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K. Srinivasan [a]
[a] Department of Biochemistry and Nutrition, Central Food Technological Research Institute, Mysore, India
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Fenugreek (*Trigonella foenum-graecum*): A Review of Health Beneficial Physiological Effects

K. SRINIVASAN

Department of Biochemistry and Nutrition, Central Food Technological Research Institute, Mysore, India

Among the spices that are esoteric food adjuncts being used to enhance flavoring and color, fenugreek (Trigonella foenum-graecum) *also modifies the texture of food. This seed spice is also employed for medicinal purpose in many traditional systems as antibacterial, gastric stimulant, against anorexia, antidiabetic agent and as a galactogogue. In recent decades, several health beneficial physiological attributes of fenugreek seeds have been seen in animal studies as well as human trials. These include antidiabetic effect, hypocholesterolemic influence, antioxidant potency, digestive stimulant action, and hepatoprotective effect. Among these beneficial physiological effects, the antidiabetic and hypocholesterolemic property of fenugreek, both of which are mainly attributable to the intrinsic dietary fiber constituent, have promising nutraceutical value. This article presents an overview of experimental evidence for the nutraceutical potential of fenugreek seeds.*

Keywords Fenugreek, *Trigonella foenum-graecum*, Nutraceutical, Antidiabetic, Hypocholesterolemic, Antioxidant, Digestive stimulant

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Introduction

Spices are natural food adjuncts that have been in use for thousands of years to enhance the sensory quality of foods. Spices impart characteristic flavour, aroma, picquancy and colour to foods. Some spices, like fenugreek, can also modify the texture of food. Fenugreek (*Trigonella foenum-graecum*) is a leguminous herb cultivated in India and North African countries. It belongs to the family *Fabaceae* and is variously called in different languages, viz., *Fenugrec* (French), *Methi* (Hindi), *Bockshorklee* (German), *Fieno greco* (Italian), *Pazhitnik* (Russian), *Alholva* (Spanish), *Koroha* (Japanese), *Hulba* (Arabian), *Halba* (Malaya), and *K'u-Tou* (China). The seeds are used as spices worldwide, whereas the leaves are used as green leafy vegetables in the diet. Fenugreek seeds are bitter to taste and are known for a long time for their medicinal qualities. Fenugreek seeds have been in use for over 2500 years. India is the major producer of fenugreek and its main consumer for culinary and medicinal uses. The seeds of fenugreek are used as a spice for seasoning, a flavoring agent and in comparatively larger quantities in making soups and pan cakes. In the indigenous system of medicine in India, it is effective against anorexia, and is a gastric stimulant.[1,2]

Address correspondence to Dr. K. Srinivasan, Department of Biochemistry and Nutrition, Central Food Technological Research Institute, Mysore 570 020, India. E-mail: ksri@sancharnet.in

The Plant

The seed sown on a prepared soil sprouts in 3 days, grows inherently resistant to most infestations and diseases to a robust, erect plant to a height of 30–60 cm, with compound pinnate trifoliate leaves, axillary white to yellowish flowers, and 3–15 cm long thin pointed beaked pods, which contain 10–20 oblong greenish-brown seeds with unique hooplike groove. As a leguminous plant, it fixes atmospheric nitrogen, thus enriching the soil. Greens are harvested at the 3 or 4 leaved stage, after which saponin content increases, making them more bitter. The seeds are harvested 30–35 days after flowering or 155–165 days after sowing.[3]

Fenugreek Greens and Fenugreek Seeds

Fresh or dried fenugreek leaves and tender stems are edible (Fig. 1). The nutrient composition of fresh fenugreek leaves is listed in Table 1. While these leaves provide a good amount of various minerals and vitamins, they are especially rich in choline. Coefficient of true digestibility of leaf protein is 77%, and its biological value is 84%.[4] Fenugreek seeds (Fig. 1) are aromatic, bitter, carminative, galactogogue, antibacterial and may be eaten raw or cooked. The bulk of the seed (50%) constitutes unavailable carbohydrates.[5] Bitterness is mainly due to the oil, steroidal saponins and alkaloids. The composition of mature fenugreek seeds is given in Table 1. The fiber portion consists of both insoluble (30%) and soluble fraction (20%), which is mostly galactomannan (Fig. 2). The 7.5% lipid present in the seed consists of mainly neutral lipids, namely, 6.3% triglycerides and 450 mg/100 g phospholipids.[5] An animal study has evidenced that the replacement of casein diet up to 10% by fenugreek seeds did not produce any deleterious effect in protein quality of casein as assessed by protein efficiency ratio, protein digestibility and net protein utilization.[6] Cooking of fenugreek is understood to have no effect on the quality seed protein.

Fenugreek Oils

The extractable oil from fenugreek, which is about 6–8%, has a foetid odour and bitter taste with marked drying properties. It has a specific gravity of 0.91, acid value 1–2,



Figure 1. Fenugreek leaves and seeds.

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Table 1
Composition of fresh fenugreek leaves and mature fenugreek seeds

Component	Fresh fenugreek leaves	Fenugreek seeds
Moisture	86.0 g	
Protein	4.4 g	30 g
Fat	1.0 g	7.5 g
Fiber	1.0 g	50 g
Sapogenins		2 g
Trigonelline		380 mg
Ca	395 mg	160 mg
Mg	67 mg	160 mg
P	51 mg	370 mg
Fe	16.5 mg	14 mg
Na	76 mg	19 mg
K	31 mg	530 mg
Cu	0.26 mg	33 mg
S	167 mg	16 mg
Cl	165 mg	165 mg
Mn		1.5 g
Zn		7.0 mg
Cr		0.1 mg
Choline	1.35 g	50 mg
Vitamin C	52 mg	43 mg
β-Carotene	2.3 mg	96 μg
Thiamine	40 μg	340 μg
Riboflavin	310 μg	290 μg
Nicotinic acid	800 μg	1.1 mg
Folic acid		84 μg

Values expressed per 100g.

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saponification value 178–183, iodine value 115, unsaponifiable matter 3.9%, and fatty acid composition of palmitic 9.6%, stearic 4.9%, arachidic 2%, oleic 35.1%, linoleic 33.7%, and α-linolenic 13.8%. About 0.02% is volatile oil (sp.gr. 0.87) with anethole as the major component.[7] The odor may resemble that of roasted coffee or maple syrup. The unsaponifiable portion contains the lactation-stimulating factor. Traditionally, whole seed is used in postpartum period to increase lactation in women and cattle. The oil is also used for cosmetic purposes, with traces used in perfumes, and is reported to have insect and pest repellent properties.[2]

Fenugreek Fibre

Dietary fibers are indigestible complex carbohydrates found in plant foods, and are an essential ingredient in a healthy diet. Some are soluble and form a gel, whereas others form insoluble roughage. Although most fruits and vegetables have insoluble fiber, legumes (guar, fenugreek, beans) have soluble fiber. Fenugreek is endospermic. Nearly

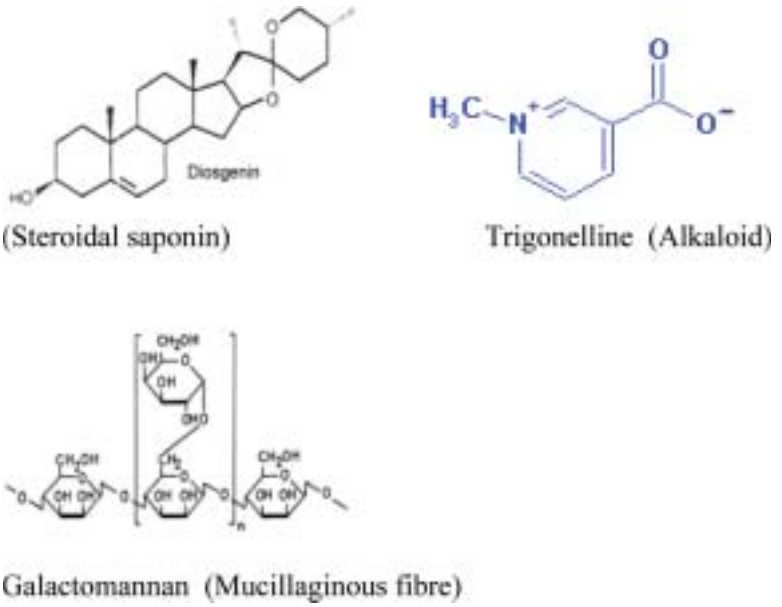


Figure 2. Bioactive chemical constituents of fenugreek.

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50% dry weight of seeds is edible dietary fiber, making it the highest concentration among all natural sources of fiber. About 30% of fenugreek seed (w/w) is gel-forming soluble fiber similar to guar gum, oat bran, and psyllium husk. The insoluble fiber, which constitutes 20% of fenugreek seed, is bulk-forming like wheat bran.[3]

Dietary fiber from fenugreek is very stable, with a long shelf life. It withstands frying, baking, cooking, and freezing. Minor modification in the physical conditions of processing can yield dietary fiber with distinct water absorption properties. Thus, dietary fiber with a high water retention capacity is made into jelly and spreads, and used as thickener. Dietary fiber can be taken as plain powder mixed in fruit juices or may be added to food items such as soups, beverages, and sauces. Adding fenugreek dietary fiber to refined flour helps to fortify with a balance of soluble and insoluble fiber. Flour fortified with 8–10% fenugreek dietary fiber has been used to prepare bakery foods like pizza, bread, muffins, and cakes. Since fenugreek dietary fiber has a very faint aroma of maple syrup, these products will gain flavor. Fenugreek dietary fiber has also been incorporated into flour to make chips, flat-bread (*chapathi*), wafers (*papads*), and taco shells. By fortifying such food items with fiber, one can increase the total dietary fiber intake.[4]

The RDA for dietary fiber is 20–30 g. Colonic transit time of diet with fenugreek dietary fiber is short. It improves regularity, reduces colonic bioburden, with little or no flatulence, increases fecal mass, reduces risk of constipation and makes defecation very smooth and easy. This reduces the risk of diverticulosis, hemorrhoids, and anal fissures. Fiber in the diet improves health by replacing calories, increasing chewing time, suppressing appetite, controlling overeating, and arresting weight-gain. Dietary fiber also induces satiety (feeling of fullness), delays gastric emptying and increases mouth-to-ceacum food transit time. With 30 g fenugreek dietary fiber a day and appropriate physical activity, gradual and significant weight-loss can be easily achieved without adverse protein-calorie malnutrition and other ill effects of dieting.[4]

Fenugreek Saponins and Alkaloids

Fenugreek contains approximately 4 to 8% saponins and about 1% alkaloids, contributing to bitterness, gastric stimulation, increased acidity, and increased appetite. Traditionally, Persians and Arabs used fenugreek seeds to increase lean muscle mass in women. Diosgenin, the main sapogenin (Fig. 2), is an estrogen precursor and may help in managing menopause. In regions where fenugreek is used in food, the symptoms of menopause are considered mild. A saponin-rich extract induces release of testosterone in males, increases secretory functions and induces uterine contractions in females. For this reason, fenugreek extract and leaf (usually rich in saponins) must be contraindicated in women during early pregnancy to avoid risk of fetal loss, and during menstruation to reduce risk of excessive bleeding. Biological enlargement of breast tissue has been claimed with the use of whole seeds and leaf. Saponins can reduce cholesterol, albeit to a small extent, via hormone synthesis without effect on triglycerides and bind to dietary lipids. Trigonelline, an alkaloid (Fig. 2), is thought to reduce glycosuria in diabetes.[7]

The seed is a source of the steroidal saponin diosgenin, which can be used to manufacture many pharmaceuticals, such as progesterone. The chemical trigonelline is converted into niacin when the seed is roasted. Researchers have reportedly found that the seeds contain substances that stimulate the pancreas to release digestive enzymes, thereby aiding in digestion. The seeds' soothing effect makes them of value in treating gastritis and gastric ulcers.[7]

Safety of Fenugreek Consumption

Fenugreek is reported to be absolutely safe for consumption based on a long-term animal study. Haematological parameters, histological observations, liver function parameters, and feed efficiency ratio in rats fed fenugreek at 5–20% in diet for 90 days remained comparable to controls.[8] Debittered fenugreek was evidenced to be safe following oral exposure at 2 g/kg body weight in mice and 5 g/kg body weight in rats and at 10% level in the diet fed to growing rats in a cumulative toxicity study.[9]

Antidiabetic Influence

It has been well recognized that dietary fiber offers substantial benefits to persons with diabetes mellitus. Epidemiological studies have shown that the prevalence of diabetes is lower in populations with high fiber intakes than in the Western population with low fiber intakes. In regions such as Japan, India and the West Indies, where intake of dietary fiber is high, the specific complications of diabetes are less frequent than in Western countries where the fiber intake is low. Heart attacks and diabetic gangrene among diabetics are less common in India and Japan than in the USA.[10] Fenugreek seeds, commonly used in India and other countries as a condiment, are an excellent source of dietary fiber and hence, are advantageous in the context of diabetes.[3]

Yemanite Jews used fenugreek seeds in the management of diabetes. Although the mechanism of fenugreek action in humans is not understood, animal studies have revealed the ability of dietary fiber to delay gastric emptying, suppress release of gastric inhibitory peptides and insulinotropic hormones.[10] The diminished post-prandial glucose peak observed with dietary fiber supplementation is extended over a longer period. Also, a normo-glycemia over longer period would ensure higher energy level without demand for frequent feeding.

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Treatment with a decoction of fenugreek seeds has been reported by several workers to improve diabetes and suppress glycosuria in mild diabetes and bring about improvement in severe diabetic condition.[10] Fenugreek contains fiber to an extent of 51.7%, containing 19.2% mucilaginous fiber, and 32.5% neutral fiber, respectively. It also contains trigonelline, an alkaloid known to have an effect on glycosuria. Exhaustive clinical trials and animal experiments conducted by the National Institute of Nutrition in India have demonstrated the beneficial effect of fenugreek in both type-1 and type-2 diabetes.

There are more than 30 reports on the antidiabetic property of fenugreek seeds, as listed in Tables 2 and 3. The observations of beneficial hypoglycemic effects of fenugreek seeds have been made in diabetic rats,[11,12,13,14,15,16,17,18,19,20,21] in diabetic mice,[22] in diabetic rabbits[23,24,25] and in diabetic dogs.[26–28] Besides many animal studies, several human trials have unequivocally demonstrated the beneficial hypoglycemic potential of this spice in both type-1 and type-2 diabetes (Table 3). It is now well documented from a number of studies that addition of fenugreek seeds to the diets of diabetic patients or animals results in a significant fall in blood glucose and improvement in glucose tolerance.

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Animal Studies

The soluble dietary fiber (sdf) fraction of fenugreek seeds has been shown to reduce postprandial elevation in blood glucose level of type-2 diabetic rats by delaying the digestion of sucrose. The sdf, when investigated for its effect on serum fructosamine, insulin and lipid levels, and on platelet aggregation in type-2 diabetic rats (by administering orally twice daily at a dose of 0.5 g/kg for 28 days),[29] lowered the serum fructosamine level with no significant change in the insulin level. Atherogenic lipids, such as triglycerides, cholesterol and Low-density lipoprotein (LDL)-cholesterol, were found to decrease significantly in sdf-fed rats. No significant effect on platelet aggregation was found although there was a tendency to lower the aggregation. Thus, it is concluded that sdf has a beneficial effect on dyslipidemia and has a tendency to inhibit platelet aggregation in type-2 model diabetic rats.

Ribes et al.[26] reported that defatted fenugreek (fiber containing portion) fed to normal or diabetic dogs for 8 day showed glucose lowering effect. Valette et al.[28] independently observed that defatted fenugreek (fiber and saponins) also caused a decrease in cholesterolemia in addition to hyperglycemia in diabetic dogs. Later, defatted fenugreek seeds in the diet were found to significantly check the rise in fasting blood glucose in Long Evans Rats over a two-week period following the administration of streptozotocin.[21] The hypoglycaemic effect of fenugreek has been evidenced with aqueous extract, methanolic extract and ethanolic extract of the spice seeds in normal and alloxan-diabetic rats[20] and in normal mice[30] and hence, led to the indication that the active compounds are polar in nature.

Beneficial alterations in serum lipids were decreased total and LDL cholesterol and decreased triglycerides, without any effect on High-density lipoprotein (HDL)-cholesterol. Oral administration of fenugreek fraction (100 mg/kg) for 15 days improved glucose tolerance in alloxan diabetic rabbits.[25] Serum insulin was also increased, along with a reduction in free fatty acids. Stimulation of peripheral utilization of glucose (in extrahepatic tissues) is inferred in addition to an effect at the pancreatic level. The galactomannan-rich endosperm isolated from fenugreek seeds was studied for its beneficial antidiabetic effect by feeding it to the streptozotocin-induced diabetic rats at 3% dietary level for 6 weeks.[31] Excretion of glucose was significantly lowered in fenugreek endosperm-fed

Table 2
Effectiveness of fenugreek (*Trigonella foenum-graecum*) on diabetes mellitus in animal studies

Animal model	Effect demonstrated	Reference
Rats		
1) Diabetic rats	Hypoglycemic action of trigonelline	(32)
2) Normal & Diabetic rats	Mild hypoglycemic effect	(11)
3) Diabetic rats	Improved glucose tolerance	(12)
4) Normal & Diabetic rats	Prevention of diabetes induction	(13)
5) Normal & Diabetic rats	Hypoglycemic effect	(14)
6) Normal & Diabetic rats	Hypoglycemic effect	(15)
7) Normal & Diabetic rats	Hypoglycemic effect	(16)
8) Normal & Diabetic rats	Prevented increase in glucose during glucose tolerance test	(17)
9) Normal & Diabetic rats	Anti-hyperglycemic effect of fenugreek leaves	(34)
10) Diabetic rats	Modulation of activities of gluconeogenic enzymes	(18)
11) Diabetic rats	Modulation of activities of gluconeogenic glycolytic & lipogenic enzymes	(19)
12) Diabetic rats	Hypoglycemic effect of alcoholic extract	(20)
13) Diabetic rats	Fenugreek leaves countered hyper-glycemia, hypoinsulinemia and glycated hemoglobin	(35)
14) Diabetic rats	Orally administered sdf lowered serum fructoseamine, triglycerides, cholesterol	(29)
15) Diabetic rats	Restoration of the activities of enzymes of carbohydrate metabolism	(36)
16) Diabetic rats	Prevention of rise in fasting blood glucose by defatted seeds	(21)
17) Diabetic rats	Hypoglycemic effect of galactomannan-enriched endosperm fraction	(31)
Mice		
18) Normal/Diabetic mice	Hypoglycemic effect of decoction and ethanolic extract	(22)
19) Normal mice	Hypoglycemic effect of aqueous/ methanolic extract	(30)
Rabbits		
20) Normal Rabbits	Hypoglycemic effect of fibre and saponin fraction	(23)

(Continued)

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Table 2
(Continued)

Animal model	Effect demonstrated	Reference
21) Diabetic Rabbits	Isolation of hypoglycemic principle and its effectiveness	(24)
22) Diabetic Rabbits	Improved glucose tolerance, Increased insulin levels; Hypolipidemic effect	(25)
23) Diabetic rabbits	Lowered fasting blood glucose and higher insulin secretion	(33)
Dogs		
24) Normal/Diabetic dogs	Defatted fraction hypoglycemic	(26)
25) Normal/Diabetic dogs	Defatted fraction hypoglycemic	(28)
26) Diabetic Dogs	Antidiabetic effects of subfractions from from fenugreek seeds	(27)
Others		
27) *In vitro* Study	Insulinotropic action of 4-hydroxy isoleucine	(75)

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diabetic animals. This was accompanied by a marked reduction in the excretion of other urinary metabolites, viz., proteins, urea, and creatinine.

A single oral dose of fenugreek has also been reported to be beneficial. Pretreatment of fenugreek suspension 1hr prior to glucose load in rats caused significant decrease in blood glucose at 30, 60 and 90 min indicating reduced rate of gastric emptying.[12] Fenugreek orally administered at 2 and 8 g/kg to normal and alloxan diabetic rats produced a significant fall in blood glucose in a dose-related manner.[15] Nahar et al.[14] observed significant blood glucose-lowering effect in normal and streptozotocin-induced diabetic rats by administering (single dose) whole fenugreek powder/methanol extract/water extract/soluble fiber.

Although the beneficial effect of fenugreek seed has been known for several years, attention to its active component has been recent. Previously, the hypoglycemic effect of fenugreek was attributed to its major alkaloid — trigonelline.[32] Jain et al.[23] also observed that an alkaloid-rich fraction from fenugreek showed maximum hypoglycemic activity in 2 hours during glucose tolerance test in rabbits. More recently, the bioactive factor isolated by Moorthy et al.[24] was found to be different from trigonelline. Now there is much evidence to believe that the hypoglycemic effect of fenugreek is attributable to the fiber and gum, which constitute as much as 52% of fenugreek seeds. The probable mechanism of hypoglycemic action is that dietary fenugreek delays gastric emptying by direct interference with glucose absorption. In addition, gel-forming dietary fiber reduces the release of insulinotropic hormones and gastric inhibitory polypeptides. The mechanism of action of an orally active hypoglycemic principle isolated from water extract of seeds of fenugreek was investigated in alloxan-induced subdiabetic and overtly diabetic rabbits.[33] When the active principle was orally administered to the subdiabetic and mild diabetic rabbits at a dose of 50 mg/kg body weight for 15 days, there was a significant attenuation of the glucose tolerance curve and improvement in the glucose-induced insulin response, suggesting that the hypoglycemic effect may be mediated through stimulating insulin synthesis and / or

Table 3
Antidiabetic efficacy of fenugreek (*Trigonella foenum-graecum*) in human trials

Human Study	Effect demonstrated	Reference
1) Normal/Diabetic humans	Hypoglycemic effect	(40)
2) NIDDM Patients	Hypoglycemic effect, reduced insulin	(76)
3) NIDDM Patients	Hypoglycemic effect with no change in insulin level	(38)
4) IDDM Patients	Hypoglycemic action of defatted seeds Improved glucose tolerance; reduced glucose excretion; Hypolipidemic effect	(41)
5) NIDDM Patients	Hypoglycemic action, improved glucose glucose tolerance; Hypolipidemic effect of defatted seeds	(42)
6) Normal subjects	Hypoglycemic effect	(43)
7) Normal subjects	Hypoglycemic effect	(14)
8) NIDDM Patients	Improved glucose tolerance; Reduction in blood / urinary glucose, and glycated hemoglobin	(39)
9) Normal & NIDDM subjects	Hypoglycemic effect of germinated seeds	(44)
10) NIDDM subjects	Hypoglycemic and hypolipidemic effect of seed powder	(59)
11) NIDDM subjects	Favorable effect on glycemic control and hypertriglyceridemia	(45)

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secretion from the pancreatic beta cells of Langerhans. Prolonged administration of the same dose of the active principle for 30 days to the severely diabetic rabbits lowered fasting blood glucose significantly, but could elevate the fasting serum insulin level to some extent, which suggests an extra-pancreatic mode of action for the active principle. The effect may also be by increasing the sensitivity of tissues to available insulin.

Hypoglycemic and anti-hyperglycemic effects have also been observed with fenugreek leaves in normal and diabetic rats.[34] The effect of supplementation of fenugreek leaves has been examined in streptozotocin-induced diabetic rats, and a significant beneficial effect of fenugreek leaves on hyperglycaemia, hypoinsulinaemia, and glycosylated hemoglobin has been evidenced.[35] Fenugreek leaves improved the body weight and liver glycogen, and showed a significant effect on key carbohydrate metabolic enzymes in diabetic rats. The antidiabetic effect of fenugreek leaves was found to be similar to that of glibenclamide.

In recent studies, the therapeutic effectiveness of fenugreek seeds in type-1 diabetes, as exemplified by studies on alloxan-diabetic rats, has been attributed to the beneficial

countering of the changes in the activities of enzymes of glucose and lipid metabolism in liver and kidney, thus stabilizing glucose homeostasis in these organs.[18,19] These authors have especially examined the activities of enzymes of glycolysis and gluconeogenesis and also lipogenic enzymes and claim that the decreased activities of glycolytic and lipogenic enzymes and elevated activities of gluconeogenic enzymes are favorably restored by dietary fenugreek. The effect of oral administration of fenugreek seed powder, on the mitochondrial enzyme activities in the alloxan diabetic rats has been investigated.[36] Rats injected with alloxan were treated with either 2 IU insulin *i.p.*, or 5% fenugreek *ad libitum* for 21 days. Selected rate-limiting enzymes of the tricarboxylic acid cycle, hydrogen shuttle system, ketone body metabolism, amino acid metabolism and urea cycle were measured in the mitochondrial and cytosolic fractions of liver, kidney, and brain tissues of the experimental rats. The majority of the mitochondrial enzymes in the tissues of the diabetic rats had significantly higher activities compared to the control rats. Similarly, the activities of mitochondrial and cytosolic aminotransferases and arginase were significantly higher in liver and kidney tissues of the diabetic rats. The administration of fenugreek to diabetic rats was able to restore the activities of these enzymes to control values. When sodium orthovanadate (0.2%) was administered in combination with fenugreek to diabetic rats the countering of these enzyme activities was even more effective. The decreased activity of creatine kinase in tissues (heart, skeletal muscle and liver) of experimental diabetic rats was observed to be normalized by fenugreek.[37]

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Human Studies

Madar and Arad[38] observed that 17 out of 21 noninsulin dependent diabetes mellitus (NIDDM) patients given 15g fenugreek per day showed significant decrease in blood glucose with no change in insulin levels. Sharma et al.[39] studied the hypoglycemic effect in a human trial involving 60 NIDDM patients. Fenugreek whole seed powder was given at 25 g per day through the diet in two doses over a period of 24 weeks. Fasting blood glucose was lowered and glucose tolerance improved. Sugar excretion was significantly reduced. Glycated haemoglobin and insulin levels were also diminished. When fenugreek seeds (25 g) were administered to diabetics for 21 days, a significant improvement in plasma glucose response was observed, while insulin levels were reduced.[40] Urinary glucose output and serum cholesterol levels were significantly reduced. Diabetic symptoms like polyuria, polydypsia, and polyphagia were found to be under control. Further, in two insulin-dependent diabetic subjects, daily administration of 25 g fenugreek seed powder significantly improved both plasma glucose profile as well as glycosuria. Their insulin requirement was also reduced from 56 units / day after 8 weeks of treatment. In a long-term trial, 100 g fenugreek was fed to both non-insulin-dependent and insulin-dependent diabetics.[41,42] Fasting blood glucose levels were reduced after fenugreek ingestion. Urinary glucose output, serum cholesterol, and triglyceride levels were also significantly reduced. Clinical symptoms of diabetes mellitus were remarkably under control.

Antidiabetic properties of subfractions of fenugreek seeds are also widely studied. Whole fenugreek seeds, defatted fenugreek seeds gum isolate of the seeds, cooked fenugreek seeds, and cooked fenugreek leaves were administered to healthy subjects and their effect in preventing the rise in plasma glucose after a dose of glucose (100 g) or after a meal was monitored. The rise in blood glucose level was prevented by ingestion of fenugreek seeds. Serum insulin levels were also modified to a similar extent. The observed effect was highest with whole seeds. Gum isolate, extracted seed, and cooked seeds in that order followed fenugreek seeds, but fenugreek leaves did not have any such

effect. This study indicated that fenugreek has blood glucose-lowering property because of the gum present in the seeds, which is not lost during the cooking process. Sharma et al.[41] observed that defatted fenugreek powder given 100 g daily through diet in two doses for 10 days to type-1 diabetic patients significantly reduced fasting blood glucose and improved glucose tolerance. There was a 50% reduction in glucose excretion. Serum cholesterol and triglycerides were also significantly lowered. Sharma and Raghuram[42] have also reported that 100 g defatted fenugreek seed powder given to 15 NIDDM patients orally for 10 days produced lowering of fasting blood glucose, improved glucose tolerance, and reduced glucose excretion.

Blood glucose lowering effect was also observed in healthy human volunteers given whole seed powder or the soluble fiber fraction as a single dose.[14] Fenugreek consumption of 10 g 3 hours prior to glucose load (1 g/kg b.w.) by fourteen fasting human volunteers (both normal and diabetic) resulted in significant hypoglycemic effect in diabetic individuals.[43] Fenugreek had no effect on blood glucose and glucose tolerance in normal individuals. In an attempt to explore the effectiveness of debitterized fenugreek, Neeraja and Rajyalakshmi[44] observed the beneficial reduction of post-prandial glucose by germinated fenugreek seeds in NIDDM human subjects.

The effects of fenugreek seeds on glycemic control and insulin resistance was evaluated in a human type-2 diabetes mellitus double-blind, placebo-controlled study involving 25 patients.[45] Group 1 received 1 g/day alcoholic extract of fenugreek seeds and Group 2 received the usual care and placebo capsules for two months. Oral glucose tolerance tests, lipid levels, fasting C-peptide, glycosylated haemoglobin, and insulin resistance were similar between the two groups initially. At the end of two months, the fasting blood glucose as well as blood glucose 2 hours after a glucose load, was similar among the two groups, but the area under curve of blood glucose as well as insulin was significantly lower. Insulin resistance showed a decrease in percent β-cell secretion in group 1 as compared to group 2 and increase in percent insulin sensitivity. Serum triglycerides decreased and HDL cholesterol increased significantly in group 1 as compared to group 2. It is thus concluded that adjunct use of fenugreek seeds improves glycemic control and decreases insulin resistance in mild type-2 diabetic patients. There is also a favorable effect on hypertriglyceridemia.

In summary, fenugreek seed, a common condiment used in Indian homes, has been found to diminish hyperglycemia in normal individuals and those with diabetes. Fasting blood glucose, 24 hour urinary sugar excretion, serum cholesterol, and triglyceride levels in diabetics were significantly reduced. Clinical symptoms like polyuria, polyphagia, and polydypsia are improved. These effects of fenugreek seeds seem to be due to the gum fiber present in them. It has been possible to debitterize fenugreek seeds without compromising their hypocholesterolemic and hypoglycemic properties. Debitterized seeds are rich in protein and lysine. Since fenugreek seeds, like pulses, are also a source of protein, they can replace pulses in the diets of diabetics. Fenugreek included in daily diet in amounts of 25–50 g can be an effective supportive therapy in the management of diabetes.

Hypocholesterolemic Property

High levels of LDL and Very low-density lipoprotein (VLDL) cholesterol are associated with atherosclerosis or plaque in the blood vessels. A reduction in LDL-cholesterol levels is considered important to reduce risk of heart attack. Several spices have been experimentally documented to possess the health beneficial lipid-lowering property (Srinivasan, 2005).[46] Dietary fenugreek has been found to be hypocholesterolemic in a number of animal studies as well as a few clinical trials.[47]

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Animal Studies

Both the seeds and leaves of fenugreek have been studied for their ability to influence cholesterol levels (Table 4). Singhal et al.[48] observed that at 50% level of fenugreek seeds in the diet, serum cholesterol levels were 42% lower in normal and 58% lower in experimental rats on a 20% hydrogenated fat diet. Sharma[49] tested the efficacy of the spice at 15, 30, and 60% levels in the diet in rats fed on a 1% cholesterol enriched diet. There was a marked prevention of the elevation of serum cholesterol levels. At the highest level of the spice, serum LDL-cholesterol + VLDL-cholesterol was also significantly reduced, whereas the accompanying increase in HDL cholesterol was only marginal. Liver cholesterol was also reduced. There was an increase in fecal bulk, as well as fecal excretion of bile acids and neutral sterols. However, even at the 60% level, fenugreek seeds did not influence serum cholesterol in rats on a normal diet. In a follow up study, Sharma[50] reported that fenugreek not only prevented the rise in serum cholesterol in rats on a hypercholesterolemic diet but could also reduce cholesterol levels in animals in which hypercholesterolemia had been previously established.

Among the various components of fenugreek tested for hypocholesterolemic property, only the fiber and saponin components of the seeds exhibited cholesterol-lowering activity. Whereas a lipid extract or trigonelline had no effect, the defatted portion, the gum and the crude saponins exhibited the cholesterol-lowering effect. It was concluded that both the fiber and saponin portions were responsible for the beneficial effect. The hypocholesterolemic property of galactomannan of fenugreek gum has been evaluated along with galactomannans differing in their galactose to mannose ratio from other sources (guar gum and locust-bean gum) in male adult rats, which were fed on diets containing 80 g/kg galactomannans in a 1% cholesterol containing diet, along with purified cellulose as control.[51] Galactomannans lowered the concentrations of cholesterol in both liver and blood plasma, and also decreased the rate of hepatic synthesis of cholesterol. Similar observations regarding the efficacy of the defatted fraction of fenugreek seeds were also made by Valette et al.[28] in diabetic hypercholesterolemia in dogs.

A recent study[52] focused on the hypocholesterolemic effects of a unique dietary fiber combination ('Fibernat') of fenugreek seed powder, guar gum, and wheat bran, such as enhancing conversion of hepatic cholesterol to bile acids or increase in catabolism of LDL via the apo B, E receptor. The study examined the effects on some aspects of lipid metabolism and cholesterol homeostasis in rats, which were administered Fibernat along with an atherogenic diet containing 1.5% cholesterol and 0.1% cholic acid. Amounts of hepatic lipids, hepatic and fecal bile acids, and activity of hepatic triglyceride lipase (HTGL) were determined along with transmission electron microscopic examination of the liver tissue and extent of uptake of ^{125}I-LDL and ^{125}I-VLDL by the hepatic apo B, E receptor. Fibernat intake significantly increased apo B, E receptor expression in rat liver as reflected by an increase in the maximum binding capacity (B(max)) of the apo B, E receptor to ^{125}I-LDL and ^{125}I-VLDL. The activity of HTGL was increased by approximately 1.5-fold in Fibernat-fed rats as compared to those fed the atherogenic diet alone. A marked hypocholesterolemic effect was observed. Cholesterol homeostasis was achieved in Fibernat-fed rats. Two possible mechanisms are postulated to be responsible for the observed hypocholesterolemic effect: a) an increase in conversion of cholesterol to bile acids and b) possibly by intra-luminal binding, which resulted in increased fecal excretion of bile acids and neutral sterols. The resulting reduction in cholesterol content of liver cells coupled with upregulation of hepatic apo B, E receptors and increased clearance of circulating atherogenic lipoproteins (LDL and VLDL) are the main mechanisms involved in the hypocholesterolemic

Table 4
Hypolipidemic potential of fenugreek (*Trigonella foenum-graecum*)

Animal/Human system	Effect demonstrated	Reference
Animal Studies		
1) Rats on normal/20ta% Hydrogenated fat	50% dietary fenugreek decreased blood cholesterol	(48)
2) Rats on 1% cholesterol	15, 30 & 60% dietary fenugreek reduced blood cholesterol	(49)
3) Diabetic Dogs	Defatted seeds (fibre & saponin) produced hypocholesterolemic effect	(28)
4) Rats on 1% cholesterol/ Hypercholesterolemic rats	Dietary fenugreek checked cholesterol raise; Reduced levels in pre-established case	(40)
5) Normal Rabbits	Fenugreek leaves lowered serum cholesterol; Raised HDL-cholesterol; Higher fecal Excretion	(55, 56)
6) Alloxan-Diabetic Rats	Significant lowering of blood cholesterol and triglycerides by dietary fenugreek	(25)
7) Diabetic Dogs	Fenugreek fraction containing saponins exhibited hypocholesterolemic effect	(53)
8) Rats on 1% cholesterol	Galactomannan of fenugreek gum lowered the concentration of cholesterol in blood and liver; decreased the rate of hepatic cholesterol synthesis	(51)
9) Hypercholesterolemic rats	Ethanolic extract (30/50 mg/kg body) for 4 week reduced blood and liver cholesterol; Effect attributable to saponins	(54)
10) Rats on 1.5% cholesterol	Hypocholesterolemic effect of 'Fibernat'; Up-regulation of hepatic apo-B, E receptors; increased conversion of cholesterol to bile acids; increased fecal excretion of bile acids and neutral sterols	(52)
11) Alloxan-Diabetic Rats	Dietary fenugreek countered elevation of lipids in liver and kidney; Countered the alteration in activity of lipogenic enzymes	(58)
12) Streptozotocin-Diabetic Rats	Dietary fenugreek leaves (0.5/1 g/kg body)	(57)
Human Studies		
13) NIDDM patients	Significant reduction in blood cholesterol by dietary fenugreek	(40)
14) NIDDM subjects	Significant lowering of blood cholesterol and triglycerides	(42)
15) IDDM patients	Significant lowering of blood cholesterol and triglycerides	(41)
16) NIDDM subjects	Hypotriglyceridemic effect of fenugreek	(59)
17) Human subjects	Significant reduction in blood total and LDL-cholesterol by dietary germinated fenugreek	(60)

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Table 5
Other health beneficial effects of fenugreek (*Trigonella foenum-graecum*)

	Effect demonstrated	Reference
Antioxidant effect		
Alloxan diabetic rats	Decreased lipid peroxidation and countering of alteration in circulatory antioxidant molecules	(61)
Alloxan diabetic rats	Restoration of tissue antioxidant molecules by dietary fenugreek	(62)
Alloxan diabetic rats	Reversal of alterations in tissue antioxidant enzymes and peroxidative damage by fenu-greek administration	(37)
Protective effect on GI tract & Liver		
Rats	Aqueous extract and gum fraction of fenugreek showed protective effect on ethanol-induced gastric ulcer	(69)
Rats	Dietary fenugreek displayed beneficial effect on colon carcinogenesis induced by 1,2-dimethyl-hydrazine by countering the activities of β-glucuronidase and mucinase in the colon	(71)
Rats	Aqueous fenugreek extract showed protective effect on liver in experimental ethnol toxicity	(70)
Immunomodulatory effect		
Swiss mice	Aqueous extract of fenugreek showed a stimu-latory effect on immune functions	(72)
Anti-hyperthyroidic effect		
Rats	Fenugreek seed extract showed ameliorative potential in induced hyperthyroidism	(73)

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effect of Fibernat. The results suggest that Fibernat's effect on plasma LDL concentration is also possibly mediated by increased receptor-mediated catabolism of VLDL.

Fenugreek subfraction rich in steroid saponins has been studied by Sauvaire et al.[53] for the contribution of saponins and/or diosgenin and other steroid sapogenins to the hypo-chole-sterolemic effect of fenugreek seeds. Results showed that saponins are partly hydrolyzed into sapogenins in the digestive tract. It was also inferred that saponins may be implicated, alone or together with diosgenin, in the observed hypocholesterolemic effect of fenugreek seeds in diabetic dogs. The hypocholesterolemic property of an ethanol extract from defatted fenugreek seeds has been investigated.[54] Purification of the crude extract by dialysis produced an isolated component with hemolytic properties. The dialysate was also found to contain saponins demonstrated by thin-layer chromatography. Experiments *in vitro* employing the everted-sac technique showed that the ethanol extract

had the ability to inhibit taurocholate and deoxycholate absorption in a dose-dependent manner. In two separate feeding experiments, hypercholesterolemic rats were fed on 30 or 50 g ethanol extract/kg for a 4-week period. Reductions in plasma cholesterol levels ranged from 18 to 26% and a tendency for lower concentrations of liver cholesterol was observed. These results indicate that the ethanol extract from fenugreek seeds contained hypocholesterolemic components, which appear to be saponins that interact with bile salts in the digestive tract.

Chaturvedi and Pant[55] studied the influence of fenugreek leaves in normal rabbits. When cooked green leaves were fed to rabbits (10 g/ca.1.5 kg b.w.), serum total cholesterol showed a progressive decrease from week 1 to week 8. This was accompanied by an increase in HDL-cholesterol. In another study,[56] (Chaturvedi and Pant, 1988) wherein 1 g of dried fenugreek leaves were boiled and fed along with the basal diet, a significant increase in the fecal excretion of lipids as well as sterols was observed. In a recent study, the lipid-lowering effect of fenugreek leaves in diabetes mellitus was shown.[57] In streptozotocin-induced diabetic rats that were maintained on dietary fenugreek leaves (0.5 and 1 g/kg of body weight) for 45 days, significant lowering of blood cholesterol and triglycerides was observed.

Several authors have observed that fenugreek seed, besides being a potential hypoglycemic agent, can also ameliorate altered lipid metabolism during diabetes. A recent study evaluated the short-term effect of oral administration of fenugreek seed powder for 3 weeks on total lipid profile and lipogenic enzymes in tissues of alloxan diabetic rats.[58] The elevated levels of total lipids, cholesterol, and triglycerides in liver and kidney of diabetic animals were significantly countered by fenugreek administration. This beneficial effect was even more dramatic when fenugreek was administered along with sodium orthovanadate (0.2%). The activities of glucose-6-phosphate dehydrogenase, malic enzyme, isocitrate dehydrogenase, adenosine triphosphate-citrate lyase, and fatty acid synthase, which were decreased significantly in liver and increased in kidney during diabetes, were also effectively countered by dietary fenugreek.

Human Studies

During studies on the effect of fenugreek seeds and leaves on blood glucose and serum insulin responses in diabetic subjects, Sharma[40] observed a significant reduction in serum cholesterol levels after fenugreek seed therapy for 3 weeks. Hypolipidemic effect of fenugreek intake characterized by significant lowering of blood cholesterol and triglycerides has been evidenced in both insulin-dependent (IDDM) and noninsulin-dependent (NIDDM) diabetic subjects and in diabetic rats.[25,41,42,59]

The effect of consumption of germinated fenugreek seed powder has been studied in human subjects (Sowmya and Rajyalakshmi, 1999).[60] The findings revealed that germination brought distinct changes in soluble fiber content of the seeds. Consumption of the germinated seeds (at 12.5 g and 18.0 g per day for 1 month) resulted in a hypocholesterolemic effect. At the higher level of consumption, i.e., 18.0 g of the germinated seed, significant reduction in total and LDL-cholesterol was observed. No significant changes were found in HDL- and VLDL-cholesterol and triglyceride levels in the subjects. Fenugreek was shown to bring about the hypocholesterolemic effect through increased excretion of fecal bile acids and neutral sterols; depletion of cholesterol stores in the liver was also involved. Dietary fenugreek also has the property of stimulating bile formation in the liver and of converting cholesterol to bile salts. The hypocholesterolemic activity of fenugreek is much more than that shown by other legumes such as chickpea, black gram, and soya bean. Changes in lipid levels produced by fenugreek administration

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represent a protective mechanism against the development of atherosclerosis and coronary heart disease.

Thus, dietary fenugreek seeds have been found to be hypocholesterolemic, by virtue of its fiber constituent, gallactomannan, in a number of animal studies, as well as a few clinical trials. In view of the role of high blood cholesterol levels in increasing the risk of atherosclerosis and cardiovascular diseases, dietary fenugreek seeds might prove advantageous. The possibility of a consequential beneficial prevention and regression of cholesterol gallstones by dietary fenugreek seeds by virtue of their blood cholesterol lowering property similar to other known hypocholesterolemic spices remains to be examined.

Antioxidant Effects

Oxidative damage at the cellular or subcellular level is now considered to be a major event in disease processes like coronary vascular disease, inflammatory disease, diabetes, carcinogenesis, and aging. Reactive oxygen radicals are detrimental to cells at both membrane and genetic levels. They induce lipid peroxidation in cellular membranes, generating lipid peroxides that cause extensive damage to membranes and membrane-mediated chromosomal damage. Dietary fenugreek seed has been shown to counter the increased lipid peroxidation and alterations in the content of circulating antioxidant molecules, such as glutathione, β-carotene and α-tocopherol, in alloxan-diabetic rats.[61] The influence of fenugreek seed powder supplementation in the diet (for 30 days at a dosage of 2 g/kg body weight) on lipid peroxidation and antioxidant status has been studied in alloxan-diabetic rats.[62] The enhanced lipid peroxidation and increased susceptibility to oxidative stress associated with depletion of antioxidants in liver, kidney and pancreas observed in diabetic rats were observed to be normalised with fenugreek seed powder treatment. The protective effect of the aqueous extract of the seeds on the activity of calcium-dependent adenosinetriphosphatase (Ca^{2+}-ATPase) in liver homogenate in the presence of Fe^{2+}/ascorbate *in vitro* was also investigated. Ca^{2+}-ATPase activity in liver was protected by the aqueous extract to nearly 80% of the initial activity.[62] The findings suggest that the soluble portion of the seeds could be responsible for the antioxidant property.

Oxygen free radicals are presumably responsible for the severity and complications of diabetes. The activities of antioxidant enzymes catalase, superoxide dismutase and glutathione peroxidase as well as the oxidative damage were examined in the tissues of diabetic rats treated with fenugreek.[37] After 3 weeks of diabetes, the activity of Cholesterol acyl transferase was significantly increased in heart in diabetes (about 6-fold) but decreased in liver. The superoxide dismutase activity decreased significantly in liver but increased in brain. The activity of glutathione peroxidase decreased significantly in liver and increased in kidney. A significant increase was observed in oxidative damage in heart and kidney and a small increase in brain with decrease in liver and muscle. Fenugreek administration to diabetic animals showed a reversal of the disturbed antioxidant levels and peroxidative damage, thus suggesting that oxidative stress plays a key role in the complications of diabetes. Fenugreek seeds show an encouraging antioxidant property that can be exploited for the treatment/reversal of the complications of diabetes.

Influence on Digestion

Spices are well recognized to stimulate gastric function. They are believed to intensify salivary flow and gastric juice secretion, and hence, aid digestion.[63] Salivary and gastric secretions are increased when the nerve centers are stimulated by the sense of smell and

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by the presence of pungent principles in the foodstuff. The role of spices in digestion is not limited to a single effect, but is a combination of their influences on salivary, gastric, biliary, and pancreatic secretions and the terminal digestive enzymes present on the mucosa of small intestine.

Several animal studies in recent years have examined the influence of dietary fenugreek seeds on gastrointestinal parameters. Dietary fenugreek (2 g% for 6 to 8 weeks) had the highest stimulatory influence on bile acid secretion in rats among the various spices examined with an increase of over 80% of the control.[64] Dietary fenugreek increased bile flow rate by 44%. Oral administration of fenugreek as a single dose (0.5 g/kg) significantly increased biliary bile acid secretion by 35%.[64] Fenugreek increased the bile flow rate by 35% when administered as a single oral dose. Dietary intake of fenugreek significantly increased pancreatic lipase activity as much as 43% over the control in experimental rats.[65] Chymotrypsin activity was also significantly higher in animals fed fenugreek (43%). Pancreatic amylase and trypsin were decreased by dietary fenugreek.[65] Single oral dose consumption of the same spice produced a significant decrease in pancreatic lipase and chymotrypsin. While dietary fenugreek had no beneficial influence on intestinal enzymes, an appreciable increase in intestinal lipase activity was observed in animals given a single oral dose of fenugreek (58% over control).[66] Single oral dose administration of fenugreek stimulated the activity of lactase among the disaccharidases. Dietary fenugreek had an undesirable decreasing effect on alkaline and acid phosphatases of the intestinal mucosa. The presence of fenugreek in the reaction medium significantly enhanced the activity of rat pancreatic amylase *in vitro* although it did not influence pancreatic lipase and intestinal disaccharidases similarly.[67] Thus, it is evidenced that the beneficial digestive stimulant action of dietary fenugreek seeds is mediated through a stimulation of the liver to produce and secrete more bile enriched in bile acids and an appropriate stimulation of activities of pancreatic lipase and chymotrypsin. Dietary fenugreek is evidenced to produce no shortening of the food transit time in rats unlike many other spices that have a favourable digestive stimulatory influence.[68]

Other Beneficial Effects

Gastroprotective effect of fenugreek seeds has been evidenced by a study on ethanol-induced gastric ulcer.[69] The aqueous extract and a gel fraction isolated from the seeds showed significant ulcer protective effects. The cytoprotective effect of the seeds seemed to be not only due to the antisecretory action but also to the effects on mucosal glycoproteins. In addition, the fenugreek seeds prevented the rise in lipid peroxidation induced by ethanol presumably by enhancing antioxidant potential of the gastric mucosa and thereby, lowering mucosal injury.

Aqueous extract of fenugreek seeds was found to have protective effect in experimental ethanol toxicity in rats.[70] Simultaneous administration of aqueous extract of fenugreek seeds with ethanol for 60 days prevented the leakage of enzyme activities aspartate transaminase, alanine transaminase and alkaline phosphatase into serum, and the rise in lipid peroxidation in liver and brain as a result of ethanol toxicity. Fenugreek aqueous extract also enhanced the antioxidant potential in terms of countering the reduced activities of superoxide dismutase, catalase, glutathione peroxidase, glutathione S-transferase and glutathione reductase in liver and brain, and countering the depletion in glutathione, ascorbic acid, and α-tocopherol concentrations. The protection of aqueous extract of fenugreek against ethanol toxicity was further evidenced by histopathological examination of liver and brain.

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The effect of fenugreek seeds on the activities of β-glucuronidase and mucinase during 1,2-dimethylhydrazine (DMH)-induced colon carcinogenesis in rats was studied.[71] Rats were given a weekly subcutaneous injection of DMH at a dose of 20 mg/kg body weight for 15 weeks. Fenugreek seed powder was given through diet at a dose of 2 g/kg body weight. After an experimental period of 30 weeks, the activity of β-glucuronidase significantly increased in the colon, which may increase the hydrolysis of carcinogen glucuronide conjugate, liberating carcinogen within the colonic lumen. Inclusion of fenugreek seed powder in the diet significantly decreased the activity of β-glucuronidase and of mucinase in the colon. This study shows that supplementation of fenugreek seeds in the diet inhibits colon carcinogenesis, by modulating the activities of β-glucuronidase and mucinase. The beneficial effect may be attributed to the presence of fiber, flavonoids, and/or saponins.

Immunomodulatory activity of aqueous extract of fenugreek seeds was evaluated in male Swiss albino mice by treating the animals with three doses of extract (50, 100, and 250 mg/kg body weight) for 10 days.[72] Overall, fenugreek showed a stimulatory effect on immune functions in mice, as indicated by Body weight, relative thymus weight, cellularity of lymphoid organs (thymus and bone marrow), delayed type of hypersensitivity response, plaque-forming cell assay, haemagglutination titre, quantitative haemolysis assay, phagocytosis, and lymph proliferation and a significant increase in phagocytic index and phagocytic capacity of macrophages.

The effect of fenugreek seed extracts (200 mg/kg body wt.) has been evidenced for its ameliorative potential in the L-thyroxine-induced hyperthyroidic rat model, which was rendered hyperthyroidic by daily injections of L-thyroxine (300 μg/kg body wt., *s.c.*).[73] Propyl-thiouracil, an antithyroid drug, was used as a reference compound. Alterations in serum triiodothyronine, thyroxine, glucose, hepatic glucose-6-phosphatase, and oxygen consumption were studied as end parameters.

Conclusions

Several health beneficial attributes of the spice, fenugreek, have been experimentally evidenced in recent decades, which have the potential of possible therapeutic application. In view of these promising beneficial physiological effects fenugreek is understood to exert (Fig. 3), this seed spice merits consideration as a natural and necessary ingredient of our

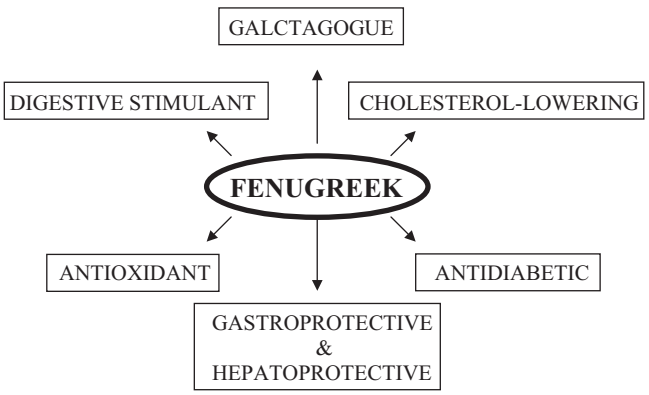


Figure 3. Summary of multibeneficial physiological effects of fenugreek.

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daily diet. The normal consumption of fenugreek seeds by the population in India is reported to be 0.3 to 0.6 g/day/adult.[74] Most of the studies, either animal or human, which have evidenced the health beneficial influence of fenugreek have employed 50 to 100 times this intake level. Such dietary levels are possible through particular dishes employing liberal amounts of fenugreek seeds and are actually in vogue in southern India. The liberal consumption of the same is proved to be safe, and may be easily implemented to derive health beneficial effects through its rich fiber content and other bioactive components.

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