Epidemiological and clinical studies continue to demonstrate that the consumption of whole grains may help reduce the risk of several chronic inflammatory conditions, cardiovascular disease, and certain neoplastic diseases. Nutrition experts and governmental agencies have recommended the consumption of three servings of whole grains per day, while the actual consumption of whole grains is far less than the recommendations for several reasons. U.S. whole grain consumption as a percent of recommendations by race and ethnicity is as follows: white, 34%; black, 25%; Hispanic, 41%; and Asian, 22% (50). Many consumers find whole grain products less desirable than refined products. Consumers frequently reject whole grain products based on color and texture as well as on differences in taste. Some of the benefits of whole grain products can be achieved with lesser-known crops, such as fenugreek. Some of these products can deliver significant benefits when consumed once or twice a day.

Fenugreek (Trigonella foenum-graecum) seeds contain several health-enhancing bioactive compounds. Fenugreek flour can be combined with whole wheat or corn flour to provide fenugreek-enriched cereal products that deliver additional health benefits.

Fenugreek-enriched bread, cookies, and tortillas had similar or better acceptability compared with whole wheat bread, regular cookies, or corn tortillas.

The fenugreek-enriched bread showed decreased insulin resistance and improved insulin sensitivity and may be considered as proof that fenugreek is a good antidiabetic functional food for individuals with type 2 diabetes.

Whole Fenugreek Seeds and Health

Fenugreek seed (Trigonella foenum-graecum L.) is a legume commonly grown in many parts of the world for both culinary purposes and health benefits, including reducing the impact of diabetes in animals and humans (27,36,39, 40,43,51). In North America, fenugreek is grown in California, U.S.A., and Saskatchewan, Canada. In the United States, fenugreek has been successfully grown in Montana as a rotating crop to wheat and has been recently planted in Wisconsin. Horses show a greater preference for fenugreek over other legumes, such as alfalfa (1).

The fenugreek seed is very bitter but does have an interesting proximate composition. Protein content ranges between 23 and 43% of the seed; carbohydrate represents up to 58%; moisture makes up about 10–13% of the seed; lipids represent 5–6%; and minerals make up less than 1% (8) (Fig. 1). Fenugreek seed contains several bioactive compounds, including proteins, protease inhibitors, a unique amino acid known as 4-hydroxyisoleucine, water-soluble dietary fiber, steroidal saponins, flavonoids, isoflavones, alkaloids, polyunsaturated oil, and phytic acid (2,6,13,16,19,28,31,35,36,41, 45,46,51,53,54,56). Fenugreek seeds are used as appetite enhancers and plasma cholesterol-lowering agents, and repeated consumption of the seeds or its extracts decreased dietary fat consumption in human volunteers and overweight individuals (4,5,38).

Although individual components of the fenugreek seeds have demonstrated specific health benefits both in vitro and in vivo, such as inhibition of inflammation or antidiabetic effects, the whole seed is better and more effective at lower levels than are individual components (4,36,43). In acute and long-term metabolic studies using noninsulin-dependent diabetic (NIDDM) and insulin-dependent diabetic (ID-DM) subjects or laboratory animals, debittered (100 g/day) fenugreek seeds, debittered (100 g/day) fenugreek seeds,
fenugreek extracts, or 15 g/day of fenugreek seeds all reduced the area under the glucose curve (by as much as 35–42%) and postprandial insulin levels, while degummed seeds showed little effect on the glycemic response (4,43). Fenugreek seeds have been shown to have a high efficacy at relatively low doses during both acute and longer-term interventions. Debittered fenugreek seeds or extracts have been shown to improve glucose tolerance tests. In long-term studies, a low dose of fenugreek showed efficacy in diabetic patients. When the degummed fenugreek seeds were fed there was little impact on glucose tolerance, suggesting that the gum in the fenugreek seed is most critical for its influence on glucose tolerance.

**Fenugreek Proteins and a Unique Amino Acid**

The protein content of fenugreek seeds ranges from 23 to 43% protein (45). The molecular weight profile of fenugreek seed protein concentrate (Emerald Seed Products, Avonlea, SK, Canada) obtained under lithium dodecyl sulfate (LDS) non-denaturing conditions indicates a wide range of proteins with molecular weights ranging from 7–8 kDa to less than 66 kDa (Fig. 2).

Like other legumes, fenugreek seeds contain a unique Bowman-Birk inhibitor (BBI) that inhibits chymotrypsin and trypsin more efficiently than the BBI reported in other legumes (26,54) (Fig. 2). The BBI has been studied in several in vitro studies as well as in animal and human studies. The results indicate that the BBI can be anticarcinogenic. The BBI also has been reported to reduce inflammation and attenuate neuronal loss in multiple sclerosis patients, making it an excellent candidate for oral therapy and the alleviation of pain (6,16,35,46,53). Recent studies have indicated that the BBI may be a good dietary supplement, potentially reducing the risk of neoplastic lesions development in mice exposed to proton or iron-ion radiation. These results imply that the BBI may be a useful supplement for astronauts during space flights (21). There are reports that indicate that the BBI may also be associated with the regression of ulcerative colitis in humans without apparent toxicity or adverse side effects (24).

Fenugreek seeds also contain a 27,350-Da glucose/mannose-binding lectin (33). Plants rich in mannose-binding lectin interact with microorganisms and provide a line of defense against various bacteria and may serve as functional foods.

Fenugreek seeds contain the unique free amino acid 4-hydroxyisoleucine (4-OH-Ile), which has been characterized by some investigators as one of the active ingredients that has insulino-tropic and anti-diabetic properties in animal models (2,9,13). There are reports that show that fenugreek extract, enriched with the free amino acid 4-OH-Ile and 4-OH-Ile, alone reduced body weight gain induced by a high-fat diet in obese mice, suggesting that fenugreek seed extract may prevent high-fat-diet-induced obesity (14). While mouse studies have indicated the beneficial effects of this amino acid, unpublished human trials have indicated that orally ingested 4-OH-Ile undergoes gastrointestinal metabolism into a malodorous and pungent compound that is not acceptable to many individuals. The results also suggest that 4-OH-Ile is not as effective in vivo as it is in vitro.

It has been reported that fenugreek contains allergens with molecular weights of 50, 52, and 74 kDa. Fenugreek 7S-vicilin and 11S-legumin shows considerable homologies to peanut allergens Ara h 1 and Ara h 3, respectively (14).

**Fenugreek Fiber**

One-quarter to one-half of fenugreek carbohydrate is made of soluble fiber galactomannan (8). Mannose and galactose are major sugars in the soluble fiber. The soluble fiber is dispersed throughout the seed coat and is also found in the endosperm (28). Galactomannans are highly hydrophilic in nature; they bind large volumes of water and form highly viscous gels even at low concentrations. Fenugreek gel consists predominantly of galactomannans with a mannose backbone grafted with galactose units on an average ratio of 1:1 (28). The unique therapeutic properties of fenugreek gums compared with other gums, such as guar or locust bean, may be due to the structure of the gel; the fenugreek gum is a 1:1 ratio of galactose and mannose, whereas guar gum has a 1:2 galactose-mannose ratio and locust bean has a 1:4 galactose-mannose ratio (7). In vitro and animal studies have demonstrated that fenugreek galactomannan efficiently lowers plasma cholesterol levels (7,23,55).

It has been reported that the soluble dietary fiber fraction of fenugreek can reduce postprandial blood glucose elevation in animal models of type 1 and type 2 diabetes by delaying carbohydrate digestion and absorption (44). Soluble viscous fibers slow down gastric emptying, increase satiety, and slow hunger, making fenugreek a potential ingredient for the fight against obesity.

**Fenugreek Oil**

The oil content of fenugreek seeds represents about 6–7% of the total seed content (15). The oil is mostly unsaturated and includes oleic, linoleic, and linolenic acids, which account for 16, 50, and 24% of the total fatty acids, respectively (3). Fenugreek seeds also contain the N-linoleyl phosphatidylethanolamine as the major N-acyl phosphatidylethanolamine as well as oleamide (cis-9,10-octadecanamide), a sleep-inducing compound. Oleamide was found at a level of 1.8 mg/100 g of seeds (3). The administration of oleamide to mice significantly reversed the scopolamine-induced memory and/or cognitive impairment, suggesting that oleamide-containing fenugreek could be a functional food for use against Alzheimer’s disease (3).

**Fenugreek Flavonoids and Isoflavones**

Vitexin (apigenin-8-C-β-D-glucopyranoside) is the major flavonoid in fenugreek seed, followed by orientin and their derivatives (35). The same authors reported that fenugreek and clover (red and white) showed flavonoid levels from 1.1 to 3.3 times higher than that in soybean. Vitexin exhibits antioxidant and anti-inflammatory properties and inhibits hypoxia-inducible factor-1 α (HIF-1α) in rat pheochromocytoma (PC12) and tube formation by human umbilical vein endothelium cells (6), suggesting that vitexin has potential as an anti-angiogenic and anti-hypoxic dietary factor, and fenugreek may be considered as an anti-angiogenic food. Other flavonoids, including tricin, iridone, formomentin, and calycosin, have also been identified in fenugreek seeds (53). Fenugreek is also a good source of isoflavones, daidzein, and 5,7,3’-trihydroxy-5’-methoxyisoflavone (53).

**Fenugreek Saponins**

The fenugreek seed contains up to 5% w/w saponins (51). The saponins in fenugreek seeds are of steroidal type and in-
clude diosgenin, protodioscin, smilagenin, sarsasapogenin, tigogenin, yamogenin, neotigogenin, β-sitosterol, 6-methyldiosgenin, yuccagenin, gitogenin, and neogitogenin (16,31,45,46,56). Diosgenin is a chemopreventive dietary factor that has shown efficacy against the viability and proliferation of colon, breast, prostate, and leukemic cancer cells (16,25,37,42,52). Fenugreek extract containing a lower amount of diosgenin alone is more effective against cancer cell viability in vitro than is diosgenin, suggesting that the synergistic effect of fenugreek against the biomarkers of disease is better than the action of a single fenugreek molecule (42). Protodioscin and methyl protodioscin induces cell cycle arrest and apoptosis in leukemia but not in lung cancer cells (16,25).

**Additional Benefits Associated with Fenugreek Seeds**

Equally important to its health-promoting potential is that there is no evidence that fenugreek produces any acute or cumulative toxicity (12,18,32,47). *Trigonella* seed powder abrogated the toxicity of vanadium when given alone as an insulin mimic agent (47). Fenugreek powder also can lower the activities of glucose-6-phosphatase and fructose-1,6-biphosphatase to almost control values in a diabetic liver or kidney (47). The seeds of fenugreek can protect against ethanol toxicity (47). A fenugreek extract, containing a minimum of 40% 4-OH-Ile and formulated and prepared as described, demonstrated the ability to add fenugreek to cereal food products.

**Fenugreek Seed-Enriched Cereal Products**

In recent years, legume flours, including faba bean, sorghum, soybean, and lupin flours, have been used to improve the protein content and increase the lysine content of wheat flour (17,34,57). Most investigators reported that as the legume flour level increased from 5 to 40%, farinogram dough development time and stability decreased. At the same time, loaf volume decreased and bread crumb grain deteriorated even in the presence of dough conditioners, such as glyceryl monostearate (GMS) or sodium stearoyl-2-lactylate (SSL) (30,49,57). For decades, fenugreek seeds have been used to produce imitation maple syrup. The intense bitter flavor of fenugreek seeds has made it difficult for food formulators to take advantage of the health benefits of fenugreek. Recently, our research group has developed several commercial prototypes of fenugreek-enriched cereal products, including breads, breakfast cereal flakes, tortillas, cookies, pastas, and other pastries, as functional foods for patients with diabetes mellitus or for individuals who like to eat healthy foods. These products have been very well accepted by consumers through clinical and consumer tests (Figs. 2 and 3).

Bread is a staple for billions of people around the world where individuals can easily consume at least two slices of bread a day. To establish the practicality of extending the use of fenugreek seeds as a functional food, the effect of adding fenugreek flour was investigated in wheat doughs and fresh bread quality. Fenugreek flour was substituted for wheat flour at levels of 2.5, 5, 7.5, or 10% as shown by the main ingredients in the bread formulation (Table I) (Fig. 2). The bread ingredients were mixed and the dough was kneaded in a commercial 5 series model #KM25G0X KitchenAid Portable Appliance, St. Joseph, MI, U.S.A.) using a McDuffy mixing bowl, proofed at 43.3°C at 85% humidity for 65 min in a proofing cabinet (Hobart, Troy, OH, U.S.A.), and baked at 221.1°C for 21 min. Bread samples were stored at −20°C until use. Similarly, whole wheat bread samples were prepared following a conventional wheat bread formula using the same equipment and preparation method and baked bread samples were stored at −20°C until use. Bread samples were analyzed for macro-nutrients, moisture, crude protein, fat, carbohydrate, and ash. Sensory analysis of the bread samples has been previously published. Briefly, sensory evaluation of the bread included rating the bread for palatability, flavor, texture, and color change. Ten panelists evaluated the fenugreek bread compared with whole wheat bread. Panelists were a mixture of untrained individuals, persons with previous sensory evaluation experience, and people with or without diabetes. The bread was presented to panelists either at their offices or homes, and each panelist was asked to evaluate attributes, namely appearance, color, flavor, texture, and overall acceptability. Panelists were also asked to rate the bread as to whether they liked it and whether they would buy it. Replacement of wheat flour by 5% or less fenugreek flour produced bread with good sensory acceptability and color and dough with good kneading properties (27). The detrimental effect at substitution levels higher than 5% fenugreek flour and less than 10% fenugreek flour was associated with the nonprotein components of the fenugreek flour, which imparted bitter flavor to the final bread. The prototype of fenugreek bread that passed the consumer test was adapted for production in a commercial bakery and stored at −20°C until use (27).

Basic recipes for chocolate chip cookies and oatmeal cookies were used to test the fenugreek in sweet baked goods (Table II) (Fig. 3). For each of the cookies, three

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**Table I. Fenugreek-enriched bread formulation.**

<table>
<thead>
<tr>
<th>Ingredient</th>
<th>Percent by weight (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Whole wheat flour</td>
<td>50.61</td>
</tr>
<tr>
<td>Water</td>
<td>35.54</td>
</tr>
<tr>
<td>Fenugreek flour</td>
<td>5.00</td>
</tr>
<tr>
<td>Honey</td>
<td>4.31</td>
</tr>
<tr>
<td>Vital wheat germ</td>
<td>3.23</td>
</tr>
<tr>
<td>Oil</td>
<td>2.15</td>
</tr>
<tr>
<td>Nonfat dry milk</td>
<td>1.62</td>
</tr>
<tr>
<td>Yeast</td>
<td>1.35</td>
</tr>
<tr>
<td>Salt</td>
<td>1.20</td>
</tr>
</tbody>
</table>

**Table II. Fenugreek-enriched cookie formulation.**

<table>
<thead>
<tr>
<th>Ingredient</th>
<th>Percent by weight (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>All-purpose flour</td>
<td>21.93</td>
</tr>
<tr>
<td>Semisweet chocolate chips</td>
<td>21.41</td>
</tr>
<tr>
<td>Butter</td>
<td>14.48</td>
</tr>
<tr>
<td>Brown sugar</td>
<td>13.85</td>
</tr>
<tr>
<td>Granulated white sugar</td>
<td>12.59</td>
</tr>
<tr>
<td>Egg</td>
<td>6.30</td>
</tr>
<tr>
<td>Water</td>
<td>6.30</td>
</tr>
<tr>
<td>Fenugreek flour</td>
<td>2.00</td>
</tr>
<tr>
<td>Vanilla extract</td>
<td>0.63</td>
</tr>
<tr>
<td>Baking soda</td>
<td>0.25</td>
</tr>
<tr>
<td>Salt</td>
<td>0.25</td>
</tr>
</tbody>
</table>

**Table III. Fenugreek-enriched tortilla formulation.**

<table>
<thead>
<tr>
<th>Ingredient</th>
<th>Percent by weight (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>All-purpose flour</td>
<td>52.82</td>
</tr>
<tr>
<td>Vegetable oil</td>
<td>22.46</td>
</tr>
<tr>
<td>Hot water</td>
<td>21.74</td>
</tr>
<tr>
<td>Sodium chloride</td>
<td>1.45</td>
</tr>
<tr>
<td>Fenugreek flour</td>
<td>0.50</td>
</tr>
</tbody>
</table>
cookies with a finished baked weight of 1.5 oz (42.5 g) were used as the serving size. Each serving of cookies delivered 0.3 g of fenugreek (2% replacement of flour). It was determined through sensory testing, using a triangle test, that the best method for incorporating the fenugreek with the least impact on flavor was to add the fenugreek with the sugar when creaming the butter. Each cookie was baked at 350°F (175°C) for 12 min and allowed to cooled for 1 h before performing any sensory analysis.

Tortillas can be made with either corn masa or flour. Since both corn masa and flour are processed carbohydrates, it was determined that the fenugreek should be applied to both systems (Table III) (Fig. 4). In each of models, one 6-in. (15.25 cm) (30 g) tortilla was determined to be the average serving size based on premade tortillas available at the local grocery stores. For each tortilla, 1% flour (0.1 g of wheat flour or 0.85 g of corn masa flour) was substituted. Both tortillas were prepared by mixing the fenugreek with the dry ingredients and then adding the liquid ingredients to form a dough. The dough was rested for 5 min before baking or cooking on a hot griddle (both common methods for tortilla production). The tortillas were presented to the sensory panel both warm and after cooling for 1 h.

Insulin resistance is thought to be the underlying cause of the metabolic syndrome. An elevated blood sugar in the range of 100 to 126 mg/dL is an accurate predictor of cardiovascular risk. Insulin resistance is also a predictor of pancreatic cancer. The results of the clinic study suggest that fenugreek bread decreases insulin resistance and improves insulin sensitivity in individuals with type 2 diabetes, but showed no effect on glycemic control (27). The data may be considered proof that fenugreek may be a good antidiabetic functional food for some individuals. We have extended the formulation of fenugreek-enriched products to tortillas and cookies and suggest that these fenugreek-enriched food products may be good for cardiovascular and pancreas health.

Conclusion
Fenugreek seeds are healthy but very bitter legumes, making these seeds difficult to be consumed as is or to formulate fenugreek-enriched food products. When incorporated into food products, including breads, cookies, pastas, and tortillas, fenugreek seeds can improve insulin sensitivity, making it a good food for individuals with type 2 diabetes mellitus. The levels of fenugreek incorporated into baked products are cost effective although technologically very challenging. The seeds are also very rich in health-enhancing bioactive compounds, including soluble galactomannan dietary fiber, saponins, proteins, unsaturated lipids, and minerals, and have never shown signs of toxicity throughout the years of consumption in many parts of the world. Fenugreek bread is proof that, when properly formulated, functional foods can alleviate and help manage
chronic degenerative diseases. The time may have come for food processors to move fenugreek from animal studies to human consumption.

Acknowledgments

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References


