Fenugreek: A Magical Herb

Khushboo Jyoti[1], Mousmi Ghatak[1], Dr. Bijendra Rai[2], Dr. Pramod Kumar Singh[1*]

[1*]Netaji Subhas University, Jamshedpur, Jharkhand, India
[2]Govt. Holkar Science College, Indore, M.P. India

[*]**Corresponding Author:** Dr. Pramod Kumar Singh
drsingh2030@gmail.com

Abstract:
Fenugreek has been utilized for several purposes in Ayurvedic and Chinese medicine, inducing labour, promoting better digestion, and supporting general health. Fenugreek has been linked to several health advantages, such as high fibre carbs, complete vitamins and minerals, and antioxidant qualities. The plant contains several active ingredients, including as alkaloids, flavonoids, steroids, saponins has shown that it has antioxidant and antiradical properties and has identified many key components that contribute to these effects. The protective efficacy of these extracts and fractions may be explained by their high content of phenolic, flavonoid, tannin, and terepenoids. Furthermore, fenugreek plant components exhibited antifungal action, indicating that fenugreek could be a useful tool for creating novel, physiologically active medications. Fenugreek is well known for its therapeutic qualities and for being a healthy culinary ingredient. Recent studies on fenugreek have revealed a number of health benefits; both human and animal trials have been conducted to evaluate the plant's physiological qualities. Research indicates that Trigonella may have therapeutic, pharmacological, and nutritional applications due to its potential medicinal qualities and health advantages in a range of indications with little to no side effects. This review describes the phytochemicals and their medicinal uses.

Key Words: Phytochemicals, Antioxidants, Saponin, Alkaloid

Introduction:
The legume family comprises fenugreek (*Trigonella foenum-graecum*), which is mostly farmed in India and many other countries, including the United States and Northern Africa [1]. Its origins are in Western Asia and South Eastern Europe. India grows fenugreek, which accounts for over 80% of global production and covers an area of over 219,000 hectares with a total production of 247,000 tonnes in 2015–16 [2]. In Indian cooking, fenugreek leaves, sprouting seeds, and delicate shoots are utilized as vegetables, but the seeds are widely used as a flavorful spice with antidiabetic and hypocholesterolemic [3], galactogouge [4-5], and carminative [6] qualities, the seeds are aromatic, pleasantly bitter, and mildly sweet. Additionally, they are said to stimulate the digestive process and offer nutritional and therapeutic qualities [7,8]. A firm, yellow embryo lies at the center of fenugreek seeds, encircled by a relatively large, corneous layer of semi-transparent endosperm that is white in color. The endosperm is encircled by a persistent, dark brown husk [9]. Fenugreek seeds are rich in minerals like calcium, iron, and β-carotene as well as high levels of proteins (27.57%), dietary fiber (20.6%), soluble (30.6%), and insoluble (20.6%) [10]. Additionally, polysaccharides and galactomannan are abundant in the seeds [11]. To reduce the bitterness and make the fenugreek seeds pleasant, they are boiled, pressure cooked, roasted, or let to germinate in India [12].
Fenugreek is one of the oldest medicinal plants used for its health advantages in many Asian and African countries. Its seeds and leaves also show several medicinal characteristics [13]. Numerous pharmacological effects have been observed in it, including hypoglycemia [14-18]; hypocholesterolemia [19-25], anti-cancer [26-28], gastro protective [29], anti-inflammatory [30, 31], anti-aging [32], laxative [33, 34], and appetite stimulation [35]. It is well recognized that dietary fiber and phytochemicals like the phenols found in fenugreek contribute to these health advantages. Fenugreek seeds are higher in numerous micronutrients (flavonoids, saponins, and coumarins) and minerals (calcium, potassium, phosphorous, iron, zinc, and manganese) than most other legumes [36]. Human nutrition requires at least sixteen different types of minerals, each with a variety of physiological roles [37]. Deficits in these minerals, particularly in iron, calcium, and zinc, can cause anemia, osteoporosis, and immune system disorders. However, the amount of a mineral that is available for absorption is what matters most in maintaining the mineral balance, not the amount consumed [38]. For the purpose of evaluating the adequacy of minerals in a diet, it is necessary to know both the amount and the bioavailability of minerals for intestinal absorption. Although minerals are widely distributed, it was found that their bioavailability varied among foods, which is influenced by a variety of factors like dietary fiber, phytic acid, proteins, and other minerals [19]. Nonetheless, it has been noted that some of the chemicals found in fenugreek may reduce the bioavailability of minerals [19] and may also impair the protein's capacity to be digested [19]. Additionally, studies have shown an inverse relationship between fenugreek consumption and the risk of diabetes [17] obesity [17], and some forms of cancer [13]. Fenugreek's antioxidant and anticarcinogenic properties have been attributed to its phenolic [11], saponin [12], and phytate [10] acids. Phenolic chemicals may chelate metals and limit the capitation of free radicals by delaying the action of the lipoxygenase enzyme [12]. Flavonoids, tannins, and phenol acids

are a few of these [12-15]. According to [11], fenugreek has been shown to contain comparatively substantial amounts of saponins, a heterogeneous group of highly surface-active amphiphilic chemicals of plants with a wide range of varied qualities. According to [11], the majority of saponins are hemolytic, binding cholesterol and possessing stable foam-forming qualities. By combining with protein and metal ions, the phytate has a strong affinity to create insoluble complexes [21]. By changing the solubility and functioning of these complexes, the phytate can decrease their absorption and digestion. However, by forming a compound with iron and lowering the production of free radicals and membrane peroxidation, phytate may have antioxidant properties that provide an anticarcinogenic effect [17]. Consequently, there is a growing interest in manipulating grains to either enhance or decrease the concentration of phytate in food [19]. Numerous polyphenolic chemicals found in fenugreek seeds contribute to their positive health effects [19] which include a decreased risk of degenerative cardiovascular illnesses [19]. Research employing in vitro spectrophotometric measurement showed the great capacity of fenugreek extract to scavenge oxygen radicals when combined with ethyl acetate and alcohol [13-15]. Additionally, quantification using HPLC analysis demonstrated the presence of five flavonoids, including vitexin, tricin, quercetin, naringenin, and tricin 7-O-β-D-glucopyranoside [13], as well as several compounds, including apigenin, number of kaempferol, and quercitin glycosides [15]. In their study, [21] employed UPLC-MS to measure the amount of 18 phenolic compounds in an ethyl acetate extract of fenugreek. They found that two flavonoids, luteolin-7-O-glycoside (725.50 ng/mg) and apigenin-7-O-glycoside (1955.55 ng/mg), were the most prevalent in the extract. According to [23], fenugreek seed has 26.8% soluble fiber that is chemically identified as galactomanns. This fiber has characteristics that are comparable to those of guar seeds, psyllium husk, and other soluble fibers [29]. According to [39], galactomanns are biopolymers made of a linear poly (1,4)-β-D-mannan backbone with varying amounts of Dgalactosyl substituents connected by 1,6-glycosidic linkages. Galactomanns originating from diverse legumes typically exhibit variations in their molecular weight, mannans to galactose ratio, and the location and mechanism of galactose moieties' attachment to the mannan backbone. The highest amount of galactose was found in the fenugreek galactomannan, with a ratio of 1:1. Other examples of locust bean galactomanan include taragum at 3:1, guar seed at 2:1, and mannans to galactose at 4:1. It implies that fenugreek gum has uniform links between the mannose and galactose moieties, which maximizes solubility and hydration [40- 44]. This M/G ratio has an inverse relationship with gum solubility and influences the physicochemical properties of galactomannans [45,46]. When fenugreek gum was compared to guar gum, locust bean gum, and tara gum, it showed the highest galactose content, which led to its highest water solubility [47]. By adhering to oil droplets, galactomannans sterically stabilize the emulsions against flocculation and coalescence. Furthermore, it has been observed that all galactomannans display surface, interfacial, and emulsification activities [48, 49]. These qualities make it a superior ingredient for many different food applications compared to other natural hydrocolloids [50]. Additionally, compared to guar gum and locust bean gum, whose G:M ratios are 1:2 and 1:4, respectively, fenugreek gums with the highest galactose content (galactose to mannose ratio, G:M is 1:1) demonstrated the greatest reduction of cholesterol in both liver and blood plasma [51]. The soluble fiber from fenugreek, also known as fenugreek gum, is a hydrocolloid that has properties that include gelling, thickening, emulsifying, stabilizing, and encapsulating. Therefore, dietary fiber—particularly soluble fiber—can be found in dairy products, cereal bars, yogurts, and nutritional drinks. Soluble fiber powders or total dietary fiber in their plain form can be combined with fruit juices, other spice blends, and seasonings. It can be formulated as tablets or capsules and taken as a direct supplement with other vitamins and nutrients. It can also be used on soups, candies, sweets, dressings, and milk shakes. Additionally, according to]17], and [18], it can be used to fortify bakery flour for items like pizza, bread, bagel, muffins, cake mix, noodles, tortilla and flat bread, fried and baked corn chips, etc.

The protein content of fenugreek seed is 25.4% [12], whereas endosperm is rich in globulin, histidine, albumin, and lecithin [12] and contains 43.8% protein. The amino acids 4-hydroxyisoleucine and histidine, which can increase insulin secretion, are also found in high protein (20 to 30%) seeds [9]. According to [7], the protein fraction from fenugreek is rich in lysine and has quality that is similar to that of soybean protein, making it suitable for use as a nutritional supplement. The proteins in fenugreek are sufficiently stable and unaffected by cooking [8]. Fenugreek, like other legumes, is a highly nutritious seed because it contains both essential and nonessential amino acids. [13], discovered that fenugreek seeds had notable levels of glutamic acid, aspartic acid, leucine, tryptophan, and arginine. They also concluded that fenugreek protein isolate is a source of protein with exceptional functional qualities.

Plant proteins are used as food based on their functional qualities, which dictate how they are ultimately used in various food applications [12]. Numerous factors, including size, shape, and conformation, the process and circumstances of protein isolation, and the fat extraction technique, can impact a protein's functional qualities [13, 17]. According to [14], plant proteins are utilized as functional ingredients in food to enhance the product's stability, texture, and nutritional value. In an alkaline pH, fenugreek protein is more soluble, according to [10]. The oil extracted from fenugreek seeds has a golden-yellow color, a disagreeable smell, and a bitter taste. Its main constituents are unsaturated fatty acids, specifically linoleic, linolenic, and oleic acid [4]. It can be used to flavor canned foods, syrups, and some perfumes [4]. It has been reported that linoleic acid, a significant polyunsaturated fatty acid (PUFA), influences the growth of the brain and nervous system as well as muscles, and plays a role in the prevention of coronary heart disease, hypertension, rheumatoid arthritis, and ulcerative colitis [7]. Furthermore, dermal, skeletal, metabolic, and reproductive systems are also benefited [5]. Another PUFA, linolenic acid, has been discovered to have some significant biological properties recently, including potent in vitro antitumor activity [7]. When assessing the nutritional value of oil, the composition of its fatty acids holds particular significance. Intervention studies have demonstrated that dietary fatty acids, especially PUFA and MUFAs, can alter the lipoprotein profile of blood plasma and lower the risk of cardiovascular disease [15, 17]. Because of their adaptability, simplicity, organoleptic appeal, and satiety, noodles are becoming more and more

popular, particularly in developing nations [14]. One of the many convenience foods made primarily with wheat flour is noodles. According to [14], these are well-liked due to their sensory appeal, tasty flavor, affordable price, ease of preparation, and stability in storage. When fenugreek flour was added to biscuits by [11], the results showed that the biscuits puffed up well and had higher amounts of protein, dietary fiber, calcium, and iron.

Trigonella foenum-graecum L., also known as fenugreek, is an annual crop in the legume family. Despite being cultivated mostly for spices, the species name "*foenum-graecum*" (which means "Greek hay") indicates that it was once used as a forage crop [13]. Regarding the likely ancestry of *T. foenum-graecum*, various authors have expressed wildly divergent views, proposing a variety of origins, including the Mediterranean region [13], Asia [9], Europe, Africa, and Australia [11]. Currently, there are reports of fenugreek cultivation in several regions of Australia, North and South America, West and South Asia, Europe, and Africa [12]. There has also been disagreement over the precise number of fenugreek species. According to [21], as many as 260 species of fenugreek have been proposed by earlier taxonomists such as Linnaeus. [12], [23], [16], and others have proposed as many as 128 species. Also, the National Gene Bank in India has received over 1287 accession of fenugreek to date. The largest producer, consumer, and exporter of spices worldwide is India. Seventeen of the sixty-three spices cultivated in the nation are seed spices [52]. Fenugreek is a dicotyledonous plant that grows annually and is a member of the *Fabaceae* family. It is also used as a spice to improve food's sensory appeal and has been used medicinally for centuries [33]. The main producers of spices are Egypt, Ethiopia, Turkey, and India. The crop, in particular the seeds, has drawn a lot of attention as an inexpensive source of high-quality protein [33] .When planted in well-prepared soil, the seed takes three days to sprout and grows into a sturdy, upright, and naturally resistant plant. Flowers are auxiliary white to yellowish in color, and leaves are compound pinnate trifoliate. Typically ranging in length from 3 to 15 centimeters, the slender pods feature pointed beaks and hold 10 to 20 oblong, greenish-brown seeds that are uniquely grooved like hoops. By stabilizing atmospheric nitrogen, it improves the soil. When greens are harvested at the third or fourth leaf stage, their bitterness increases as the amount of insapon increases. After 30–35 days of flowering, or 155–165 days after sowing, the seeds are harvested [37]. Hardy annual, the plant has branched growth at the base and can reach heights of 0.3-0.8 m [43], 40 cm [39], and 31 cm [40]. Its aroma is spicy and sharp. The most significant and beneficial portion of the plant is the fenugreek seed, which is golden-yellow in color, small, hard, and shaped like a four-faced stone [36]. The seeds are bitter but aromatic, with carminative, galactogouge, antibacterial, and antiviral qualities. The seeds measure 3-6 x 2-5 x 2 mm and contain 26% mucilage, 50% soluble and insoluble fiber, and 22% protein made up of albumin, histidine, and globulin along with significant amounts of phosphorus, sulfur, and lecithin [22]. The seed of fenugreek is the most used part and is widely used as a tonic, as a remedy against stomach disorders, diabetes, fever, anemia, constipation, and as a galactogogue and for stimulating appetite [21]. It is also popular in snacks and savory recipes [23, 25]. It is used in many domains including medicine, nutrition, beverages, fragrances, cosmetics, and for other industrial purposes [24]. Owing to the fiber, protein, and gum content, it serves as a stabilizer, adhesive, and food emulsifier. A corneous and comparatively large layer of white, semi-transparent endosperm surrounds the hard yellow embryo in the center of the seeds [33]. Proteins including globulin, histidine, albumin, and lecithin are abundant in fenugreek endosperm [33, 25]. The protein content of fenugreek seeds has been reported to range from 20 to 30% [24], 25% [17], 26% [22], 21.7% [27], and 9% [24]. [14], reported that fenugreek seeds had a moisture content of 6.83%, crude fiber content of 17%, total ash content of 3.566%, 7.15%, and 28.45%, as well as a calorie value of 5544.9 kcal/100g and a carbohydrate content of 1340 mg/100g. [12], observed that the fenugreek protein fractions are lysine-rich and of a quality similar to soybean protein. They are also sufficiently stable and unaffected by cooking [27]. In addition to being rich in calcium, iron, and β-carotene, fenugreek seeds have high protein (25%) and lysine (5.7g/16g N). They also include dietary fiber, both soluble (20%) and insoluble (28%). As such, they may be a beneficial addition to cereals.[13]. Fenugreek seeds, on a dry basis, comprise 11.8% moisture, 25.8% crude protein, 6.53% oil, 3.26% ash, 6.28% crude fibre, and 58.13% total carbs, according to [16]. [14], mentioned that linoleic, linolenic, and oleic acids dominated the fatty acid profile of fenugreek, with values of 50%, 24.4%, and 16.3%, respectively. They also found that fenugreek had protein, crude fiber, and crude fat of 28.4%, 9.3%, and 7.1%, respectively. According to [12], fenugreek's moisture (3-5%), protein (25-30%), insoluble fiber (20-25%), lipids (7-9%), saponins (5-7%), and ash content (3–4%), which includes mucilaginous fiber, lysine-rich protein, free amino acids, saponins, flavonoids, and volatile oils, are all thought to contribute to its health benefits. The average protein, fat, and carbohydrate contents of fenugreek seeds were determined to be 2.74%, 6.33%, and 77.04%, respectively [28], who studied the physicochemical parameters of the seeds. The average values of 0.1137 mg/g, 0.0366 mg/g, 0.0495 mg/g, 0.8710 mg/g, 10.54 mg/g, and 0.0386 mg/g were obtained for the contents of vitamins B1, B2, B6, B12, vitamin C, and folic acid, respectively. Saponins (4.8%), flavonoids (10%), alkaloids (35%) and diosgenin (0.2-0.9%) are the three primary classes of fenugreek secondary metabolites [53- 55]. The characteristic aroma and bitter taste of fenugreek are mostly caused by alkaloids and a few other volatile chemicals [53, 55]. Fenugreek contains anti-nutrients called alkaloids and saponins [54].

According to [55], fenugreek extract's capacity to control the digestive tracts glucose metabolism is partly due to its high fiber content. Fenugreek seed has 30% insoluble fiber and 20% gel-forming soluble fiber, according to [22] and [45]. According to [45], fenugreek seeds are an excellent source of soluble dietary fiber, carbohydrates, and mucilaginous fiber, which is primarily made up of galactomannans [56]. The high concentration of soluble fiber in fenugreek contributes to its capacity to boost glucose tolerance. One of the primary soluble fibers found in fenugreek seeds is galactomannan, which has the effect of lowering the intestinal absorption of bile salts as well as the body's digestion and absorption of starch [33]. The endosperm of the seeds is where fenugreek gum is made up of galactose and manose units. In the aqueous solution, it results in high viscosity [37]. Food ingredients can be thickened, stabilized, and

emulsified with the help of fenugreek gum [38]. In the food sector, fenugreek gum is used less frequently than other gums like guar and locust bean. The earliest reports of manganese, magnesium, zinc, and copper concentrations in fenugreek seeds were from [43]. Higher levels of calcium, iron, and zinc were found in fenugreek, according to [35]. Fenugreek has a good amount of phosphorus and sulfur, according to [35]. [21], identified 13 components in the concentrations of fenugreek in the following order: Fe≈K>Pb> Na > Cd > Cr > Ni > Mg > Zn > Mn> Cu > Co. According to [15], fenugreek seeds have a mineral composition that ranges from 2.89 to 3.04%. The seeds are a rich source of calcium (0.10 to 0.16%) and phosphorus (0.12 to 0.16%). The seeds contain 7% oil, which has a harsh flavor and an unpleasant odor [12]. According to [21], the fatty acid profile of oil is made up of oleic, linoletic, and linolenic acids. According to [22], the overall amount of lipids in seeds is 5.5-7.5%. These lipids are primarily made up of neutral lipids (85%), phospholipids (10%), and glycolipids (5%). Oleic (14%), linolenic (25%) and linoleic (40%) acids are unsaturated lipids [12, 15]. According to [15], fenugreek has a very modest volatile oil concentration (<0.02%), a brown color, and a faint smell. [16], state that it is a good source of minerals (Na, Ca, Cu, and Zn), vitamin C, and important amino acids (lysine, leucine, and total aromatic amino acids). According to [16], the seeds are an excellent source of leucine, valine, threonine, and lysine. Fenugreek possesses powerful analgesic and appetite stimulant properties due to the presence of oleamide and N-acylethanolamines (NAEs) [16].

According to [39], fenugreek seed has trace amounts of both volatile and fixed oils. Fenugreek seeds have roughly 7% fixed oil, which is mostly made up of linoleic, oleic, and linolenic acids, according to [33]. [32], discovered that the lipids from fenugreek seeds that were subjected to gas chromatography included 17% saturated fatty acid (stearic acid) and 83% unsaturated fatty acid (linoleic and oleic acid).Fenugreek is particularly high in choline and vitamins A, B1, B2, C, niacin, and nicotinic acid, according to [14]. Vitamin C, β-carotene, thiamine, riboflavin, nicotinic acid, and folic acid concentrations were reported by [13] to be 52 mg, 2.3 mg, 40 µg, 310 µg, 800 µg, and 0 µm in leaves and 43 mg, 96 µg, 340 µg, 290 µg, 1.1 mg, and 84 µg in seeds. After researching the essential oil composition and antioxidant activity of *Trigonella foenum graecum* L., [14] found 35 oil essence components that make up 94% of the overall essence. α-bisabolol (2.3%), γ-cadinene (1.8%), farnesol (0.9%), cadinol (1.7%), γeudesmol (0.8%), trigonellin (0.6%), and diosgenin (0.8%) are the principal constituents of essence.

Major Phytochemicals of fenugreek

The term "phytochemical" refers to any naturally occurring chemical found in plants and is derived from the Greek word "phyto," which means plant. Phytochemicals give host plants color, flavor, and scent in addition to a built-in defense mechanism [51]. The plant kingdom contains a vast array of physiologically active substances, many of which are found in plants that are consumed as human and animal food [52]. These consist of grains, seeds, fruits, vegetables, herbs, and spices. Spices and herbs are safe ways to get antioxidants from nature [53]. Pharmacological properties of fenugreek include being hypoglycemic [54], hypercholesterolaemic [51], gastroprotective [52], chemo-preventive [53], antioxidant [53], alkaloids [52], and flavonoids [53]. According to [51], fenugreek seeds contain antioxidant activity, the capacity to counteract free radicals, and an increase in antioxidant potential. According to [51], who assessed the fenugreek seeds' husk and endosperm's chemical and antioxidant activity, the endosperm had the highest concentration of protein (43.8%) and saponin (4.63%).Alkaloids, flavonoids and phenolic acids, triterpenoids , steroidal sapogenin, and nicotinic acid are among the substances found in fenugreek. [54]. [55], regarded saponins and alkaloids as anti-nutritional elements in human diet; nevertheless, fenugreek extract, which contains saponins, has been shown to increase hunger, lower plasma cholesterol, and treat hypocholesterolaemia in rats. Alkaloids, flavonoids, steroids, tannins, free amino acids, and saponins were calculated by [54] to be 1.8%, 12.13%, 214 mg/100 g, 63.69 mg/100 g, 70 mg/100 g, and 25%, respectively, in fenugreek seeds. They came to the conclusion that fenugreek seeds are high in antioxidants and energy. As a result, the seeds can be used as a cheap source of nutrients because they are high in protein, fat, carbs, and amino acids.

According to [56], fenugreek has flavonoid and phenolic components that contribute to its increased antioxidant potential. According to [55], fenugreek contains potent antioxidant properties that are good for the pancreas and liver. Since the health benefits of natural products have been associated with their antioxidant properties, the properties of fenugreek studied with germinated seeds were found to be more advantageous than those of dried seeds due to the fact that germinated seeds increase the bioavailability of various fenugreek constituents. [55], found that aqueous extracts had higher antioxidant activity than other solvents like ethanol, methanol, etc. This is likely because the extracts contain flavonoids, polyphenols, and other components that are soluble in water. The aqueous extracts shown protective action against Fe2+-ascorbate-induced lipid peroxidation in addition to improved iron-reducing capacity. The ability of fenugreek to scavenge free radicals and generate iron complexes, as demonstrated by the ferric-reducing ability of plasma test, led to the hypothesis of a potential mode of action. Experimental research by [54], has demonstrated a clear relationship between the concentration of polyphenols in fenugreek seeds and their antioxidant activity. Husk had a higher quantity of polyphenols than seed or endosperm, with IC50 values of 138, 158, and 176 µg for scavenging the DPPH radical, respectively. Furthermore, fenugreek's polyphenols have been shown by [55] to have an RBC protective effect against oxidative damage caused by the peroxide treatment. According to [56], fenugreek aqueous extract also had a protective effect against ethanol toxicity and prevented the promoter of lipid peroxidation by producing reactive chemicals that are thiobarbituric acid. According to [54], fenugreek's antioxidative capability was shown to be on par with other well-known antioxidants like glutathione and α-tocopherol. Based on his research, [54] found that fenugreek is a nutrient-dense diet full of health-promoting phytochemicals. He investigated the effects of extraction solvent on TPC, DPPH, and FRAP test using three different solvents: acetone, methanol, and ethanol. The TPC varied between

15.45 and 25.90 mg GAE/100 g, whereas the antioxidant activity, FRAP, and DPPH ranged from 31.85 to 47.49 mg TE /100 g DW and 43.61 to 67.30%, respectively. Acetone and 50% ethanol showed the highest and lowest values of these parameters. He also came to the conclusion that the phenolic components in the fenugreek seed extract and their antioxidant activity are significantly influenced by the extraction solvent. Folin-Ciocalteu, DPPH, and the AlCl3 assay were used by [54] to assess the TPC, antioxidant capacity, and TFC of the aqueous methanol extracts of fenugreek. According to their study, there was a substantial increase in TPC (150.80±0.33 mg GAE/g) and DPPH radical scavenging assay (51.6-78.0% inhibition) in the seed extract.

The effectiveness of fenugreek seeds as a possible natural source of antioxidants and antimicrobials was examined by [51]. They used ethanol, methanol, and water as extraction solvents to generate fenugreek seed (FS) extracts. Water (W-GeFS) was obtained from germinated FS, whereas ethanol (E-FSP), methanol (M-FSP), water (W-FSP), and hot water (HW-FSP) extracts were obtained from ground FS. They came to the conclusion that the fenugreek seed extract known as W-GeFS, which is derived from germination, has the potential to be utilized as a natural source of bioactive substances with a variety of uses in the food sector. One such usage is active film packaging, which extends the shelf life of food items. [53], examined the nutritional makeup, anti-nutritional activity, and antioxidant content of fenugreek seeds after processing them using three distinct methods: soaking, germination, and roasting. They found that the amount of dietary fiber in raw fenugreek seed flour was higher (45.4%) than in soaking seed flour (41.7%), roasted seed flour (40.9%), and germinated seed flour (31.3%). When compared to raw fenugreek seed flour, processing improved the in vitro digestibility of starch and protein, as well as the total phenolic content and antioxidant activity. Strong antioxidant qualities of fenugreek are connected to its health advantages. It's interesting to note that in this case, germination is preferable to ungerminated dry seeds. However, compared to flavonoids and phenolics, the aqueous fraction of fenugreek exhibited significantly more antioxidant activity [53]. Flavonoids, alkaloids, saponins, and other antioxidants are present in fenugreek in quite high concentrations [53]. Gallic acid (1.7 mg), protocatechuic acid (4.0 mg), catechin (0.4 mg), gentisic acid (35.8 mg), chlorogenic acid (0.7 mg), vanillic acid (58.5 mg), and syringic acid (0.3 mg) are among the principal class of phenolics present in 100 g of the seed extract. As per [55], fenugreek seed has about 100 mg/g of flavonoids, although 35% of the endosperm of the plant is made up of alkaloids, mostly trigonelline. Because they all have pharmacological effects on the human body when consumed, these substances are all categorized as biologically active. Their hypoglycemic, antilipidemic, anticarcinogenic, and cholagogic qualities make them valuable additions to a daily diet for the management of hypercholesterolemia, cancer, and diabetes mellitus [55]. But the main ingredients that give anything a terrible taste and smell are volatile oils and alkaloids, which is why they should be eliminated before using. [56] found that fenugreek seeds contained gallic, chlorogenic, coumeric, sinapic, vanillic, caffeic, cinamic, and benzoic acids. They also found that the primary phenolic acid in the seeds was gallic acid (65.26 µg/g), while the second and third highest penolic acids were determined to be benzoic (16.21 µg/g) and sinapic (16.13µg/g). According to [56] the presence of certain bioactive chemicals such as steroidal diosgenin, alkaloid trigonelline, flavonoid quercetin, galactomannan, and the unique amino acid 4-hydroxyisoleucine is responsible for the pharmacological effects of fenugreek seed. Diosgenin and quercetin are two of the major bioactive components of fenugreek that have been reported to be quite important and to have the intended effects on humans. According to [56], quercetin is a bioflavonoid that has been shown to possess anti-inflammatory, antidiabetic, and anticancer qualities in addition to other attributes including enhancing mental and physical performance. According to [55], the most prevalent class of phytoconstituents found in fenugreek is saponins. Saponins are classified structurally as having a steroidal skeleton or a hydrophobic triterpenoid ring that is glycosylated via an O-glycosidic link at various places with a variable amount of hydrophilic sugar units.

Protein

Legumes are a great food that have many health and functional benefits and are reasonably priced [57]. With a total protein composition of between 25 and 38.6%, fenugreek seeds are a fantastic source of plant proteins. The major components in fenugreek seeds are albumins (43.8%), globulins (27.2%), glutelins (17.2%), and prolamines (7.4%) [57]. Using three distinct techniques, [57] looked into the protein extraction from the flour of three legumes: fenugreek, chick peas, and faba beans. There were three different methods used to prepare the proteins: extraction in an aqueous or saline solution with the presence of pepsin or pancreatin (partially hydrolyzed protein preparation, PHP); extraction with 0.5 M NaCl solution and precipitation by ionic strength reduction (protein micellar mass, PMM); and extraction with an alkaline extraction and precipitation at an isoelectric pH (protein isoelectric precipitate, PIP). Depending on the kind of legume and the isolation circumstances, the three isolates' protein recoveries differed; faba beans showed the highest protein recoveries across all three techniques. With the exception of fenugreek, two of the protein isolates' fat and water absorption values were higher than those of their respective parent flours. The isolates were oil emulsified in the following order: PMM>PHP>PIP. At pH 2.4, PHP isolate had the highest nitrogen solubility index value, followed by PMM at pH 5.7–6.4 and PIP at pH 4.5–5.5. The solubility of the proteins was raised by the enzymes by roughly 10% to 15%. [57], used distilled water, salt solution, and alkaline solution to extract protein concentrations from fenugreek seeds. They found that the alkaline solution had the maximum extraction yield (82%). An in vitro enzymatic technique was used to determine the protein concentrate's good digestibility (above 90°C). The protein was low in sulfur-containing amino acids including tryptophan (1.03%), methionine (0.71%), and cysteine (1.09%), but high in lysine (6.51%).According to [58], 4-hydroxyisoleucine is the most prevalent free amino acid in fenugreek seeds, making up as much as 80% of the total free amino acids. This special amino acid's hypoglycemic and insulinotropic qualities were also shown in vivo and in vitro using animal and human models, indicating that it may have some use as an antidiabetic

drug. Likewise, [57], discovered that fenugreek has a significant percentage of protein (20 to 30%) and, in particular, the insulin-stimulating amino acid 4-hydroxyisoleucine. It was discovered that the lysine-rich fenugreek protein fraction was of a quality similar to soybean protein. The proximate composition and physicochemical characteristics of the protein concentrate (FPC) made from fenugreek seeds were ascertained by [57]. Additionally, the impact of NaCl content and pH on these characteristics were examined. It was discovered that fenugreek had 28.4% protein, 9.3% crude fiber, and 7.1% crude fat. The pH values of 11 (91.3%) and 4.5 (18.5%) were found to have the highest and lowest protein solubility, respectively. pH values and NaCl concentrations also had a significant impact on the emulsion and foaming characteristics of FPC. The isoelectric point, pH 4.5, yielded the lowest values of both emulsion and foam qualities, whereas pH 2 and pH 12 produced the highest values. In both basic and acidic conditions, FPC exhibited good dispersibility; the lowest dispersibility was seen at pH 4.5 (41.3%). The least gelation concentration exhibited behaviour that was dependent on pH and protein concentration; at low concentrations (2% and 4%), no gel formed, but at higher concentrations (8% and 10%), a robust gel did form. The FPC exhibited high bulk density (0.66 g/ml), water absorption capacity (1.68 ml H2O/g protein), and oil absorption capacity (1.56 ml oil/g protein).In order to optimize the protein extraction process, [57], conducted experimental design utilizing response surface methodology (RSM), selecting two factors (pH 6 to 12 and NaCl concentration 0 to 1 mol/L). They also investigated the amino acid composition, functional characteristics, and thermal properties of the fenugreek protein isolate (FPI).It was shown that both pH and NaCl significantly affected the extractability of proteins; pH 9.25 and 0.33 mol/L of NaCl were the ideal values for protein extraction from fenugreek seeds. In these circumstances, 2.1g of protein weight and 891.00 g/kg of protein content were generated as FPI. The contents of FPI in terms of moisture, fat, ash, and carbohydrates were 53.0, 60.0, 19.0, and 30.0 g/kg, in that order. The amino acid composition of FPI was shown to be deficient in sulfur-containing amino acids, but abundant in glutamic acid, aspartic acid, leucine, threonine, arginine, and lysine. The first peak, with To 100°C, Td 104.96°C, Te 120°C, and ΔH 2.69 J/g, was smaller than the second peak, with To 120°C, Td 121.4°C, Te 130°C, and ΔH 5.66 J/g, according to the DSC data, which indicated that FPI had two transition temperatures. In addition to having exceptional functional qualities—such as protein solubility, foaming stability, and oil binding capacity—FPI also exhibited pH-dependent behavior. These attributes were greater than those of commercial SPI. More bands were visible in the FPI electrophoretic pattern under reducing circumstances compared to non-reducing conditions, with and without 2-mercaptoethanol. In the electrophoretic pattern of FPI, there were two bands and one band in the 30-39 kDa range under both circumstances.For plant proteins to be successfully and effectively used in various dietary applications, they should ideally have a number of desirable qualities known as functional attributes. The size, structure, and conformation of proteins are just a few of the numerous variables that influence their functional characteristics. It has also been noted that the conditions and process used to isolate fat impact the functional characteristics of protein [58]. Comparing the chemical, structural, and functional characteristics of fenugreek protein isolates (FPI) made using various defatting solvents, such as hexane (PIHD), diethyl ether (PIDD), chloroform (PICD), ethanol (PIED), and acetone (PIAD), was documented by [58], PICD exhibited the lowest protein solubility and amino acid content of all the PIs. The FTIR verified the structural differences across all protein isolates, leading to the conclusion that distinct defatting solvents alter the secondary structure of FPIs through diverse processes. Both defatting solvents and pH-dependent activity were displayed by the protein solubility. PIAD showed the highest protein solubility (5.00 mg/mL) when compared to other samples, based on the average protein solubility at pH 2-10 for each FPI. FPIs produced with hexane and diethyl ether have similar Td, SDS-PAGE profile, coagulated protein, interfacial tension, emulsifying qualities, and surface hydrophobicity. The order of the coagulate proteins was PIDD (3.04%)<PIHD (3.17%)<PIAD (4.12%)<PICD (6.03%)<PIED (7.1%). Given PIED's significant foaming characteristics, its lowest surface tension made sense. In PIAD, maximum Td and ΔH were noted. PIHD and PIAD have the largest concentrations of charged hydrophilic and hydrophobic amino acids. [58], investigated how three distinct drying techniques affected the solubility and colour characteristics of protein isolates made from fenugreek. FPIs were dried using a variety of techniques, including oven drying, vacuum oven drying, and freezing. Fenugreek protein isolate was 89% protein by weight. pH had a major impact on the protein isolates' solubility when dried using various techniques, with the exception of pH 4.5.The freeze-dried protein isolate had the maximum solubility across all pH ranges, followed by vacuum- and oven-dried FPI and then oven-dried FPI. The freeze-drying approach proved to be more appropriate than other techniques due to its reduced ability to denaturize and destroy proteins and colorants. The solubilization and characterization of the proteins in fenugreek seeds were assessed by [58]. About 70% of the proteins in cotyledons and embryo(s) (C+E) are soluble in water, 5% in NaCl (0.86 M), and 7% in NaOH (0.05 M), according to the results. In order to eliminate saponins for steroid preparations, which significantly reduce the solubility of proteins in water, C+E was treated with 2-propanol at 78°C.The solubility of proteins is not significantly affected by the initial pH of a solution, with the exception of extreme values, such as pH 1-4 and pH-11. It was discovered that the solubilization conditions had an impact on the heterogeneous electrophoretic compositions of albumins, globulins, and glutelins. The electrophoretic patterns (PAGE-SDS) of albumins and globulins are significantly altered when proteins are reduced using mercaptoethanol. According to [58], boiling has no effect on the protein quality of fenugreek seeds. Furthermore, an animal study demonstrated that adding fenugreek to a casein diet up to 10% did not negatively impact the protein's quality, as evidenced by the protein efficiency ratio, protein digestibility, and net protein consumption [58]. Additionally, he came to the conclusion that proteinaceous materials had no discernible impact on the fenugreek gum's surface activity. Remaining proteins were found to be crucial in lowering the tension at the oil-water interface by [56].

Lipids

Fenugreek seed oil has been used to flavor a variety of canned foods and syrups, as well as some perfumes [51]. It is primarily composed of unsaturated acids, specifically oleic, linoleic, and linolenic acid [53]. When petroleum ether was used as a solvent in the Soxhlet extraction of fenugreek seed oil, [51], discovered a yield of 6.7%. 46 different genotypes of fenugreek showed a larger range of lipid content (3.25–6.88%) [51]. The maximum oil yield of roughly 8% was discovered by [51] when they investigated the impact of grinding on the yield of fenugreek seed oil using Soxhlet extraction. The impact of temperature on the rate of fenugreek oil extraction was noted by [55]. They discovered that the yield was temperature dependent, rising to a maximum of 40°C; beyond that point, the yield of oil remained constant. After optimizing the extraction conditions, they found that the maximum yield of lipid content was produced at an extraction temperature of 43.24°C, an extraction time of 32.80 minutes, and a particle size of 0.26 mm. [54] investigated the ideal circumstances for using supercritical CO_2 fluids to extract oil from fenugreek seeds, and they found that the maximum extraction yield in fenugreek under these ideal circumstances was 8.95%. [54] measured the fatty acid and chemical composition of different spices and found that fenugreek contained 4.51% crude fat. In fenugreek seeds of Indian origin, [53] reported a lipid content of 7.5%; [55] found lipid content ranging from 5.8 to 15.2%. In their study [55], examined the impact of genetic variation on the fatty acid composition of fenugreek seed, noting that different varieties ranged in oil content from 4.32 to 11.62%.

Fatty acid composition

In addition to the major lipid classes, the makeup of minor lipid classes—which are known to have significant physiological roles in plants and animals—has drawn more attention in recent years [53], characterized and refined the fenugreek seed oil extraction process. They found that there was little difference in the fatty acid composition of oils obtained through accelerated solvent extraction and subcritical butane under ideal conditions. Linoleic acid (42.71%–42.80%), linolenic acid (26.03%–26.15%), and oleic acid (14.24%–14.40%) were abundant in the oils. The oils had a high concentration of linoleic acid (C18:2), roughly eight times more than virgin olive oil [59]. An essential polyunsaturated fatty acid that is vital to the development of the nervous system, muscles, and brain is linoleic acid. Furthermore advantageous to the skeletal, metabolic, dermal, and reproductive systems [58]. The fatty acid profile of fenugreek seed oil, with its high content of unsaturated fatty acids, particularly polyunsaturated fatty acids, makes it unique for use as edible oil in functional applications. Fenugreek oil was found to have a cholesterol content ranging from 6.8% to 1.9 percent [59]. According to [59], fenugreek oil has an amount of 82.3% unsaturated fatty acids and 17.7% saturated fatty acids. The highest content of unsaturated fatty acids was found in linoleic acid (43.2%), which was followed by linolenic acid (22%) and oleic acid (16.7%). According to research by [59], fenugreek oil contained sixteen fatty acids, and the study examined the impact of genetic variation on the fatty acid composition of fenugreek seed. The main contributor (33.36-43.41%) was linoleic acid (18:2 n-6). The other contents are oleic acid (18:1 n-9), stearic acids (18:0), palmitic (16:0), and linolenic acid (18:3 n-3). About 2% of the total fatty acids were made up of other fatty acids, which were also detected in small amounts. [59] found that fenugreek oil has an observed 84% natural lipid content, with lower concentrations of phospholipids and glycolipids. In fenugreek seed oil, [59] found that there were roughly 93% unsaturated fatty acids and 7% saturated fatty acids. The main sources of unsaturated fatty acids were linolenic and linoleic acid, which were found to be 34.85 and 30%, respectively. The bioactive lipid compounds in fenugreek seed were examined by [60], who discovered that the fatty acids in fenugreek oil had a considerable amount of bioactivity. They found that unsaturated acids, specifically oleic, linoleic, and linolenic acids, which make up 16.3%, 50%, and 24.4% of the total fatty acids in fenugreek oil, dominated the fatty acid profile. When [59] examined the fatty acid profile of fenugreek seed, they discovered that the main fatty acids in fenugreek oil were linoleic acid (45.1–47.5%), linolenic acid (18.3-22.8%), oleic acid (12.4–17.0%), palmitic acid (9.8–11.2%), and stearic acid (3.8–4.2%). It was discovered that the ratios of n-6 to n-3 fatty acids ranged from 2.1 to 2.7.

Physicochemical properties of oil:

When fenugreek seed oil was extracted using subcritical butane under ideal circumstances, [61] observed its physicochemical properties and discovered that, at room temperature, the oil was yellow and had a refractive index of 1.479, which was equal to that of soybean oil (1.477) and corn oil (1.473). On the other hand, [62] reported that oil had a similar refractive index value and a golden yellow color at room temperature. The high content of UFA in the fenugreek seed oil contributed to its high refractive index value, indicating that it possessed edible oil properties. The oil's low SFA content contributed to its high iodine value of 148.564 g/100 g of oil. Low molecular weight triacylglycerols make up a large portion of the oil, as indicated by the high saponification value (190.277 mg KOH/g of oil). According to [59] there was 3.790% unsaponifiable matter in the seed oil, whereas a previous study [60] found that fenugreek oil had a higher amount of unsaponifiable matter (10.18%).Tocopherols, sterols, triterpenic alcohols, hydrocarbons, and aliphatic alcohols are present in the unsaponifiable matter of the seed oil [60]. According to [60], fenugreek oil had a relative density of 0.922 and an acid value of 6.413 mg/g of oil. They discovered that the oil's peroxide value was 0.627 meq. O2/kg.

Health benefits of fenugreek

Diabetic management

Spices are natural food additives that have been used to enhance food's sensory appeal for thousands of years. Spices give food its distinct flavor, aroma, piquancy, and color. Certain spices, such as fenugreek, can also alter the food's

consistency. Globally, the prevalence of diabetes mellitus is raising, with 50% of people in Asia having the disease [62]. One of the most prevalent endocrine disorders, diabetes mellitus is defined as a hyperglycaemic clinical manifestation brought on by a malfunction of metabolic systems, specifically protein, lipid, and carbohydrate metabolism. According to the[59] it is commonly understood to be caused by abnormal pancreatic β-cell secretion of insulin, inability of insulin to stimulate peripheral utilization, and/or increased endogenous glucose production by the liver. In many parts of the world, particularly China, Egypt, India, and the Middle East, fenugreek is used in cooking as well as for the treatment of diabetes [62]. While the leaves are consumed as green leafy vegetables, the seeds are used as spices all over the world. Fenugreek seeds have a bitter flavor and have long been recognized for their therapeutic benefits. India is the world's largest producer and consumer of fenugreek, both in culinary and medicinal applications. Fenugreek seeds are used in relatively larger amounts to make pan cakes and soups, as well as a spice for seasoning and flavoring. It is a gastric stimulant and an effective anorexic preventive in India's traditional medical system [62]. Dietary fiber is known to provide significant benefits to individuals with diabetes mellitus. Epidemiological research had demonstrated a relationship between dietary fiber consumption and the prevalence of diabetes in populations. Compared to Western nations where dietary fiber intake is low, countries with higher levels of dietary fiber, such as Japan, India, and the West Indies, had lower rates of diabetes. Because they consume more dietary fiber, diabetics in India and Japan are less likely than those in the USA to experience heart attacks and diabetic gangrene [63]. Fenugreek seeds are widely used as a condiment in India and other countries. They are beneficial in the context of diabetes because they are a great source of dietary fiber [63] .After studying fenugreek's effects on rats, [63] discovered that fenugreek can effectively lower blood glucose levels when taken orally once. After studying fenugreek seed extract's effects on animals, [63] came to the conclusion that it might lower post-prandial glucose levels by decreasing gastrointestinal absorption of glucose and slowing the enzymatic digestion of carbohydrates. Moreover, fenugreek exhibited insulinotropic qualities in isolated rat pancreatic cells [62] and increased glucose uptake in peripheral tissues [63]. Human postprandial glucose and insulin levels were found to be sharply lowered by fenugreek seeds [63]. The high fiber content and saponin content of fenugreek are believed to play a role in its antidiabetic properties. Frequent seed consumption may aid in the management of diabetes as well as the prevention of coronary heart disease and atherosclerosis [63] According to [62], fenugreek seeds exhibit promising antioxidant activity, making them a potential treatment option for diabetes-related complications.

Antioxidant activity

It is highly likely that oxygen free radicals are to blame for the severity and complications of diabetes. The impact of antioxidant enzyme activities in the tissues of diabetic rats given fenugreek treatment was noted by [57]. After three weeks of diabetes, it was found that the activity of cholesterol acyl transferase was significantly elevated in the heart but decreased in the liver. It was discovered that giving alloxan-diabetic rats fenugreek seed supplementation had a counteracting effect on the elevated lipid peroxidation and changes in the amount of circulating antioxidant molecules [63, 65]. Aqueous fenugreek seed extract was found by [59] to have a protective effect against experimental ethanol toxicity in rats. It was found that after consuming an aqueous extract of fenugreek seeds with ethanol continuously for two months, the amount of lipid peroxidation in the liver and brain rose and the leakage of enzyme activity into the serum were inhibited. In terms of combating the decreased activities of superoxide dismutase, catalase, glutathione peroxidase, glutathione S transferase, and glutathione reductase in the liver and brain, fenugreek aqueous extract also improved antioxidant potential. When fenugreek was given to diabetic animals, the abnormal antioxidant levels and peroxidative damage were reversed, indicating that oxidative stress is a major factor in the complications associated with diabetes [58].

Hypocholesterolemic Property

There is evidence linking high levels of very low-density lipoprotein and low-density lipoprotein cholesterol to atherosclerosis, or plaque, in the blood vessels. Lowering low density lipoprotein cholesterol levels may be a significant factor in lowering the risk of a heart attack. It has been discovered through experiments that several spices have lipid-lowering properties that are beneficial to health [53]. The hypocholesterolemic effect of dietary fenugreek was demonstrated by numerous animal and clinical studies [57]. According to [54], fenugreek not only lowers animal cholesterol levels but also stops rats fed a hypercholesterolemic diet from having an increase in serum cholesterol. Only the fiber and saponin components of fenugreek seeds showed evidence of cholesterol-lowering activity among the various compounds studied for their hypocholesterolemic properties. Gum and crude saponins were found to have a cholesterol-lowering effect, but lipid extract and trigonelline were found to have no such effect [59].

Other benefits

According to [63], roasting fenugreek seeds converted their steroidal saponin diosgenin trigonelline into niacin, which had a gastroprotective effect on gastric ulcers caused by ethanol. There were notable benefits against ulcers in both the gel fraction and the aqueous extract that were separated from the seeds. The antisecretory action was not the only factor contributing to this effect; mucosal glycoproteins were also found to be significant. Moreover, it was found that fenugreek seeds increased the stomach mucosa's antioxidant capacity, which decreased mucosal damage. In a study, [62] examined the immunomodulatory effects of fenugreek seed aqueous extract in male Swiss albino mice. The mice were given varying dosages of extract (50, 100, and 250 mg/kg body weight) for a period of ten days. Fenugreek was found to have a stimulatory effect on immune functions in mice, as evidenced by changes in lymphoid organ cellularity

(thymus and bone marrow), body weight, relative thymus weight, lymph proliferation, delayed type hypersensitivity response, and a significant increase in macrophage phagocytic index and capacity.

References:

1. Altuntaş, E., Özgöz, E. and Taşer, Ö. F. (2005). Some physical properties of fenugreek (*Trigonella foenum–graceum* L.) seeds. Journal of Food Engineering, 71, 37–43.
2. NHB (National Horticulture Board). (2017). http://agricoop.nic.in/sites/ default/files/
3. Tiran, D. (2003). The use of fenugreek for breast feeding women. Complementary Therapies in Nursing and Midwifery; 9, 155–156
4. Zuppa, A. A., Sindico, P., Orchi, C., Carducci, C., Cardiello, V., Romagnoli, C. and Catenazzi P. (2010). Safety and efficacy of galactogogues: Substances that induce, maintain and increase breast milk production. Journal of Pharmacy and Pharmaceutical Sciences, 13, 162–174
5. Sauvare, Y., Pett, P., Baissao, Y. and Ribes, G. (2000). Chemistry and pharmacology of fenugreek. In: Mazza G., Oomah B.D. (Eds.), Herbs, Botanicals and Teas. Technomic Publishing Company Inc., PA, USA, p. 107–129.
6. Srinivasan, K. (2006). Fenugreek (Trigonella foenum-graecum): a review of health beneficial physiological effects. Food Reviews International, 22 , 203–224.
7. Betty, R. (2008). The many healing virtues of fenugreek. Spice India, 1,17–19.
8. Naidu, M. M., Shyamala, B. N. and Naik, J. P. (2011). Chemical composition and antioxidant activity of the husk and endosperm of fenugreek seeds. LWTFood Science and Technology, 44, 451–456.
9. Jiang, J. X., Zhu, L. W., Zhang, W. M. and Sun, R. C. (2007). Characterization of galactomannan gum from fenugreek (Trigonella foenum graecum) seeds and its rheological properties. International Journal of Polymeric Materials, 56, 1145–1154.
10. Mathur, P. and Choudhry, M. (2009). Consumption pattern of fenugreek seeds in Rajasthani families. Journal Human Ecology, 25, 9–12
11. Basch, E., Ulbricht, C., Kuo, G., Szapary, P. and Smith, M. (2003). Therapeutic applications of fenugreek. Alternative Medicine Review, 8, 20–27.
12. Kumari, S. and Sinha, M. (2012). Hypoglycemic effect of fenugreek incorporated therapeutic food on selected diabetic subjects, Department of Food and Nutrition, College of Home Science, Rajendra Agricultural University, Pusa, Samastipur, Bihar 848 125.
13. Roberts, K. T. (2011). The potential of fenugreek (*Trigonella foenum-graecum*) as a functional food and nutraceutical and its effects on glycemia and lipidemia. Journal of Medicinal Food, 14, 1485–1489.
14. Xue, W. L., Li, X. S., Zhang, J., Liu, Y. H., Wang, Z. L. and Zhang, R. J. (2007). Effect of Trigonella foenum-graecum (fenugreek) extract on blood glucose, blood lipid and hemorheological properties in streptozotocin-induced diabetic rats. Asia Pacific Journal of Clinical Nutrition, 16 , 422–426.k8
15. Zia, T., Hasnain, S. N. and Hasan, S. K. (2001). Evaluation of the oral hypoglycaemic effect of Trigonella foenum-graecum L. (methi) in normal mice. Journal of Ethnopharmacology, 75, 191–195.
16. Belguith–Hadriche, O., Bouaziz, M., Jamoussi, K., Simmonds, S .M. J., Feki, A. El and Makni–Ayedi, F. (2013). Comparative study on hypocholesterolemic and antioxidant activities of various extracts of fenugreek seeds. Food Chemistry, 138, 1448–1453.
17. Yoshinari, O. and Igarashi, K. (2010). Anti-diabetic effect of trigonelline and nicotinic acid, on KK-Ay mice. Current Medicinal Chemistry, 17, 2196– 2202.
18. Mohamed, W. S., Mostafa, A. M., Mohamed, K. M. and Serwah, A. H. (2015). Effects of fenugreek, Nigella, and termis seeds in nonalcoholic fatty liver in obese diabetic albino rats. Arab Journal of Gastroenterology, 16, 1–9
19. Abdelgawad, M. R., Mustafa, M. M. M. and Kottb, M. K. I. (2012). Phytochemical protection against diethylnitrosoamine induced hepatocarcinogenesis by Trigonella foenum graecum in female rats. Arab Journal of Nuclear Sciences and Applications, 45 , 523–536.
20. Pandian, R. S., Anuradha, C. V. and Viswanathan, P. (2002). Gastroprotective effect of fenugreek seeds (Trigonella foenum graecum) on experimental gastric ulcer in rats. Journal of Ethnopharmacology, 81, 393–397.
21. Ahmadiani, A., Javan, M., Semnanian, S., Barat, E. and Kamalinejad, M. (2001). Anti–inflammatory and antipyretic effects of Trigonella foenum–graecum leaves extract in the rat. Journal of Ethnopharmacology, 75, 283–286.
22. Kaviarasan, S., Naik, G., Gangabhagirathi, R., Anuradha, C. and Priyadarsini, K. (2007). In vitro studies on antiradical and antioxidant activities of fenugreek (Trigonella foenum graecum) seeds. Food Chemistry, 1, 31–37.
23. James, A. D., Bogenschutz–Godwin, M. J., duCellier, J. and Duke, K. P. (2002). Medicinal Herbs. Handbook, second ed. CRC Press, Boca Raton, London, New York, Washington, D.C., p. 296.
24. Mahmoud, N. Y., Salem, R. H. and Mater, A. A. (2012). Nutritional and biological assessment of wheat biscuits supplemented by fenugreek plant to improve diet of anemic rats. Journal of the Academy of Nutrition and Dietetics, 1, 1–9.
25. Kaviarasan, S., Vijayalakshmi, K., Anuradha, C.V. and Priyadarshini, K. J. (2004). A polyphenol–rich extract of fenugreek seeds protect erythrocytes from oxidative damage. Plant Foods for Human Nutrition, 59, 143–147.
26. Schryver, T. (2002). Fenugreek. Total Health; 24, 42–44
27. Frontela, C., Ros, G. and Martínez, C. (2011). Phytic acid content “in vitro” iron, calcium and zinc bioavailability in bakery products: the effect of processing. Journal of Cereal Science, 54, 173–179

28. Amin, A., Alkaabi, A., Al–Falasi, S. and Daoud, S. A. (2005). Chemopreventive activities of Trigonella foenum–graecum (Fenugreek) against breast cancer. Cell Biology International, 29, 687–694.
29. Al–Habori, M. and Raman, A. (2002). Pharmacological Properties in Fenugreek – The genus Trigonella (1st edition) by G. A. Petropoulos (ed.), Taylor and Francis, London and New York, 10, 163–182.
30. Anuradha, C. V., Ravikumar, P. (2001). Restoration of tissue antioxidants by fenugreek (Trigonella foenum graecum) seeds in alloxan–diabetic rats. Indian Journal of Physiology and Pharmacology, 45, 408–420.
31. Genet, S., Kale, R. K. and Baquer, N. Z. (2002). Alterations in antioxidant enzymes and oxidative damage in experimental diabetic rat tissue: Effect of vanadate and fenugreek (Trigonella foenum-graecum). Molecular and Cellular Biochemistry, 236, 7–12.
32. Dixit, P., Ghaskadbi, S., Mohan, H. and Devasagayam, T. P. A. (2005). Antioxidant properties of germinated fenugreek seeds. Phytotherapy Research, 19, 977– 983.
33. Khole, S., Chatterjee, S., Variyar, P., Sharma, A., Devasagayam, T. P. A. and Ghaskadbi, S. (2014). Bioactive constituents of germinated fenugreek seeds with strong antioxidant potential. Journal of Functional Foods, 6, 270–279.
34. Coelho, C. M. M., Bellato, C. M., Garcia, A. K. M., Vitorello, V. A. and Azevedo, R. A. (2008). Variation in phytate accumulation in common bean (Phaseolus vulgaris L.) fruit explants. Brazilian Achieves of Biology and Technology, 51,163–173.
35. Coelho, C. M. M., Bellato, C. M., Santos, J. C. P., Ortega, E. M. M. and Tsai, S. M. (2007a). Effect of phytate and storage conditions on the development of the "hard–to–cook" phenomenon in common beans. Journal of the Science of Food and Agriculture, 87, 1237–1243.
36. Coelho, C. M. M., Benedito, V. A., Figueira, A., Vitorello, V. A. and Azevedo, R. A. (2007b). Variation in the enzyme activity and gene expression of myoinositol-3- phosphate synthase and phytate accumulation during seed development in common bean (Phaseolus vulgaris L.). Acta Physiologiae Plantarum, 29, 265–271.
37. Coelho, C. M. M., Tsai, S. M. and Vitorello, V. A. (2005). Dynamics of inositol phosphate pools (tris-, tetrakis- and pentakisphosphate) in relation to the rate of phytate synthesis during seed development in common bean (Phaseolus vulgaris). Journal of Plant Physiology, 162, 1–9
38. Rayyan, S., Fossen, T. and Andersen, Ø. M. (2010). Flavone C-glycosides from seeds of fenugreek, Trigonella foenum-graecum L. Journal of Agricultural and Food Chemistry, 58(12), 7211–7217.
39. Wang, S., Melnyk, J. P., Tsao, R. and Marcone, M. F. (2011). How natural dietary antioxidants in fruits, vegetables and legumes promote vascular health. Food Research International, 44, 14–22
40. Kenny, O., Smyth, T. J., Hewage, C. M. and Brunton, N. P. (2013). Antioxidant properties and quantitative UPLC–MS analysis of phenolic compounds from extracts of fenugreek (Trigonella foenum–graecum) seeds and bitter melon (Momordica charantia) fruit. Food Chemistry, 141, 4295–4302
41. Chatterjee, S., Variyar, P. S. and Sharma, A. (2009). Stability of lipid constituents in radiation processed fenugreek seeds and turmeric: Role of phenolic antioxidants. Journal of Agricultural and Food Chemistry, 57, 9226–9233.
42. Im, K. K. and Maliakel, B. P. (2008). Fenugreek dietary fibre a novel class of functional food ingredient. Agro Food Industry Hi–Tech, 19, 18–21.
43. Brummer, Y., Cui, W. and Wang, Q. (2003). Extraction, purification and physicochemical characterization of fenugreek gum. Food Hydrocolloids, 17, 229–236.
44. Wu, Y., Cui, W., Eskin, N. A. M. and Goff, H. D. (2009b). An investigation of four commercial galactomannans on their emulsion and rheological properties. Food Research International, 42, 1141–1146.
45. El Nasri, N. A. and El Tinay, A. H. (2007). Functional properties of fenugreek (Trigonella foenum graecum) protein concentrate. Food Chemistry, 103, 582– 589.
46. Işıklı, N. D. and Karababa, E. (2005). Rheological characterization of fenugreek paste (çemen). Journal of Food Engineering, 69, 185–190.
47. Meghwal, M. and Goswami, T. (2012a). A review on the functional properties, nutritional content, medicinal utilization and potential application of fenugreek. Journal of Food Processing and Technology, 3, 9. http://dx .doi.org/10.4172/2157-7110.1000181
48. Feyzi, S., Varidi, M., Zare, F. and Varidi, J. (2015). Fenugreek (Trigonella foenum graecum) seed protein isolate: extraction optimization, amino acid composition, thermo and functional properties. Journal of Science of Food and Agriculture, 95, 3165–3176.
49. Ren, X. F. and Zhu, W. J. (2011) Optimal conditions for extraction of oil from fenugreek (Trigonella foenum-graecum L.) by supercritical CO2 fluids (SFECO2). Advanced Materials Research, 236–238, 2980–29
50. Prasad, R. (2014). Identification of high seed yielding and stable fenugreek mutants. Masters' Thesis, University of Lethbridge, Lethbridge, AB, Canada.
51. Rai, A., Mohanty, B. and Bhargava, R. (2016). Supercritical extraction of sunflower oil: A central composite design for extraction variables. Food Chemistry, 192, 647–659.
52. Wang, L., Wang, X., Wang, P., Xiao, Y. and Liu, Q. (2016). Optimization of supercritical carbon dioxide extraction, physicochemical and cytotoxicity properties of Gynostemmapentaphyllum seed oil: A potential source of conjugated linolenic acids. Seperation and Purification Technology, 159, 147– 156.
53. Omeire, G. C., Umeji, O. F. and Obasi, N. E. (2014). Acceptability of noodles produced from blends of wheat, acha and soyabean composite flours. Nigerian Food Journal, 32, 31–37.

54. Kaur, M., Sandhu, K. S., Arora, A. P. and Sharma, A. (2015). Gluten free biscuits prepared from buckwheat flour by incorporation of various gums: physicochemical and sensory properties. LWT-Food Science and Technology, 62, 628–632.
55. Hooda, S. and Jood, S. (2005). Organoleptic and nutritional evaluation of wheat biscuits supplemented with untreated and treated fenugreek flour. Food Chemistry, 90, 427–435.
56. Petropoulos, G. A. (2002). Fenugreek-The Genus *Trigonella*, Taylor and Francis: London, UK; New York, NY, USA, p. 1–255
57. Anonymous (2009). Annual Progressive Report, National Research Centre on Seed Spices, Tabiji, Ajmer, 34–36.
58. Raje, R. S., Singhania, D. L. and Singh, D. (2003). Evaluation of early generation progenies (F2) of fenugreek (Trigonella foenum-graecum L.) crosses for seed yield and yield related characters. Journal of Spices and Aromatic Crops, 12, 127–134.
59. Ebubekir, A., Engin, O. and Faruk, T. (2005). Some physical properties of fenugreek (Trigonella foenum-graceum L.) seeds. Journal of Food Engineering, 71, 37– 43
60. Djeridane, A., Yousfi, M., Nadjemi, B., Boutassouna, D., Stocker, P. and Vidal, N. (2006). Antioxidant activity of some Algerian medicinal plants extracts containing phenolic compounds. Food Chemistry, 97, 654–6k60.
61. Betty, R. (2008). The many healing virtues of fenugreek. Spice India, 1,17–19.
62. Mathur, P. and Choudhry, M. (2009). Consumption pattern of fenugreek seeds in Rajasthani families. Journal Human Ecology, 25, 9–12
63. Mahmooda, M. N. and Yahya, I. K. (2017). Nutrient and phytochemical of fenugreek (Trigonella foenum graecum) seeds. International Journal of Sciences: Basic and Applied Research 36, 203–213.