as well as the serum Lipid peroxide levels were restored by GTP (100 mg/kg bw). In addition there was a significant increase in the liver glycogen and the antioxidant potential evident from the improvements in the superoxide dismutase and glutathione levels [183]. In STZ-rats administered epicatechin (30 mg/kg) twice a day for 6 days hyperglycemia and weight loss were not observed and islet morphology was well preserved compared with the STZ-treated rats [184]. Dietary gallate esters of tea catechins (epigallocatechin gallate and epicatechin gallate) fed to rats at 1% level for 23 days reduced the activities of enzymes related to hepatic fatty acid synthesis thereby causing reduction of hepatic triacylglycerol and possibly of visceral fat deposition [185]. Green tea extract was found to have an obvious hypoglycemic effect on diabetic rats, which may be associated with the inhibitory effects on α-glucosidase activity and glucose transport ability in small intestinal mucosa [186].

Red wine

Red wine consumption (300 ml) during a meal was associated with significant preservation of plasma antioxidant defenses and reduction of both LDL oxidation and thrombotic activation in Type 2 diabetics there by preventing cardiovascular diseases in diabetic patients [187].

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A polyphenol extract from red wine (200 mg/kg) administered for 6 weeks reduced glycemia and decreased food intake and body growth in STZ-diabetic and non-diabetic animals. Ethanol (1 ml/kg) administered alone or in combination with polyphenols corrected the diabetic state [188].

Among beverages tea is most popular and has the most effective antidiabetic action on account of polyphenols (epicatechin) which exert hypocholesterolemic effect through extra pancreatic mechanisms.

Conclusion

The incidences of modern lifestyle diseases like Type 2 diabetes widely prevalent in industrialized countries are on the rise in developing countries. The burden of T2DM is enormous when the costs of diagnosis and treatment are considered. Among the various lifestyle approaches for the management of this disease dietary intervention with a vegetarian diet seems to be an economical, physiological and safe approach for the prevention and possible management of T2DM. Most of the studies which we have reviewed. A well balanced vegetarian diet chosen form a variety of foods such as fresh fruits, vegetables, whole grains, cereals, nuts, seeds legumes, beans and soybean is rich in monounsaturated and polyunsaturated fatty acids, minerals, fibre, complex carbohydrate, antioxidant vitamins (vitamin E, C and carotenoids), flavanoids, folic acid and phytoestrogens and is restricted in saturated fat. Such a diet when complemented with other healthy lifestyle practices such as regular exercise and abstinence from smoking, excessive alcohol and narcotic drugs would significantly decrease the risk for diabetes mellitus.

It is concluded from the above literature that dietary interventions not only have effect on blood glucose lowering but also provide additional effects through complex mechanisms (like decreasing free radical moieties, etc.) on decreasing risk factors for cardiovascular and cerebral morbidities. Also, they are absolutely natural without any harmful side effects and very economical which could make them applicable for masses at large.

Future scope

This review of various observational studies was a small effort in the direction of adopting healthy food practices towards treating lifestyle diseases like diabetes. Although large controlled studies have to be carried out to evolve certain specific recommendations. The state governments should come forward for creating mass awareness through various available means so as to adopt a low cost, healthy and therapeutic diet plan.

Most of the studies that we have reviewed include dietary interventions carried out on animals and only a few were conducted on humans. Since, these food materials form a major portion of our diet it is imperative that systematic studies be designed and carried out over a long duration in suitable populations so as to evolve major dietary recommendations.

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