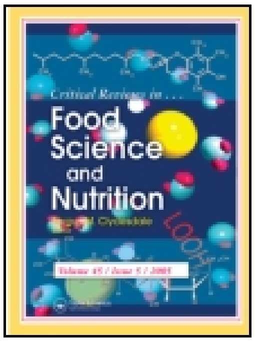

Critical Reviews in Food Science and Nutrition

ISSN: 1040-8398 (Print) 1549-7852 (Online) Journal homepage: http://www.tandfonline.com/loi/bfsn20

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To cite this article: Poonam Singhal , Geetanjali Kaushik & Pulkit Mathur (2014) Antidiabetic Potential of Commonly Consumed Legumes: A Review, Critical Reviews in Food Science and Nutrition, 54:5, 655-672, DOI: 10.1080/10408398.2011.604141

To link to this article: https://doi.org/10.1080/10408398.2011.604141

Accepted author version posted online: 31 May 2013.
Published online: 31 May 2013.

Critical Reviews in Food Science and Nutrition, 54:655–672 (2014)

ISSN: 1040-8398 / 1549-7852 online
DOI: 10.1080/10408398.2011.604141

Antidiabetic Potential of Commonly Consumed Legumes: A Review

POONAM SINGHAL,[1] GEETANJALI KAUSHIK,[1] and PULKIT MATHUR[2]

[1]Centre for Rural Development and Technology, Indian Institute of Technology-Delhi, New Delhi 110016, India
[2]Department of Food and Nutrition, Lady Irwin College, University of Delhi, New Delhi 110001, India

Over the last few decades, lifestyle changes have resulted in a drastic increase in the incidence of diabetes all over the world, especially in the developing countries. Oral hypoglycemic agents and insulin form the mainstay in controlling diabetes, but they have prominent side effects and fail to significantly alter the course of diabetic complications. Appropriate diet and exercise programs that form a part of lifestyle modifications have proven to be greatly effective in the management of this disease. Dietary therapy is showing a bright future in the prevention and treatment of diabetes. Legumes, owing to their high nutritive value, are increasingly being used in dietetic formulations in the treatment and prevention of diabetes on account of their antidiabetic potential. Given this background, this paper reviews the glucose- and lipid-lowering action possessed by various commonly consumed legumes through several animal and human studies. It is concluded that the various legumes not only have varying degrees of antidiabetic potential but are also beneficial in decreasing the risk factors for cardiovascular and renal disease.

Keywords Diabetes, antidiabetic, legumes, cholesterol

INTRODUCTION

Diabetes mellitus (DM), a global public health problem, is now emerging as an epidemic the world over. According to a widely accepted estimation, the prevalence of diabetes for all age groups was 2.8% in 2000, and the number of patients with diabetes is expected to reach 4.4%, i.e., 366 million by the year 2030 (Wild et al., 2004). The situation is particularly grim in the developing countries such as India, which has the world's largest diabetic population, encompassing an estimate of 35 million people out of an overall population of 1 billion. Another 79 million people have impaired glucose tolerance. In just over 20 years (i.e., 2025), the country will have almost 200 million people (approximately 15% of the population) affected by diabetes or its precursor (Kaushik et al., 2010).

Forms, Complications, and Preventive Measures for DM

Diabetes is a metabolic disease that affects not only glucose metabolism but also lipid and protein metabolism. There are mainly two types of diabetes: type 1 and type 2. In type 1 or insulin-dependent diabetes, the hormone insulin is not produced in the absence of pancreatic ß-cells, while type 2 diabetes mellitus (T2DM) is characterized by a progressive impairment of insulin secretion by pancreatic ß-cells and by a relative decreased sensitivity of target tissues to the action of this hormone (Burcelin et al., 1999). DM is a major worldwide health problem predisposing to markedly increased cardiovascular mortality (Savage, 1996). Other serious morbidities and mortalities are related to the development of nephropathy (kidney damage), neuropathy (nerve damage), and retinopathy (blindness) due to diabetes (David, 1993; Clark and Lee, 1995). Increased oxidative stress has been implicated in the pathogenesis of DM. Hyperglycemia-induced protein glycation generates superoxide free radicals (Cunningham et al., 1995; Lipinski, 2001; Memisogullari et al., 2003). The generation of active oxygen species may lead to lipid peroxidation and formation of reactive products, which may be involved in the severe damage of cell molecules and structures. As a result of these, the chances of cardiovascular and cerebral morbidities become manifold.

DM in youth has been recognized to be frequent in populations of native North Americans. Among Japanese school children, T2DM is seven times more common than type 1, and its incidence has increased more than 30-fold over the past 20 years, concomitant with changing food patterns and increasing obesity rates (Rosenbloom et al., 1999). As the prevalence of T2DM continues to increase worldwide, there is an enhanced need for

Address correspondence to Poonam Singhal, Centre for Rural Development and Technology, Indian Institute of Technology-Delhi, New Delhi 110016, India. E-mail: singhalpoonam6@gmail.com

effective disease management. T2DM is managed through a stepwise program of intensive therapy that consists of lifestyle modification, including appropriate diet and exercise programs, and sequential addition of oral antihyperglycemic agents such as oral hypoglycemic agents (OHAs) and insulin. Improvement in blood glucose level through a combination of lifestyle modifications and oral modifications may slow the rate of progression of this disease and enhance the quality of life for people with T2DM (Warren, 2004).

About one-third of patients with type 2 diabetes are treated with OHAs to stimulate insulin secretion. These drugs however risk inducing hypoglycemia and, over time, lose their efficacy (Burcelin et al., 1999). Although OHAs and insulin are the mainstay of the treatment of diabetes and are effective in controlling hyperglycemia, they have prominent side effects and fail to significantly alter the course of diabetic complications. The common side effects associated with the main classes of drugs used for the treatment of T2DM are hypoglycemia, weight gain, gastrointestinal disorders, peripheral edema, and liver disease (Mallare et al., 2005).

The overall management of diabetes not only entrusts upon achieving normoglycemic and lipid states. While the pharmacological therapies are in use for management, the diabetes prevention trials in China (Pan et al., 1997; Tuomilehto et al., 2001; Diabetes Prevention Program Research Group 2002) remind us that nutrition and lifestyle approaches can be more effective in delaying the onset of this disease.

Dietary Therapy for DM Management

Dietary therapy especially has a bright future in the management of T2DM. Currently, the American Diabetes Association (ADA) recommends the use of diabetes food pyramid for T2DM patients. The use of low-glycemic index (GI) diets (comprising whole-grain cereals and legumes) in the management of diabetes has been recommended around the world (Wolever et al., 1992; Brand-Miller et al., 2003; Canadian Diabetes Association, 2008). Physical exercise, along with diet, forms an effective combination for the prevention of DM (Eriksson and Lindgirde 1991). Since diet forms the mainstay in the management of DM, there is an urgent need to exploit plant food materials possessing hypoglycemic activity for a possible beneficial use. Legumes form an important part of our diet on account of their nutritive value. Several studies implicate legumes in the prevention and treatment of DM. Hence, with this background, this paper reviews different legume grains that have been shown to possess antidiabetic properties.

LEGUMES AS ANTIDIABETIC AGENTS

Legumes belong to the family *Leguminosae*, with 18,000 species classified into around 650 genera (Polhill and Raven 1981). Legumes, the poor man's meat, are important sources of food proteins consumed all over the world (Duranti and Gius 1997). They are generally good sources of complex carbohydrates (namely dietary fibers) and are rich in proteins (∼18–25%), soybean being the exception, containing about 35–43% proteins. They are also good sources of vitamin C, riboflavin, and niacin, especially the germinated legumes (Tharanathan and Mahadevamma 2003). General information on legumes regarding their scientific name, common names, and major nutrients has been given in Table 1.

Legumes are normally consumed after processing, which not only improves their palatability but also increases the bioavailability of nutrients, by inactivating phytic acid, trypsin inhibitors, and hemagglutinins, although resulting in some loss of water-soluble nutrients (Tharanathan and Mahadevamma, 2003). Several reports claim that the inclusion of legumes in the daily diet has many beneficial physiological effects in controlling and preventing various metabolic diseases such as DM

Table 1 General information on legumes

			Macronutrients				
S. No.	Scientific name	Common name	Carbohydrates (%)	Protein (%)	Fat (%)	Fiber (%)	Reference
1.	*Cajanus cajan*	Pigeon pea, Red gram	62.7	19.3	2.0	6.4	(Singh and Singh, 1992)
2.	*Cicer arietinum*	Chickpea, Bengal gram	63.4	20.7	4.16	2.49	(Bravo et al., 1999)
3.	*Dolichos biflorus*	Horse gram	59.3	24.9	0.58	5.61	(Bravo et al., 1999)
4.	*Dolichos lablab*	Field bean	60.1	24.9	0.8	1.4	(Patwardhan, 1962)
5.	*Lens culinaris*	Lentils	56.4	20.6	2.15	6.83	(Almeida Costa et al., 2006)
6.	*Pisum sativum*	Garden pea	52.5	21.9	2.34	10.4	(Almeida Costa et al., 2006)
7.	*Phaseolus aconitifolius*	Moth bean, Tepary bean	61.8	25.3	0.69	4.57	(Bravo et al., 1999)
8.	*Phaseolus angularis*	Adzuki bean, Red bean	64.4	19.9	0.6	7.8	(Sacks, 1977)
9.	*Phaseolus aureus*	Green gram, Mung bean	63	24	1	16	(US Department of Agriculture, 2001)
10.	*Phaseolus lunatus*	Lima bean	—	22.5	3.35	4.46	(Adeparusi, 2001)
11.	*Phaseolus mungo*	Black gram	67	23.6	0.45	6.60	(Bravo et al., 1999)
12.	*Phaseolus vulgaris*	Kidney bean, Navy bean, Pinto bean	52.5	20.9	2.49	8.55	(Almeida Costa et al., 2006)
13.	*Vicia faba*	Broad bean, Field bean	58	26	1–2	25	(US Department of Agriculture, 2001)
14.	*Glycine max*	Soybean	35	36	19	17	(Mateos-Aparicio et al., 2008)

(Jenkins et al., 1981; Kaushik et al., 2010) and coronary heart disease (Anderson et al., 2000), cancer (Kennedy, 1995) in lowering of serum cholesterol (Duane, 1997). Currently, the role of legumes as therapeutic agents in the diets of persons suffering from metabolic disorders is gaining interest (Simpson et al., 1981; Shehata et al., 1988; Jang et al., 2001). According to a recent report, these can be considered as nutraceutical products with an immense potential to prevent metabolic disorders (Duranti, 2006). Effect of various legumes on the changes in lipid profile and blood glucose in human subjects has been compiled in Table 2.

It is in this context that an attempt has been made to review the various food legumes which have been investigated in human and animal trials for their antidiabetic potential and the mechanism of their action.

Cajanus cajan: *Pigeon Pea*

Pigeon pea (*Cajanus cajan*) is a woody perennial legume. This crop is important because of its diverse uses as food, medicine, and fuel. It is widely cultivated in India and Eastern and Southern Africa. Pigeon peas are an important staple in India, East Africa, and the Caribbean. About 90% of the world's supply is produced in the Indian subcontinent (Amarteifio et al., 2002). It contributes immensely to African diets because of its high protein content (20–28%) and palatability (Obizoba, 1991).

Antihyperglycemic Action

Animal studies focusing on the antidiabetic potential of pigeon pea are numerous. Aqueous fraction of the leaves and stems of *C. cajan* (500 and 1000 mg/kg) lacked the hypoglycemic effect in normoglycemic mice. However, it significantly increased glucose tolerance at one hour and two hours in the oral glucose tolerance test (OGTT) (Esposito Avella et al., 1991). Single doses of unroasted seeds of *C. cajan* (60 and 80%) administered to normal and alloxanized mice caused a significant reduction in the serum glucose levels after one to two hours and a significant rise at three hours, while in the case of roasted seeds, there was a significant increase in the serum glucose levels during the three-hour experimental period. Roasting of seeds at high temperature for 30 minutes resulted in the total loss of the hypoglycemic principle but not the hyperglycemic principle present in the seeds (Amalraj and Ignacimuthu 1998). In contrast to the above studies, a recent investigation also studied the usefulness of the extract in controlling hypoglycemia. Single oral administration of graded doses of aqueous extract of *C. cajan* leaves showed a significant increment of 14.3% in fasting blood glucose levels of normal rats. The dose of 1000 mg/kg showed the maximum rise of 17.1, 71.2, and 50.7% in blood glucose levels of normal, sub-, and mild diabetic rats, respectively, during the OFTT (Jaiswal et al., 2008). Studies on human subjects for testing the hypoglycemic effect of legumes are limited. Cooked diet of *C. cajan* showed lower blood glucose response and a lower glycemic index when tested in healthy human volunteers. The lower glycemic response could be due to dietary fiber, amylase content, and the presence of antinutrients. It can therefore be added to the list of possible foods for patients with diabetes and those with hyperlipidemia (Panlasigui et al., 1995).

Anticholesterolemic Action

Globulin fraction from red gram at 10% level when administered to rats fed on a high-fat-high-cholesterol diet showed a prominent hypolipidemic effect (Prema and Kurup, 1973b). Stilbene extract from *C. cajan* L. (sECC) at a dose of 200 mg/kg in hyperlipidemic Kunming mice for four weeks lowered the serum and hepatic total cholesterol by 31.5% and 22.7% ($P < 0.05$), respectively. The triglyceride contents of serum and liver were also lowered by 23.0% and 14.4%, respectively. Serum low-density lipoprotein (LDL) cholesterol also decreased by 53.0% ($P < 0.01$). The mRNA expressions of HMG-CoA reductase, CYP7A1, and LDL receptor were significantly enhanced. These results indicated that sECC reduced the atherogenic properties of dietary cholesterol in mice (Luo et al., 2008).

Cicer arietinum: *Chickpea*

It is commonly known as chickpea or Bengal gram and is considered the most important pulse in India. These are of two types: kabuli and desi. India grows about 75% of the world's total production of chickpea. The crop is prepared by traditional processing practices such as soaking, sprouting, fermentation, boiling, roasting, parching, frying, and steaming for human consumption (Singh, 1985).

Antihyperglycemic Action

A number of studies support the hypoglycemic and associated hypercholesterolemic action of chickpeas through animal models. Blood glucose got lowered in the high-dosage group by 15.81 ± 4.57 mmol/L as compared with the low-dosage group (23.78 ± 4.34 mmol/L) in diabetic rats after administering refined chickpea powder (Xiao et al., 2005). Postprandial plasma glucose level in six healthy subjects after taking 50 g of Bengal gram dal (channa dal) decreased by 82.1% when compared with wheat and rice (Dilawari et al., 1981). Inclusion of spaghetti containing wheat and chickpea flour decreased starch hydrolysis, with glycemic index $GI_{\text{wheat+chickpea spaghetti}}$ being 58 ± 6 as compared with $GI_{\text{wheat spaghetti}}$ 73 ± 5 in 12 volunteers, indicating low postprandial glycemic response (Goi and Valentn-Gamazo, 2003). Chickpea-based single meal given to healthy middle-aged men and women for six weeks substantially lowered the plasma glucose 30 and 60 minutes after the meal than after the wheat-based meal, and plasma insulin and the calculated homeostasis model assessment (HOMA; an index of insulin sensitivity) were also lowered at 120 minutes ($P <$ 0.05 for both) (Nestel et al., 2004).

Table 2 Characteristics of study design and effect of various legumes on lipid profile and blood glucose in human subjects

Legume	Subjects (*n*)	Age	Intervention (legume form and amount)	Study duration	Changes in blood lipid	Changes in blood glucose	Reference
Pigeon pea	—	—	Cooked pigeon pea	—	NA	Lower blood glucose response of pigeon pea compared with that of bread. The glycemic index (GI) of pigeon pea was found lower (30.99 ± 4.1) but was not significantly lower as compared with other legumes.	(Panlasigui et al., 1995)
Chickpea	30 male subjects free from any systemic disease	15–50 (33.5 years)	High fat + Bengal gram diet	67 weeks	Serum total cholesterol lowered from 11.35 to 8.8 mmol/l	NA	(Mathur et al., 1968)
	Six healthy males	36.3 years	50 g cooked bengal gram dal	Four weeks	NA	Rise in plasma glucose decreased by 82.1%	(Dilawari et al., 1981)
	12 healthy female volunteers	23.25 ± 2.42 years	50 g available carbohydrate in the form of pasta (75% durum wheat flour and 25% chickpea flour)	Two hour after consumption	NA	$GI_{wheat+chickpea}$ spaghetti is 58 ± 6 than GI_{wheat} spaghetti, which is 73 ± 5	(Goi and Valentn-Gamazo, 2003)
	Acute study (19 middle-aged men and women) Long-term study (20 middle-aged men and women)	Acute (61.5 ± 6.4 years) Long-term (56.6 ± 7.6 years)	Cooked, drained, and canned chickpeas, 50 g raw peas	Six weeks	Addition of chickpeas to a meal did not modify postprandial TAG concentrations	Plasma glucose lowered after chickpea meal (6.01 and 5.09 mmol/l) than after standard (7.63 and 6.98 mmol/l) at 30 and 60 minutes.	(Nestel et al., 2004)
	45 free-living adults	NA	728 g of canned chickpeas	12 weeks, followed by four weeks without chickpeas	Serum total cholesterol and LDL cholesterol were 0.20 mmol/l and 0.19 mmol/l less, respectively, after the chickpea phase	Fasting insulin was 5.21 pmol/l less	(Pittaway et al., 2008)
Field bean	24 NIDDM patients	42–58 years	50 g available carbohydrate in the form of unleavened bread	Blood samples taken after three hours at an interval of 30 minutes	NA	GI was 31.6 ± 3.15, lower peak increment in blood glucose response (3.2 mmol/minute) than standard (9.6 mmol/minute)	(Fatima, Kapoor 2006)
Soybean	13 normocholesterolemic and 13 hypercholesterolemic men	20–50 years normocholesterolemic (35.5 ± 7.2), hypercholesterolemic (41.4 ± 7.8)	Soy protein diet	Five weeks	LDL cholesterol lowered by 6% and the ratio of LDL:HDL cholesterol lowered by 11% with the soy protein diet	NA	(Wong et al., 1998)
	32 NIDDM postmenopausal women	62.5 ± 6.77 years	Soy protein 30 g/day, isoflavones 132 mg/day	12 weeks, separated by a two-week washout period	Cholesterol after 12 weeks for soy 5.52 ± 0.92 mmol/l and for placebo 5.75 ±1.07 mmol/l	Fasting glucose after 12 weeks for soy 7.37 ± 1.63 mmol/l and for placebo 7.57 ± 1.93 mmol/l	(Jayagopal et al., 2002)

	15 NIDDM subjects (7 men and 8 women)	60.3 ± 3.1 years old	Soy pinitol (1.2 g or 0.6 g dose) prior to cooked white rice containing 50 g available carbohydrate	Blood samples taken after four hours	NA	Less incremental area under the plasma glucose response curve for subjects who consumed both pinitol and rice ($P < 0.05$), but pinitol had no apparent effect on postprandial insulin levels.	(Kang et al., 2006)
	20 subjects (14 men and 6 women)	63.6 ± 7.5 years	Abalon providing 50 g soy protein, 165 mg isoflavones, and 20 g cotyledon fiber in a day	Six weeks, separated by a three-week washout period	Lowered LDL cholesterol (10 ± 15%), LDL/HDL ratio (12 ± 18%), triglycerides (22 ± 10%), and total cholesterol (8 ± 15%)	NA	(Hermansen et al., 2001)
Lentils	Eight healthy volunteers (2 men and 6 women)	29 ± 8 years	50 g lentils cooked by four different ways	Blood samples taken after two hours at an interval of 15 minutes	NA	0.87 ± 0.11 mmol/l for 20-minute-boiled lentils as compared with 2.44 ± 0.3 mmol/l for 12-hour-dried lentils.	(Jenkins et al., 1982)
	30 NIDDM patients	45–60 years (50.2 ± 3.8 years)	50 g cooked lentil	15 weeks	Total cholesterol lowered from 12.54 to 12.10 mmol/l in the treatment group	Fasting blood sugar reduced from 8.48 to 8.35 mmol/l in the treatment group	(Shams et al., 2008)
Adzuki bean	33 women student volunteers	21.3 ± 0.8 years	150 g juice five times a day	Five days	Reductions in TG concentrations in the azuki and CA juice groups by 15.4% and 17.9%, respectively.	NA	(Maruyama et al., 2008)
Green gram	14 normal and 14 male subjects with diabetes	Normal (35.2 ± 1.54 years), With diabetes (52.5 ± 2.46 years)	Test meals containing 46 g green gram	Blood samples taken after three hours at an interval of 30 minutes	NA	GI of *Phaseolus aureus* is 56 as compared with bread (100)	(Akhtar et al., 1987)
	Eight fasting NIDDM patients	NA	50 g available carbohydrates as mung bean noodles	Blood samples taken after three hours at an interval of 30 minutes	NA	Slower glucose digestion leading to a low GI of mung bean noodles	(Juliano et al., 1989)
Lima bean	Eight healthy volunteers (5 males and 3 females)	21–24 years	25 g of meal	One week	NA	GI and insulin index for lima bean were 36 ± 3 and 51 ± 3 as compared with corn (40 ± 5 and 53 ± 4, respectively)	(Brand et al., 1990)

(Continued on next page)

Table 2 Characteristics of study design and effect of various legumes on lipid profile and blood glucose in human subjects *(Continued)*

Legume	Subjects (n)	Age	Intervention (legume form and amount)	Study duration	Changes in blood lipid	Changes in blood glucose	Reference
Black gram	30 NIDDM patients (17 men and 13 women)	Over 40 years	Cooked meals providing 50 g carbohydrate	Seven days	NA	Lower GI for semolina-black gram dhal (46 ± 12) and lower blood glucose response (12 ± 1.8) at one hour postprandially as compared with the GI of semolina alone (76 ± 6)	(Mani et al., 1992)
Kidney bean	13 male students	18–26 years	450 g can of baked beans/day	Four weeks	Total plasma cholesterol level fell significantly from 5.1 to 4.5 mmol/l	NA	(Shehata et al., 1988)
	18 healthy volunteers (9 males and 9 females)	29 ± 4.8 years	*Phaseoli vulgari* pericarpium (PVP) extract	–	NA	Incremental blood glucose (IBG), together with AUC changes, was significantly lower in males compared with females in both the groups.	(Cerović et al., 2006)
Garden pea	Nine NIDDM patients (6 men and 3 women)	48–75 years (61± 3)	Three meals: first containing 90 g peas, second containing 60 g peas, and third containing no peas	Three different days separated by weekly intervals	NA	Area under the glucose curve was 164 ± 40, 257 ± 57, and 381 ± 40 mmol/l at 180 minutes for first, second, and third meal	(Schfe et al., 2003)
Broad bean	40 healthy male students	18–21 years	90 g field bean flour/day	30 days	Reduction in serum cholesterol (mmol/l) (from 5.81 in group A to 5.7, 5.35, and 5.28 in groups B, C, and D)	Reduction in serum glucose (mmol/l) (from 5.27 in group A to 4.73, 4.8, and 4.74 in groups B, C, and D)	(Frllhbeck et al., 1997)

NA = Not assessed.

Anticholesterolemic Action

Both protein and fat fractions of Bengal gram were found to not only prevent but also reverse the experimentally induced high levels of cholesterol in both tissues and serum in cholesterol–cholic acid-fed rats (Mathur et al., 1964). Two isoflavones, biochanin-A and formononetin, isolated from Bengal gram when administered as a crude extract or as individual compounds to Triton WR-1339-induced hyperlipidemia in male albino rats exhibited hypolipidemic properties (Siddiqui and Siddiqi, 1976). Germinated chickpea was more effective in lowering the cholesterol levels of hypercholesterolemic rats as compared with the ungerminated chickpea. The lipid fraction (from ungerminated chickpea) and the carbohydrate fractions (from both germinated and ungerminated chickpea)-fed rats showed lower cholesterol levels compared with those fed whole legumes (Jaya and Venkataraman, 1979). Pangamic acid was isolated and identified as the principle component in stamina building, antistress, and antihyperlipidemic effects (Singh et al., 1983). Bengal gram showed highest reduction in serum and tissue cholesterol and triglycerides, and the fecal excretion of bile acids was also greater when compared with the hypocholesterolemic effect of tannin, phytate, and pectin in rats (Sharma, 1984). Both proteins and lipid constituents of Bengal gram flour lowered serum cholesterol in rats, whereas liver cholesterol was lowered by proteins and not by the lipid fraction (Murthy and Urs 1985). Four active fractions of gram, i.e., total lipid, fatty acid, globulin, and insoluble carbohydrate fractions effectively controlled fructose-induced hyperlipidemia in rats. These fractions decreased the levels of cholesterol, triglycerides, and phospholipids in the serum, liver, and aorta (Malik et al., 1985). Saponins contained in chickpeas form an insoluble complex with cholesterol and thus prevent its absorption from the small intestine and hence are shown to have a hypocholesterolemic effect (Sidhu and Oakenfull 1986). Supplementation of diet with chickpea significantly decreased the concentrations of total cholesterol (54%), triacylglyerols (70%) as well as the levels of LDL (54%) and very-low-density lipoproteins (VLDL) (70%) in hypercholesterolemic rats (Zulet and Martinez, 1995). Feeding chickpea or casein as a protein source to hypercholesterolemic rats for 16 days improved the lipid disturbances, with the legume being more effective than casein in decreasing the total and LDL cholesterol (LDL-C). The chickpea constituents (protein, fat, fiber, saponins, isoflavones) were believed to be involved in normalization of the lipid metabolism (Alzorriz and Hernandez, 1999). Rats fed a diet enriched with coconut oil (25%) and cholesterol (1%) for 42 days showed a situation of type IIa hyperlipoproteinemia. However, these hypercholesterolemic rats receiving chickpea diet for 16 days confirmed normalization of triglycerides as well as total and LDL-C levels. Rats receiving chickpea re-established the liver glycogen deposition as compared with the hyperlipoproteinemic group. Also, the chickpea intake increased the glucokinase activity. Chickpea intake may thus be recommended in humans with altered lipid profile such as type IIa hyperlipoproteinemia (Zulet et al., 1999). Administration of a high-fat plus chickpea diet (HFD + CP) for eight months reduced the epididymal fat pad weight of rats [0·023 g/g (SD 0·0072)]. Chickpea-treated obese rats also showed a markedly lower leptin and lipoprotein lipase (LPL) mRNA content in the epididymal adipose tissue. Furthermore, chickpea treatment also induced a favorable plasma lipid profile reflecting decreased triacylglycerides (TAG), LDL-C, and LDL-C:HDL-C (high-density lipoprotein cholesterol) levels ($P < 0.05$). Addition of chickpeas to the HFD drastically lowered the TAG concentration (muscle, 39%; liver, 23%). In addition to the above improvements, chickpeas significantly improved insulin resistance and prevented postprandial hyperglycemia and hyperinsulinemia induced by the chronic HFD. Consumption of chickpeas may thus be beneficial for correcting dyslipidemia and in preventing diabetes (Yang et al., 2007).

Enormous amount of work has been done on the hypoglycemic role of chickpeas in human subjects as well. A long-term study of 67 weeks in men also showed the hypocholesterolemic effect reducing the mean serum total cholesterol level from 206.4 ± 20.0 mg/100 mL to 160.0 ± 24.1 mg/100 mL, respectively (Mathur et al., 1968). Incorporation of chickpeas in the ad libitum diet of 45 free-living adults who consumed 728 g of canned chickpeas per week for 12 weeks, followed by four weeks of without chickpeas, caused the PUFA:SFA (polyunsaturated fatty acids:saturated fatty acids) ratio to change from 0.39 to 0.47. In the chickpea phase, the mean dietary fiber intake rose to 6.77 g/day and the mean PUFA consumption was 2.66%. Serum total cholesterol and LDL-C were 7.7 mg/dL (0.20 mmol/L) and 7.3 mg/dL (0.19 mmol/L) less, respectively, fasting insulin was 0.75 microIU/mL (5.21 pmol/L) less, and the HOMA of insulin resistance was 0.21 less (Pittaway et al., 2008).

Dolichos biflorus: *Horse Gram*

Horse gram (*Dolichos biflorus*) is considered to be an important food legume in India. In addition to proteins, horse gram is a rich source of iron and molybdenum. Horse gram is consumed as whole seeds or sprouts by a large population in rural areas of southern India. Like other legumes, the utilization of horse gram for human nutrition is constrained by the presence of flatulence-producing oligosaccharide such as raffinose (Anisha and Prema 2008). The hypoglycemic effect of horse gram has not been described in human volunteers but a few animal studies support this evidence.

Antihyperglycemic Action

The seeds of horse gram showed antihyperglycemic potential in normal fasting albino rats (Pant et al., 1968). An earlier report also suggests that horse gram possesses hypoglycemic properties (Vaidya et al., 1989).

Anticholesterolemic Action

The globulin fraction from horse gram in rats fed a high-fat-high-cholesterol diet lowered the total and free cholesterol, phospholipids, and triglycerides in the serum, liver, and aorta, although the hypolipidemic activity was less as compared with the other legume (red gram) (Prema and Kurup, 1973a). Administration of methanolic extract of *D. biflorus* (400 mg/kg body weight) to high-fat-diet-fed rats showed normalization of levels of these lipids in the plasma and tissues (Kottai et al., 2005).

Antioxidant Action

Administration of methanolic extract of *D. biflorus* (400 mg/kg body weight) in high-fat-diet-fed rabbits significantly lowered the level of thiobarbituric acid reactive substances (TBARS) and enhanced the level of reduced glutathione (GSH). Activities of antioxidant enzymes superoxide dismutase (SOD) and catalase (CAT) showed a marked reduction in the liver, heart, and aorta of rabbits (Kottai et al., 2006).

Dolichos lablab: *Field Bean*

Dolichos lablab L. var lignosus is a lesser-known legume that has not received much attention by biochemists and nutritionists. It is a high-yielding legume shrub even with minimum rainfall and management (Ndlovu and Sibanda 1996). Some animal studies suggest the hypoglycemic and hypolipidemic activity of field bean.

Antihyperglycemic Action

Green pods of *D. lablab* showed hypoglycemic activity in alloxaninduced diabetic rats (Satyavati et al., 1989). Human studies indicating the use of field bean as a therapeutic agent in diabetes are scarce. The in vivo response of field bean in subjects with non-insulin-dependent diabetes (NIDD) was determined by studying the glycemic index. Lower fasting blood glucose (8.5 $\pm$ 0.12 mmol/minute), peak increment (3.2 mmol/minute), and glycemic response (31.6 $\pm$ 3.15) were produced as compared with standard glucose in 24 NIDDM patients when given 50 g available carbohydrate from legumes in the form of unleavened bread (Fatima and Kapoor, 2006). The seed of this bean was used as an antidiabetic agent to treat diabetes (Pandian et al., 2008).

Anticholesterolemic Action

Addition of field beans into the diet of hypercholesterolemic rats corrected the cholesterol levels (Saraswati and Shurpalekar 1986). The hypocholesterolemic effect of protein concentrates (PCs) prepared from *D. lablab* seeds relative to that of casein led to significantly lower levels of triglyceride and total cholesterol and LDL cholesterol in the blood serum as well as lower liver total lipids and cholesterol contents (Chau et al., 1998). Insoluble dietary fibers (IDFs) prepared from the seeds relative to cellulose fed to hamsters for 30 days lowered the levels of serum LDL cholesterol as well as liver cholesterol. Moreover, *D. lablab* IDF diet led to a significantly ($P < 0.05$) higher level of HDL cholesterol relative to the control. The cholesterol-lowering effect might partially be due to IDFs' indirect influence on lowering the intestinal absorption of cholesterol due to the physicochemical properties (Chau and Cheung 1999). Supplementation of the diet with dried powder of soaked Indian bean (*Dolichos lablab* L. var lignosus) to hypercholesterolemic rats brought the plasma cholesterol to 72.5 $\pm$ 0.75 from 178 $\pm$ 1.85 compared with that of the control (61.5 $\pm$ 0.70), although the liver cholesterol was still three times higher as compared with the control. The 24-hour germinated Indian bean cotyledons could effectively counteract the effects of cholesterol on the liver and plasma by their high fiber content coupled with the enormous increase in ascorbic acid levels (Ramakrishna et al., 2007).

Glycine max: *Soybean*

Soybean is a singular food because of its rich nutrient content. Soybean foods represent an excellent source of high-quality protein, are low in saturated fat, and are cholesterol-free, and contain oligosaccharides, dietary fibers, phytochemicals (especially isoflavones), and minerals (Mateos-Aparicio et al., 2008). In October 1999, the US Food and Drug Administration (FDA) approved a health claim that allowed food label claims for reduced risk of heart disease on foods that contain $\geq$6.25 g of soybean protein per serving. In particular, a daily soybean protein intake of 25 g was considered beneficial, based on a number of previous clinical observations (Duranti, 2006). There are numerous studies and clinical trials indicating soybean as an ideal vegetable protein in the prevention of diabetes, cardiovascular disease, cancer, etc.

Antihyperglycemic Action

The three major isoflavones found in soybeans are genistin, daidzin, and glycitin. Soybean isoflavones (SI) had strong inhibitive effects on α-glucosidase, an enzyme important in carbohydrate digestion and there was a dose-dependent effect. Among the isoflavones, genistein had the strongest inhibitive effects, followed by daidzein and daidzin (Jishu et al., 2005). Feeding 0.1% genistein in a 20% casein diet (20C) for five weeks to KK-Ay/Ta mice suppressed increases in blood glucose levels and the suppressive effect was significant at the first and fifth week of feeding as compared with the diabetic control mice. Genistein also suppressed urinary glucose excretion as compared with the control mice during the feeding period (Kazumi et al., 2008). The hypoglycemic effects of SI and soyasaponins (SS) in diabetes and their inhibitory activities on alpha-glucosidase and alpha-amylase were studied. Soybean hypocotyl extracts (SHE) given to type 2 diabetic rats at the rate of 20 g/kg for 20 weeks decreased blood glucose significantly in type 2 diabetic rats and improved glucose tolerance in both normal and diabetic rats. In an alpha-glucosidase inhibitory assay, saponins showed potent inhibitory activities, with half maximal (50%) inhibitory concentration IC_{50} values of 10–40 μmol/l. Isoflavone aglycons also showed potent inhibitory activities against alpha-glucosidase, with IC_{50} values of 20–150 μmol/l, while isoflavone glycosides showed a little lower potency (Jishu et al., 2004). The influence of soybean phytochemical extract (SPE) containing isoflavones and soyasaponins was observed in diabetic rats that were fed fodder containing 20 g/kg of SPE for 20 week. The level of blood glucose, atherosclerotic index, and plasma level of lipid peroxide (11.9 ± 0.9 mmol/l, 0.40 ± 0.14, and 15.7 ± 0.5 mmol/l, respectively) got lowered in diabetic rats than in control rats (14.2 ± 2.0 mmol/l, 0.58 ± 0.22, and 20.7 ± 3.0 mmol/l, respectively) (Xuezhe et al., 2004). The antidiabetic effects of raw soybean examined in KK-Ay mice, a type 2 diabetes model for 13 weeks, became evident when the soybean diet suppressed the increase in blood and urinary glucose levels, plasma insulin levels, and water intake (Yoshiaki, 2007). Dietary soybean had also been studied for protecting the streptozotocin-induced ß-cell damage and for restraining the development of hyperglycemia in rats. Expression of insulin mRNA in pancreatic ß cells was significantly increased in rats fed raw soybean as compared with those fed a normal diet. In those rats and upon injection of streptozotocin, only few ß cells underwent cell death, most of them demonstrating active viability with enhanced mRNA expression and insulin content. This is consistent with the fact that the blood glucose level was normalized (72.51 ± 1.54 mg/dl) after a transitory hyperglycemic state (>300 mg/dl), implying its potential in preventing ß-cell injury by streptozotocin. (Lee and Park 2000).

Apart from the numerous investigations done on animal models, a huge number of clinical trials had been performed on human subjects to quantify the effects of soybean on blood glucose and lipid profiles. Consumption of soybeans was found to be inversely associated with the risk type T2DM in middle-aged Chinese women with no history of T2DM, cancer, or cardiovascular disease (Villegas et al., 2008). The effect of 3-O-methyl-D-*chiro*-inositol (D-pinitol), purified from soybean, on the postprandial blood glucose response in 15 patients with T2DM who ingested cooked white rice containing 50 g of available carbohydrate with or without prior ingestion of soy pinitol was examined. Pinitol was given either as a 1.2 g dose at 0, 60, 120, or 180 minutes prior to rice ingestion or as a 0.6 g dose at 60 minutes prior to rice ingestion. The ingestion of 1.2 g of pinitol 60 minutes prior to rice ingestion controlled postprandial capillary blood glucose most effectively. Moreover, the incremental area under the plasma glucose response curve for subjects who consumed both pinitol and rice was significantly lower than that for subjects who consumed only rice ($P < 0.05$), but pinitol had no apparent effect on postprandial insulin levels. Therefore, soybean-derived pinitol may be useful in controlling postprandial increases in blood glucose in patients with type 2 diabetes (Kang et al., 2006). Several animal and human studies suggest that the isoflavone fraction in soybean seems to play an important role in exerting the hypoglycemic action.

Anticholesterolemic Action

The first in vivo evidence of the involvement of the 7S globulin family of soybean storage proteins was obtained in 1992. In this study, a direct effect on a 35% reduction of plasma cholesterol levels in rats was observed, with dosage and effects comparable with those obtained with clofibrate. The results also showed a statistically significant decrease of triglyceride levels in rats (Lovati et al., 1992). Soybean oligosaccharides significantly reduced abnormal blood glucose, lipid level, and oxidative stress in rats that recieved the high-fat diet and were orally fed with soybean oligosaccharides at a single dose of 150, 300, and 450 mg/kg body weight, respectively (Chen et al., 2010). The effect of the undigested fraction (UDF) of soybean protein in relation to soybean protein (SOY) was studied in hamsters in combination with different fat sources, either perilla oil (PER) or safflower oil (SAF). Cholesterol-enriched (0.2%) diets containing 20% protein and 10% fat were fed to hamsters for four weeks. UDF was more hypocholesterolemic than SOY in hamsters regardless of the dietary fat source. Serum total cholesterol (mg/dl) for PER-UDF and SAF-UDF was 387 ± 30 and 351 ± 13, respectively, as compared with PER-SOY and SAF-SOY with higher values (681 ± 13 and 717 ± 11). UDF markedly prevented a rise in serum and liver cholesterol levels in rats by stimulating fecal steroid excretion more than soybean protein (Gatchalian-Yee et al., 1997). Further preventive effects could be observed when the diet of male Wistar rats was supplemented with 10, 25, and 50% soybean, respectively, for 14 days. High intake of soybean (25% and 50%) in the diet significantly ($P < 0.05$) reduced the level of the serum enzymes, glutamate–oxaloacetate and glutamate pyruvate transaminases, and alkali and acid phosphatases, and serum glucose. Soybean incorporation at the 50% level significantly reduced the total serum cholesterol (Anosike et al., 2008).

Several investigators have tried to find out the anticholesterolemic effect of soybean on human subjects. The hypocholesterolemic effects of soybean protein in hypercholesterolemic men who ate a soybean protein diet for five weeks, followed by a washout period of 10–15 weeks, and then again continuing the diet for five weeks were indicated by the decreased plasma concentration of LDL cholesterol and LDL-C:HDL-C ratio (Wong et al., 1998). Dietary supplementation with phytoestrogens (soy protein 30 g/day, isoflavones 132 mg/day) in postmenopausal women with diet-controlled type 2 diabetes significantly lowered mean values for fasting insulin ($8.09 \pm 21.9\%$, $P = 0.006$), insulin resistance ($6.47 \pm 27.7\%$, $P = 0.003$), total cholesterol ($4.07 \pm 8.13\%$, $P = 0.004$), LDL-C ($7.09 \pm 12.7\%$, $P = 0.001$), cholesterol:HDL-C ratio ($3.89 \pm 11.7\%$, $P = 0.015$), and free thyroxine ($2.50 \pm 8.47\%$, $P = 0.004$). No significant change occurred in HDL-C and triglycerides (Jayagopal et al., 2002). Supplementation with Abalon [soy protein (50 g/day) with high levels of isoflavones (minimum 165 mg/day) and cotyledon fibers (20 g/day)] or placebo [casein (50 g/day) and cellulose (20 g/day)] in 20 subjects with type 2 diabetes for six weeks, separated by a three-week washout period, suggested significantly lower mean values for LDL-C ($10 \pm 15\%$, $P < 0.05$), LDL:HDL ratio ($12 \pm 18\%$, $P < 0.05$), and triglycerides ($22 \pm 10\%$, $P < 0.05$), whereas the total cholesterol value tended to be less significant but still lower ($8 \pm 15\%$, $P < 0.08$) (Hermansen et al., 2001). Meta-analysis critically reviewed 38 controlled clinical studies examining the effects of the intake of soy protein, either textured or isolated, on serum lipid concentrations. Soy protein intake averaged 47 g/day in these studies. Of the 38 studies, 34 (89%) reported a net decrease in serum cholesterol concentrations with soy protein intake. Soy protein exerted a favorable effect on all lipoprotein risk factors compared with animal protein control diets in the following manner: serum cholesterol concentrations were 0.59 mmol/l (9.3%) lower ($P < 0.001$); LDL-C concentrations were 0.56 mmol/l (12.7%) lower ($P < 0.001$); TAG concentrations were 0.15 mmol/l (10.5%) lower ($P < 0.001$); and HDL-C concentrations were 0.03 mmol/l (2.4%) higher ($P > 0.05$) (Anderson et al., 1995). Another recent meta-analysis was conducted to explore the influence of covariates on net lipid change. Soy protein with isoflavones intact was found to be associated with significant decreases in serum total cholesterol (by 0.22 mmol/l, or 3.77%), LDL-C (by 0.21 mmol/l, or 5.25%), and TAG (by 0.10 mmol/l, or 7.27%) and significant increases in serum HDL cholesterol (by 0.04 mmol/l, or 3.03%). The reductions in total cholesterol and LDL-C were larger in men than in women. Studies with intakes >80 mg showed better effects on the lipid profile. The strongest lowering effects of soy were only observed in studies of >12-week duration. Tablets containing extracted soy isoflavones did not have a significant effect on total cholesterol reduction (Zhan and Ho, 2005).

Lens culinaris: *Lentils*

Lentil is a grain legume widely grown in Turkey for food. The grain forms an important source of protein, with 25–30% protein content, and its yield ranges between 850 and 1100 kg/ha (Carman, 1996).

Antihyperglycemic Action

The hypoglycemic role of lentils has not been researched in animal models. In animal studies, only one study reported the reduced incidence of developing diabetes in diabetes-prone BB rats that were fed red lentils (Hoorfar et al., 1991). The blood-glucose-lowering ability of lentils has not been well established by investigators, although a few human studies have been conducted. A decreased blood glucose response was observed in a group of eight healthy volunteers who consumed breakfast test meals containing lentils (processed in four different ways) over white bread. Lentils boiled for 20 minutes or blended for an hour resulted in a flattened blood glucose response. However, the blood glucose response was significantly enhanced by drying the boiled blended lentils for 12 hours at 121.1°C, because of rapid liberation of carbohydrates, than when using the 20-minute-boiled lentils (Jenkins et al., 1982). In a randomized crossover clinical trial, 30 patients with T2DM, followed a diet of 50 g cooked lentils and 6 g canula oil substitute of 30 g bread and 20 g cheese for six weeks, were put on a washout period for three weeks, and later continued the diet for another six weeks. Total cholesterol (before: 228.07 ± 15.8 mg/dl, after: 220.1 ± 14.6 mg/dl) and fasting blood glucose (before: 154.3 ± 14.7 mg/dl, after: 151.9 ± 12.6 mg/dl) decreased significantly in the regimen containing lentils ($P < 0.05$) (Shams et al., 2008).

Phaseolus aconitifolius: *Moth Bean*

Moth bean is recognized as a potential source of protein and other nutrients. It is cultivated for its immature pods and mature seeds and is consumed by people all around the world, especially in the developing nations. The seeds are consumed following processing such as soaking/dry heating and cooking (Siddhuraju, 2006).

Anticholesterolemic Action

Only one study has reported the hypocholesterolemic effect of the PC prepared from moth bean (*Phaseolus aconitifolius* Jacq.) seeds in albino rats (Wistar strain), where 45 days of supplementation produced significantly lower levels of liver total lipid and cholesterol levels, including LDL-C. Moreover, moth bean PC produced a significantly higher level of serum HDL-C. Lowering of the elevated hepatic and serum lipids and cholesterol levels were attributed to the amino acid profile of this lesser-known legume (Mayilvaganan et al., 2004).

Phaseolus angularis: *Adzuki Bean*

Adzuki is a very important bean in the Far East. Adzuki beans have long been widely cultivated and consumed in confectionary and other traditional dishes in Asian countries (Namba, 1980). It is used as a diuretic, antidote, and remedy for dropsy and beri-beri in traditional Chinese medicine (Dictionary of Chinese, 1977). Adzuki beans contain dietary fibers, saponins, and polyphenols (Kojima et al., 2006a).

Antihyperglycemic Action

The ability of adzuki beans to lower blood glucose by influencing lipid metabolism is well established through animal models. Results from animal studies help to elucidate its potential as a hypoglycemic agent. Hot-water extract obtained by boiling adzuki beans to produce a bean paste for a Japanese cake showed inhibitory activity, with the IC_{50} values of 0.78 mg/ml, 2.45 mg/ml, 5.37 mg/ml, and 1.75 mg/ml against alpha-amylase, maltase, sucrase, and isomaltase, respectively. The active 40% ethanol fraction showed potential hypoglycemic activity in both normal mice and streptozotocin (STZ)-induced diabetic rats after an oral administration of sucrose by inhibiting α-glucosidase and α-amylase, irrespective of the endogenous blood insulin level (Itoh et al., 2004). The effect of adzuki bean seed coats (ABSC), containing polyphenols, on the complications of diabetic nephropathy was studied in STZ-induced diabetic rats fed with 0% (commercial diet), 0.1%, and 1.0% ABSC diet for 10 weeks. No difference in plasma glucose levels but a reduction in plasma levels of malondialdehyde (MDA) was observed in the ABSC-treated diabetic rats. Histopathologically, the percentage of fibrotic areas in the glomeruli, number of macrophages, and MCP-1 mRNA expression were lowered in the ABSC-treated diabetic rats than in untreated diabetic rats (Sato et al., 2005).

Anticholesterolemic Action

Rats fed a cholesterol-free diet with 150 g/kg adzuki starch (AS) for four weeks showed a significant decrease in serum total cholesterol, VLDL + intermediate density lipoprotein + LDL-C and HDL-C concentrations, and total cholesterol:HDL-C ratio at the end of the feeding period. The relative quantity of hepatic apolipoprotein B (Apo B) mRNA was 1.2 times higher and the hepatic LDL receptor mRNA levels were 1.8–2.0 times higher in the AS group (Fukushimaa et al., 2001). In a similar kind of study, rats fed with 50 g of an enzyme-resistant fraction of AS per kilogram for four weeks also showed a lowering of lipid fractions in the serum (Han et al., 2003a). The same investigator found out that a lower dose of 25 g AS/100 g diet fed to rats for four weeks produced similar results (Han et al., 2003b). Adzuki resistant starch containing 15% adzuki resistant starch + 0.5% cholesterol diet had a serum-cholesterol-lowering function via enhancement of the hepatic LDL-receptor mRNA and cholesterol 7a-hydroxylase mRNA levels (Han et al., 2005). Another mechanism revealed that the ethanol extract of adzuki bean seeds at concentrations of 1.10–5.56 mg/ml may inhibit the increase in serum cholesterol, thus inhibiting micellization of cholesterol in the gatrointenstinal tract, leading to reduced absorption of cholesterol and its excretion in feces and a reduction in the activity of cholesterol synthase in the liver (Kojima et al., 2006b). In a recent study, 0.5 ml solution of adzuki polyphenols (Adzuki-PP; 4 mg/ml) given to mice for two weeks via a catheter has been shown to improve the atherosclerotic index by inhibiting the serum cholesterol. Supplementation of Adzuki-PP to a concentration of 290 ppm lowered the solubility of micellar cholesterol, indicating that Adzuki-PP inhibits cholesterol micellization (Nishi et al., 2008).

Only one investigation in human subjects showed the beneficial effect in preventing hypertriglyceridemia. The effect of adzuki and concentrated adzuki (CA) bean juice supplementation (150 g daily) on healthy young Japanese women showed a decrease in triglyceride concentrations in the adzuki and CA juice groups by 0.170 mmol/l (15.4%) and 0.159 mmol/l (17.9%), respectively ($P < 0.05$). Serum LDL-C and HDL-C concentrations remained unchanged (Maruyama et al., 2008).

Phaseolus aureus: *Green Gram*

The mung bean is an ancient crop of Asia. Mung beans, or green gram, are similar in composition to other members of the legume family (US Department of Agriculture, 2001). Cooking improves the nutritive value by eliminating trypsin inhibitors and other antinutrients. Mung beans are commonly eaten as bean sprouts, and extruded mung bean starch is used in the production of vermicelli or glass noodles (Madar and Stark 2002).

Antihyperglycemic Action

Chronic replacement of a high glycemic index starch (waxy cornstarch) by a low glycemic index starch (mung bean) increased insulin-stimulated glucose oxidation, decreased glucose incorporation into total lipids, and decreased the epididymal adipocyte diameter in both normal and diabeteic rats after three weeks of intake (Kabir et al., 1998a). Glycemic responses to traditional Pakistani meals containing a mash of *Phaseolus aureus* were found to be less (Indira and Kurup, 1989) as compared with a bread-based meal (Akhtar et al., 1987; Memisogullari et al., 2003). When tested in subjects with NIDD, cooked noodles from mung beans were shown to have a lower glycemic index than two types of cooked rice and five other types of noodles. In addition, in vitro starch digestibility was low and the amylase content was high (Juliano et al., 1989).

Anticholesterolemic Action

Studies carried out in animal models showed that a whole-seed diet of green gram lowered serum total lipids and triglyceride levels ($P < 0.01$) when given to normal and alloxan-induced diabetic guinea pigs for four weeks. Total cholesterol:phospholipid ratio decreased from 0.630 to 0.625 in normal and from 1.039 to 0.850 in diabetic guinea pigs, indicating the diet's antiatherogenic nature (Srivastava et al., 1989). Another study indicated that the mung bean starch contained approximately 77 ± 4% resistant starch. In healthy rats, feeding of mung bean starch for five weeks led to lowered non-fasting plasma glucose and free fatty acid levels in comparison with rats fed wheat starch. In both healthy and diabetic rats, the mung bean starch reduced plasma TAG concentrations and the adipocyte volume, indicating its use in improving glucose and lipid metabolism (Lerer-Metzger et al., 1996). Another study revealed that the use of mung bean starch from cooked and powdered Chinese noodles over waxy cornstarch led to lower fatty acid synthase activity and mRNA expression in the adipose tissue but not in the liver of healthy rats. Furthermore, Glut4 expression was lower in the adipose tissue, suggesting that less glucose is available for lipogenesis (Kabir et al., 1998b). Dietary fiber prepared from crude mung bean sprouts was tested for its cholesterol-lowering effects in rats. A period of 21 days on a fiber-enriched diet led to a significant reduction in total plasma cholesterol levels, along with an increase in total cecal short-chain fatty acids. These data confirm that mung bean sprouts contain fermentable dietary fibers (Nishimura et al., 2000). The reduction in weight further reduces the risk of developing DM. Long-term feeding (12 weeks) of mung bean starch in rats resulted in significantly higher levels of plasma leptin and lower levels of circulating free fatty acids. These results indicate that consumption of starch from a legume source influences plasma leptin levels and may have a beneficial effect in preventing weight gain or increasing fat mass (Kabir et al., 2000).

Phaseolus lunatus: *Lima Bean*

Lima bean has desirable agronomic and nutritional characteristics. It is widely available and thrives in lowland tropical rainforest areas and on poor soils where most crops cannot grow well. However, like other tropical legumes, lima bean seed contains some antinutritional factors such as phytins and tannins, hydrogen cyanide, and trypsin inhibitors that get destroyed upon cooking (Akinmutimi and Ezea, 2006).

Antihyperglycemic Action

A study conducted on healthy Caucasian volunteers determined the in vivo glycemic and insulin responses and in vitro starch digestibility by feeding 25 g of cooked lima beans (broth). The glycemic indices (36 $\pm$ 3), insulin index (51 $\pm$ 3), and in vitro starch digestibility (38 $\pm$ 5) for lima bean broth indicated that the slow digestion and absorption of starch in traditional Pima foods helped in protecting from developing diabetes (Brand et al., 1990).

Anticholesterolemic Action

According to a few animal studies, a significant reduction ($P < 0.05$) in the amount of serum lipids (total cholesterol: 39.6 $\pm$ 3.7 mg/dl, HDL-C: 30.0 $\pm$ 1.7 mg/dl, LDL-C: 14.0 $\pm$ 0.5 mg/dl, VLDL-C: 26.0 $\pm$ 1.5 mg/dl, TAG: 104.0 $\pm$ 2.3 mg/dl) occurred in rats fed with heat-treated lima beans diet when observed after 30 days, due to the presence of saponin in the legume (Obon and Omofoma, 2008). The cholesterolemic effects in rats fed with a diet containing 330 g/kg legumes, namely Bambara groundnuts (*Vignu subterrunea*), baked beans (*Phuseofus vulgms*), marrowfat peas (*Pisum sutivum*), lentils (*Lens culinaris* Medik.), and butter beans (*Pheolus lunatus*), were compared after the supplementation period of eight weeks. The plasma cholesterol levels measured at weeks 4 and 8 showed a reduction with the diet of *Phaseouls lunatus* (Dabai et al., 1996). Hence, consumption of lima bean could be recommended to lower cholesterol and promote cardiovascular health.

Phaseolus mungo: *Black Gram*

Black gram (*Phaseolus mungo* Roxb.) is grown in India, Pakistan, and Sri Lanka. It is one of the major pulse crops in India. It is used as whole seed or dehusked splits (cotyledons) for making dhal. Black gram is extensively used in fermented products such as idli, dosa, and papad (Tiwari et al., 2007).

Antihyperglycemic Action

Human studies showing a hypoglycemic effect of black gram are scarce. In one human study, 50 g portions of a combined meal consisting of semolina (*Triticum aestivum*) and black gram dhal given to 30 NIDDM patients elicited a lower postprandial glucose response at 2 hours. This combination also showed a lower mean glycemic index as compared with other combinations (Mani et al., 1992).

Anticholesterolemic Action

The effect of black gram on the blood glucose level has been well documented in various research papers. A positive correlation between intake of black gram and hypoglycemia is documented in many animal studies. As early as in 1972, a protein and an insoluble polysaccharide fraction isolated from black gram decreased the level of total cholesterol and phospholipid in the serum, liver, and aorta in rats fed a high-fat-high-cholesterol diet. The fatty acids isolated from the lipid fractions also have some hypolipidemic effect (Devi and Kurup, 1972). The globulin fraction from black gram at the 5% dose level and the polysaccharide fraction at the 56% dose level showed a similar lipid-lowering effect. Thus, the protein fraction seemed to be more effective in decreasing the total cholesterol and triglyceride levels than the polysaccharide fraction (Devi and Kurup, 1973). Black gram polysaccharide has the highest fiber content and showed the most hypocholesterolemic effect over rice and wheat starch (Vijayagopal et al., 1973). The polysaccharide produced lower levels of total cholesterol and phospholipids in the serum, liver, and aorta and the fasting blood glucose level was found to be normal (Devi and Kurup, 1970; Menon and Kurup, 1974). Administration of germinated black gram comprising 30% NDF (neutral detergent fiber) to rats lowered the concentration of cholesterol and triglycerides in the serum, liver, and heart and aorta (Indira and Kurup, 1982) by increasing the excretion of fecal sterols and bile salts (Jayakumari and Kurup, 1979) and by binding of inorganic cations and bile acids (Indira and Kurup, 1989). It also brought an increase in the glycogen level and decreased blood glucose. Activities of enzymes phosphor-glucomutase and glucose 6-phosphate were lowered, indicating its hypoglycemic action (Boby and Leelamma, 2003). Normal and alloxan-induced diabetic guinea pigs given a diet containing whole seed of *Phaseolus mungo* for four weeks showed a significant lowering of blood glucose, serum total lipids, triglycerides, and the esterified fraction of cholesterol. The total cholesterol:phospholipid ratio also decreased in both the groups, indicating the antiatherogenic nature of *P. mungo* (Srivastava and Joshi, 1990).

Phaseolus vulgaris: *Kidney Bean*

Kidney bean (*Phaseolus vulgaris* L.) is the most widely produced and consumed food legume in Africa, India, Latin America, and Mexico (Food and Agriculture Organization, 1993). It is an excellent source of proteins (20–25%) and carbohydrates (50–60%) and a fairly good source of minerals and vitamins. However, its wide acceptability is adversely affected by the presence of tannins, saponins, and other antinutritional substances, but the destruction of these antinutritional substances in cooked forms increases its consumption as well (Rehman et al., 2001). Consumption of the bean in the normal Guatemala diet has been associated with a low glycemic response, low serum cholesterol levels, and a decrease of colon cancer risk factors (Serrano and Goi, 2004).

Antihyperglycemic Action

Differently processed beans elicited a lower metabolic response to glycemic and insulin indices over white bread (Tovar et al., 1994). Gastric administration of the decoction prepared by bean pods to 27 healthy rabbits significantly decreased the area under the glucose tolerance curve and the hyperglycemic peak (Roman-Ramos et al., 1995). Oral administration of 200 mg/kg of aqueous extract of *P. vulgaris* pods (PPEt) to diabetic animals for 45 days decreased blood glucose and glycosylated hemoglobin and increased total hemoglobin and plasma insulin. The lipogenic enzyme and hexokinase activity decreased significantly, whereas the activities of gluconeogenic enzymes increased in the diabetic liver (Pari and Venkateswaran, 2003). Purified pancreatic alpha-amylase inhibitor (alpha-AI) from white beans (*P. vulgaris*) when administered orally (100 mg/kg body weight) for 22 days to non-diabetic (ND) and type 2 diabetic STZ rats declined the mean glycemia (mmol/l) from day 4 of administration in both the groups (Tormo et al., 2006). Continuous oral administration of alpha-AI isolated from white kidney beans (*P.s vulgaris* L.) at a dose level of 150 mg/kg/day for seven days lowered fasting blood glucose and a dose of 300 mg/kg/day improved the sugar tolerance in alloxan-induced diabetic rats (Zhang et al., 2007). Alpha-amylase inhibitor isoform 1 (alpha-AI1) from *P. vulgaris* through its starch-blocking mechanism caused a reduction in postprandial plasma hyperglycemia and insulin levels (Obiro et al., 2008). The hypoglycemic activity of the vegetal complex of kidney bean in experimental diabetes was also observed (Khaleeva et al., 1987). Daily consumption of 450 g of baked beans reduced the mean total plasma cholesterol level of normocholesterolemic male students from 5.1 to 4.5 mmol/l (Shutler et al., 1989). Eighteen healthy participants aged 29 $\pm$ 4.8 years, body mass index (BMI) 23 $\pm$ 3.7 kg/m^2 receiving *Phaseoli vulgari* pericarpium (PVP) extract before a 50 g OGTT showed a lowered effect on incremental blood glucose (IBG), together with areas under the curve (AUC), in males (Cerović et al., 2006).

Anticholesterolemic Action

Hypercholesterolemic pigs fed diets containing baked beans at a dose of 300 g/kg for 28 days showed a reduction in the plasma total cholesterol by 35.5%, while the level of LDL-C was reduced by 48%. A significant lowering of about 50% in cholesterol deposition in the liver was observed compared with the controls (Costa et al., 1993). Administration of 200 mg/kg of aqueous extract of PPEt decreased the concentrations of lipids and fatty acids, namely palmitic, stearic, and oleic acids, whereas linolenic and arachidonic acids were elevated (Pari and Venkateswaran 2004). Dietary supplement containing 445 mg of *P. vulgaris* extract derived from the white kidney bean for 30 days produced decrements in body weight, BMI, fat mass, adipose tissue thickness, and waist/hip/thigh circumferences, while maintaining lean body mass (Celleno et al., 2007).

Antioxidant Action

Administration of 200 mg/kg of aqueous extract of PPEt caused a significant reduction in elevated blood glucose, serum triglycerides, free fatty acids, phospholipids, total cholesterol, VLDL, and LDL by decreasing the plasma TBARS and hyroperoxides. The decreased serum levels of HDL cholesterol, plasma insulin, and vitamin C were restored to normal levels (Venkateswaran et al., 2002). The extract also caused a significant increase in reduced glutathione, superoxide dismutase, catalase, glutathione peroxidase, and glutathione-S-transferase in the liver and kidneys of rats, thus showing its antioxidant property (Venkateswaran and Pari 2002).

Pisum sativum: *Garden Pea*

Peas are important food legumes, with a world production exceeded only by soybeans, peanuts, and dry beans. For both humans and animals, dry pea seeds are a potentially rich source of protein and carbohydrates (Adsule et al., 1989).

Antihyperglycemic Action

A few studies on the antidiabetic effect of *Pisum sativum* have been investigated in both animal and human subjects. Administration of peas in a rat model of NIDD significantly declined the glycemia (varying between 8.3 and 10.0 mmol/l with the standard diet) from the second day and stayed at levels near normal for the rest of the study. The inhibitory activity of pancreatic amylase was suggested as a possible mechanism in the raw pea extract (Tormo et al., 1997). The glycemic and insulinemic responses to three different meals (prepared according to local recipes and consumed at weekly intervals) based on dried peas (meal 1), potatoes (meal 3), or both (meal 2) in patients with type 2 diabetes were compared. Analysis of peripheral and venous blood samples over 180 minutes showed a delayed and smaller increase in postprandial plasma glucose and insulin concentrations after the pea meal than after the potato meal. The areas under the glucose curve were 164 ± 40, 257 ± 57, and 381 ± 40 mmol · 180 minutes/l for meal 1, 2, and 3, respectively ($P < 0.01$). The areas under the insulin curve were 13.8 ± 4.3, 15.4 ± 3.9, and 31.2 ± 6.9 mmol · 180 minutes/l for meal 1, 2, and 3, respectively ($P = 0.0514$) (Schfe et al., 2003).

Anticholesterolemic Action

Raw peas possess a hypocholesterolimic activity, where diet-induced hypercholesterolemia was significantly inhibited when a semi-purified + cooked peas (70:30 w/w) + 10 g cholesterol/kg was fed to pigs for 42 days (Kingman et al., 1993). A lipid-lowering activity was also observed when cholesterol-enriched (2.8 g/kg) raw pea seed (RP) diet fed to six pigs for three weeks lowered the plasma total cholesterol through a significant decrease in LDL-C. The RP diet also decreased the hepatic concentration of esterified cholesterol and increased the 3-hydroxy-3-methylglutaryl CoA reductase activity and LDL receptor synthesis. The biliary total cholesterol and bile acid concentrations were greater in RP, suggesting a hypocholesterolemic effect (Martins et al., 2004).

Vicia faba: *Broad Bean, Field Bean*

The faba bean is one of the world's oldest crops, and its economic importance is considerable. Two types of faba beans are eaten, one with an average weight of 800 mg (*V. faba* major or broad bean) and the other weighing approximately 550 mg (*V. faba* minor, horse bean, tick bean) (US Department of Agriculture, 2001; Madar and Stark, 2002).

Antihyperglycemic Action

Feeding growing mice on diets containing raw field beans *(V. faba* var. minor) as the only source of protein brought a reduction in serum glucose and zinc levels. Plasma protein, TAG, and cholesterol values were not affected by the dietary treatment. The serum glucose level in mice fed with raw field beans was 2200 (±100) mg/l as compared with the casein-fed mice, where the glucose level was 2600 (±160) mg/l (Martinezm and Macarulla 1992).

Anticholesterolemic Action

The lipid-lowering effects of *V. faba* have been documented more extensively in animal studies. An early investigation noticed that dietary faba bean PC lowered serum cholesterol and LDL-C in hypercholesterolemic rats when given for four weeks. Triglycerides and phospholipid levels were unaffected by the faba bean diet (FBD). Increased excretion of fecal bile acids with FBD suggested that the protein exerts its cholesterol-lowering effect by triggering the conversion of cholesterol to bile acid in the liver, due to increased intestinal drainage of bile acids (Jaya et al., 1981). Later on, ethanol extracts of faba bean (*V. faba*) PC given to rats for five weeks showed a marked decrease in the level of circulating cholesterol associated with the lower-density lipoproteins as compared with the level found in diets containing casein or the faba bean PC deprived of ethanol-soluble factors (Mengheri et al., 1985). A study also observed a significant decrease in plasma cholesterol levels after two weeks of intervention when faba beans were added to a hypercholesterolemia-inducing diet fed to rats (Bonilla et al., 1998). The rats fed on *V. faba* diets containing whole seeds or the protein isolate (prepared by isoelectric precipitation and spray drying) for two weeks ad libitum showed a significant reduction in plasma TAG. There was also a significant decrease in plasma (LDL + VLDL) cholesterol but not in HDL-C. Hepatic cholesterol and TAG were also reduced. The hypocholesterolemic effects of *V. faba* were suggested because of an increase in steroid fecal excretion (Macarulla et al., 2001).

Investigations made by various researchers reveal the beneficial impact of faba beans on lipid profiles. In human studies, another study demonstrated that in subjects with hypercholesterolemia (type IIa), faba bean protein had a cholesterol-reducing efficacy comparable with that of soya protein (Weck et al., 1983). Thirty-day supplementation with 90 g *V. faba* L. (field bean) flour to young men with high serum cholesterol resulted in a hypocholesterolemic effect. After 30 days, serum glucose, insulin, TAG, total, LDL-C, and VLDL-C values were significantly lower than the initial values in all subjects who consumed diets containing field bean flour. The legume intake also resulted in a significant increase in glucagon and HDL-C (Frllhbeck et al., 1997).

CONCLUSION

With increasing development and affluence, the changes in lifestyle and dietary habits have resulted in increasing incidences of lifestyle diseases such as T2DM, especially in the developing countries. The disease has an enormous burden in terms of diagnosis and treatment costs, and lifestyle approaches, including appropriate diet and exercise programs, are effective in managing this disease. Dietary intervention with a diet rich in legumes seems to be a natural, cost-effective, and free from side effects solution for the prevention and treatment of T2DM. It is concluded that the above-discussed legumes, which form a part of diet all over the world, possess antidiabetic properties and help in lowering blood glucose levels and in maintaining blood cholesterol by increasing bile salt excretion.

ABBREVIATIONS

OGTT	Oral glucose tolerance test
LDL	Low-density lipoproteins
VLDL	Very-low-density lipoproteins

HDL	High-density lipoproteins
TAG	Triacylglycerides
HOMA	Homeostasis model assessment
PUFA	Polyunsaturated fatty acids
SFA	Saturated fatty acids

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