Available online at www.sciencedirect.com
SCIENCE DIRECT
Journal of Ethnopharmacology 106 (2006) 1–28
Journal of ETHNO-PHARMACOLOGY
www.elsevier.com/locate/jethpharm

Review

Leads from Indian medicinal plants with hypoglycemic potentials

Pulok K. Mukherjee [a,b,*], Kuntal Maiti [b], Kakali Mukherjee [b], Peter J. Houghton [a]

[a] *Pharmacognosy Research Laboratories, Department of Pharmacy, Franklin-Wilkins Building, King's College, London, 150 Stamford Street, London SE1 9NH, UK*
[b] *School of Natural Product Studies, Department of Pharmaceutical Technology, Jadavpur University, Kolkata 700032, India*

Received 27 November 2005; received in revised form 13 March 2006; accepted 23 March 2006
Available online 3 April 2006

Abstract

Diabetes mellitus is caused due to deficiency in production of insulin by the pancreas, or by the ineffectiveness of the insulin produced. It is a global problem and number of those affected is increasing day by day. The plants provide a potential source of hypoglycemic drugs because many plants and plant derived compounds have been used in the treatment of diabetes. Several medicinal plants have found potential use as hypoglycemic in the Indian system of medicines, including ayurveda. Many Indian plants have been investigated for their beneficial use in different types of diabetes and reports occur in numerous scientific journals. This article aims to provide a comprehensive review on various plant species from Indian biosphere and their constituents, which have been shown to display potent hypoglycemic activity. The use of herbs as hypoglycemic is a major avenue in Indian perspectives particularly for treating diabetes, which require to be explored more effectively as there are so many literatures available on these aspects. This paper describes the chemistry, activity and usage of the constituents isolated from these plants from India for the treatment of diabetes.

Keywords: Diabetes; Ayurveda; Hypoglycemic; Indian medicinal plants; Antioxidants

Contents

* Corresponding author. Tel.: +91 33 24298313; fax: +91 33 24146046.
E-mail address: pulokm@gmail.com (P.K. Mukherjee).

0378-8741/$ – see front matter © 2006 Elsevier Ireland Ltd. All rights reserved.
doi:10.1016/j.jep.2006.03.021

1. Introduction

Diabetes mellitus (DM) is a chronic disease caused by inherited and/or acquired deficiency in production of insulin by the pancreas, or by the ineffectiveness of the insulin produced. Such a deficiency results in increased concentrations of glucose in the blood, which in turn damage many of the body's systems, in particular the blood vessels and nerves. Diabetes affects about 5% of the global population (Chakraborty and Rajagopalan, 2002) and management of diabetes without any side effects is still a challenge to the medical system (Kameswara Rao et al., 2003a). Chronic hyperglycemia during diabetes causes glycation of body proteins that in turn leads to secondary complications affecting eyes, kidneys, nerves and arteries (Sharma, 1993). These may be inhibited or lowered by maintaining blood glucose values close to normal. The therapeutic measurements include use of insulin and other agents like amylin analogues, alpha glycosidase inhibitors like acarbose, miglitol and voglibiose, sulphonylureas, biguanides for the treatment of hyperglycemia. These drugs also have certain adverse effects like causing hypoglycemia at higher doses, liver problems, lactic acidosis and diarrhea. Apart from currently available therapeutic options, many herbal medicines have been recommended for the treatment of diabetes. Traditional plant medicines are used throughout the world for a range of diabetic presentations. Herbal drugs are prescribed widely because of their effectiveness, less side effects and relatively low cost (Venkatesh et al., 2003). Therefore, investigation on such agents from traditional medicinal plants has become more important (Suba et al., 2004a). India has a rich history of using various potent herbs and herbal components for treating diabetes. Many Indian plants have been investigated for their beneficial use in different types of diabetes and reported in numerous scientific journals. The present review, deals with some selective Indian medicinal plants having pharmacologically established hypoglycemic potential.

2. Indian medicinal plants with hypoglycemic activity

Since time immemorial, various plants and plant derived compounds have been used in the treatment of diabetes to control the blood sugar of the patients. The use of herbs in the management of diabetes mellitus has been prevalent in Indian society from a long time. Several medicinal plants have reported to possess potential hypoglycemic activity in Indian system of medicines. There have been several reviews on the hypoglycemic medical plants (Ivorra et al., 1989; Rahman and Zaman, 1989), more particularly use of Indian botanicals for hypoglycemic activity (Grover et al., 2002a; Saxena and Vikram, 2004). This article highlights on the chemo profiles from Indian biosphere for treating diabetes with major thrust on the dosage and possible mode of action of the herbal hypoglycemic so far reported. Various plant species from Indian biosphere, having potent hypoglycemic activity are described in the following section.

2.1. *Acacia arabica (Lam.) Muhl. ex Willd. (Family: Mimosaceae)*

Acacia arabica (Lam.) Muhl. ex Willd. is a moderate sized, almost evergreen tree found throughout the drier parts of India, ascending to an altitude of 900 m. The bark of this plant has various traditional uses (Anonymous, 1976). It has also been reported for significant hypoglycaemic activity, which is described further in Table 1.

2.2. *Aegle marmelos (L.) Correa ex Roxb. (Family: Rutaceae)*

A moderated sized tree found throughout the deciduous forests of India. Different extracts obtained from the leaves, bark and fruit of this plant have been investigated for possible hypoglycemic activity in various experimental animal models of diabetes like streptozotocin and alloxan induced diabetes along with possible mechanism of action (Table 1).

2.3. *Allium cepa L. (Family: Liliaceae)*

Allium cepa L. commonly known as onion, is an essential dietary ingredient, cultivated throughout India. Several studies indicated the hypoglycemic activity of this plant along with its hypolipidemic and antioxidant activity (Roman-Ramos et al., 1995; Campos et al., 2003; El-Demerdash et al., 2005). A study with the seedling, seedling parts and callus cultures of onion suggested that the callus cultures exhibited much higher hypoglycemic activity as compared to natural bulbs of onion and the same can be used as an alternative source for the isolation of hypoglycemic compounds (Kelkar et al., 2001). Investigations revealed the presence of a sulfur containing amino acid, S-methyl cysteine sulphoxide, in onion, which shown to impart potent hypoglycemic activity when administered at a dose of 200 mg/kg for 45 days to alloxan induced diabetic rats (Kumari et al., 1995). Another compound S-allyl cysteine sulphoxide was also found to be effective in reducing the blood glucose level of alloxan induced diabetic rats (Sheela et al., 1995). Several clinical studies also strongly substantiated the hypoglycemic claim of *Allium cepa* (Mathew and Augusti, 1975; Sharma et al., 1977; Tjokroprawiro et al., 1983) explained further in Table 1.

2.4. *Allium sativum L. (Family: Alliaceae)*

Another essential dietary component cultivated throughout India, and familiar worldwide as garlic. The hypoglycemic activity of garlic has been extensively studied and reported. Pioneering works by many researchers proved the potent hypoglycemic activity of *Allium sativum* L. (Zacharias et al., 1980; Roman-Ramos et al., 1995; Kasuga et al., 1999). Garlic contains S-allyl cysteine sulphoxide, a sulphur containing amino acid, which produced significant blood glucose lowering activity in experimental diabetic animals (Sheela and Augusti, 1992). Allicin (thio-2-propene-1-sulfinic acid S-allyl ester) another

Table 1
Selected Indian medicinal plants with blood sugar lowering activity

Name of the plant	Activity with route of administration/dosage	Reported mechanism of action
Acacia arabica (Lam.) Muhl. ex Willd. Common name: Indian Gum Arabic tree [Family: Leguminosae]	Hypoglycaemic activity of 94% seed diet in normal rats orally with no blood sugar lowering activity in alloxanized rats at the same dose level (Singh et al., 1975) Hypoglycemic effect of powdered seeds in normal rabbits (2, 3 and 4 mg/kg) administered orally (Wadood et al., 1989)	Acts through release of insulin from pancreatic beta cells, which accounts for the hypoglycemic activity (Singh et al., 1975; Wadood et al., 1989)
Aegle marmelos (L.) Correa ex Roxb. Common name: Holy Fruit Tree [Family: Rutaceae]	Hypoglycemic effect of aqueous decoction of the plant root bark (1 ml/100 mg) in normal fasted rats (Karunanayake et al., 1984) Antihyperglycemic activity of aqueous leaf extract in alloxanized rats (Ponnachan et al., 1993) Antihyperglycemic activity of aqueous leaf extract in streptozotocin induced diabetic rats (Das et al., 1996; Seema et al., 1996) Hypoglycemic and antioxidant activity of leaves in diabetic male albino rats (Upadhya et al., 2004) Antihyperglycemic and antioxidant activity of the plant in alloxanized rats (Sabu and Kuttan, 2004) Antihyperglycemic activity of the leaves in glucose induced hyperglycemic rat at an oral dose equivalent to 250 mg/kg (Sachdewa et al., 2001a) Antihyperglycemic activity of aqueous fruit extract (250 mg/kg, twice daily for 1 month) in streptozotocin induced female albino Wistar diabetic rats (Kamalakkanan et al., 2003) Hypoglycaemic activity of water extract of fruits in streptozotocin-induced diabetic Wistar rats (125 and 250 mg/kg) twice a day for 4 weeks, orally (Kamalakkannan and Prince, 2003) Antioxidant activity of the aqueous extract of fruits in streptozotocin diabetic rats (125 and 250 mg/kg), orally for 30 days (Kamalakkannan and Stanely, 2003)	Increases utilization of glucose; either by direct stimulation of glucose uptake or via the mediation of enhanced insulin secretion (Sachdewa et al., 2001a) and also decreases the elevated glucose and glycosylated hemoglobin levels (Kamalakkanan et al., 2003)
Allium cepa L. Common name: onion [Family: Liliaceae]	Hypoglycemic activity of ether soluble fraction of onion (0.25 mg/kg p.o.) in normal rabbits (Augusti, 1973) Hypoglycemic activity of the bulb in rabbits in an oral glucose tolerance test at 2 g/kg (Gupta et al., 1977) Antihyperglycemic, antioxidant and hypolipidemic activity of a diet containing 3% freeze dried onion powder upon prolonged administration in STZ diabetic rats (Babu and Srinivasan, 1997)	Lowers blood glucose level and has potent antioxidant activity, which may account for the hypoglycemic potential (Augusti, 1973)
Allium sativum L. Common name: garlic [Family: Alliaceae]	Antihyperglycemic activity of ethanol, petroleum ether and ethyl acetate extract in alloxanized rabbits at a dose of 0.25 mg/kg, orally (Jain and Vyas, 1975) Antioxidant activity of allicin, isolated from garlic (Rabinkov et al., 1998)	Has strong antioxidant activity and rapid reactivity with thiol containing proteins responsible for the hypoglycemic property (Rabinkov et al., 1998)
Aloe vera (L.) Burm.f. Common name: Aloe [Family: Aloaceae]	Hypoglycemic activity of the plant (200 and 300 mg/kg p.o.) on normal fasted rats, oral glucose-loaded rats and streptozotocin-induced diabetic rats (Rajasekaran et al., 2004) Hypoglycaemic activity of leaf pulp extracts in type I and type II diabetic rats (Okyar et al., 2001) Hypoglycemic effect of aloe and its bitter principle in alloxanized mice (Ajabnoor, 1990) Antihyperglycemic activity of dried sap in five non-insulin-dependent diabetic patients and in alloxanized Swiss albino mice (Ghannam et al., 1986)	Maintains glucose homeostasis by controlling the carbohydrate metabolizing enzymes (Rajasekaran et al., 2004) and stimulates insulin release from pancreatic beta cells (Ajabnoor, 1990)
Artemisia pallens Wall. ex DC. Common Name: Davana [Family: Compositae]	Antihyperglycemic activity of aerial parts (100 mg/kg, orally) in glucose-fed hyperglycaemic and alloxan-induced diabetic rats. Moderate hypoglycaemic effect (1000 mg/kg) in fasted normal rats (Subramoniam et al., 1996)	Inhibits glucose re-absorption or increase in peripheral glucose utilization (Subramoniam et al., 1996)
Annona squamosa L. Common name: Sugar apple [Family: Annonaceae]	Hypoglycemic activity of aqueous leaf extracts in streptozotocin-nicotinamide induced diabetic rats (Shirwaikar et al., 2004) Hypoglycemic and antihyperglycemic activities of ethanolic leaf-extract (350 mg/kg, orally) in normal, streptozotocin (STZ)-diabetic rats and alloxanized rabbits (Gupta et al., 2005)	Lowers blood glucose level (Shirwaikar et al., 2004)

Table 1 (*Continued*)

Name of the plant	Activity with route of administration/dosage	Reported mechanism of action
Andrographis paniculata Nees Common name: King of Bitter. [Family: Acanthaceae]	Hypoglycemic and antihyperglycemic activity of *Andrographis paniculata* and andrographolide in normal and streptozotocin induced diabetic rats, orally (Borhanuddin et al., 1994; Yu et al., 2003) Antioxidant activity of *Andrographis paniculata* extract in diabetic rats (Zhang and Tan, 2000a)	Prevents glucose absorption from gut (Borhanuddin et al., 1994; Yu et al., 2003). Has hypotriglyceridemic effect and antioxidant activity, which may be responsible for beneficial effect in the diabetic state (Zhang and Tan, 2000a,b)
Azadirachta indica A.Juss. Common name: Neem [Family: Meliaceae]	Hypoglycemic activity of hydro alcoholic plant extract in normal rats and hypoglycemic activity in glucose fed and streptozotocin induced diabetic rats (Chattopadhyay et al., 1987a; Chattopadhyay, 1996) Hypoglycemic and antihyperglycemic activities of leaf extract in normal and streptozotocin-induced diabetic rat (Chattopadhyay, 1999; Gholap and Kar, 2004) Hypoglycemic activity of crude ethanolic extract of the plant in alloxan diabetic albino rats (Kar et al., 2003)	Inhibits action of epinephrine on glucose metabolism, resulting in increased utilization of peripheral glucose (Chattopadhyay et al., 1987b; Chattopadhyay, 1996) and exhibits hypoglycaemic activity without altering the serum cortisol concentration (Chattopadhyay, 1999; Gholap and Kar, 2004)
Biophytum sensitivum (L.) DC. Common name: Life Plant [Family: Oxalidaceae]	Hypoglycemic activity of the plant leaf extract in alloxan diabetic male rabbits (Puri and Baral, 1998) Hypoglycemic activity of the plant on glucose homeostasis in rabbits (Puri, 2001)	Stimulates pancreatic beta cells to release insulin (Puri and Baral, 1998)
Beta vulgaris L. Common name: Garden beet [Family: Chenopodiaceae]	Hypoglycemic activity of Betavulgarosides II–IV, isolated from the root of *Beta vulgaris* L. in an oral glucose tolerance test in rats (Yoshikawa et al., 1996)	Lowers blood glucose level (Yoshikawa et al., 1996)
Brassica juncea (L.) Czern. Common name: Brown Mustard [Family: Brassicaceae]	Hypoglycemic activity of *Brassica juncea* diet (10%, w/w) in normal rats upon oral administration for 60 days (Khan et al., 1995)	Increases the concentration of hepatic glycogen and glycogenesis and suppressed the activity of glycogen phosphorylase and gluconeogenic enzymes, lead to reduction in glycogenolysis and gluconeogenesis (Khan et al., 1995)
Boerhavia diffusa L. Common name: Tar vine [Family: Nyctaginaceae]	Hypoglycemic activity of aqueous leaf extract at a dose of 100, 200 and 400 mg/kg in alloxan induced diabetic rats (Chude et al., 2001) Hypoglycemic and antihyperglycemic activity of aqueous leaf extract (200 mg/kg p.o., daily for 4 weeks) in normal and alloxan induced diabetic rats (Pari and Amarnath Satheesh, 2004; Satheesh and Pari, 2004)	Increases plasma insulin levels and improves glucose tolerance, produced significant antioxidant activity (Pari and Amarnath Satheesh, 2004; Satheesh and Pari, 2004)
Cassia auriculata L. Common name: Tanner's Cassia [Family: Leguminosae]	Antihyperglycemic and antihyperlipidemic activity of aqueous flower extract in streptozotocin-induced diabetic rats upon oral administration at different doses for 30 days (Pari and Latha, 2002; Latha and Pari, 2003b) Antioxidant activity of aqueous flower extract in the brain of streptozotocin diabetic rats (Latha and Pari, 2003a; Abesundara et al., 2004)	Suppresses enhanced gluconeogenesis during diabetes and enhance utilization of glucose through increased glycolysis (Pari and Latha, 2002; Latha and Pari, 2003b) in addition to pronounced alpha-glucosidase inhibitory actions resulting in a significant and potent lowering of blood glycemic response (Latha and Pari, 2003c; Abesundara et al., 2004)
Caesalpinia bonducella (L.) Roxb. Common name: Chinese Cinnamon [Family: Caesalpiniaceae]	Hypoglycemic and antihyperglycemic activities of the aqueous and 50% ethanolic seed extracts in normal and streptozotocin-diabetic rats (Sharma et al., 1997) Antihyperglycemic activity of the seed extracts in type II diabetic Long Evans rat (Chakrabarti et al., 2003) Hypoglycemic activity of aqueous and ethanolic extracts in chronic type II diabetic model with an increase in secretion of insulin from isolated islets (Chakrabarti et al., 2005)	Increases the release of insulin from pancreatic cells (Sharma et al., 1997)
Cajanus cajan (L.) Millsp. Common name: Pigeon pea [Family: Fabaceae]	Glucose tolerance enhancing activity of aqueous leaf and stem extract in oral glucose tolerance test (Esposito Avella et al., 1991) Hypoglycemic activity of cooked diet in healthy human volunteers (Panlasigui et al., 1995)	Lowers plasma glucose level (Amalraj and Ignacimuthu, 1998a)
Citrullus colocynthis (L.) Schrad. Common name: Bitter apple [Family: Cucurbitaceae]	Hypoglycemic activity of aqueous extract (300 mg/kg), glycosidic and saponin extract (50 mg/kg), orally in normal rabbits (Abdel-Hassan et al., 2000; Nmila et al., 2000) Blood glucose lowering activity of aqueous seed extract in normal and streptozotocin (STZ)-induced diabetic rats upon daily oral administration for 2 weeks (Al-Ghaithi et al., 2004)	Exerts an insulinotropic effect (Abdel-Hassan et al., 2000; Nmila et al., 2000)

Table 1 (*Continued*)

Name of the plant	Activity with route of administration/dosage	Reported mechanism of action
Coccinia indica Wight & Arn. Common name: Ivy gourd [Family: Cucurbitaceae]	Hypoglycemic activity of alcoholic leaf extract in normoglycemic guinea pig (Mukherjee et al., 1972) Hypoglycemic activity of the leaves in alloxanized dogs upon oral administration (Singh et al., 1985) Hypoglycemic and antihyperglycemic activity of the ethanolic root extract in fasted and glucose-loaded animal models (Chandrasekar et al., 1989) Hypoglycemic effect of 95% ethanol extract of the leaves in normal fed and 48 h starved rats (Hossain et al., 1992) Blood glucose lowering activity of 60% ethanol leaf extract (200 mg/kg, orally) (Shibib et al., 1993) Hypoglycemic activity of the leaf extract in a double blind control trial in human subjects (Azad Khan et al., 1979; Platel and Srinivasan, 1997) Antihyperglycemic activity of dried extract (500 mg/kg p.o., for 6 weeks) in 30 diabetic patients (Kamble et al., 1998)	Suppresses glucose synthesis, through depression of the key gluconeogenic enzymes glucose-6-phosphatase and fructose-1,6-bisphosphatase and enhances glucose oxidation by shunt pathway through activation of its principal enzyme glucose-6-phosphate dehydrogenase (Shibib et al., 1993). Also has an insulin secretagogue effect (Azad Khan et al., 1979; Platel and Srinivasan, 1997) and acts like insulin by correcting elevated enzymes in glycolytic pathway and restoring LPL activity in lypolytic pathway with control of hyperglycemia in diabetes (Kamble et al., 1998)
Casearia esculenta Roxb. Common name: Carilla Fruit [Family: Flacourtiaceae]	Antihyperglycaemic activity of root extract (300 mg/kg p.o. for 45 days) in normal and streptozotocin-induced diabetic rats (Prakasam et al., 2002) Blood glucose lowering activity of aqueous extract in normal and glucose loaded rats. Antihyperglycemic activity of the extract in streptozotocin-diabetic rats along with reduction in the increased plasma thiobarbituric acid reactive substance and blood urea (Prakasam et al., 2003a) Antioxidant activity of aqueous extract in STZ diabetic rats at doses of 200 and 300 mg/kg for 45 days (Prakasam et al., 2003b)	Exhibits significant reduction in blood glucose level, a decrease in the activities of glucose-6-phosphatase and fructose-1,6-bishosphatase and an increase in the activity of liver hexokinase, resulting in potent hypoglycemic activity (Prakasam et al., 2002)
Catharanthus roseus (L.) G. Don Common name: Madagascar periwinkle [Family: Apocynaceae]	Hypoglycemic activity of ethanolic leaf extract in normal rats upon oral administration at graded dose. Hypoglycemic activity of the extract (500 mg/kg) in streptozotocin rats and in oral glucose tolerance test (Chattopadhyay et al., 1991) The hypoglycemic activity of dichloromethane: methanol extract of leaves and twigs in streptozotocin (STZ) induced diabetic rat (500 mg/kg p.o., for 7 and 15 days) (Singh et al., 2001) Hypoglycemic and antihyperglycemic activity of leaf juice or water decoction of the plant in normal and alloxan-induced diabetic rabbits (Nammi et al., 2003)	Increases metabolization of glucose (Singh et al., 2001) and enhances secretion of insulin either from the beta cells of Langerhans or through extrapancreatic mechanism (Nammi et al., 2003)
Camellia sinensis Kuntze. Common name: Green tea [Family: Theaceae]	Antihyperglycemic activity of hot water extract of green tea in streptozotocin (STZ)-diabetic rats (Gomes et al., 1995; Anderson and Polansky, 2002)	Epigallocatechin gallate, present in tea increases insulin activity and prevent oxidative damages, responsible for the hypoglycemic activity (Gomes et al., 1995; Anderson and Polansky, 2002)
Enicostemma littorale Blume [Family: Gentiaceae]	Antihyperglycemic activity of whole plant aqueous extract in alloxan induced diabetic rats along with reduction of glycosylated haemoglobin and glucose-6-phosphatase activity in liver (Vijayvargia et al., 2000) Insulin enhancing activity of a single dose of aqueous extract of plant (15 g dry plant equivalent extract per kg) in alloxan-induced diabetic rats (Maroo et al., 2002) Glucose lowering activity of aqueous extract (2 g/kg p.o.) daily for 6 weeks in neonatal non-insulin-dependent diabetes mellitus (NIDDM) rats along with a decrease in the elevated cholesterol, triglyceride and creatinine levels (Murali et al., 2002) Reduction in glycosylated haemoglobin, liver glucose-6-phosphatase activity and significant increase in serum insulin levels of the diabetic rats by aqueous extract (Maroo et al., 2003) Antioxidant activity of the whole plant aqueous extract (1 and 2 g/kg) in alloxanized rats upon oral administration for 45 days (Srinivasan et al., 2005)	Enhances glucose-induced insulin release from isolated rat pancreatic islets, mediated through K (+)-ATP channel-dependent pathway (Maroo et al., 2002)

Table 1 (*Continued*)

Name of the plant	Activity with route of administration/dosage	Reported mechanism of action
Eugenia jambolana Lam. (syn. *Syzygium cumini* L.) Common name: Indian black berry [Family: Myrtaceae]	Hypoglycemic activity of pulp extract of the fruits in normal as well as STZ diabetic rats upon oral administration (Achrekar et al., 1991) Blood glucose lowering activity of aqueous seed extract (2.5 and 5.0 g/kg body weight p.o. for 6 weeks) along with an increase in total haemoglobin and antioxidant activity in diabetic rats (Prince et al., 1998) The blood glucose lowering activity of alcoholic extract (100 mg/kg p.o.) in alloxan diabetic rats along with reduction in urine sugar and lipids in serum and tissues (Prince et al., 2004a) Hypoglycemic effect of aqueous, alcoholic extracts and lyophilized powder (200 mg/kg per day) of the plant in hyperglycemic animals (Grover et al., 2000) Antihyperglycemic and antihyperinsulinemic activity of aqueous extracts (400 mg per day) in fructose fed rats (Vikrant et al., 2001) Reduction in plasma glucose concentration by the extract (200 mg/kg) upon administration for 50 days in STZ induced diabetic mice (Grover et al., 2002b) Hypoglycemic activity of ethanolic seed extract in alloxan-induced diabetic rabbits along with hypolipidemic effect (Sharma et al., 2003) Hypoglycemic activity of ethanolic whole seeds, kernel (100 mg/kg of body weight) and seed coat extracts in streptozotocin-induced diabetic rats (Ravi et al., 2004a) Hypoglycemic activity of inorganic trace elements, obtained from the seeds in streptozotocin-induced diabetic rats (Ravi et al., 2004b) Antioxidant activity of ethanolic seed kernel extract in streptozotocin-induced diabetic rats upon oral administration (Ravi et al., 2004c) Blood glucose lowering activity of seed powder in streptozotocin diabetic female albino Wistar rats at a dose of 250, 500 or 1000 mg/kg, orally (Sridhar et al., 2005)	May be mediated through an insulin release mechanism (Achrekar et al., 1991) or due to alteration in hepatic and skeletal muscle glycogen content and hepatic glucokinase, hexokinase, glucose-6-phosphate and phosphofructokinase levels in diabetic mice (Grover et al., 2000). It also enhances serum insulin activity (Sharma et al., 2003) and exhibits normoglycemia and better glucose tolerance (Ravi et al., 2004a)
Ficus bengalensis L. Common name: Banyan tree Family: Moraceae	Hypoglycemic activity of ethabolic bark extract and a glucoside isolated from the plant in normal and alloxan diabetic rabbits (Augusti, 1975) Blood glucose lowering activity of bark extract in streptozotocin-induced diabetic animals upon oral administration and enhancement of serum insulin levels in normoglycemic and diabetic rats (Achrekar et al., 1991) Blood sugar lowering activity of a dimethoxy derivative of leucocyandin 3-*O*-beta-D-galactosyl cellobioside isolated from the bark in normal and moderately diabetic rats along with an increase in serum insulin in the diabetic rats at a dosage of 250 mg/kg for a 2 h period upon oral administration (Kumar and Augusti, 1989) Antihyperglycemic activity of dimethoxy derivative of perlargonidin 3-*O*-alpha-L rhamnoside (250 mg/kg, single dose study and 100 mg/kg/day long term study) in moderately diabetic rats. Hypoglycemic and serum insulin raising activity in normal and moderately diabetic dogs during a period of two hours (Cherian et al., 1992; Augusti et al., 1994) Hypoglycemic, hypolipidemic and serum insulin raising effects of glycoside of leucopelargonidin isolated from the bark in moderately diabetic rats (Cherian and Augusti, 1993) Hypoglycemic activity of Leucodelphinidin derivative in normal and alloxan diabetic rats at a dosage of 250 mg/kg (Geetha et al., 1994)	Stimulates insulin secretion from beta cells of islets of langerhans (Achrekar et al., 1991; Cherian et al., 1992; Augusti et al., 1994) and inhibits insulin degradative processes (Kumar and Augusti, 1989)

Table 1 (*Continued*)

Name of the plant	Activity with route of administration/dosage	Reported mechanism of action
Hibiscus rosa sinensis L. Common name: China Rose [Family: Malvaceae]	Hypoglycemic activity of single dose of ethanol extract of the plant in glucose-loaded rats at 120 min and blood glucose lowering effect after repeated administration for seven consecutive days at 30, 90 and 120 min after glucose loading (Sachdewa and Khemani, 1999) Hypoglycemic activity of alcoholic leaf extract (250 mg/kg p.o. for seven consecutive days) in glucose induced hyperglycemia model in rats (Sachdewa et al., 2001b) Blood glucose lowering activity of ethanol flower extract in streptozotocin induced diabetic rats along with a reduction in total cholesterol and serum triglycerides (Sachdewa and Khemani, 2003)	Stimulates insulin secretion from pancreatic beta cells (Sachdewa and Khemani, 1999) and increases utilization of glucose, either by direct stimulation of glucose uptake or via the mediation of enhanced insulin secretion (Sachdewa et al., 2001b)
Helicteres isora L. Common name: Screw tree [Family: Sterculiaceae]	Plasma glucose lowering activity of ethanolic root extract (300 mg/kg, after 9 days of administration) in insulin resistant and diabetic C57BL/KsJdb/db mice associated with a reduction in plasma triglyceride level (Chakrabarti et al., 2002) Antihyperglycemic activity of butanol root extracts (250 mg/kg) in glucose loaded rats (Venkatesh et al., 2004)	Acts through insulin-sensitizing activity (Chakrabarti et al., 2002)
Ipomoea batatas (L.) Lam. Common name: Sweet potato [Family: Convolvulaceae]	Hypoglycemic effect of the plant against diabetic Zucker fatty rats and inhibition of the increased blood glucose level in a glucose tolerance test in rats (Kusano and Abe, 2000) Postprandial glucose suppression effect (reduced blood glucose level by 16.5% at 30 min) of Peonidin 3-*O*-[2-*O*-(6-*O*-*E*-feruloyl-beta-D-glucopyranosyl)-6-*O*-*E*-caffeoyl-beta-D-glucopyranoside]-5-*O*-beta-D-glucopyranoside, a diacylated anthocyanin, isolated from storage roots in male 8-week-old Sprague-Dawley rats upon single oral administration (Matsui et al., 2002)	Reduces insulin resistance (Kusano and Abe, 2000) and possibly acts by maltase inhibition, not by sucrase or glucose transport inhibition at the intestinal membrane (Matsui et al., 2002)
Mangifera indica L. Common name: Mango [Family: Anacardiaceae]	Hypoglycemic activity of aqueous leaf extract (1 g/kg p.o.), given along with as well as 60 min before glucose administration in streptozotocin-induced diabetic rats (Aderibigbe et al., 1999) Hypoglycemic activity of Mangiferin (10 and 20 mg/kg, i.p. once daily for 28 days) in STZ induced diabetic rats and improvement in oral glucose tolerance in glucose-loaded normal rats upon chronic administration (10 and 20 mg/kg, i.p.) for 14 days (Muruganandan et al., 2005)	Possibly acts through intestinal reduction of the absorption of glucose (Aderibigbe et al., 1999) as well as pancreatic and extrapancreatic mechanisms (Muruganandan et al., 2005)
Momordica cymbalaria Fenzl ex Naudin [Family: Cucurbitaceae]	Blood glucose level reducing activity of fruit powder in fasted alloxan-induced diabetic rats after a treatment for 15 days (Rao et al., 1999) Blood glucose lowering effect of aqueous fruit extract in alloxan diabetic rats (Rao et al., 2001) Antihyperglycemic activity of aqueous fruit extract (0.5 g/kg dose for 6 weeks) in alloxan-induced diabetic rats upon oral administration (Kameswara Rao et al., 2003a)	May act by increasing hepatic glycogen (Rao et al., 1999)
Mucuna pruriens (L.) DC. Common name: Velvet bean [Family: Leguminosae]	Blood glucose lowering activity of powdered seeds (0.5, 1 and 2 g/kg) in normal rabbits and hypoglycemic activity of the seed (1 and 2 g/kg body weight) in alloxan-diabetic rabbits (Akhtar et al., 1990) Blood glucose lowering activity of plant extract (200 mg/kg) upon daily oral feeding for 40 days in STZ-diabetic mice (Grover et al., 2001) Antihyperglycaemic effect of alcohol extract of the plant (100, 200 and 400 mg/kg/day) in alloxanized rats and insignificant glucose lowering effect in streptozotocin (STZ) diabetic mice (Rathi et al., 2002)	Possibly acts through stimulation of the release of insulin and/or by a direct insulin-like action due to the presence of trace elements like manganese, zinc, etc. (Akhtar et al., 1990)
Morus alba L. Common name: White mulberry [Family: Moraceae]	Hypoglycemic activity of hot water extract of leaves in fasted and non-fasted streptozotocin induced diabetic mice at a dose of 200 mg/kg, i.p. (Chen et al., 1995) Degranulation effect of leaf-extract on the beta cells of islets of langerhans of rabbits upon chronic subcutaneous administration (Gulubova and Boiadzhiev, 1975)	Acts by increasing glucose uptake (Chen et al., 1995)

Table 1 (*Continued*)

Name of the plant	Activity with route of administration/dosage	Reported mechanism of action
Murraya koenigii (L.) Spreng. Common name: curry-leaf tree [Family: Rutaceae]	Fasting as well as post-prandial blood sugar lowering effect of leaf-powder in Type II diabetic patients upon administration for a period of 1 month (Iyer and Mani, 1990) Blood sugar lowering effect of the leaves in normal rats when administered as a diet (10%, v/v) for 60 days (Khan et al., 1995)	Increases glycogenesis and decreases glycogenolysis and gluconeogenesis (Khan et al., 1995)
Ocimum sanctum L. Common name: Holy Basil [Family: Lamiaceae]	Hypoglycemic activity of 70% ethanolic leaf extract in normal, glucose fed and STZ diabetic rats, orally. The extract also potentiated the action of exogenous insulin in normal rats (Chattopadhyay, 1993) Fasting blood glucose level reducing activity of the leaf powder, given along with food for 1 month, in normal and diabetic rats (Rai et al., 1997) Plasma glucose lowering activity of plant extract (200 mg/kg for 30 days) in STZ induced diabetic animals revealing the effect of the extract on three important enzymes of carbohydrate metabolism, namely glucokinase, hexokinase and phosphofructokinase (Vats et al., 2004a) Glucose and cortisol lowering activity of the plant in male mice (Gholap and Kar, 2004)	Acts by cortisol inhibiting potency (Gholap and Kar, 2004)
Punica granatum L. Common name: Pomegranate Family: Punicaceae	Blood glucose lowering activity of a 50% (v/v) ethanolic flower extract in glucose fed and alloxanized hyperglycemic rats (Jafri et al., 2000) Hypoglycemic activities of methanolic seed extract (150, 300 and 600 mg/kg p.o.) in strepotozotocin diabetic rats at the end of 12 h (Das et al., 2001) Plasma glucose lowering activity of methanolic extract of the flowering part in non-fasted Zucker diabetic fatty rats (Li et al., 2005)	Inhibits intestinal alpha-glucosidase activity, leading to antihyperglycemic property (Li et al., 2005)
Salacia reticulata Wight. Common name: Salacia Family: Celastaceae	Blood glucose lowering effect of aqueous decoction in fasted animals with improved glucose tolerance in laboratory animals (Karunanayake et al., 1984; Yoshikawa et al., 1998) Hypoglycemic activity of plant tea in type II diabetic patients in a randomised single centre double blind cross over clinical trial (Jayawardena et al., 2005)	Inhibits alpha-glucosidase activity (Karunanayake et al., 1984; Yoshikawa et al., 1998)
Salacia Oblonga Wall. Family: Celastaceae	Serum glucose lowering activity of aqueous methanolic extract of the roots in sucrose and maltose loaded rats and alpha-glucosidase and aldose reductase inhibitory activities of water soluble and ethyl acetate soluble fractions of the aqueous methanolic extract in same animal model (Matsuda et al., 1999) Antihyperglycemic, antihypoinsulinemic and antioxidant activity of petroleum ether extract of the root bark in streptozotocin diabetic rats (Krishnakumar et al., 1999) Antihyperglycemic effect of water extract in the obese Zucker rat (OZR) (genetic model of Type II diabetes) along with the effect on cardiac fibrosis upon chronic administration (Li et al., 2004) Plasma glucose and serum insulin reducing activity of the extract (1000 mg/kg) along with an alpha glucosidage inhibitory activity in a double-masked randomized cross over clinical study in healthy adults (Heacock et al., 2005)	Acts through inhibition of alpha-glucosidase activity (Matsuda et al., 1999)
Swertia chirayita (Roxb. ex Fleming) H. Karst. Common name: Indian Gentian Family: Gentianaceae	Blood glucose lowering activity of hexane fraction of 95% ethanol extract (250 mg/kg) in fed, glucose loaded and tolbutamide pretreated animals (Sekar et al., 1987) Insulin releasing effect of the hexane fraction of the plant (250 mg/kg body weight p.o. per day for 28 days) in albino rats along with a significant rise in liver glycogen (Chandrasekar et al., 1990) Blood sugar lowering activity of swerchirin, (1,8-dihydroxy-3,5-dimethoxyxanthone), isolated from hexane fraction of the plant in fasted, fed, glucose loaded and tolbutamide pretreated albino rats (Bajpai et al., 1991) Blood sugar lowering effect of Swerchirin (50 mg/kg p.o.) in healthy and streptozotocin treated (35 mg/kg i.v.) Charles Foster strain albino rats (Saxena et al., 1991, 1993)	Stimulates insulin release from islets of Langerhans by depleting aldehyde-fuchsin stained beta-granules and immunostained insulin (Saxena et al., 1993)

Table 1 (*Continued*)

Name of the plant	Activity with route of administration/dosage	Reported mechanism of action
Scoparia dulcis L. Common name: Sweet Broomweed Family: Scrophulariaceae	Hypoglycemic activity of aqueous leaf extract (0.15, 0.30 and 0.45 g/kg body weight for 45 days p.o.) in experimental diabetic rats along with a reduction in glycosylated haemoglobin and an increase in total haemoglobin (Pari and Venkateswaran, 2002) Blood glucose, sorbitol dehydrogenase, glycosylated hemoglobin, thiobarbituric acid reactive substances, hydroperoxides reducing and plasma insulin, glutathion peroxidase, glutathion *S*-transferase enhancing activities of aqueous plant extract (200 mg/kg) in the liver of streptozotocin adult diabetic male albino Wistar rats (Latha and Pari, 2004) Plasma insulin and plasma antioxidants enhancing activity of aqueous extract for 6 weeks at a dose of 200 mg/kg p.o. in diabetic rats (Pari and Latha, 2004) The insulin secretagogue activity of the plant extracts in isolated mice pancreatic islets at a dose of 10 mg/ml (Latha et al., 2004a) In vitro insulin secretagogue activity of the extract of this plant in rat insulinoma cell lines (RINm5F cells) treated with streptozotocin (Latha et al., 2004b)	Suppresses glucose influx into the polyol pathway leading to increased activities of antioxidant enzymes and plasma insulin and decreases activity of sorbitol dehydrogenase (Latha and Pari, 2004). Also potentiates insulin release from pancreatic islets (Latha et al., 2004a)

sulphur compound isolated from garlic (Fig. 1, [I]) resulted in pronounced hypoglycemia in mildly diabetic rabbits upon oral administration (0.25 mg/kg) but failed to produce such effect in severe diabetes in the animals at same dose (Mathew and Augusti, 1973). The hypoglycemic activity of *Allium sativum* and antioxidant activity of its active component, allicin have been explained in Table 1 with possible mechanism of action.

2.5. *Aloe vera (L.) Burm.f. (Family: Aloaceae)*

An acaulescent herb cultivated through out India. Aloes have long been used all over the world for their various medicinal properties. The extract of aloe gum is effective in enhancing glucose tolerance in normal as well as diabetic rats (Al-Awadi and Gumaa, 1987). Several other works have revealed the hypoglycemic activity of this plant along with possible mode of action (Table 1).

2.6. *Areca catechu L. (Family: Arecaceae)*

Areca catechu L. commonly known as betel nut, is a handsome tree cultivated throughout India. The nut contains a large quantity of tannin, gallic acid, fixed oil gum, volatile oil, lignin and alkaloids like arecoline, arecain, guracine, etc. Arecoline (Fig. 1, [II]) was investigated and reported to have hypoglycemic activity in an animal model of diabetes upon subcutaneous administration (Chempakam, 1993).

2.7. *Artemisia pallens Wall. ex DC. (Family: Compositae)*

It is a shrub used in the treatment of diabetes mellitus in the southern part of India. The hypoglycemic activity of the methanol extract of the aerial parts of *Artemisia pallens* Wall has been reported (Table 1).

2.8. *Annona squamosa L. (Family: Annonaceae)*

Annona squamosa L. commonly known as sugar apple is a 10–20 ft long tree found in different parts of India. According to the folklore claim *Annona squamosa* L. has hypoglycemic properties, which has been further supported by different research findings described in Table 1.

2.9. *Andrographis paniculata Nees (Family: Acanthaceae)*

It is an erect annual herb commonly known as Kalmegh or 'King of Bitters', found throughout India and cultivated in many states of India. A number of studies have shown that *Andrographis paniculata* extract and the active metabolite andrographolide (Fig. 1, [III]) can exert potent antihyperglycemic activity (Table 1).

2.10. *Aerva lanata (L.) Juss. ex Schult. (Family: Amaranthaceae)*

Aerva lanata (L.) Juss. ex Schult., commonly known as 'Sunny khur' is a many branched plant and widely used in Indian folk medicine for the treatment of diabetes mellitus. The effect of an alcoholic extract of *Aerva lanata* on blood glucose and other biochemical parameters in alloxan-induced diabetic rats was studied and it was observed that the extract reduced the increase of blood sugar in alloxanized rats by 42% at 375 mg/kg and 48% at 500 mg/kg body weight. The extract also reduced blood sugar level of alloxanized rats significantly upon chronic administration for 2 weeks (Vetrichelvan and Jegadeesan, 2002).

2.11. *Azadirachta indica A. Juss. (Family: Meliaceae)*

Azadirachta indica A. Juss., commonly referred as the neem tree, is a broad-leaved evergreen tree with a height of 20–30 m and a trunk girth of 2.5 m, found throughout India and is

widely recognized as potent insecticide. The hypoglycemic activity of various parts of *Azadirachta indica* is explained in Table 1.

2.12. *Biophytum sensitivum (L.) DC. (Family: Oxalidaceae)*

It is an annual herb found throughout tropical India and used in traditional folk medicine for the treatment of hyperglycemic patients. The hypoglycaemic activity of the plant leaf extract was investigated in experimental animal models with possible mechanism of action (Table 1).

2.13. *Bombax ceiba L. (Family: Bombacaceae)*

Bombax ceiba L., commonly known as silk cotton tree is distributed throughout India, particularly in Andhra Pradesh, usually occurring scattered in mixed deciduous forests. Shamimin (Fig. 1, [IV]), a flavonol glucoside isolated from the leaves of the plant has been reported to possess significant hypoglycemic activity at 500 mg/kg in rats (Saleem et al., 1999).

2.14. *Beta vulgaris L. (Family: Chenopodiaceae)*

Commonly known as garden beet is used traditionally in the management of diabetes in different parts of India. Various glycosides (Beta vulgarosides I–IV) isolated from the root of this plant were investigated for hypoglycemic activity (Table 1). The extract of the plant was also found to be effective in inhibiting non-enzymatic glycolization of skin proteins in streptozotocin-induced diabetic rats (Tunali et al., 1998).

2.15. *Brassica juncea (L.) Czern. (Family: Brassicaceae)*

This is a small herb cultivated throughout India and used as a spice in food and has been reported to exert significant hypoglycemic activity (Table 1).

2.16. *Barleria lupulina Lindl. (Family: Acanthaceae)*

A popular medicinal plant distributed in mountains of southern and western India Aerial parts of *Barleria lupulina* Lindl. (300 mg/kg) has been found to possess significant hypoglycemic activity (Suba et al., 2004a,b).

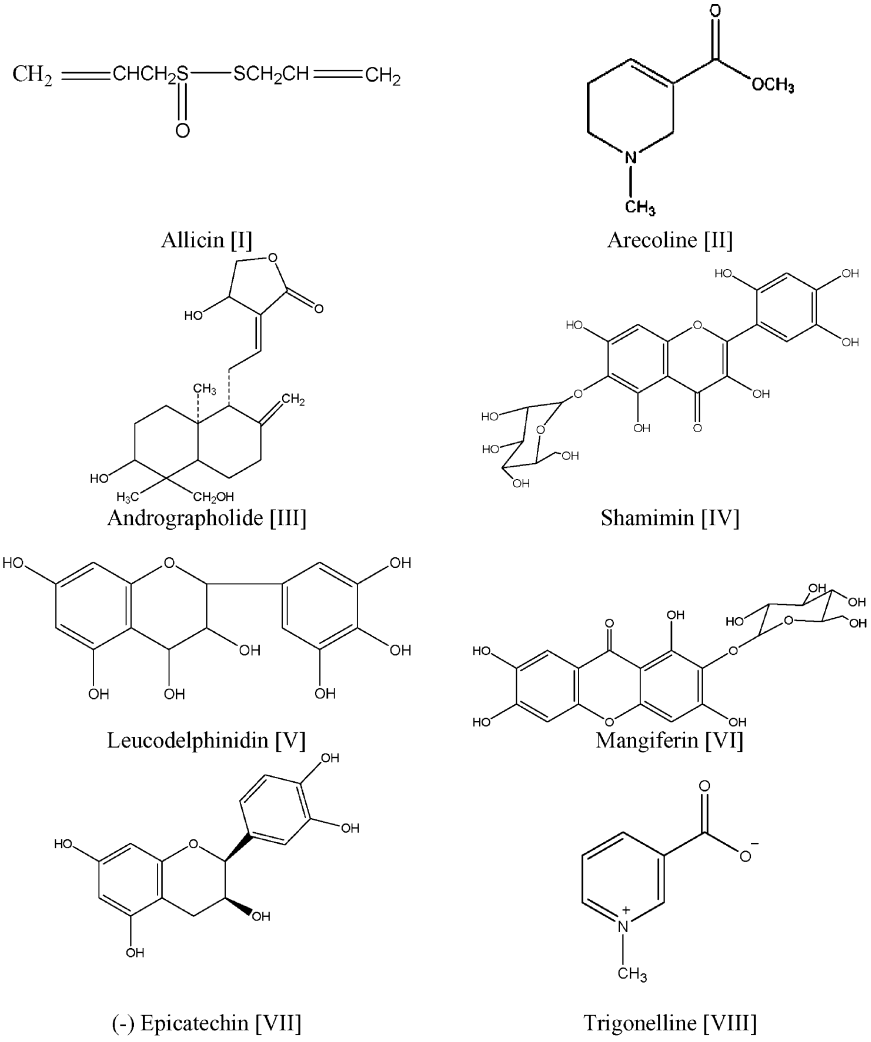


Fig. 1. Hypoglycemic phytoconstituents.

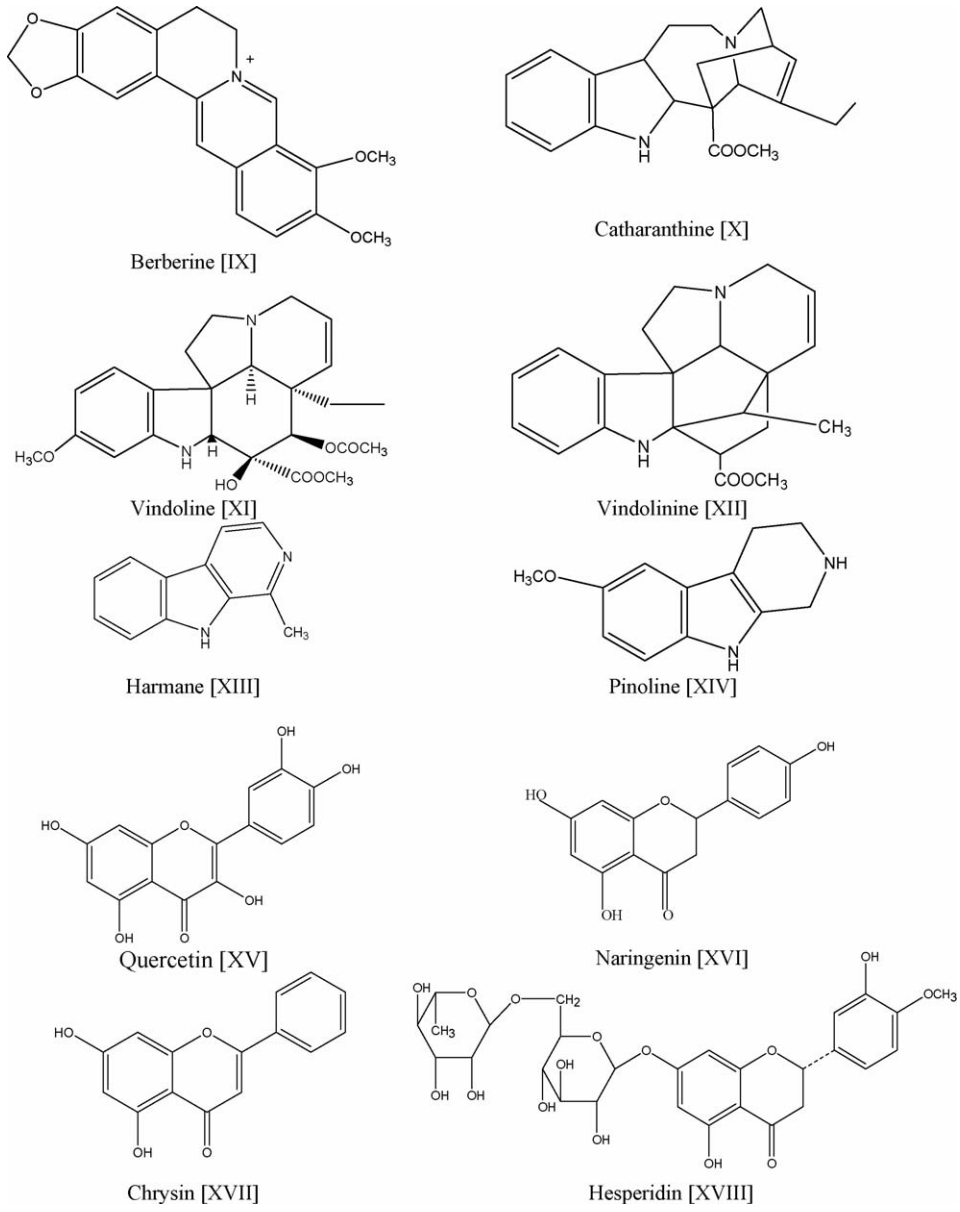


Fig. 1. (*Continued*).

2.17. *Boerhavia diffusa L. (Family: Nyctaginaceae)*

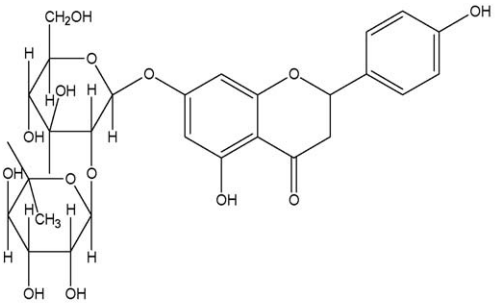
It is a common plant grows widely in the tropics in both dry and rainy seasons in India, Nigeria and many other countries. The aqueous leaf extract of *Boerhaavia diffusa* L. was shown to produce significant hypoglycemic activity with an increase in plasma insulin levels in normal and diabetic rats at varied doses upon oral administration and found to exert antioxidant activity in experimental animal model (Table 1).

2.18. *Cassia auriculata L. (Family: Leguminosae)*

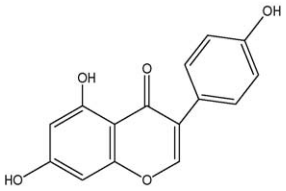
It is an evergreen Indian shrub commonly known as Tanner's Cassia, having vivid yellow flowers, whose bark is used in tanning. The hypoglycemic potential of the plant was studied extensively by several workers and it was found that the flower of *Cassia auriculata* possess significant hypoglycemic activity along with potent antioxidant and alpha glucosidase inhibitory actions, responsible for the blood glucose lowering property of the plant (Table 1).

2.19. *Caesalpinia bonducella (L.) Roxb. (Family: Cesalpinaceae)*

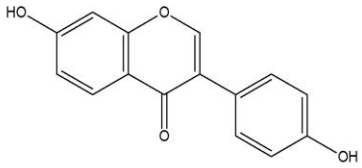
Caesalpinia bonducella is a shrub widely distributed throughout the coastal region of India. The tribal people of India use it for controlling blood sugar. Several workers have reported the hypoglycemic activity of different parts of this plant



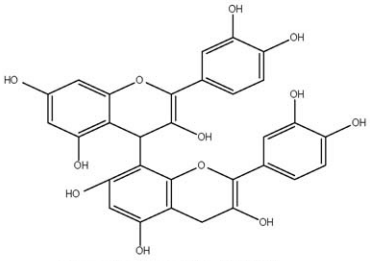
Naringin [XIX]



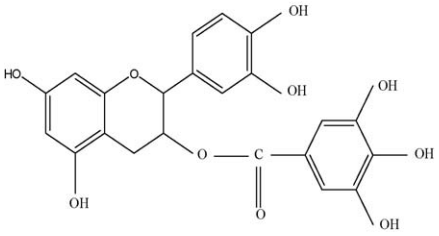
Genistein [XX]



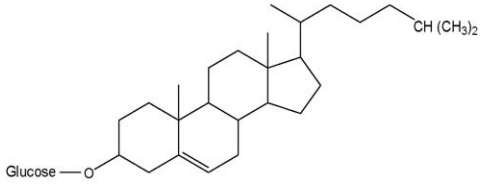
Daidzein [XXI]



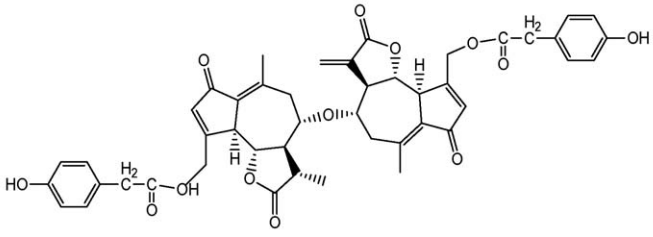
Proanthocyanidin [XXII]



Epigallocatechin -3-O-gallate [XXIII]



Charantin [XXIV]



Lactucain C [XXV]

Fig. 1. (*Continued*).

in various animal models highlighting the possible mechanism of action (Table 1).

2.20. *Capparis decidua (Forsk.) Edgew. (Family: Capparidaceae)*

It is a climbing shrub with vine-like branches hanging in bundles found in the western part of India, particularly in Rajasthan. The hypoglycemic activity of the powdered fruit of the plant was investigated in alloxan-induced diabetic rats. The effect was assessed on lipid peroxidation and the antioxidant defense system in rat tissues. It lowered lipid peroxidation in these tissues and significantly increased the activity of enzymes associated with antioxidant defense system. The increase in glucose-6-phosphate dehydrogenase in the kidney and heart of diabetic rats was also decreased with *Capparis decidua* treatment (Yadav et al., 1997a,b).

2.21. *Cajanus cajan (L.) Millsp. (Family: Fabaceae)*

Perennial woody shrub grows throughout India and traditionally used in the treatment of diabetes mellitus. The effect of roasted and unroasted seeds of this plant was examined on serum glucose levels of normal and alloxan diabetic mice by Amalraj and Ignacimuthu (1998a). The aqueous leaf extract was also studied for possible glucose lowering activity. Even a study in healthy human volunteers also showed significant hypoglycemic activity (Table 1).

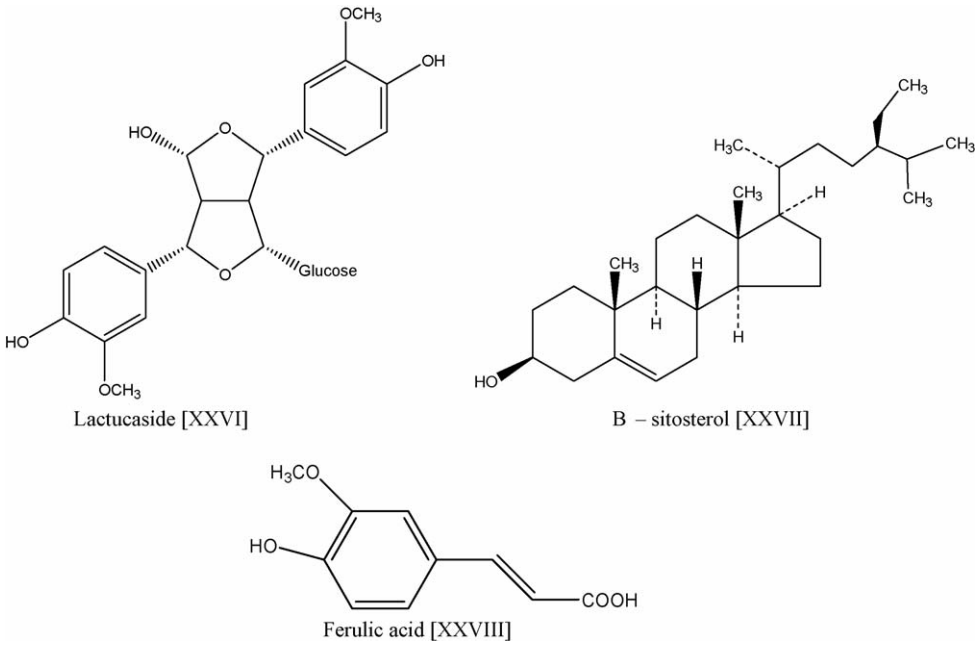


Fig. 1. (*Continued*).

2.22. *Citrullus colocynthis (L.) Schrad. (Family: Cucurbitaceae)*

It is an annual or perennial (in wild) herbaceous vine commonly known as "Bitter apple", distributed and cultivated throughout India. The effects of various extracts of the plant were investigated for plasma glucose lowering activity in normoglycemic as well as hyperglycemic rabbits and the results with mechanism of action have been described in Table 1.

2.23. *Coccinia indica Wight & Arn. (Family: Cucurbitaceae)*

A creeper grows wildly in many parts of the Indian subcontinent and is well known as an hypoglycemic herb. The hypoglycemic activity of the plant was reported by Khan et al. (1980) (Table 1). Hypoglycaemic activity of Pectin, isolated from the fruit of *Coccinia indica* was studied in normal rats at a dose of 200 mg/100 g/day upon oral administration and it showed significant reduction in blood glucose and an increase in the liver glycogen level (Kumar et al., 1993). Ethanolic leaf extract of *Coccinia indica* (200 mg/kg for 45 days) also produced a modulatory effect on the aortic collagen content of STZ diabetic rats by reducing the accumulation and cross-linking of collagen (Venkateswaran et al., 2003). The extract also exhibited significant antioxidant activity (Venkateswaran and Pari, 2003a,b) and hypolipidaemic activity (Pari and Venkateswaran, 2003) in streptozotocin induced diabetic rats.

2.24. *Casearia esculenta Roxb. (Family: Flacourtiaceae)*

It is a shrub or a tree with a pale yellow bark found in various parts on India and well known as hypoglycemic in folk medicine. The hypoglycemic activity of this plant has been studied and reported by many workers (Choudhury and Basu, 1967; Gupta et al., 1967). Antihyperglycemic activity of the plant has been studied extensively revealing the mechanism of its blood glucose lowering potential (Table 1). The plant root extract also possesses significant hypolipidaemic (Prakasam et al., 2003c) and antiperoxidative activity in red blood cells of streptozotocin (STZ) diabetic rats (Prakasam et al., 2003d). The extract produced an alleviative effect in liver and renal damage associated with STZ-induced diabetes in rats (Prakasam et al., 2004).

2.25. *Catharanthus roseus (L.) G. Don. (Family: Apocynaceae)*

It is a perennial, evergreen herb distributed throughout India. It was used as a folk remedy for diabetes in various parts of India. Various parts of this plant along with the leaves, twigs have been investigated for possible hypoglycemic activity in normoglycemic as well as hyperglycemic rats (Table 1).

2.26. *Camellia sinensis Kuntze (Family: Theaceae)*

Camellia sinensis Kuntze commonly known as tea, is a small evergreen tree. Native to Southeast Asia, from Sri Lanka and India to Nepal and China, tea has been planted widely in tropical and subtropical areas. The blood glucose lowering activity of *Camellia sinensis* was studied by many workers and the results of the investigations substantiated its claim as an hypoglycemic agent (Table 1).

2.27. *Eugenia uniflora L. (Family: Myrtaceae)*

It is a small tree or shrub native to south east Asia. 70% ethanol extracts from the leaves of *Eugenia uniflora*, separated into different fractions were examined and it was found that

two fractions inhibited the increase in plasma glucose level. The increased plasma triglyceride level was inhibited by the extract in an oral corn oil tolerance test. The glucose inhibitory effect of the extract in different tests may be due to the inhibition of the decomposition of carbohydrates and fats in the intestine (Arai et al., 1999).

2.28. *Eucalyptus globulus Labill. (Family: Myrtaceae)*

It is a handsome ornamental tree most widely found in subtropical India. An aqueous extract of eucalyptus (0.5 g/l) enhanced 2-deoxy-glucose transport by 50%, glucose oxidation by 60% and incorporation of glucose into glycogen by 90% in mouse abdominal muscle. It also enhanced insulin secretion from the clonal pancreatic beta-cell line. The insulin-releasing effect of the aqueous extract of *Eucalyptus globulus* is probably responsible for antihyperglycemic activity (Gray and Flatt, 1998).

2.29. *Enicostemma littorale Blume (Family: Gentiaceae)*

Perennial herb attaining height of 5–20 in., found throughout India up to height of 1500 ft. The hypoglycemic potential of the plant was studied by several workers, indicating significant blood glucose lowering activity (Table 1). A clinical study involving 84 patients with Type II Diabetes showed that pills prepared from *Enicostemma littorale* Blume administered for three months reduced blood glucose as well as serum insulin levels and prevented the progression of complications in diabetic patients. It also improved kidney function, lipid profile and blood pressure significantly (Upadhyay and Goyal, 2004).

2.30. *Eugenia jambolana Lam. (Family: Myrtaceae)*

Large evergreen tree of Indian subcontinent, also known as *Syzygium cumini* L. commonly known as 'jamun'. In India, the decoction of kernels of *Eugenia jambolana* is used as a household remedy for diabetes. The seeds and decoction of dry leaves were found to produce hypoglycemic effect (Mahapatra et al., 1985; Coimbra et al., 1992; Nandkarni, 1992). The protective effect of the alcoholic (100 mg/kg) and the aqueous (5 g/kg) extracts of the seed of this plant against tissue damage in diabetic rat brain was studied and it was observed that both the extract effectively protected the tissues, the alcoholic extract having more pronounced effect than the water extract (Stanely et al., 2003) (Table 1).

2.31. *Ficus bengalensis L. (Family: Moraceae)*

It is a very large tree with spreading branches distributed throughout India. Various active components isolated from the plant including the dimethoxy derivative of leucocyandin 3-*O*-beta-D-galactosyl cellobioside, dimethoxy derivative of perlargonidin 3-*O*-alpha-L rhamnoside, glycoside of leucopelargonidin, leucodelphinidin (Fig. 1, [V]), isolated from the bark of this plant have been reported for their hypoglycemic activity as explained in Table 1 (Deshmukh et al., 1960; Brahmachari and Augusti, 1964; Kumar and Augusti, 1994).

2.32. *Gymnema montanum Hook.f. (Family: Asclepiadaceae)*

It is an endemic and endangered plant species of India found mainly in Western Ghats. Blood glucose lowering activity of alcoholic leaf extract (200 mg/kg orally) was studied in alloxan diabetic rats along with an increase in plasma insulin level (Ananthan et al., 2003a). The extract also produced significant antioxidant and antiperoxidative activity in alloxanized rats (Ananthan et al., 2003b, 2004; Ramkumar et al., 2004). The leaf extract was also reported to exert potent antihyperlipidemic activity in alloxanized rats (Ananthan et al., 2003c).

2.33. *Gymnema sylvestre R. Br. (Family: Asclepiadaceae)*

Gymnema sylvestre R. Br. is one of the Asclepiad strains, native to the tropical regions of India and commonly known as the "sugar destroyer" because the leaves effectively block sweet tastes in the mouth when chewed. The plant has been used in the treatment of diabetes mellitus for a long time in India and reported by different workers for its blood glucose lowering activity both in vitro and in vivo (Shanmugasundaram et al., 1983; Fushiki et al., 1992; Tominaga et al., 1995; Shimizu et al., 1997; Yoshikawa et al., 1997a,b; Chattopadhyay, 1998, 1999; Persaud et al., 1999; Sugihara et al., 2000; Gholap and Kar, 2003).

2.34. *Glycyrrhiza glabra L. (Family: Fabaceae)*

Glycyrrhiza glabra L. commonly known as licorice, is a flavorful perennial herb that grows 3–7 ft high and has been used in food and medicinal remedies for thousands of years. The effect of hydrophobic flavonoids from this plant was studied on abdominal fat accumulation and blood glucose level in obese diabetic KK-A (y) mice. The findings indicated that the flavonoids have abdominal fat-lowering and hypoglycemic effects, possibly mediated through activation of peroxisome proliferator-activated receptor-gamma (PPAR-gamma) (Nakagawa et al., 2004).

2.35. *Hibiscus rosa sinensis L. (Family: Malvaceae)*

These are large shrubs or small trees grow to 15 ft high in frost-free climates and are native to southern Asia. The plant was studied extensively by many workers for its hypoglycemic activity in various models of experimental diabetes like glucose-loaded rats, streptozotocin diabetic rats, etc. and it was found that the plant has potent blood glucose lowering activity (Table 1).

2.36. *Helicteres isora L. (Family: Sterculiaceae)*

It is a well-known plant of Indian subcontinent. The root juice of this plant has been used in the treatment of diabetes by several ethnic groups in different parts of India. The root

extracts has been reported to possess significant hypoglycemic activity because of the insulin-sensitizing property of the plant (Table 1).

2.37. *Ipomoea batatas (L.) Lam. (Family: Convolvulaceae)*

It is a tuberous-rooted perennial plant commonly known as Sweet potato, cultivated in many tropical and subtropical countries and has become an important food crop, especially in India, China, Philippine Islands, and the South Seas Islands. Hypoglycemic effect of this plant was investigated by several workers and reported as described in Table 1.

2.38. *Lantana camara L. (Family: Verbenaceae)*

It is a rugged evergreen shrub found throughout India. The leaf juice of this plant at a dose of 1500 mg/kg p.o. daily for 14 days produced significant hypoglycemic activity in rats (Garg et al., 1997).

2.39. *Mangifera indica L. (Family: Anacardiaceae)*

It is a well-known perennial tree commonly known as Mango, distributed and widely cultivated throughout India. The aqueous leaf-extract (1 g/kg) failed to exert any hypoglycemic activity in normoglycemic as well as streptozotocin-induced diabetic rats upon oral administration (Aderibigbe et al., 1999). Antihyperglycemic activity of the leaf extract at the same dose level was investigated by the same author in different experimental condition (Table 1) along with its antioxidant activity (Martinez et al., 2000). The glucose lowering effect of mangiferin (Fig. 1, [VI]), a xanthone glucoside, isolated from the leaves of *Mangifera indica* was also studied (Table 1).

2.40. *Memecylon umbellatum Burm. f. (Family: Melastomataceae)*

Alcoholic extract of the leaves of *Memecylon umbellatum* (250 mg/kg) exerted significant serum glucose lowering effect in normal and alloxan-induced diabetic mice upon oral administration (Amalraj and Ignacimuthu, 1998b).

2.41. *Momordica cymbalaria Fenzl ex Naudin (Family: Cucurbitaceae)*

It is a well-known medicinal plant found in different parts of India. Fruit powder and aqueous fruit extract of *Momordica cymbalaria* was investigated for its effect on blood glucose and other biochemical parameters in alloxan-induced diabetic rats and found to exert potent blood glucose lowering effect (Table 1).

2.42. *Mucuna pruriens (L.) DC. (Family: Leguminosae)*

Mucuna pruriens (L.) DC. is one of the popular medicinal plants of India and is constituent of many indigenous drug formulations. The seed and plant extracts were investigated for possible blood sugar lowering activity in different animal models of diabetes and the results indicated a strong hypoglycemic potential of the plant (Table 1).

2.43. *Musa sapientum L. (Family: Musaceae)*

It is a perennial herbaceous plant commonly known as 'banana'. It is mainly used in Indian folk medicine for the treatment of diabetes mellitus. Several studies revealed its hypoglycemic activity (Jain, 1968, 1969). Blood glucose lowering activity of flower extract (0.15, 0.20 and 0.25 g/kg p.o. for 30 days) in experimental animals in an oral glucose tolerance test along with a reduction in glycosylated haemoglobin and an increase in total haemoglobin as well as significant antioxidant activity at the same dose levels were investigated and reported (Pari and Maheswari, 1999; Pari and Umamaheswari, 2000).

2.44. *Momordica charantia L. (Family: Cucurbitaceae)*

It's a slender, climbing annual vine commonly known as 'bitter gourd' and 'karela' grows in India and other tropical countries. Several earlier and recent studies have indicated the hypoglycemic activity of various parts of this plant (Sharma et al., 1960; Gupta and Seth, 1962; Vimla Devi et al., 1977; Khanna et al., 1981; Kedar and Chakrabarti, 1982; Welihinda et al., 1982; Ng et al., 1986a,b, 1987; Karunanayake et al., 1990; Ali et al., 1993; Shibib et al., 1993; Cakici et al., 1994; Sarkar et al., 1996; Sitasawad et al., 2000; Miura et al., 2001, 2004; Kar et al., 2003; Sekar et al., 2005; Yadav et al., 2005).

2.45. *Morus alba L. (Family: Moraceae)*

It is a small to medium-sized monoecious or dioecious shrub or tree, up to 15 m tall extensively grown in India for its leaves as food for silkworms. The hypoglycemic activity of the leaf extract of this plant has been reported by many workers (Table 1).

2.46. *Murraya koeingii (L.) Spreng. (Family: Rutaceae)*

Commonly known as curry-leaf tree, a native of India and Sri Lanka, is a small tree with very pungent aromatic leaves. The leaves of this plant exhibited blood sugar lowering effect attributed to increased glycogenesis and decreased glycogenolysis and gluconeogenesis (Table 1).

2.47. *Nelumbo nucifera Gaertn. (Family: Nymphaeaceae)*

It is an aquatic perennial herb commonly known as sacred lotus, found through out India. Oral administration of the ethanolic extract of rhizomes of *Nelumbo nucifera* Gaertn. markedly reduced the blood sugar level of normal, glucose-fed hyperglycemic and streptozotocin-induced diabetic rats. The extract also found to improve glucose tolerance and potentiated the action of exogenously injected insulin in normal rats (Mukherjee et al., 1995, 1997).

2.48. *Ocimum sanctum L. (Family: Lamiaceae)*

A tropical much branched, annual herb, up to 18 inches tall, commonly known as Holy Basil distributed throughout India. The plant showed significant hypoglycemic activity as evident from various experiments. Table 1 demonstrates the blood glucose lowering activity of the plant and its effect on important enzymes of carbohydrate metabolism. It is thought that the hypoglycemic effect of the plant extract may be mediated by its cortisol inhibiting potency and the plant may be used effectively in regulating corticosteroid-induced diabetes mellitus (Gholap and Kar, 2004).

2.49. *Picrorrhiza kurroa Royle ex Benth. (Family: Scrophulariaceae)*

A small herb grows in the Himalayas at 3000–5000 m and used extensively in the ayurvedic medicine. Alcoholic extract at dose of 75 mg/kg produced maximum reduction in serum glucose after 2 h. It also reduced the enhanced glucose level in serum of alloxan-induced diabetic rats. The extract was also found to reduce the increased blood urea nitrogen and serum lipid peroxides in alloxan-induced diabetic animals (Joy and Kuttan, 1999).

2.50. *Phyllanthus amarus Schumach. & Thonn. (Family: Euphorbiaceae)*

Oral administration of the whole plant with a dose of 5 g/day for 10 days produced reduction in blood glucose in diabetic rats and in non-diabetic subjects (Srividya and Periwal, 1995). The methanolic extract was found to reduce the blood sugar in alloxan diabetic rats at fourth hour by 6% at a dose of 200 mg/kg and 18.7% at a concentration of 1000 mg/kg and produced significant ($P < 0.001$) reduction in blood sugar upon continued administration for 15 days and also found to have potential antioxidant activity (Raphael et al., 2002).

2.51. *Pterocarpus marsupium Roxb. (Family: Fabaceae)*

It is a well-known plant commonly known as Vijaysar, found throughout India. In folk medicine the plant is used as hypoglycemic, which was proved by some earlier studies (Bose and Sepaha, 1956; Gupta, 1963; Shah, 1967). Different parts of the plant like bark, latex, etc. were investigated and reported to have hypoglycemic activity (Vats et al., 2002, 2004a,b; Kar et al., 2003; Abesundara et al., 2004). Various active components like (−)-epicatechin (Fig. 1, [VII]), marsupsin, pterosupin and pterostilbene, isolated from the bark and heartwood of the plant, were also found to possess blood sugar lowering activity (Sheehan et al., 1983; Ahmad et al., 1989, 1991; Rizvi et al., 1995; Manickam et al., 1997).

2.52. *Punica granatum L. (Family: Punicaceae)*

It is a traditional hypoglycemic plant, commonly known as pomegranate. The hypoglycemic activity of the flower and seeds of this plant is shown in Table 1. The fruit juice has been reported to possess significant antihyperlipidemic activity in type II diabetic patients (Esmaillzadeh et al., 2004). The fruit juice (500 mg/kg) also reported to have potent inhibitory activity in abnormal cardiac tryglyceride accumulation and hyperlipidemia in Zucker diabetic fatty (ZDF) rats upon long-term oral administration (Huang et al., 2005). Other findings suggest that the extract improves postprandial hyperglycemia in type II diabetes and partly inhibits intestinal alpha-glucosidase activity (Table 1).

2.53. *Pterocarpus santalinus L. f. (Family: Leguminosae)*

It is a small tree attains a height of 7.5 m and traditionally used in the treatment of diabetes, bleeding piles, dysentery and in all skin inflammations (Nadkarni, 1976). The bark extracts of *Pterocarpus santalinus* L. at a dose of 0.25 g/kg body weight showed maximum antihyperglycemic activity but failed to produce any hypoglycemic activity in normal rats (Kameswara Rao et al., 2001).

2.54. *Salacia reticulata Wight. (Family: Celastaceae)*

Salacia reticulata Wight. is distributed in Sri Lankan and Indian forests and has been used as a supplementary food to prevent obesity and diabetes. Studies by Karunanayake et al. (1984) and Yoshikawa et al. (1998) suggested the hypoglycemic activity and possible mechanism behind the activity of the plant (Table 1). The plant contains Salacinol, a potent alpha-glucosidase inhibitor (Muraoka et al., 2001), which may account for the glucose lowering effect of the plant. A clinical trial investigating the effects of *Salacia reticulata* Wight. in type II diabetic patients also proved its effectiveness (Table 1).

2.55. *Salacia oblonga Wall. (Family: Celastaceae)*

This is a woody plant found in the forests of Sri Lanka and India. The roots and stems of this plant have been used extensively in Aryuveda and traditional Indian medicine for the treatment of diabetes. Augusti et al. (1995) reported the presence of hypoglycemic components in the root bark of this plant. Several other studies in various animal models of diabetes as well as clinical investigations have revealed the hypoglycemic activity of different parts of the plant (Table 1) and supported its claim of being used as an hypoglycemic agent.

2.56. *Swertia chirayita (Roxb. ex Fleming) H. Karst. (Family: Gentianaceae)*

It is a traditional Ayurvedic herb commonly known as Chiretta. The hypoglycemic and antihyperglycemic efficacy of the plant extract as well as swerchirin (1,8-dihydroxy-3,5-dimethoxyxanthone), an active constituent isolated from the hexane fraction of the plant have been studied in various animal models of diabetes and found to exert potent hypoglycemic activity (Saxena et al., 1993) (Table 1).

2.57. *Scoparia dulcis L. (Family: Scrophulariaceae)*

Commonly known as 'Sweet Broomweed' is widely used in Indian folk medicine for the treatment of diabetes mellitus. Various extracts of the plant has been reported to increase the activities of insulin and to reduce the blood glucose level in streptozotocin diabetic rats. The extracts also produced significant antioxidant activity in liver, kidney and brain of the diabetic rats (Latha and Pari, 2003a). The beneficial effect of the extract on glycoproteins of diabetic rats (Latha and Pari, 2005) and insulin-receptor-binding effect, resulting in significant increase in plasma insulin has been rerpoted (Pari et al., 2004).

2.58. *Syzygium alternifolium Walp. (Family: Myrtaceae)*

Aqueous, ethanolic and hexane extracts of the seeds of this plant was studied in normal and alloxan diabetic rats and the extracts showed significant hypoglycemic and antihyperglycemic activity, with aqueous extract showing the maximum effect (Rao and Rao, 2001).

2.59. *Sida cordifolia L. (Family: Malvaceae)*

It is a perennial shrub of a height up to 1 m. It has been used in India for over 2000 years to treat different disease conditions. The methanol extract of root of this plant has been reported to possess significant hypoglycaemic activity (Kanth and Diwan, 1999).

2.60. *Trigonella foenum graecum L. (Family: Fabaceae)*

Commonly known as fenugreek, is a well-known hypoglycemic agent used in traditional Indian medicines. Various extracts of different parts of this plant; fibres, proteins and saponins isolated from the seeds were investigated and found to possess significant hypoglycemic activity (Ghafghazi et al., 1977; Ribes et al., 1986; Ali et al., 1995; Khosla et al., 1995; Abdel-Barry et al., 1997; Anuradha and Ravikumar, 2001; Genet et al., 2002; Mukherjee, 2003; Thakran et al., 2004; Vats et al., 2004b). Shani et al. (1974) reported that trigonella seeds and the major alkaloid component, Trigonelline (Fig. 1, [VIII]), exerted a mild hypoglycemic effect

2.61. *Terminalia catappa L. (Family: Combretaceae)*

It is a large deciduous stately tree from India, growing up to 90 ft tall with horizontal whorls of branches. The effect of petroleum ether, methanol, and aqueous extracts of the fruit was examined on fasting blood sugar levels and serum biochemical parameters in alloxan-induced diabetic rats and produced significant hypoglycemic activity and alleviated the pancreatic necrosis produced by alloxan administration (Nagappa et al., 2003).

2.62. *Terminalia pallida Brandis (Family: Combretaceae)*

It is a well-known plant found in various parts of India. Ethanolic fraction of fruits of *Terminalia pallida* has been reported to exhibit a significant antihyperglycemic activity in alloxan diabetic rats at a dose of 0.5 g/kg orally but failed to reduce the blood sugar level in normal rats (Kameswara Rao et al., 2003b).

2.63. *Tinospora cordifolia (Willd.) Hook.f. & Thomson (Family: Menispermaceae)*

It is a large climbing shrub found throughout India and used in various ailments. Various extracts of the leaves of this plant were investigated for their blood sugar lowering activity in normal and alloxanized rabbits in graded doses and the findings have proved that the plant has potent hypoglycemic activity (Wadood et al., 1992; Prince and Menon, 1999; Stanely et al., 1999; Grover et al., 2000; Stanely and Menon, 2000, 2001, 2003; Prince et al., 2004b,c).

2.64. *Zingiber officinale Roscoe (Family: Zingiberaceae)*

It is a dietary component widely cultivated in India and commonly known as ginger. The juice of *Zingiber officinale* administered at a dose of 4 ml/kg p.o. daily for 6 weeks significantly prevented hyperglycaemia and hypoinsulinaemia in streptozotocin (STZ)-induced type I diabetic rats. It also produced a significant increase in insulin levels and a decrease in fasting glucose levels in diabetic rats. In an oral glucose tolerance test, the extract was found to decrease the glucose level and to increase the insulin level significantly in STZ-diabetic rats and suggested that hypoglycemic activity of the juice of *Zingiber officinale* in type I diabetic rats possibly involved 5-HT receptors (Akhani et al., 2004).

2.65. *Zizyphus sativa Gaertn. (Family: Rhamnaceae)*

It is a small spreading tree with drooping branches. An alcoholic extract of the leaves of this plant showed dose-dependent reduction in blood glucose level but failed to produce significant hypoglycemic activity in alloxan-diabetic rats (Anand et al., 1989).

3. Phytoconstituents with hypoglycemic potentials

Compound with different structure but with the same therapeutic activity isolated from different plant species act as active moieties for the treatment of various diseases. Some of these active principles originate from edible plants and their inclusion in the diet would undoubtedly be of some value because of their hypoglycemic potential. Several phytomolecules including flavonoids, alkaloids, glycosides, saponins, glycolipids, dietary fibres, polysaccharides, peptidoglycans, carbohydrates, amino acids and others obtained from various plant sources have been reported as potent hypoglycemic agent as has been further explained in the following section. The chemical structures of a few potential phytomolecules with hypoglycemic activity are shown in Fig. 1.

3.1. Alkaloids

Various alkaloids have been isolated from numerous Indian medicinal plants and investigated for their possible hypoglycemic activity in different animal models. Berberine (Fig. 1, [IX]) is known to have potent hypoglycemic activity. It is obtained from *Tinospora cordifolia* (Singh et al., 2003). The mode of its antihyperglycemic activity was investigated in the Caco-2 cell line. Berberine effectively inhibited the activity of disaccharidases in Caco-2 cells, decreased sucrase activity after preincubation with Caco-2 cells for 72 h but failed to produce any significant effect on gluconeogenesis and glucose consumption of Caco-2 cells, suggesting that the antihyperglycaemic activity of berberine is at least partly due to its ability to inhibit alpha-glucosidase and decrease glucose transport through the intestinal epithelium (Pan et al., 2003). Alkaloids like catharanthine [X], vindoline [XI] and vindolinine [XII] (Fig. 1), obtained from *Catharanthus roseus* also lower blood sugar level (Chattopadhyay, 1999).

3.2. Imidazoline compounds

Certain imidazoline compounds are known to have a stimulatory action on insulin secretion by activation of imidazoline I (3) binding sites in the pancreatic beta cell. Beta-carbolines, having activity at imidazoline sites been studied for their effects on insulin secretion. Harmane (Fig. 1, [XIII]), norharmane and pinoline (Fig. 1, [XIV]), the beta-carbolines were found to increase insulin secretion two- to three-fold from isolated human islets of Langerhans. Harmane and norharmane obtained from *Tribulus terrestris* L. and may account for the hypoglycemic property of the plant (Nadkarni, 1976; Kirtikar and Basu, 1993). Harmane stimulates insulin secretion in a glucose-dependent manner. The results strongly substantiated the claim of beta-carbolines as potent insulin secretagogues (Cooper et al., 2003).

3.3. Polysaccharides

Various Indian hypoglycemic plants like *Aloe vera*, *Ocimum sanctum*, *Alpinia galanga* are found to contain polysaccharides. A protein-bound polysaccharide, isolated from water-soluble substances of pumpkin was investigated for hypoglycemic activity in various doses (500 and 1000 mg/kg body weight) in alloxan diabetic rats. The results indicated that the polysaccharides increased the levels of serum insulin, reduce the blood glucose levels and improve tolerance of glucose (Quanhong et al., 2005).

3.4. Flavonoids

Flavonoids represent another beneficial group of naturally occuring compounds with hypoglycemic potentials. These are widely distributed in plant kingdom and exhibit distinctive pharmacological properties. The flavonoids can be widely classified into different categories like flavanols, flavones, catechins, flavanones, etc. Some flavonoids have hypoglycemic properties because they improve altered glucose and oxidative metabolisms of diabetic states. Quercetin (Fig. 1, [XV]) is an important flavonoid known to possess a vast array of pharmacological activities. Intraperitoneal administration of quercetin to normal as well as streptozocin-induced diabetic rats resulted in marked reduction in plasma glucose level of diabetic animals while the glucose level of the normoglycemic rats remained unalterd. Quecrcetin also suppressed the glucose level in diabetic rats in a glucose tolerance tests, reduced plasma cholesterol and triglycerides significantly and increased their hepatic glucokinase activity probably by enhancing the insulin release from pancreatic islets of the diabetic rats (Vessal et al., 2003). Some flavonoid molecules like quercetin, naringenin [XVI], chrysin [XVII] (Fig. 1) significantly enhanced the insulin release from isolated rat islets of langerhans in presence of 20 mmol glucose/l. Quercetin exerted its stimulatory effect on insulin release partly by changing Ca^{2+} metabolism (Hii and Howell, 1985). Effect of citrus bioflavonoids, hesperidin [XVIII] and naringin [XIX] (Fig. 1), on blood glucose level, hepatic glucose-regulating enzymes activities, hepatic glycogen concentration, and plasma insulin levels was investigated in male C57BL/KsJ-db/db mice, an animal model for Type II diabetes. Supplementation of the citrus flavonoids (0.2 g/kg diet) in the diet significantly reduced the blood glucose level as well as increased hepatic glucokinase activity and glycogen concentration in diabetic rats. Naringin also markedly lowered the activity of hepatic glucose-6-phosphatase and phosphoenolpyruvate carboxykinase and the plasma insulin, C-peptide, and leptin levels in the diabetic mice were significantly increased as a result of supplementation. The findings suggested that hesperidin and naringin both play important roles in preventing the progression of hyperglycemia, partly by increasing hepatic glycolysis and glycogen concentration and/or by lowering hepatic gluconeogenesis (Jung et al., 2004). The soy isoflavones genistein [XX] or daidzein [XXI] (Fig. 1) were investigated for their possible hypoglycemic activity in male and female obese Zucker rats, a model of Type II diabetes. Peroxisome-proliferator activated receptors (PPAR) are promiscuous nuclear receptors that regulate the transcription of genes involved in lipid and glucose homeostasis and lipid metabolism within the cell. The results of the study indicated that the isoflavones significantly improved lipid and glucose metabolism by acting as an hypoglycemic PPAR agonist (Mezei et al., 2003). Proanthocyanidins (Fig. 1, [XXII]) the flavonoids with an oligomeric structure, are found to improve the pathological oxidative state of a diabetic situation. An extract of grape seed procyanidins administered orally to streptozotocin-induced diabetic rats produced significant antihyperglycemic activity possibly by its insulinomimetic activity. It also stimulated glucose uptake in insulin sensitive cells in vitro (Pinent et al., 2004). Another flavonoid glycoside Kaempferitrin (Kaempferol-3,7-*O*-(alpha)-L-dirhamnoside) was found to have an acute lowering effect on blood glucose in diabetic rats and stimulated the glucose uptake, as efficiently as insulin in muscle from normal rats in vitro, suggesting that blood glucose lowering activity of the compound attributed to altered intrinsic activity of the glucose transporter (Jorge et al., 2004). The hypoglycemic activity of the compound was also studied along with its antioxidant potential in normal and in alloxan-induced diabetic rats. Oral administration of the compound (200 mg/kg)

significantly reduced the blood glucose level in normal rats 1 h after treatment and the antihyperglycemic activity in diabetic rats was observed at all doses tested (50, 100, and 200 mg/kg) throughout the period of the study. Green tea flavonoid, epigallocatechin gallate (Fig. 1, [XXIII]) is reported to have glucose-lowering effects in animals. It was found to decrease hepatic glucose production and increased tyrosine phosphorylation of the insulin receptor and insulin receptor substrate-1 (IRS-1) like insulin. It also reduces phosphoenolpyruvate carboxykinase gene expression in a phosphoinositide 3-kinase-dependent manner and mimics insulin by increasing phosphoinositide 3-kinase, mitogen-activated protein kinase, and p70 (s6k) activity. These findings suggest that epigallocatechin gallate is an important hypoglycemic agent (Waltner-Law et al., 2002). Another flavonoid molecule, (−)-epicatechin (VII), has been reported to possess insulin-like activity. Chakravarthy et al. (1981) suggested that the molecule protected the experimental albino rats against the diabetogenic actions of alloxan. This flavonoid molecule mimics insulin in its effect on erythrocyte membrane acetylcholinesterase (AChE) and has a pronounced insulin-like effect on erythrocyte membrane-bound AChE in Type II diabetic patients (Rizvi et al., 1995; Rizvi and Zaid, 2001).

3.5. Dietary fibers

The role of dietary fibers in diabetes has been studied by several workers. Long term dietary treatment with increased amounts of fiber-rich low-glycaemic index natural foods improves blood glucose levels and reduces the number of hypoglycemic events in type I diabetic patients (Nandini et al., 2003). The hypgolycaemic and antihyperglycaemic actions of fenugreek have been attributed both to gastrointestinal effects of local dietary fibre (Madar et al., 1988). A study investigated the effect of dietary carbohydrate and fiber on mucosal insulin receptors in order to correlate changes in cellular proliferation with hormonal responsiveness. It revealed that insulin binding was significantly affected by the consumption of dietary fiber (MacDonald et al., 1991). A high insoluble-fiber diet containing 15% cellulose in dry matter, high soluble-fiber diet containing 15% pectin in dry matter and low-fiber diet was tested for effect on glycemic control in six dogs with alloxan-induced insulin-dependent diabetes mellitus. High insoluble-fiber and soluble-fiber diet fed animals showed significant lowering in the mean postprandial plasma glucose concentration in comparison to the low fiber diet fed dogs (Nelson et al., 1991). Effect of soluble (5%guar gum) and insoluble (10% wheat bran) dietary fibre supplementation on glycaemic control and nephropathy was investigated in streptozotocin-treated diabetic rats and the results indicated that both soluble and insoluble dietary fibers ameliorated a significant increase in the activity of GFAT and decrease in the renal content of heparan sulfate in diabetic animals (Nandini et al., 2003). Another study involving insoluble fiber-rich fractions including insoluble dietary fiber, alcohol-insoluble solid, and water-insoluble solid, obtained from the peel of *Citrus sinensis* L. cv. Liucheng showed that the fiber rich fraction effectively adsorbed glucose, retard glucose diffusion and inhibit the activity of alpha-amylase to different extents and may be responsible for decreasing the rate of glucose absorption and concentration of postprandial serum glucose (Chau et al., 2003).

3.6. Saponins: triterpenoid and steroidal glycosides

Triterpenoid and steroidal glycosides, referred to collectively as saponins, are bioactive compounds present naturally in many plants and known to possess potent hypoglycemic activity (Rao and Gurfinkel, 2000). Charantin (Fig. 1, [XXIV]), a steroidal saponin, obtained from *Momordica charantia* is known to have an insulin-like activity, responsible for its hypoglycemic effect (Ng et al., 1986a). Charantin stimulates the release of insulin and blocks the formation of glucose in the bloodstream, which may be helpful in the treatment of diabetes, particularly in non-insulin-dependent diabetes. Lactucain C (Fig. 1, [XXV]) and furofuran lignan, lactucaside (Fig. 1, [XXVI]), obtained from *Lactuca indica* found to produce significant hypoglycemic activity (Hou et al., 2003). β-Sitosterol (Fig. 1, [XXVII]), a steroid obtained from *Azadirachta indica*, may be responsible for its hypoglycemic property. Andrographolide, another diterpenoid lactone, obtained from *Andrographis paniculata* Nees was found to possess significant hypoglycemic activity (Yu et al., 2003). Gymnemic acid IV, obtained from leaves of *Gymnema sylvestre* R. BR. exhibits potent hypoglycemic activity in experimental animals models of diabetes (Sugihara et al., 2000).

3.7. Ferulic acid

It is 4-hydroxy-3-methoxycinnamic acid (Fig. 1, [XXVIII]) found in the leaves and seeds of many plants like *Curcuma longa* L. Oral administration of ferulic acid at low dose produced significant hypoglycemic activity in both types of diabetes as evident from a study on streptozotocin-induced diabetic mice and KK-Ay mice. The study suggested potent antioxidant activity of the compound in addition to its blood glucose lowering activity in experimental hyperglycemia in animals (Ohnishi et al., 2004). An in vitro study utilising rat pancreatic RIN-5F cell suggested that amide compounds, derived from ferulic acid have stimulatory effects on insulin secretion (Nomura et al., 2003).

4. Conclusion

Diabetes is a disorder of carbohydrate, fat and protein metabolism attributed to diminished production of insulin or mounting resistance to its action. Herbal treatments for diabetes have been used in patients with insulin-dependent and non-insulin-dependant diabetes, diabetic retinopathy, diabetic peripheral neuropathy, etc. Scientific validation of several Indian plant species has proved the efficacy of the botanicals in reducing the sugar level. From the reports on their potential effectiveness against diabetes, it is assumed that the botanicals have a major role to play in the management of diabetes, which needs further exploration for necessary development of drugs and nutraceuticals from natural resources (Mukherjee, 2001, 2002). However many herbal remedies used today have not undergone careful scientific assessment and some have the potential to cause serious toxic effects and major drug-to-drug interaction. Continuing

research is necessary to elucidate the pharmacological activities of herbal remedies now being used to treat diabetes mellitus.

Acknowledgements

The authors wish to express their gratitude to the Commonwealth Scholarship Commission, Association of Commonwealth Universities, UK, for the Commonwealth Academic Staff Fellowship Award to Dr. Pulok K. Mukherjee through the selection made from the University Grants Commission (UGC), India. Thanks are also due to the Department of Science and Technology (DST), Department of Biotechnology (DBT), Government of India for providing financial assistance through research projects to the School of Natural Product Studies, Jadavpur University.

References

Abdel-Barry, J.A., Abdel-Hassan, I.A., Al-Hakiem, M.H., 1997. Hypoglycemic and antihyperglycemic effects of *Trigonella foenum graecum* leaf in normal and alloxan induced diabetic rats. Journal of Ethnopharmacology 58, 149–155.

Abdel-Hassan, I.A., Abdel-Barry, J.A., Tariq Mohammeda, S., 2000. The hypoglycemic and antihyperglycemic effect of *Citrullus colocynthis* fruit aqueous extract in normal and alloxan diabetic rabbits. Journal of Ethnopharmacology 71, 325–330.

Abesundara, K.J., Matsui, T., Matsumoto, K., 2004. Alpha-glucosidase inhibitory activity of some Sri Lanka plant extracts, one of which, *Cassia auriculata*, exerts a strong antihyperglycemic effect in rats comparable to the therapeutic drug acarbose. Journal of Agricultural and Food Chemistry 52, 2541–2545.

Achrekar, S., Kaklij, G.S., Pote, M.S., Kelkar, S.M., 1991. Hypoglycemic activity of *Eugenia jambolana* and *Ficus bengalenesis*: mechanism of action. In Vivo 5, 143–147.

Aderibigbe, A.O., Emudianughe, T.S., Lawal, B.A., 1999. Antihyperglycaemic effect of *Mangifera indica* in rat. Phytotherapy Research 13, 504–507.

Ahmad, F., Khalid, P., Khan, M.M., Rastogi, A.K., Kidwai, J.R., 1989. Insulin like activity in (−)-epicatechin. Acta Diabetologica Latina 26, 291–300.

Ahmad, F., Khan, M.M., Rastogi, A.K., Chaubey, M., Kidwai, J.R., 1991. Effect of (−)-epicatechin on cAMP content, insulin release and conversion of proinsulin to insulin in immature and mature rat islets in vitro. Indian Journal of Experimental Biology 29, 516–520.

Ajabnoor, M.A., 1990. Effect of aloes on blood glucose levels in normal and alloxan diabetic mice. Journal of Ethnopharmacology 28, 215–220.

Akhani, S.P., Vishwakarma, S.L., Goyal, R.K., 2004. Anti-diabetic activity of *Zingiber officinale* in streptozotocin-induced type I diabetic rats. Journal of Pharmacy and Pharmacology 56, 101–105.

Akhtar, M.S., Qureshi, A.Q., Iqbal, J., 1990. Hypoglycemic evaluation of *Mucuna pruriens* Linn. seeds. Journal of Pakistan Medical Association 40, 147–150.

Al-Awadi, F.M., Gumaa, K.A., 1987. Studies on the activity of individual plants of an hypoglycemic plant mixture. Acta Diabetologica Latina 24, 37–41.

Al-Ghaithi, F., El-Ridi, M.R., Adeghate, E., Amiri, M.H., 2004. Biochemical effects of *Citrullus colocynthis* in normal and diabetic rats. Molecular and Cellular Biochemistry 261, 143–149.

Ali, L., Azad Khan, A.K., Hassan, Z., Mosihuzzaman, M., Nahar, N., Nasreen, T., Nur-e-Alam, M., Rokeya, B., 1995. Characterization of the hypoglycemic effects of *Trigonella foenum graecum* seed. Planta Medica 61, 358–360.

Ali, L., Khan, A.K., Mamun, M.I., Mosihuzzaman, M., Nahar, N., Nur-e-Alam, M., Rokeya, B., 1993. Studies on hypoglycemic effects of fruit pulp, seed and whole plant of *Momordica charantia* on normal and diabetic model rats. Planta Medica 59, 408–412.

Amalraj, T., Ignacimuthu, S., 1998a. Hypoglycemic activity of *Cajanus cajan* (seeds) in mice. Indian Journal of Experimental Biology 36, 1032–1033.

Amalraj, T., Ignacimuthu, S., 1998b. Evaluation of the hypoglycaemic effect of *Memecylon umbellatum* in normal and alloxan diabetic mice. Journal of Ethnopharmacology 62, 247–250.

Anand, K.K., Singh, B., Chand, D., Chandan, B.K., Gupta, V.N., 1989. Effect of *Zizyphus sativa* leaves on blood glucose levels in normal and alloxan-diabetic rats. Journal of Ethnopharmacology 27, 121–127.

Ananthan, R., Baskar, C., NarmathaBai, V., Pari, L., Latha, M., Ramkumar, K.M., 2003b. Hypoglycemic effect of *Gymnema montanum* leaves: effect on lipid peroxidation induced oxidative stress in experimental diabetes. Pharmacological Research 48, 551–556.

Ananthan, R., Latha, M., Pari, L., Ramkumar, K.M., Baskar, C.G., Bai, V.N., 2003a. Effect of *Gymnema montanum* on blood glucose, plasma insulin, and carbohydrate metabolic enzymes in alloxan-induced diabetic rats. Journal of Medicinal Food 6, 43–49.

Ananthan, R., Latha, M., Ramkumar, K.M., Pari, L., Baskar, C., Narmatha Bai, V., 2004. Modulatory effects of *Gymnema montanum* leaf extract on alloxan-induced oxidative stress in Wistar rats. Nutrition 20, 280–285.

Ananthan, R., Latha, M., Ramkumar, K.M., Pari, L., Baskar, C., Narmatha Bai, V., 2003c. Effect of *Gymnema montanum* leaves on serum and tissue lipids in alloxan diabetic rats. Experimental Diabesity Research 4, 183–189.

Anderson, R.A., Polansky, M.M., 2002. Tea enhances insulin activity. Journal of Agricultural and Food Chemistry 50, 7182–7186.

Anonymous, 1976. Medicinal Plants of India, vol. 1. Indian Council of Medical Research, New Delhi, pp. 6–8.

Anuradha, C.V., Ravikumar, P., 2001. Restoration on tissue antioxidants by fenugreek seeds (*Trigonella foenum graecum*) in alloxan-diabetic rats. Indian Journal of Physiology and Pharmacology 45, 408–420.

Arai, I., Amagaya, S., Komatsu, Y., Okada, M., Hayashi, T., Kasai, M., Arisawa, M., Momose, Y., 1999. Improving effects of the extracts from *Eugenia uniflora* on hyperglycemia and hypertriglyceridemia in mice. Journal of Ethnopharmacology 68, 307–314.

Augusti, K.T., 1973. Studies on the effects of a hypoglycemic principle from *Allium Cepa* Linn. Indian Journal of Medical Research 61, 1066–1071.

Augusti, K.T., 1975. Hypoglycemic action of bengalenoside, a glucoside isolated from *Ficus bengalenesis* Linn., in normal and alloxan diabetic rabbits. Indian Journal of Physiology and Pharmacology 19, 218–220.

Augusti, K.T., Daniel, R.S., Cherian, S., Sheela, C.G., Nair, C.R., 1994. Effect of leucopelargonin derivative from *Ficus bengalenesis* Linn. on diabetic dogs. Indian Journal of Medical Research 99, 82–86.

Augusti, K.T., Joseph, P., Babu, T.D., 1995. Biologically active principles isolated from *Salacia oblonga* wall. Indian Journal of Physiology and Pharmacology 39, 415–417.

Azad Khan, A.K., Akhtar, S., Mahtab, H., 1979. *Coccinia indica* in the treatment of patients with diabetes mellitus. Bangladesh Medical Research Council Bulletin 5, 60–66.

Babu, P.S., Srinivasan, K., 1997. Influence of dietary capsaicin and onion on the metabolic abnormalities associated with streptozotocin induced diabetes mellitus. Molecular and Cellular Biochemistry 175, 49–57.

Bajpai, M.B., Asthana, R.K., Sharma, N.K., Chatterjee, S.K., Mukherjee, S.K., 1991. Hypoglycemic effect of Swerchirin from the hexane fraction of *Swertia chirayita*. Planta Medica 57, 102–104.

Borhanuddin, M., Shamsuzzoha, M., Hussain, A.H., 1994. Hypoglycaemic effects of *Andrographis paniculata* Nees on non-diabetic rabbits. Bangladesh Medical Research Council Bulletin 20, 24–26.

Bose, S.N., Sepaha, G.C., 1956. Clinical observations on the hypoglycemic properties of *Pterocarpus marsupium* and *Eugenia jambolana*. Journal of the Indiana State Medical Association 27, 388–391.

Brahmachari, H.D., Augusti, K.T., 1964. Isolation of orally effective hypoglycemic compounds from *Ficus bengalensis* Linn. Indian Jornal of Physiology and Pharmacology 13, 60–64.

Cakici, I., Hurmoglu, C., Tunctan, B., Abacioglu, N., Kanzik, I., Sener, B., 1994. Hypoglycemic effect of *Momordica charantia* extracts in normoglycemic or cyproheptadine-induced hyperglycemic mice. Journal of Ethnopharmacology 44, 117–121.

Campos, K.E., Diniz, Y.S., Cataneo, A.C., Faine, L.A., Alves, M.J., Novelli, E.L., 2003. Hypoglycaemic and antioxidant effects of onion, *Allium cepa*: dietary onion addition, antioxidant activity and hypoglycaemic effects on diabetic rats. International Journal of Food Sciences and Nutrition 54, 241–246.

Chakrabarti, R., Vikramadithyan, R.K., Mullangi, R., Sharma, V.M., Jagadheshan, H., Rao, Y.N., Sairam, P., Rajagopalan, R., 2002. Hypoglycemic and hypolipidemic activity of *Helicteres isora* in animal models. Journal of Ethnopharmacology 81, 343–349.

Chakrabarti, S., Biswas, T.K., Rokeya, B., Ali, L., Mosihuzzaman, M., Nahar, N., Khan, A.K., Mukherjee, B., 2003. Advanced studies on the hypoglycemic effect of *Caesalpinia bonducella* F. in type 1 and 2 diabetes in Long Evans rats. Journal of Ethnopharmacology 84, 41–46.

Chakrabarti, S., Biswas, T.K., Seal, T., Rokeya, B., Ali, L., Azad Khan, A.K., Nahar, N., Mosihuzzaman, M., Mukherjee, B., 2005. Hypoglycemic activity of *Caesalpinia bonducella* F. in chronic type 2 diabetic model in Long-Evans rats and evaluation of insulin secretagogue property of its fractions on isolated islets. Journal of Ethnopharmacology 97, 117–122.

Chakraborty, R., Rajagopalan, R., 2002. Diabetes and insulin resistance associated disorders: disease and the therapy. Current Science 83, 1533–1538.

Chakravarthy, B.K., Gupta, S., Gambhir, S.S., Gode, K.D., 1981. The prophylactic action of (−)-epicatechin against alloxan induced diabetes in rats. Life Sciences 29, 2043–2047.

Chandrasekar, B., Bajpai, M.B., Mukherjee, S.K., 1990. Hypoglycemic activity of *Swertia chirayita* (Roxb ex Flem) Karst. Indian Journal of Experimental Biology 28, 616–618.

Chandrasekar, B., Mukherjee, B., Mukherjee, S.K., 1989. Blood sugar lowering potentiality of selected Cucurbitaceae plants of Indian origin. Indian Journal of Medical Research 90, 300–305.

Chattopadhyay, R.R., 1993. Hypoglycemic effect of *Ocimum sanctum* leaf extract in normal and streptozotocin diabetic rats. Indian Journal of Experimental Biology 31, 891–893.

Chattopadhyay, R.R., 1996. Possible mechanism of antihyperglycemic effect of *Azadirachta indica* leaf extract, part IV. General Pharmacology 27, 431–434.

Chattopadhyay, R.R., 1998. Possible mechanism of antihyperglycemic effect of *Gymnema sylvestre* leaf extract, part I. General Pharmacology 31, 495–496.

Chattopadhyay, R.R., 1999. A comparative evaluation of some blood sugar lowering agents of plant origin. Journal of Ethnopharmacology 67, 367–372.

Chattopadhyay, R.R., Chattopadhyay, R.N., Nandy, A.K., Poddar, G., Maitra, S.K., 1987a. Preliminary report on antihyperglycemic effect of a fraction of fresh leaves of *Azadirachta indica* (Beng. Neem). Bulletin of the Calcutta School of Tropical Medicine 35, 29–33.

Chattopadhyay, R.R., Chattopadhyay, R.N., Nandy, A.K., Poddar, G., Maitra, S.K., 1987b. The effect of fresh leaves of *Azadirachta indica* on glucose uptake and glycogen content in the isolated rat hemi diaphragm. Bulletin of the Calcutta School of Tropical Medicine 35, 8–12.

Chattopadhyay, R.R., Sarkar, S.K., Ganguly, S., Banerjee, R.N., Basu, T.K., 1991. Hypoglycemic and antihyperglycemic effect of leaves of *Vinca rosea* Linn. Indian Journal of Physiology and Pharmacology 35, 145–151.

Chau, C.F., Huang, Y.L., Lee, M.H., 2003. In vitro hypoglycemic effects of different insoluble fiber-rich fractions prepared from the peel of *Citrus sinensis* L. cv. Liucheng. Journal of Agricultural and Food Chemistry 51, 6623–6626.

Chempakam, B., 1993. Hypoglycemic activity of arecoline in betel nut *Areca catechu* L. Indian Journal of Experimental Biology 31, 474–475.

Chen, F., Nakashima, N., Kimura, I., Kimura, M., 1995. Hypoglycemic activity and mechanisms of extracts from mulberry leaves (*Folium mori*) and cortex mori radicis in streptozotocin-induced diabetic mice. Yakugaku Zasshi 115, 476–482.

Cherian, S., Augusti, K.T., 1993. Hypoglycemic effects of a glycoside of leucopelargonidin isolated from *Ficus bengalenesis* Linn. Indian Journal of Experimental Biology 31, 26–29.

Cherian, S., Kumar, R.V., Augusti, K.T., Kidwai, J.R., 1992. Hypoglycemic effect of a glycoside of pelargonidin isolated from the bark of *Ficus bengalenesis* Linn. Indian Journal of Biochemistry and Biophysics 29, 380–382.

Choudhury, K.D., Basu, N.K., 1967. Phytochemical and hypoglycemic investigation of *Casearia esculenta*. Journal of Pharmaceutical Sciences 56, 1405–1409.

Chude, M.A., Orisakwe, O.E., Afonne, O.J., Gamaniel, K.S., Vongtau, O.H., Obi, E., 2001. Hypoglycaemic effect of the aqueous extract of *Boerhavia diffusa* leaves. Indian Journal of Pharmacology 33, 215–216.

Coimbra, T.C., Danni, F.F., Blotta, R.M., da Periara, C.A., Guedes, M.D., Graf, R.G., 1992. Plants employed in the treatment of diabetes mellitus; results of an ethnopharmacological survey in Porto Alegre, Brazil. Fitoterapia 63, 320–322.

Cooper, E.J., Hudson, A.L., Parker, C.A., Morgan, N.G., 2003. Effects of the beta-carbolines, harmane and pinoline, on insulin secretion from isolated human islets of Langerhans. European Journal of Pharmacology 482, 189–196.

Das, A.K., Mandal, S.C., Banerjee, S.K., Sinha, S., Saha, B.P., Pal, M., 2001. Studies on the hypoglycaemic activity of *Punica granatum* seed in streptozotocin induced diabetic rats. Phytotherapy Research 15, 628–629.

Das, A.V., Padayatti, P.S., Paulose, C.S., 1996. Effect of leaf extract of *Aegle marmelose* (L.) Correa ex Roxb. on histological and ultrastructural changes in tissues of streptozotocin induced diabetic rats. Indian Journal of Experimental Biology 34, 341–345.

Deshmukh, V.K., Shrotri, D.S., Aiman, R., 1960. Isolation of a hypoglycemic principle from the bark of *Ficus bengalensis* Linn. A preliminary note. Indian Journal of Physiology and Pharmacology 4, 182–185.

El-Demerdash, F.M., Yousef, M.I., El-Naga, N.I., 2005. Biochemical study on the hypoglycemic effects of onion and garlic in alloxan-induced diabetic rats. Food and Chemical Toxicology 43, 57–63.

Esmaillzadeh, A., Tahbaz, F., Gaieni, I., Alavi-Majd, H., Azadbakht, L., 2004. Concentrated pomegranate juice improves lipid profiles in diabetic patients with hyperlipidemia. Journal of Medicinal Food 7, 305–308.

Esposito Avella, M., Diaz, A., de Gracia, I., de Tello, R., Gupta, M.P., 1991. Evaluation of traditional medicine: effects of *Cajanus cajan* L. and of *Cassia fistula* L. on carbohydrate metabolism in mice. Revista Medica de Panama 16, 39–45.

Fushiki, T., Kojima, A., Imoto, T., Inoue, K., Sugimoto, E., 1992. An extract of *Gymnema sylvestre* leaves and purified gymnemic acid inhibits glucose-stimulated gastric inhibitory peptide secretion in rats. Journal of Nutrition 122, 2367–2373.

Garg, S.K., Shah, M.A., Garg, K.M., Farooqui, M.M., Sabir, M., 1997. Anti-lymphocytic and immunosuppressive effects of *Lantana camara* leaves in rats. Indian Journal of Experimental Biology 35, 1315–1318.

Geetha, B.S., Mathew, B.C., Augusti, K.T., 1994. Hypoglycemic effects of leucodelphinidin derivative isolated from *Ficus bengalensis* (Linn). Indian Journal of Physiology and Pharmacology 38, 220–222.

Genet, S., Kale, R.K., Baquer, N.Z., 2002. Alterations in antioxidant enzymes and oxidative damage in experimental diabetic rat tissues: effect of vanadate and fenugreek (*Trigonella foenum graecum*). Molecular and Cellular Biochemistry 236, 7–12.

Ghafghazi, T., Sheriat, H.S., Dastmalchi, T., Barnett, R.C., 1977. Antagonism of cadmium and alloxan-induced hyperglycemia in rats by *Trigonella foenum graecum*. Pahlavi Medical Journal 8, 14–25.

Ghannam, N., Kingston, M., Al-Meshaal, I.A., Tariq, M., Parman, N.S., Woodhouse, N., 1986. The hypoglycemic activity of aloes: preliminary clinical and experimental observations. Hormone Research 24, 288–294.

Gholap, S., Kar, A., 2003. Effects of *Inula racemosa* root and *Gymnema sylvestre* leaf extracts in the regulation of corticosteroid induced diabetes mellitus: involvement of thyroid hormones. Pharmazie 58, 413–415.

Gholap, S., Kar, A., 2004. Hypoglycaemic effects of some plant extracts are possibly mediated through inhibition in corticosteroid concentration. Pharmazie 59, 876–878.

Gomes, A., Vedasiromoni, J.R., Das, M., Sharma, R.M., Ganguly, D.K., 1995. Anti-hyperglycemic effect of black tea (*Camellia sinensis*) in rat. Journal of Ethnopharmacology 45, 223–226.

Gray, A.M., Flatt, P.R., 1998. Antihyperglycemic actions of *Eucalyptus globulus* (Eucalyptus) are associated with pancreatic and extrapancreatic effects in mice. Journal of Nutrition 128, 2319–2323.

Grover, J.K., Rathi, S.S., Vats, V., 2002b. Amelioration of experimental diabetic neuropathy and gastropathy in rats following oral administration of plant extracts. Indian Journal of Experimental Biology 40, 273–276.

Grover, J.K., Vats, V., Rathi, S.S., 2000. Anti-hyperglycemic effect of *Eugenia jambolana* and *Tinospora cordifolia* in experimental diabetes and their effects on key metabolic enzymes involved in carbohydrate metabolism. Journal of Ethnopharmacology 73, 461–470.

Grover, J.K., Vats, V., Rathi, S.S., Dawar, R., 2001. Traditional Indian antidiabetic plants attenuate renal hypertrophy, urine volume and albuminuria in streptozotocin induced diabetic mice. Journal of Ethnopharmacology 76, 233–238.

Grover, J.K., Yadav, S., Vats, V., 2002a. Medicinal plants of India with hypoglycemic potentials. Journal of Ethnopharmacology 81, 81–100.

Gulubova, R., Boiadzhiev, T.S., 1975. Morphological changes in the endocrine pancreas of the rabbit after the administration of a *Morus alba* extract. Eksperimentalna Meditsina i Morfologiia 14, 166–171.

Gupta, R.K., Gupta, S., Samuel, K.C., 1977. Blood sugar lowering effect of various fractions of onion. Indian Journal of Experimental Biology 15, 313–314.

Gupta, R.K., Kesari, A.N., Murthy, P.S., Chandra, R., Tandon, V., Watal, G., 2005. Hypoglycemic and hypoglycemic effect of ethanolic extract of leaves of *Annona squamosa* L. in experimental animals. Journal of Ethnopharmacology 99, 75–81.

Gupta, S.S., 1963. Effect of *Gymnema sylvestre* and *Pterocarpus marsupium* on glucose tolerance in albino rats. Indian Journal of Medical Science 17, 501–505.

Gupta, S.S., Seth, C.B., 1962. Effect of *Momordica charantia* Linn. (Karela) on glucose tolerance in albino rats. Journal of Indian Medical Association 39, 581–584.

Gupta, S.S., Verma, S.C., Garg, V.P., Khandelwal, P., 1967. Studies on the anti-diabetic effects of *Casearia esculenta*. Indian Journal of Medical Research 55, 754–763.

Heacock, P.M., Hertzler, S.R., Williams, J.A., Wolf, B.W., 2005. Effects of a medical food containing an herbal alpha-glucosidase inhibitor on postprandial glycemia and insulinemia in healthy adults. Journal of the American Diabetic Association 105, 65–71.

Hii, C.S., Howell, S.L., 1985. Effects of flavonoids on insulin secretion and $45Ca^{2+}$ handling in rat islets of Langerhans. Journal of Endocrinology 107, 1–8.

Hossain, M.Z., Shibib, B.A., Rahman, R., 1992. Hypoglycemic effects of *Coccinia indica*: inhibition of key gluconeogenic enzyme, glucose-6-phosphatase. Indian Journal of Experimental Biology 30, 418–420.

Hou, C.C., Lin, S.J., Cheng, J.T., Hsu, F.L., 2003. Hypoglycemic dimeric guianolides and a lignan glycoside from *Lactuca indica*. Journal of Natural Products 66, 625–629.

Huang, T.H., Peng, G., Kota, B.P., Li, G.Q., Yamahara, J., Roufogalis, B.D., Li, Y., 2005. Pomegranate flower improves cardiac lipid metabolism in a diabetic rat model: role of lowering circulating lipids. British Journal of Pharmacology 145, 767–774.

Ivorra, M.D., Payáa, M., Villarb, A., 1989. A review of natural products and plants as potential hypoglycemic drugs. Journal of Ethnopharmacology 27, 243–275.

Iyer, U.M., Mani, U.V., 1990. Studies on the effect of curry leaves supplementation (*Murraya koeingii*) on lipid profile, glycated proteins and amino acids in non-insulin-dependent diabetic patients. Plant Foods and Human Nutrition 40, 275–282.

Jafri, M.A., Aslam, M., Javed, K., Singh, S., 2000. Effect of *Punica granatum* Linn. (flowers) on blood glucose level in normal and alloxan-induced diabetic rats. Journal of Ethnopharmacology 70, 309–314.

Jain, R.C., Vyas, C.R., 1975. Garlic in alloxan-induced diabetic rabbits. American Journal of Clinical Nutrition 28, 684–685.

Jain, S.R., 1968. Hypoglycaemic principle in *Musa sapientum* L. and its isolation. Planta Medica 16, 43–47.

Jain, S.R., 1969. A note on the chemical study of the hypoglycaemic substance from *Musa sapientum* L. Planta Medica 17, 99.

Jayawardena, M.H., de Alwis, N.M., Hettigoda, V., Fernando, D.J., 2005. A double blind randomised placebo controlled cross over study of a herbal preparation containing *Salacia reticulata* in the treatment of type 2 diabetes. Journal of Ethnopharmacology 97, 215–218.

Jorge, A.P., Horst, H., de Sousa, E., Pizzolatti, M.G., Silva, F.R., 2004. Insulinomimetic effects of kaempferitrin on glycaemia and on 14C-glucose uptake in rat soleus muscle. Chemico-Biological Interactions 149, 89–96.

Joy, K.L., Kuttan, R., 1999. Anti-diabetic activity of *Picrorrhiza kurroa* extract. Journal of Ethnopharmacology 67, 143–148.

Jung, U.J., Lee, M.K., Jeong, K.S., Choi, M.S., 2004. The hypoglycemic effects of hesperidin and naringin are partly mediated by hepatic glucose-regulating enzymes in C57BL/KsJ-db/db mice. Journal of Nutrition 134, 2499–2503.

Kamalakkanan, N., Rajadurai, M., Prince, P.S., 2003. Effect of *Aegle marmelos* fruits on normal and streptozotocin-diabetic Wistar rats. Journal of Medicinal Food 6, 93–98.

Kamalakkannan, N., Prince, P.S., 2003. Hypoglycaemic effect of water extracts of *Aegle marmelos* fruits in streptozotocin diabetic rats. Journal of Ethnopharmacology 87, 207–210.

Kamalakkannan, N., Stanely, P., 2003. Effect of *Aegle marmelos* Correa. (Bael) fruit extract on tissue antioxidants in streptozotocin diabetic rats. Indian Journal of Experimental Biology 41, 1285–1288.

Kamble, S.M., Kamlakar, P.L., Vaidya, S., Bambole, V.D., 1998. Influence of *Coccinia indica* on certain enzymes in glycolytic and lipolytic pathway in human diabetes. Indian Journal of Medical Science 52, 143–146.

Kameswara Rao, B., Giri, R., Kesavulu, M.M., Apparao, C., 2001. Effect of oral administration of bark extracts of *Pterocarpus santalinus* L. on blood glucose level in experimental animals. Journal of Ethnopharmacology 74, 69–74.

Kameswara Rao, B., Renuka Sudarshan, P., Rajasekhar, M.D., Nagaraju, N., Appa Rao, Ch., 2003b. Hypoglycemic activity of *Terminalia pallida* fruit in alloxan induced diabetic rats. Journal of Ethnopharmacology 85, 169–172.

Kameswara Rao, B., Kesavulu, M.M., Apparao, C., 2003a. Evaluation of hypoglycemic effect of *Momordica cymbalaria* fruit in alloxan-diabetic rats. Fitoterapia 74, 7–13.

Kanth, V.R., Diwan, P.V., 1999. Analgesic, antiinflammatory and hypoglycaemic activities of *Sida cordifolia*. Phytotherapy Research 13, 75–77.

Kar, A., Choudhary, B.K., Bandyopadhyay, N.G., 2003. Comparative evaluation of hypoglycaemic activity of some Indian medicinal plants in alloxan diabetic rats. Journal of Ethnopharmacology 84, 105–108.

Karunanayake, E.H., Jeevathayaparan, S., Tennekoon, K.H., 1990. Effect of *Momordica charantia* fruit juice on streptozotocin-induced diabetes in rats. Journal of Ethnopharmacology 30, 199–204.

Karunanayake, E.H., Welihinda, J., Sirimanne, S.R., Sinnadorai, G., 1984. Oral hypoglycemic activity of some medicinal plants of Sri Lanka. Journal of Ethnopharmacology 11, 223–231.

Kasuga, S., Ushijima, M., Morihara, N., Itakura, Y., Nakata, Y., 1999. Effect of aged garlic extract (AGE) on hyperglycemia induced by immobilization stress in mice. Nippon Yakurigaku Zasshi 114, 191–197.

Kedar, P., Chakrabarti, C.H., 1982. Effects of bittergourd (*Momordica charantia*) seed and glibenclamide in streptozotocin induced diabetes mellitus. Indian Journal of Experimental Biology 20, 232–235.

Kelkar, S.M., Kaklij, G.S., Bapat, V.A., 2001. Determination of hypoglycemic activity in *Allium cepa* (onion) tissue cultures. Indian Journal of Biochemistry and Biophysics 38, 277–279.

Khan, A.K., Akhtar, S., Mahtab, H., 1980. Treatment of diabetes mellitus with *Coccinia indica*. British Medical Journal 280, 1044.

Khan, B.A., Abraham, A., Leelamma, S., 1995. Hypoglycemic action of *Murraya koeingii* (curry leaf) and *Brassica juncea* (mustard): mechanism of action. Indian Journal of Biochemistry and Biophysics 32, 106–108.

Khanna, P., Jain, S.C., Panagariya, A., Dixit, V.P., 1981. Hypoglycemic activity of polypeptide-p from a plant source. Journal of Natural Products 44, 648–655.

Khosla, P., Gupta, D.D., Nagpal, R.K., 1995. Effect of *Trigonella foenum graecum* (Fenugreek) on blood glucose in normal and diabetic rats. Indian Journal of Physiology and Pharmacology 39, 173–174.

Kirtikar, K.R., Basu, B.D., 1993. Indian Medicinal Plants, vols. 1–4. Periodical Experts, Delhi.

Krishnakumar, K., Augusti, K.T., Vijayammal, P.L., 1999. Hypoglycemic and anti-oxidant activity of *Salacia oblonga* Wall. extract in streptozotocin-induced diabetic rats. Indian Journal of Physiology and Pharmacology 43, 510–514.

Kumar, G.P., Sudheesh, S., Vijayalakshmi, N.R., 1993. Hypoglycemic effect of *Coccinia indica*: mechanism of action. Planta Medica 59, 330–332.

Kumar, R.V., Augusti, K.T., 1989. Hypoglycemic effect of a leucocyanidin derivative isolated from the bark of *Ficus bengalensis* Linn. Indian Journal of Biochemistry and Biophysics 26, 400–404.

Kumar, R.V., Augusti, K.T., 1994. Insulin sparing action of a leucocyanidin derivative isolated from *Ficus bengalensis* Linn. Indian Journal of Biochemistry and Biophysics 31, 73–76.

Kumari, K., Mathew, B.C., Augusti, K.T., 1995. Hypoglycemic and hypolipidemic effects of S-methyl cysteine sulfoxide isolated from *Allium cepa* Linn. Indian Journal of Biochemistry and Biophysics 32, 49–54.

Kusano, S., Abe, H., 2000. Hypoglycemic activity of white skinned potato (*Ipomoea batatas*) in obese Zucker fatty rats. Biological and Pharmaceutical Bulletin 23, 23–26.

Latha, M., Pari, L., 2003a. Modulatory effect of *Scoparia dulcis* in oxidative stress-induced lipid peroxidation in streptozotocin diabetic rats. Journal of Medicinal Food 6, 379–386.

Latha, M., Pari, L., 2003b. Preventive effects of *Cassia auriculata* L. flowers on brain lipid peroxidation in rats treated with streptozotocin. Molecular and Cellular Biochemistry 243, 23–28.

Latha, M., Pari, L., 2003c. Antihyperglycaemic effect of *Cassia auriculata* in experimental diabetes and its effects on key metabolic enzymes involved in carbohydrate metabolism. Clinical and Experimental Pharmacology and Physiology 30, 38–43.

Latha, M., Pari, L., 2004. Effect of an aqueous extract of *Scoparia dulcis* on blood glucose, plasma insulin and some polyol pathway enzymes in experimental rat diabetes. Brazilian Journal of Medical and Biological Research 37, 577–586.

Latha, M., Pari, L., 2005. Effect of an aqueous extract of *Scoparia dulcis* on plasma and tissue glycoproteins in streptozotocin induced diabetic rats. Pharmazie 60, 151–154.

Latha, M., Pari, L., Sitasawad, S., Bhonde, R., 2004a. Insulin-secretagogue activity and cytoprotective role of the traditional hypoglycemic plant *Scoparia dulcis* (Sweet Broomweed). Life Science 75, 2003–2014.

Latha, M., Pari, L., Sitasawad, S., Bhonde, R., 2004b. *Scoparia dulcis*, a traditional hypoglycemic plant, protects against streptozotocin induced oxidative stress and apoptosis in vitro and in vivo. Journal of Biochemical and Molecular Toxicology 18, 261–272.

Li, Y., Peng, G., Li, Q., Wen, S., Huang, T.H., Roufogalis, B.D., Yamahara, J., 2004. *Salacia oblonga* improves cardiac fibrosis and inhibits postprandial hyperglycemia in obese Zucker rats. Life Science 75, 1735–1746.

Li, Y., Wen, S., Kota, B.P., Peng, G., Li, G.Q., Yamahara, J., Roufogalis, B.D., 2005. *Punica granatum* flower extract, a potent alpha-glucosidase inhibitor, improves postprandial hyperglycemia in Zucker diabetic fatty rats. Journal of Ethnopharmacology 99, 239–244.

MacDonald, R.S., Steel-Goodwin, L., Smith, R.J., 1991. Influence of dietary fiber on insulin receptors in rat intestinal mucosa. Annals of Nutrition and Metabolism 35, 328–338.

Madar, Z., Abel, R., Samish, S., Arad, J., 1988. Glucose-lowering effect of fenugreek in non-insulin dependent diabetics. European Journal of Clinical Nutrition 42, 51–54.

Mahapatra, P.K., Pal, M., Chaudhauri, A.K.N., Chakarborty, D., Basu, A., 1985. Preliminary studies on glycemic effect of *Syzigium cumini* seeds. IRCS. Medical Science Biochemistry 13, 631–632.

Manickam, M., Ramanathan, M., Jahromi, M.A., Chansouria, J.P., Ray, A.B., 1997. Antihyperglycemic activity of phenolics from *Pterocarpus marsupium*. Journal of Natural Products 60, 609–610.

Maroo, J., Vasu, V.T., Aalinkeel, R., Gupta, S., 2002. Glucose lowering effect of aqueous extract of *Enicostemma littorale* Blume in diabetes: a possible mechanism of action. Journal of Ethnopharmacology 81, 317–320.

Maroo, J., Vasu, V.T., Gupta, S., 2003. Dose dependent hypoglycemic effect of aqueous extract of Enicostemma littorale Blume in alloxan induced diabetic rats. Phytomedicine 10, 196–199.

Martinez, G., Delgado, R., Perez, G., Garrido, G., Nunez Selles, A.J., Leon, O.S., 2000. Evaluation of the in vitro antioxidant activity of *Mangifera indica* L. extract. Phytotherapy Research 14, 424–427.

Mathew, P.T., Augusti, K.T., 1973. Studies on the effect of allicin (diallyl disulphide-oxide) on alloxan diabetes. Hypoglycemic action and enhancement of serum insulin effect and glycogen synthesis. Indian Journal of Biochemistry and Biophysics 10, 209–212.

Mathew, P.T., Augusti, K.T., 1975. Hypoglycemic effects of onion, *Allium cepa* Linn. on diabetes mellitus—a preliminary report. Indian Journal of Physiology and Pharmacology 19, 213–217.

Matsuda, H., Murakami, T., Yashiro, K., Yamahara, J., Yoshikawa, M., 1999. Hypoglycemic principles of natural medicines. IV. Aldose reductase and alpha-glucosidase inhibitors from the roots of Salacia oblonga Wall. (Celastraceae): structure of a new friedelane-type triterpene, kotalagenin 16-acetate. Chemical and Pharmaceutical Bulletin (Tokyo) 47, 1725–1729.

Matsui, T., Ebuchi, S., Kobayashi, M., Fukui, K., Sugita, K., Terahara, N., Matsumoto, K., 2002. Anti-hyperglycemic effect of diacylated anthocyanin derived from *Ipomoea batatas* cultivar Ayamurasaki can be achieved through the alpha-glucosidase inhibitory action. Journal of Agricultural and Food Chemistry 50, 7244–7248.

Mezei, O., Banz, W.J., Steger, R.W., Peluso, M.R., Winters, T.A., Shay, N., 2003. Soy isoflavones exert hypoglycemic and hypolipidemic effects through the PPAR pathways in obese Zucker rats and murine RAW 264.7 cells. Journal of Nutrition 133, 1238–1243.

Miura, T., Itoh, C., Iwamoto, N., Kato, M., Kawai, M., Park, S.R., Suzuki, I., 2001. Hypoglycemic activity of the fruit of the *Momordica charantia* in type 2 diabetic mice. Journal of Nutritional Science and Vitaminology (Tokyo) 47, 340–344.

Miura, T., Itoh, Y., Iwamoto, N., Kato, M., Ishida, T., 2004. Suppressive activity of the fruit of *Momordica charantia* with exercise on blood glucose in type 2 diabetic mice. Biological and Pharmaceutical Bulletin 27, 248–250.

Mukherjee, K., Ghosh, N.C., Datta, T., 1972. *Coccinia indica* Linn. as potential hypoglycemic agent. Indian Journal of Experimental Biology 10, 347–349.

Mukherjee, P.K., 2001. Evaluation of Indian traditional medicine. Drug Information Journal 35, 623–631.

Mukherjee, P.K., 2002. Quality Control of Herbal Drugs. Business Horizons, New Delhi, pp. 543–545.

Mukherjee, P.K., 2003. Plant products with hypocholesterolemic potentials. In: Taylor, S.L. (Ed.), Advances in Food and Nutrition Research. Elsevier Academic Press, USA, pp. 323–324.

Mukherjee, P.K., Pal, S.K., Saha, K., Saha, B.P., 1995. Hypoglycemic activity of *Nelumbo nucifera* rhizome (methanolic extract) in streptozotocin induced diabetic rats. Phytotherapy Research 9, 522–524.

Mukherjee, P.K., Saha, K., Pal, M., Saha, B.P., 1997. Effect of *Nelumbo nucifera* rhizome extract on blood sugar level in rats. Journal of Ethnopharmacology 58, 207–213.

Murali, B., Upadhyaya, U.M., Goyal, R.K., 2002. Effect of chronic treatment with *Enicostemma littorale* in non-insulin-dependent diabetic (NIDDM) rats. Journal of Ethnopharmacology 81, 199–204.

Muraoka, O., Ying, S., Yoshikai, K., Matsuura, Y., Yamada, E., Minematsu, T., Tanabe, G., Matsuda, H., Yoshikawa, M., 2001. Synthesis of a nitrogen analogue of salacinol and its alpha-glucosidase inhibitory activity. Chemical and Pharmaceutical Bulletin (Tokyo) 49, 1503–1505.

Muruganandan, S., Srinivasan, K., Gupta, S., Gupta, P.K., Lal, J., 2005. Effect of mangiferin on hyperglycemia and atherogenicity in streptozotocin diabetic rats. Journal of Ethnopharmacology 97, 497–501.

Nadkarni, K.M., 1976. Indian Materia Medica, vol. 1. Popular Prakashan, Bombay, p. 498.

Nagappa, A.N., Thakurdesai, P.A., Venkat Rao, N., Singh, J., 2003. Hypoglycemic activity of *Terminalia catappa* Linn. fruits. Journal of Ethnopharmacology 88, 45–50.

Nakagawa, K., Kishida, H., Arai, N., Nishiyama, T., Mae, T., 2004. Licorice flavonoids suppress abdominal fat accumulation and increase in blood glucose level in obese diabetic KK-A(y) mice. Biological and Pharmaceutical Bulletin 27, 1775–1778.

Nammi, S., Boini, M.K., Lodagala, S.D., Behara, R.B., 2003. The juice of fresh leaves of *Catharanthus roseus* Linn. reduces blood glucose in normal and alloxan diabetic rabbits. BMC Complementary and Alternative Medicine 3, 4.

Nandini, C.D., Sambaiah, K., Salimath, P.V., 2003. Dietary fibres ameliorate decreased synthesis of heparan sulphate in streptozotocin induced diabetic rats. Journal of Nutritional Biochemistry 14, 203–210.

Nandkarni, A.K., 1992. Indian Materia Medica, vol. 1. Popular Prakashan, Bombay, p. 157.

Nelson, R.W., Ihle, S.L., Lewis, L.D., Salisbury, S.K., Miller, T., Bergdall, V., Bottoms, G.D., 1991. Effects of dietary fiber supplementation on glycemic control in dogs with alloxan-induced diabetes mellitus. American Journal of Veterinary Research 52, 2060–2066.

Ng, T.B., Wong, C.M., Li, W.W., Yeung, H.W., 1986a. Insulin-like molecules in *Momordica charantia* seeds. Journal of Ethnopharmacology 15, 107–117.

Ng, T.B., Wong, C.M., Li, W.W., Yeung, H.W., 1986b. Isolation and characterization of a galactose binding lectin with insulinomimetic activities. From the seeds of the bitter gourd Momordica charantia (Family Cucurbitaceae). International Journal of Peptide and Protein Research 28, 163–172.

Ng, T.B., Wong, C.M., Li, W.W., Yeung, H.W., 1987. Acid-ethanol extractable compounds from fruits and seeds of the bitter gourd Momordica charantia: effects on lipid metabolism in isolated rat adipocytes. American Journal of Chinese Medicine 15, 31–42.

Nmila, R., Gross, R., Rchid, H., Roye, M., Manteghetti, M., Petit, P., Tijane, M., Ribes, G., Sauvaire, Y., 2000. Insulinotropic effect of *Citrullus colocynthis* fruit extracts. Planta Medica 66, 418–423.

Nomura, E., Kashiwada, A., Hosoda, A., Nakamura, K., Morishita, H., Tsuno, T., Taniguchi, H., 2003. Synthesis of amide compounds of ferulic acid, and their stimulatory effects on insulin secretion in vitro. Bioorganic and Medicinal Chemistry 11, 3807–3813.

Ohnishi, M., Matuo, T., Tsuno, T., Hosoda, A., Nomura, E., Taniguchi, H., Sasaki, H., Morishita, H., 2004. Antioxidant activity and hypoglycemic effect of ferulic acid in STZ-induced diabetic mice and KK-Ay mice. Biofactors 21, 315–319.

Okyar, A., Can, A., Akev, N., Baktir, G., Sutlupinar, N., 2001. Effect of *Aloe vera* leaves on blood glucose level in type I and type II diabetic rat models. Phytotherapy Research 15, 157–161.

Pan, G.Y., Huang, Z.J., Wang, G.J., Fawcett, J.P., Liu, X.D., Zhao, X.C., Sun, J.G., Xie, Y.Y., 2003. The antihyperglycaemic activity of berberine arises from a decrease of glucose absorption. Planta Medica 69, 632–636.

Panlasigui, L.N., Panlilio, L.M., Madrid, J.C., 1995. Glycemic response in normal subjects to five different legumes commonly used in the Philippines. International Journal of Food Science and Nutrition 46, 155–160.

Pari, L., Amarnath Satheesh, M., 2004. Hypoglycemic activity of *Boerhaavia diffusa* L.: effect on hepatic key enzymes in experimental diabetes. Journal of Ethnopharmacology 91, 109–113.

Pari, L., Latha, M., 2002. Effect of *Cassia auriculata* flowers on blood sugar levels, serum and tissue lipids in streptozotocin diabetic rats. Singapore Medical Journal 43, 617–621.

Pari, L., Latha, M., 2004. Effect of *Scoparia dulcis* (Sweet Broomweed) plant extract on plasma antioxidants in streptozotocin-induced experimental diabetes in male albino Wistar rats. Pharmazie 59, 557–560.

Pari, L., Latha, M., Rao, C.A., 2004. Effect of *Scoparia dulcis* extract on insulin receptors in streptozotocin induced diabetic rats: studies on insulin binding to erythrocytes. Journal of Basic and Clinical Physiology and Pharmacology 15, 223–240.

Pari, L., Maheswari, J.U., 1999. Hypoglycaemic effect of *Musa sapientum* L. in alloxan-induced diabetic rats. Journal of Ethnopharmacology 68, 321–325.

Pari, L., Umamaheswari, J., 2000. Antihyperglycaemic activity of *Musa sapientum* flowers: effect on lipid peroxidation in alloxan diabetic rats. Phytotherapy Research 14, 136–138.

Pari, L., Venkateswaran, S., 2002. Hypoglycaemic activity of *Scoparia dulcis* L. extract in alloxan induced hyperglycaemic rats. Phytotherapy Research 16, 662–664.

Pari, L., Venkateswaran, S., 2003. Protective effect of *Coccinia indica* on changes in the fatty acid composition in streptozotocin induced diabetic rats. Pharmazie 58, 409–412.

Persaud, S.J., Al-Majed, H., Raman, A., Jones, P.M., 1999. *Gymnema sylvestre* stimulates insulin release in vitro by increased membrane permeability. Journal of Endocrinology 163, 207–212.

Pinent, M., Blay, M., Blade, M.C., Salvado, M.J., Arola, L., Ardevol, A., 2004. Grape seed-derived procyanidins have an antihyperglycemic effect in streptozotocin-induced diabetic rats and insulinomimetic activity in insulin-sensitive cell lines. Endocrinology 145, 4985–4990.

Platel, K., Srinivasan, K., 1997. Plant foods in the management of diabetes mellitus: vegetables as potential hypoglycemic agents. Die Nahrung 41, 68–74.

Ponnachan, P.T., Paulose, C.S., Panikkar, K.R., 1993. Effect of leaf extract of *Aegle marmelose* in diabetic rats. Indian Journal of Experimental Biology 31, 345–347.

Prakasam, A., Sethupathy, S., Pugalendi, K.V., 2002. Antihyperglycaemic effect of *Casearia esculenta* root extracts in streptozotocin-induced diabetic rats. Pharmazie 57, 758–760.

Prakasam, A., Sethupathy, S., Pugalendi, K.V., 2003a. Effect of *Casearia esculenta* root extract on blood glucose and plasma antioxidant status in streptozotocin diabetic rats. Polish Journal of Pharmacology 55, 43–49.

Prakasam, A., Sethupathy, S., Pugalendi, K.V., 2003b. Erythrocyte redox status in streptozotocin diabetic rats: effect of *Casearia esculenta* root extract. Pharmazie 58, 920–924.

Prakasam, A., Sethupathy, S., Pugalendi, K.V., 2003c. Glycaemic control by *Casearia esculenta*—a short duration study in albino rats. Pharmazie 58, 49–52.

Prakasam, A., Sethupathy, S., Pugalendi, K.V., 2003d. Hypolipidaemic effect of *Casearia esculenta* root extracts in streptozotocin-induced diabetic rats. Pharmazie 58, 828–832.

Prakasam, A., Sethupathy, S., Pugalendi, K.V., 2004. Influence of *Casearia esculenta* root extract on protein metabolism and marker enzymes in streptozotocin-induced diabetic rats. Polish Journal of Pharmacology 56, 587–593.

Prince, P.S., Kamalakkannan, N., Menon, V.P., 2004a. Hypoglycemic and antihyperlipidaemic effect of alcoholic *Syzigium cumini* seeds in alloxan induced diabetic albino rats. Journal of Ethnopharmacology 91, 209–213.

Prince, P.S., Kamalakkannan, N., Menon, V.P., 2004b. Restoration of antioxidants by ethanolic *Tinospora cordifolia* in alloxan-induced diabetic Wistar rats. Acta Poloniae Pharmaceutica 61, 283–287.

Prince, P.S., Menon, V.P., 1999. Antioxidant activity of *Tinospora cordifolia* roots in experimental diabetes. Journal of Ethnopharmacology 65, 277–281.

Prince, P.S., Menon, V.P., Pari, L., 1998. Hypoglycaemic activity of *Syzigium cumini* seeds: effect on lipid peroxidation in alloxan diabetic rats. Journal of Ethnopharmacology 61, 1–7.

Prince, P.S., Padmanabhan, M., Menon, V.P., 2004c. Restoration of antioxidant defence by ethanolic *Tinospora cordifolia* root extract in alloxan-induced diabetic liver and kidney. Phytotherapy Research 18, 785–787.

Puri, D., 2001. The insulinotropic activity of a Nepalese medicinal plant *Biophytum sensitivum*: preliminary experimental study. Journal of Ethnopharmacology 78, 89–93.

Puri, D., Baral, N., 1998. Hypoglycemic effect of *Biophytum sensitivum* in the alloxan diabetic rabbits. Indian Journal of Physiology and Pharmacology 42, 401–406.

Quanhong, L., Caili, F., Yukui, R., Guanghui, H., Tongyi, C., 2005. Effects of protein-bound polysaccharide isolated from pumpkin on insulin in diabetic rats. Plant Foods for Human Nutrition 60, 13–16.

Rabinkov, A., Miron, T., Konstantinovski, L., Wilchek, M., Mirelman, D., Weiner, L., 1998. The mode of action of allicin: trapping of radicals and interaction with thiol containing proteins. Biochimica et Biophysica Acta 1379, 233–244.

Rahman, A.U., Zaman, K., 1989. Medicinal plants with hypoglycemic activity. Journal of Ethnopharmacology 26, 1–55.

Rai, V., Iyer, U., Mani, U.V., 1997. Effect of Tulsi (*Ocimum sanctum*) leaf powder supplementation on blood sugar levels, serum lipids and tissue lipids in diabetic rats. Plant Foods and Human Nutrition 50, 9–16.

Rajasekaran, S., Sivagnanam, K., Ravi, K., Subramanian, S., 2004. Hypoglycemic effect of *Aloe vera* gel on streptozotocin-induced diabetes in experimental rats. Journal of Medicinal Food 7, 61–66.

Ramkumar, K.M., Latha, M., Venkateswaran, S., Pari, L., Ananthan, R., Bai, V.N., 2004. Modulatory effect of *Gymnema montanum* leaf extract on brain antioxidant status and lipid peroxidation in diabetic rats. Journal of Medicinal Food 7, 366–371.

Rao, A.V., Gurfinkel, D.M., 2000. The bioactivity of saponins: triterpenoid and steroidal glycosides. Drug Metabolism and Drug Interactions 17, 211–235.

Rao, B.K., Kesavulu, M.M., Apparao, C., 2001. Antihyperglycemic activity of *Momordica cymbalaria* in alloxan diabetic rats. Journal of Ethnopharmacology 78, 67–71.

Rao, B.K., Kesavulu, M.M., Giri, R., Appa Rao, C., 1999. Hypoglycemic and hypolipidemic effects of *Momordica cymbalaria* Hook. fruit powder in alloxan-diabetic rats. Journal of Ethnopharmacology 67, 103–109.

Rao, B.K., Rao, C.H., 2001. Hypoglycemic and antihyperglycemic activity of *Syzygium alternifolium* (Wt.) Walp. seed extracts in normal and diabetic rats. Phytomedicine 8, 88–93.

Raphael, K.R., Sabu, M.C., Kuttan, R., 2002. Hypoglycemic effect of methanol extract of *Phyllanthus amarus* Schum & Thonn on alloxan induced diabetes mellitus in rats and its relation with antioxidant potential. Indian Journal of Experimental Biology 40, 905–909.

Rathi, S.S., Grover, J.K., Vats, V., 2002. The effect of *Momordica charantia* and *Mucuna pruriens* in experimental diabetes and their effect on key metabolic enzymes involved in carbohydrate metabolism. Phytotherapy Research 16, 236–243.

Ravi, K., Ramachandran, B., Subramanian, S., 2004a. Protective effect of *Eugenia jambolana* seed kernel on tissue antioxidants in streptozotocin-induced diabetic rats. Biological and Pharmaceutical Bulletin 27, 1212–1217.

Ravi, K., Sekar, D.S., Subramanian, S., 2004b. Hypoglycemic activity of inorganic constituents in *Eugenia jambolana* seed on streptozotocin-induced diabetes in rats. Biological Trace Element Research 99, 145–155.

Ravi, K., Sivagnanam, K., Subramanian, S., 2004c. Anti-diabetic activity of *Eugenia jambolana* seed kernels on streptozotocin-induced diabetic rats. Journal of Medicinal Food 7, 187–191.

Ribes, G., Sauvaire, Y., Da Costa, C., Baccou, J.C., Loubatieres- Mariani, M.M., 1986. Hypoglycemic effects of subfractions from fenugreek seeds in diabetic dogs. Proceedings of the Society for Experimental Biology and Medicine 182, 159–166.

Rizvi, S.I., Abu Zaid, M., Suhail, M., 1995. Insulin-mimetic effect of (−)-epicatechin on osmotic fragility of human erythrocytes. Indian Journal of Experimental Biology 33, 791–792.

Rizvi, S.I., Zaid, M.A., 2001. Insulin-like effect of (−)-epicatechin on erythrocyte membrane acetylcholinesterase activity in type 2 diabetes mellitus. Clinical and Experimental Pharmacology and Physiology 28, 776–778.

Roman-Ramos, R., Flores-Saenz, J.L., Alarcon-Aguilar, F.J., 1995. Anti-hyperglycemic effect of some edible plants. Journal of Ethnopharmacology 48, 25–32.

Sabu, M.C., Kuttan, R., 2004. Hypoglycemic activity of *Aegle marmelos* and its relationship with its antioxidant properties. Indian Journal of Physiology and Pharmacology 48, 81–88.

Sachdewa, A., Khemani, L.D., 1999. A preliminary investigation of the possible hypoglycemic activity of *Hibiscus rosa-sinensis*. Biomedical and Environmental Sciences 12, 222–226.

Sachdewa, A., Khemani, L.D., 2003. Effect of *Hibiscus rosa sinensis* Linn. ethanol flower extract on blood glucose and lipid profile in streptozotocin induced diabetes in rats. Journal of Ethnopharmacology 89, 61–66.

Sachdewa, A., Nigam, R., Khemani, L.D., 2001b. Hypoglycemic effect of *Hibiscus rosa sinensis* L. leaf extract in glucose and streptozotocin induced hyperglycemic rats. Indian Journal of Experimental Biology 39, 284–286.

Sachdewa, A., Raina, D., Srivastava, A.K., Khemani, L.D., 2001a. Effect of *Aegle marmelos* and *Hibiscus rosa sinensis* leaf extract on glucose tolerance in glucose induced hyperglycemic rats (Charles foster). Journal of Environmental Biology 22, 53–57.

Saleem, R., Ahmad, M., Hussain, S.A., Qazi, A.M., Ahmad, S.I., Qazi, M.H., Ali, M., Faizi, S., Akhtar, S., Husnain, S.N., 1999. Hypotensive, hypoglycaemic and toxicological studies on the flavonol C-glycoside shamimin from *Bombax ceiba*. Planta Medica 65, 331–334.

Sarkar, S., Pranava, M., Marita, R., 1996. Demonstration of the hypoglycemic action of *Momordica charantia* in a validated animal model of diabetes. Pharmacological Research 33, 1–4.

Satheesh, M.A., Pari, L., 2004. Antioxidant effect of *Boerhavia diffusa* L. in tissues of alloxan induced diabetic rats. Indian Journal of Experimental Biology 42, 989–992.

Saxena, A., Vikram, N.K., 2004. Role of selected Indian plants in management of type 2 diabetes: a review. Journal of Alternative and Complementary Medicine 10, 369–378.

Saxena, A.M., Bajpai, M.B., Mukherjee, S.K., 1991. Swerchirin induced blood sugar lowering of streptozotocin treated hyperglycemic rats. Indian Journal of Experimental Biology 29, 674–675.

Saxena, A.M., Bajpai, M.B., Murthy, P.S., Mukherjee, S.K., 1993. Mechanism of blood sugar lowering by a Swerchirin-containing hexane fraction (SWI) of *Swertia chirayita*. Indian Journal of Experimental Biology 31, 178–181.

Seema, P.V., Sudha, B., Padayatti, P.S., Abraham, A., Raghu, K.G., Paulose, C.S., 1996. Kinetic studies of purified malate dehydrogenase in liver of streptozotocin-diabetic rats and the effect of leaf extract of *Aegle marmelose* (L.) Correa ex Roxb. Indian Journal of Experimental Biology 34, 600–602.

Sekar, B.C., Mukherjee, B., Chakravarti, R.B., Mukherjee, S.K., 1987. Effect of different fractions of *Swertia chirayita* on the blood sugar level of albino rats. Journal of Ethnopharmacology 21, 175–181.

Sekar, D.S., Sivagnanam, K., Subramanian, S., 2005. Hypoglycemic activity of *Momordica charantia* seeds on streptozotocin induced diabetic rats. Pharmazie 60, 383–387.

Shah, D.S., 1967. A preliminary study of the hypoglycemic action of heartwood of *Pterocarpus marsupium* Roxb. Indian Journal of Medical Research 55, 166–168.

Shani, J., Goldsehmied, A., Joseph, B., Ahronson, Z., Sulman, F.G., 1974. Hypoglycaemie effect of *Trigonella foenum graecum* and *Lupinus termis* (Leguiminosae) seeds and their major alkaloids in alloxan-diabetic and normal rats. Archives Internationales de Pharmacodynamie et de Therapie 210, 27–37.

Shanmugasundaram, K.R., Panneerselvam, C., Samudram, P., Shanmugasundaram, E.R., 1983. Enzyme changes and glucose utilization in diabetic rabbits: the effect of *Gymnema sylvestre*, R.Br. Journal of Ethnopharmacology 7, 205–234.

Sharma, A.K., 1993. In: Galadari, E.O., Behara, I., Manchandra, M., Abdulrazzaq, S.K., Mehra, M.K. (Eds.), Diabetes Mellitus and Its Complications: An Update, 1st ed. Macmillan, New Delhi.

Sharma, K.K., Gupta, R.K., Gupta, S., Samuel, K.C., 1977. Antihyperglycemic effect of onion: effect on fasting blood sugar and induced hyperglycemia in man. Indian Journal of Medical Research 65, 422–429.

Sharma, S.B., Nasir, A., Prabhu, K.M., Murthy, P.S., Dev, G., 2003. Hypoglycaemic and hypolipidemic effect of ethanolic extract of seeds of *Eugenia jambolana* in alloxan-induced diabetic rabbits. Journal of Ethnopharmacology 85, 201–206.

Sharma, S.R., Dwivedi, S.K., Swarup, D., 1997. Hypoglycemic, antihyperglycemic and hypolipidemic activities of *Caesalpinia bonducella* seeds in rats. Journal of Ethnopharmacology 58, 39–44.

Sharma, V.N., Sogani, R.K., Arora, R.B., 1960. Some observations on hypoglycemic activity of *Momordica charantia*. Indian Journal of Medical Research 48, 471–477.

Sheehan, E.W., Zemaitis, M.A., Slatkin, D.J., Schiff Jr., P.L., 1983. A constituent of *Pterocarpus marsupium*, (−)-epicatechin, as a potential hypoglycemic agent. Journal of Natural Products 46, 232–234.

Sheela, C.G., Augusti, K.T., 1992. Hypoglycemic effects of S-allyl cysteine sulphoxide isolated from garlic *Allium sativum* Linn. Indian Journal of Experimental Biology 30, 523–526.

Sheela, C.G., Kumud, K., Augusti, K.T., 1995. Anti-diabetic effects of onion and garlic sulfoxide amino acids in rats. Planta Medica 61, 356–357.

Shibib, B.A., Khan, L.A., Rahman, R., 1993. Hypoglycemic activity of *Coccinia indica* and *Momordica charantia* in diabetic rats: depression of the

hepatic gluconeogenic enzymes glucose-6-phosphatase and fructose-1,6-bisphosphatase and elevation of both liver and red-cell shunt enzyme glucose-6-phosphate dehydrogenase. Biochemistry Journal 292, 267–270.

Shimizu, K., Iino, A., Nakajima, J., Tanaka, K., Nakajyo, S., Urakawa, N., Atsuchi, M., Wada, T., Yamashita, C., 1997. Suppression of glucose absorption by some fractions extracted from *Gymnema sylvestre* leaves. Journal of Veterinary Medical Science 59, 245–251.

Shirwaikar, A., Rajendran, K., Dinesh Kumar, C., Bodla, R., 2004. Hypoglycemic activity of aqueous leaf extract of *Annona squamosa* in streptozotocin-nicotinamide type 2 diabetic rats. Journal of Ethnopharmacology 91, 171–175.

Singh, K.N., Chandra, V., Barthwal, K.C., 1975. Letter to the editor: hypoglycemic activity of *Acacia arabica*, *Acacia benthami* and *Acacia modesta* leguminous seed diets in normal young albino rats. Indian Journal of Physiology and Pharmacology 19, 167–168.

Singh, N., Singh, S.P., Vrat, S., Misra, N., Dixit, K.S., Kohli, R.P., 1985. A study on the anti-diabetic activity of *Coccinia indica* in dogs. Indian Journal of Medical Science 39, 27–29.

Singh, S.N., Vats, P., Suri, S., Shyam, R., Kumria, M.M., Ranganathan, S., Sridharan, K., 2001. Effect of an hypoglycemic extract of *Catharanthus roseus* on enzymic activities in streptozotocin induced diabetic rats. Journal of Ethnopharmacology 76, 269–277.

Singh, S.S., Pandey, S.C., Srivastava, S., Gupta, V.S., Patro, B., Ghosh, A.C., 2003. Chemistry and medicinal properties of *Tinospora cordifolia* (Guduchi). Indian Journal of Pharmacology 35, 83–91.

Sitasawad, S.L., Shewade, Y., Bhonde, R., 2000. Role of bittergourd fruit juice in stz-induced diabetic state in vivo and in vitro. Journal of Ethnopharmacology 73, 71–79.

Sridhar, S.B., Sheetal, U.D., Pai, M.R., Shastri, M.S., 2005. Preclinical evaluation of the hypoglycemic effect of *Eugenia jambolana* seed powder in streptozotocin-diabetic rats. Brazilian Journal of Medical and Biological Research 38, 463–468.

Srinivasan, M., Padmanabhan, M., Prince, P.S., 2005. Effect of aqueous *Enicostemma littorale* Blume extract on key carbohydrate metabolic enzymes, lipid peroxides and antioxidants in alloxan-induced diabetic rats. Journal of Pharmcy and Pharmacology 57, 497–503.

Srividya, N., Periwal, S., 1995. Diuretic, hypotensive and hypoglycemic effect of *Phyllanthus amarus*. Indian Journal of Experimental Biology 33, 861–864.

Stanely, P., Kamalakkannan, N., Menon, V.P., 2003. *Syzigium cumini* seed extracts reduce tissue damage in diabetic rat brain. Journal of Ethnopharmacology 84, 205–209.

Stanely, P., Menon, V.P., 2000. Hypoglycemic and other related actions of *Tinospora cordifolia* roots in alloxan-induced diabetic rats. Journal of Ethnopharmacology 70, 9–15.

Stanely, P., Menon, V.P., 2001. Antioxidant action of *Tinospora cordifolia* root extract in alloxan diabetic rats. Phytotherapy Research 15, 213–218.

Stanely, P., Menon, V.P., 2003. Hypoglycaemic and hypolipidaemic action of alcohol extract of *Tinospora cordifolia* roots in chemical induced diabetes in rats. Phytotherapy Research 17, 410–413.

Stanely, P., Menon, V.P., Gunasekaran, G., 1999. Hypolipidaemic action of *Tinospora cordifolia* roots in alloxan diabetic rats. Journal of Ethnopharmacology 64, 53–57.

Suba, V., Murugesan, T., Arunachalam, G., Mandal, S.C., Saha, B.P., 2004a. Anti-diabetic potential of *Barleria lupulina* extract in rats. Phytomedicine 11, 202–205.

Suba, V., Murugesan, T., Rao, R.B., Ghosh, L., Pal, M., Mandal, S.C., Saha, B.P., 2004b. Hypoglycemic potential of *Barleria lupulina* extract in rats. Fitoterapia 75, 1–4.

Subramoniam, A., Pushpangadan, P., Rajasekharan, S., Evans, D.A., Latha, P.G., Valsaraj, R., 1996. Effects of *Artemisia pallens* Wall. on blood glucose levels in normal and alloxan-induced diabetic rats. Journal of Ethnopharmacology 50, 13–17.

Sugihara, Y., Nojima, H., Matsuda, H., Murakami, T., Yoshikawa, M., Kimura, I., 2000. Antihyperglycemic effects of gymnemic acid IV, a compound derived from *Gymnema sylvestre* leaves in streptozotocin-diabetic mice. Journal of Asian Natural Product Research 2, 321–327.

Thakran, S., Siddiqui, M.R., Baquer, N.Z., 2004. Trigonella foenum graecum seed powder protects against histopathological abnormalities in tissues of diabetic rats. Molecular and Cellular Biochemistry 266, 151–159.

Tjokroprawiro, A., Pikir, B.S., Budhiarta, A.A., Pranawa, Soewondo, H., Donosepoetro, M., Budhianto, F.X., Wibowo, J.A., Tanuwidjaja, S.J., Pangemanan, M., 1983. Metabolic effects of onion and green beans on diabetic patients. Tohoku Journal of Experimental Medicine 141, 671–676.

Tominaga, M., Kimura, M., Sugiyama, K., Abe, T., Igarashi, K., Igarashi, M., Eguchi, H., Sekikawa, A., Ogawa, A., Manaka, H., 1995. Effects of seishin-renshi-in and *Gymnema sylvestre* on insulin resistance in streptozotocin-induced diabetic rats. Diabetes Research and Clinical Practice 29, 11–17.

Tunali, T., Yarat, A., Yanardag, R., Ozcelik, F., Ozsoy, O., Ergenekon, G., Emekli, N., 1998. The effect of chard (*Beta vulgaris* L. var. cicla) on the skin of streptozotocin induced diabetic rats. Die Pharmazie 53, 638–640.

Upadhya, S., Shanbhag, K.K., Suneetha, G., Balachandra Naidu, M., Upadhya, S., 2004. A study of hypoglycemic and antioxidant activity of *Aegle marmelos* in alloxan induced diabetic rats. Indian Journal of Physiology and Pharmacology 48, 476–480.

Upadhyay, U.M., Goyal, R.K., 2004. Efficacy of *Enicostemma littorale* in Type 2 diabetic patients. Phytotherapy Research 18, 233–235.

Vats, V., Grover, J.K., Rathi, S.S., 2002. Evaluation of antihyperglycemic and hypoglycemic effect of *Trigonella foenum graecum*, *Ocimum sanctum* and *Pterocarpus marsupium* in normal and alloxanized diabetic rats. Journal of Ethnopharmacology 79, 95–100.

Vats, V., Yadav, S.P., Biswas, N.R., Grover, J.K., 2004b. Anti-cataract activity of *Pterocarpus marsupium* bark and *Trigonella foenum-graecum* seeds extract in alloxan diabetic rats. Journal of Ethnopharmacology 93, 289–294.

Vats, V., Yadav, S.P., Grover, J.K., 2004a. Ethanolic extract of *Ocimum sanctum* leaves partially attenuates streptozotocin-induced alterations in glycogen content and carbohydrate metabolism in rats. Journal of Ethnopharmacology 90, 155–160.

Venkatesh, S., Dayanand Reddy, G., Reddy, Y.S., Sathyavathy, D., Madhava Reddy, B., 2004. Effect of *Helicteres isora* root extracts on glucose tolerance in glucose-induced hyperglycemic rats. Fitoterapia 75, 364–367.

Venkatesh, S., Reddy, G.D., Reddy, B.M., Ramesh, M., Appa Rao, A.V.N., 2003. Antihyperglycemic activity of *Caralluma attenuata*. Fitoterapia 74, 274–279.

Venkateswaran, S., Pari, L., 2003a. Effect of *Coccinia indica* leaf extract on plasma antioxidants in streptozotocin-induced experimental diabetes in rats. Phytotherapy Research 17, 605–608.

Venkateswaran, S., Pari, L., 2003b. Effect of *Coccinia indica* leaves on antioxidant status in streptozotocin-induced diabetic rats. Journal of Ethnopharmacology 84, 163–168.

Venkateswaran, S., Pari, L., Suguna, L., Chandrakasan, G., 2003. Modulatory effect of *Coccinia indica* on aortic collagen in streptozotocin-induced diabetic rats. Clinical and Experimental Pharmacology and Physiology 30, 157–163.

Vessal, M., Hemmati, M., Vasei, M., 2003. Hypoglycemic effects of quercetin in streptozocin-induced diabetic rats. Comparative Biochemistry and Physiology C: Toxicology and Pharmacology 135C, 357–364.

Vetrichelvan, T., Jegadeesan, M., 2002. Anti-diabetic activity of alcoholic extract of *Aerva lanata* (L.) Juss. ex Schultes in rats. Journal of Ethnopharmacology 80, 103–107.

Vijayvargia, R., Kumar, M., Gupta, S., 2000. Hypoglycemic effect of aqueous extract of *Enicostemma littorale* Blume (chhota chirayata) on alloxan induced diabetes mellitus in rats. Indian Journal of Experimental Biology 38, 781–784.

Vikrant, V., Grover, J.K., Tandon, N., Rathi, S.S., Gupta, N., 2001. Treatment with extracts of *Momordica charantia* and *Eugenia jambolana* prevents hyperglycemia and hyperinsulinemia in fructose fed rats. Journal of Ethnopharmacology 76, 139–143.

Vimla Devi, M., Venkateswarlu, M., Krishana Rao, R.V., 1977. Hypoglycemic activity of the leaves of *Momordica charantia*. Indian Journal of Pharmacology 39, 167–169.

Wadood, A., Wadood, N., Shah, S.A., 1989. Effects of *Acacia arabica* and *Caralluma edulis* on blood glucose levels of normal and alloxan diabetic rabbits. Journal of Pakistan Medical Association 39, 208–212.

Wadood, N., Wadood, A., Shah, S.A., 1992. Effect of *Tinospora cordifolia* on blood glucose and total lipid levels of normal and alloxan-diabetic rabbits. Planta Medica 58, 131–166.

Waltner-Law, M.E., Wang, X.L., Law, B.K., Hall, R.K., Nawano, M., Granner, D.K., 2002. Epigallocatechin gallate, a constituent of green tea, represses hepatic glucose production. Journal of Biological Chemistry 277, 34933–34940.

Welihinda, J., Arvidson, G., Gylfe, E., Hellman, B., Karlsson, E., 1982. The insulin-releasing activity of the tropical plant *Momordica charantia*. Acta Biologica et Medica Germanica 41, 1229–1240.

Yadav, P., Sarkar, S., Bhatnagar, D., 1997a. Action of *Capparis decidua* against alloxan-induced oxidative stress and diabetes in rat tissues. Pharmacological Research 36, 221–228.

Yadav, P., Sarkar, S., Bhatnagar, D., 1997b. Lipid peroxidation and antioxidant enzymes in erythrocytes and tissues in aged diabetic rats. Indian Journal of Experimental Biology 35, 389–392.

Yadav, U.C., Moorthy, K., Baquer, N.Z., 2005. Combined treatment of sodium orthovanadate and Momordica charantia fruit extract prevents alterations in lipid profile and lipogenic enzymes in alloxan diabetic rats. Molecular and Cellular Biochemistry 268, 111–120.

Yoshikawa, M., Murakami, T., Kadoya, M., Li, Y., Murakami, N., Yamahara, J., Matsuda, H., 1997b. Medicinal foodstuffs. IX. The inhibitors of glucose absorption from the leaves of *Gymnema sylvestre* R. BR. (Asclepiadaceae): structures of gymnemosides a and b. Chemical and Pharmaceutical Bulletin (Tokyo) 45, 1671–1676.

Yoshikawa, M., Murakami, T., Kadoya, M., Matsuda, H., Muraoka, O., Yamahara, J., Murakami, N., 1996. Medicinal foodstuff. III. Sugar beet. Hypoglycemic oleanolic acid oligoglycosides, betavulgarosides I, II, III, and IV, from the root of *Beta vulgaris* L. (Chenopodiaceae). Chemical and Pharmaceutical Bulletin (Tokyo) 44, 1212–1217.

Yoshikawa, M., Murakami, T., Matsuda, H., 1997a. Medicinal foodstuffs. X. Structures of new triterpene glycosides, gymnemosides-c, -d, -e, and -f, from the leaves of *Gymnema sylvestre* R. Br. : influence of gymnema glycosides on glucose uptake in rat small intestinal fragments. Chemical and Pharmaceutical Bulletin (Tokyo) 45, 2034–2038.

Yoshikawa, M., Murakami, T., Yashiro, K., Matsuda, H., 1998. Kotalanol, a potent alpha-glucosidase inhibitor with thiosugar sulfonium sulfate structure, from hypoglycemic Ayurvedic medicine *Salacia reticulata*. Chemical and Pharmaceutical Bulletin (Tokyo) 46, 1339–1340.

Yu, B.C., Hung, C.R., Chen, W.C., Cheng, J.T., 2003. Antihyperglycemic effect of andrographolide in streptozotocin-induced diabetic rats. Planta Medica 69, 1075–1079.

Zacharias, N.T., Sebastian, K.L., Philip, B., Augusti, K.T., 1980. Hypoglycemic and hypolipidemic effects of garlic in sucrose fed rabbits. Indian Journal of Physiology and Pharmacology 24, 151–154.

Zhang, X.F., Tan, B.K., 2000a. Anti-diabetic property of ethanolic extract of *Andrographis paniculata* in streptozotocin-diabetic rats. Acta Pharmacologica Sinica 21, 1157–1164.

Zhang, X.F., Tan, B.K., 2000b. Antihyperglycaemic and anti-oxidant properties of Andrographis paniculata in normal and diabetic rats. Clinical and Experimental Pharmacology and Physiology 27, 358–363.