



REVIEW

Fenugreek a multipurpose crop: Potentialities and improvements



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Abstract Fenugreek is one of the oldest medicinal plants with exceptional medicinal and nutritional profile. Fenugreek seeds contain a substantial amount of fiber, phospholipids, glycolipids, oleic acid, linolenic acid, linoleic acid, choline, vitamins A, B1, B2, C, nicotinic acid, niacin, and many other functional elements. It may grow well under diverse and a wide range of conditions; it is moderately tolerant to drought and salinity, and can even be grown on marginal lands in profitable way. Owing to these characteristics and heavy metal remediation potential, fenugreek may well fit several cropping systems. In addition to its medicinal uses, it may serve as an excellent off-season fodder and animal food supplement. However, efforts should be initiated to develop strategies for improving its biomass production; genetic diversity among different accessions may be mapped, breeding and crop improvement programs may be initiated to improve the biomass and nutritional and functional elements. This review highlights the morphology, adaptability, nutritional constituents and associated functionality and medicinal significance of fenugreek; its ethno-historical uses, pharmacological assumptions

Abbreviations: AAS, Atomic Absorption Spectrophotometer; CAT, catalase; EMS, ethylmethane sulfonate; ESP, exchangeable sodium percentage; HPLC, high performance liquid chromatography; HDL-C, high-density lipoprotein-cholesterol; IU, international unit; ISSR, inter-simple sequence repeat; LDL-C, low density lipoproteins-cholesterol; NAEs, N-acyl ethanolamines; PGRs, plant growth regulators; RAPD, random amplified polymorphic DNA; RAE, retinol activity equivalents; SOD, superoxide dismutase

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1. Introduction

Fenugreek belongs to Fabaceae family; it was named, *Trigonella*, from Latin language that means “little triangle” due to its yellowish-white triangular flowers (Flammang et al., 2004). It is named as Methi (Hindi, Urdu, Punjabi and Marathi), Hulba (Arabic), Moshoseitaro (Greek), Uluva (Malayalam), Shoot (Hebrew), Dari (Persian), and heyseed in English. Fenugreek (*Trigonella foenum-graecum* L.) is one of the oldest medicinal plants from Fabaceae family originated in central Asia ~4000 BC (Altuntas et al., 2005). Its description and benefits had been reported in the Ebers Papyrus (one of the oldest maintained medicinal document) earlier in 1500 BC in Egypt (Betty, 2008). It is being commercially grown in India, Pakistan, Afghanistan, Iran, Nepal, Egypt, France, Spain, Turkey, Morocco, North Africa, Middle East and Argentina (Flammang et al., 2004; Altuntas et al., 2005).

Fenugreek seeds contain a substantial amount of fiber (Montgomery, 2009; Meghwal and Goswami, 2012), phospholipids, glycolipids, oleic acid, linolenic acid, linoleic acid (Suliman et al., 2000; Chatterjee et al., 2010), choline, vitamin A, B1, B2, C, nicotinic acid, niacin (Leela and Shafeekh, 2008), and many other functional elements. Despite its exceptional nutritional and medicinal values, only a few studies have been done for its genetic enhancements and development of production agronomy. In this review, we have discussed the morphology, adaptability, nutritional constituents and

associated functionality and medicinal significance of fenugreek; its ethno-historical uses, pharmacological assumptions have also been discussed. Researchable areas are also indicated to improve its production and adaptability.

2. Morphological description, phenology and cultivation

Fenugreek is an annual legume, diploid ($2n = 16$) plant (Ahmad et al., 1999) with no aneuploidy (Petropoulos, 2002; Trease and Evans, 2002; Flammang et al., 2004). Morphologically, it is an erect, aromatic annual closely resembling large clover. The stem is long cylindrical (30–60 cm long) and pinkish in color; whereas its roots are massive finger like structures (Basu, 2006; Mehrafarin et al., 2011; Moradi kor and Moradi, 2013). Fenugreek has pinnate, trifoliate, long stalked compound leaves having toothed, lanceolate, stipules triangular, obovate to oblanceolate leaflets (Srinivasan, 2006; Basu, 2006). It blooms with white to yellowish white, axillary and sessile flowers that are hermaphrodite and insect pollinated. Flowers have 5 petals referred as banner, wing and keel. The ovary is deep green and glaucous while the pollen grains are oval to circular in shape (Basu, 2006; Montgomery, 2009; Mehrafarin et al., 2011). Fenugreek flower produces brownish to yellowish brown ~15 cm long 2–8 pods. Each pod contains 10–20 seeds per pod; seeds are small (~5 mm long), hard, smooth, dull yellow to brownish yellow in color (Altuntas et al., 2005; Moradi kor and Moradi, 2013).

Fenugreek requires 5–10 days for germination while the first trifoliate leaf appears 5–8 days after germination. It is a fast growing plant, which may grow on dry grasslands, cultivated or uncultivated lands, hillsides, planes as well as field edges but it requires a fair amount of sunlight. Fenugreek needs four to seven months to reach maturity (Petropoulos, 2002). Flowering period is midsummer (June to August) and seeds ripen during late summer (August to September). It is a drought tolerant plant and grows well in tropical climate with mild winter and cool summer; however, its leaf and flower development is temperature dependent (McCormick et al., 2006).

3. Nutritional constituents and associated functionality

Fenugreek green leaves are one of the most ancient medicinal herbs containing β -carotene (19 mg/100 g), ascorbate (220 mg/100 g) (Table 1; Thomas et al., 2011), fiber, iron, calcium and zinc even more than the regular food items (Table 1; Muralidhara et al., 1999). Its seeds, biologically endosperm, are the most valuable plant part. Raw seeds are golden in color with maple flavor but bitter in taste. However, this bitterness may be reduced by roasting. The seeds are fibrous, sticky and gummy in nature (Jani et al., 2009). Saponins and alkaloids are considered as anti-nutritional factors in seeds. However, defatted seeds are free from these compounds and may be consumed by people having problem with fat (Altuntas et al., 2005).

3.1. Fiber

Fenugreek seeds are a rich source of fiber (50–65 g/100 g) mainly non-starch polysaccharides (Table 1; Montgomery, 2009). Medicinally, fenugreek fiber is capable of moderating the human glucose metabolism. Moreover, mucilage, tannins, pectin and hemicellulose inhibit bile salt absorption in the colon and hence facilitate low density lipoprotein-cholesterol

(LDL) reduction in blood. It binds the toxins of food and indirectly protects intestinal epithelial membrane from onset of cancer. Moreover, it helps to lower the blood glucose absorption and control sugar level, and thus facilitates the insulin action. Galactomannans constitute the major portion of soluble fiber in seeds that lower glucose absorption in body (Meghwal and Goswami, 2012). Seed gum consists of mannose and galactose that gives high viscosity to an aqueous solution (Youssef et al., 2009). It has a higher water solubility due to more galactose in comparison to guar and many others of the same family. However, fenugreek gum has not been well exploited in the food industry. Purified gum contains 0.8% residual protein that could reduce the surface tension and form stable emulsions with oil droplets (2–3 μ m) as compared to other hydrocolloids (Meghwal and Goswami, 2012).

3.2. Protein

Fenugreek endosperm is rich in proteins (43.8 g/100 g): globulin, lecithin and albumin (Table 1; Mathur and Choudhry, 2009; Naidu et al., 2011). It has a high proportion of free amino acids (20–30%), particularly 4-hydroxyisoleucine and histidine, which may stimulate insulin activity (Isikli and Karababa, 2005). Fenugreek proteins are stable enough, and are not affected during cooking (Srinivasan, 2006). Moreover, debittered fenugreek seeds are rich in protein and lysine contents.

3.3. Fat

Seeds contain 5.5–7.5% lipids in total mainly comprised of neutral lipids (85%), phospholipids (10%) and glycolipids (5%) (Table 2). Unsaturated lipids constitute oleic (14%), linolenic (25%) and linoleic (40%) acids (Suliman et al., 2000; Chatterjee et al., 2010). Owing to the presence of N-acyl ethanolamines (NAEs) and oleamide, fenugreek has strong pain relieving and appetite stimulating potential (Kaviarasan et al., 2007).

3.4. Aromatic compounds

Aroma of fenugreek seeds attributed to the presence of volatile oils. For instance, Meghwal and Goswami (2012) detected butanoic acid, 1-octene-3-one, 3-isobutyl-2-methoxypyrazine by gas chromatography. Moreover, diacetyl, linalool, acetic acid, eugenol, 4-dihydro-2(5H)-furanone, caproic acid sotolon and isovaleric acid were detected by olfactometry. Sotolon is the predominant substance in this regard with strong metallic,

Table 1 Crude or proximate composition of fenugreek seeds and leaves.

Particulars	Contents (g/100 g)	References
Carbohydrates	42.3	El Nasri and El Tinay (2007)
Gum (seeds)	20.9	Kakani et al. (2009)
Ash (seeds)	3.38	Sowmya and Rajyalakshmi (1999)
Fiber (seeds)	50.0	Montgomery (2009)
Soluble		
Raw	21.7	Muralidhara et al. (1999)
Germinated	10.3	Muralidhara et al. (1999)
Insoluble		
Raw	26.8	Muralidhara et al. (1999)
Germinated	23.9	Muralidhara et al. (1999)
Fiber (leaves)		
Soluble	0.7	Altuntas et al. (2005)
Insoluble	4.2	Altuntas et al. (2005)
Dietary fiber	48.0	Brummer et al. (2003)
Fats (seeds)	7.9	El Nasri and El Tinay (2007) Montgomery (2009)
Fats (leaves)	1.0	Montgomery (2009)
Protein (seeds)	25.4	El Nasri and El Tinay (2007)
Protein (leaves)	4.4	Montgomery (2009)
Moisture (seeds)	7.49	Sowmya and Rajyalakshmi (1999)
Moisture (leaves)	86.0	Sowmya and Rajyalakshmi (1999)

Table 2 Lipid profile of fenugreek seeds (adopted from Chatterjee et al., 2010).

Lipid Species Identified	Amount (g/100 g)
Triacylglycerols	4.330 \pm 0.011
Diacylglycerols	0.280 \pm 0.008
Monoacylglycerols	0.180 \pm 0.005
Phosphatidylcholine	0.110 \pm 0.002
Phosphatidylethanolamine	0.036 \pm 0.003
Phosphatidylinositol	0.009 \pm 0.001
Free fatty acids	0.160 \pm 0.001

Table 3 Vitamin profile and their respective concentrations in fenugreek.

Particulars	Plant part	Units	Value/100 g	References
Vitamin C	Seed	Mg	12–43	Leela and Shafeekh (2008) Srinivasan (2006)
Vitamin C	Leaves	Mg	52.0	Srinivasan (2006)
Vitamin B ₁	Seed	mg	0.41	Leela and Shafeekh (2008)
Vitamin B ₂	Seed	mg	0.36	Leela and Shafeekh (2008)
Vitamin B ₆	Seed	Mg	0.600	USDA (2011)
Vitamin A, RAE	Seed	µg-RAE	3.0	USDA (2011)
Vitamin A, IU	Seed	IU	60–100	Leela and Shafeekh (2008) USDA (2011)
Niacin	Seed	mg	6.0	Leela and Shafeekh (2008)
Nicotinic Acid	Seed	Mg	1.1	Leela and Shafeekh (2008) Srinivasan (2006)
Nicotinic Acid	Leaves	µg	800	Srinivasan (2006)
β-carotene	Leaves	mg	2.3	Srinivasan (2006)
β-carotene	Seeds	µg	96	Srinivasan (2006)
Thiamine	Leaves	µg	40	Srinivasan (2006)
Thiamine	Seeds	µg	340	Srinivasan (2006)
Riboflavin	Leaves	µg	310	Srinivasan (2006)
Riboflavin	Seeds	µg	290	Srinivasan (2006)
Folic acid	Seeds	µg	84	Srinivasan (2006)

mushroom like, roasty, pungent, buttery and spicy aroma. Human sweat after fenugreek ingestion produces a maple-syrup odor due to the presence of camphor, neryl acetate, 2,5-dimethylpyrazine, 3-octen-2-one, 4-isopropylbenzaldehyde, β-pinene and β-caryophyllene.

3.5. Vitamins and minerals

Fenugreek seed is a rich source of vitamins viz. choline, vitamin A, B₁, B₂, C, nicotinic acid and niacin (Table 3). Germinating seeds contain biotin, calcium pantothenate, pyridoxine, vitamin C and cyanocobalamine. However, exposure to β and γ radiations significantly reduces the vitamin contents (Leela and Shafeekh, 2008). Its leaves also contain vitamins, but on boiling, steaming or frying, 7–11% of them may be lost. Fenugreek seeds contain fair amount of sulfur, phosphorus (El Nasri and El Tinay, 2007) and calcium (Jani et al., 2009) (Table 4).

Table 4 Mineral contents (mg/100 g) of fenugreek seeds (Reported by Al Jasass and Al Jasser, 2012).

Minerals	mg/100 g of fenugreek seed extract
Potassium (K)	603.0 ± 15.0
Magnesium (Mg)	42.0 ± 5.0
Calcium (Ca)	75.0 ± 9.0
Zinc (Zn)	2.4 ± 0.2
Manganese (Mn)	0.9 ± 0.1
Copper (Cu)	0.9 ± 0.1
Iron (Fe)	25.8 ± 1.2

3.6. Biologically active compounds

Fenugreek has powerful antioxidant properties linked to its health benefits. Interestingly, germinating seeds are more beneficial than un-germinated dry seeds in this regard. On the other hand, the aqueous fraction of fenugreek portrays considerable antioxidant activity than flavonoids and phenolics (Balch, 2003; Meghwal and Goswami, 2012; Khole et al., 2014). Fenugreek contains (Table 5) a fairly high amount of flavonoids, alkaloids, saponins and other antioxidants. It contains a major class of phenolics like gallic acid (1.7), protocatechuic acid (4.0), catechin (0.4), gentisic acid (35.8), chlorogenic acid (0.7), vanillic acid (58.5) and syringic acid (0.3) as mg per 100 g of the seed extract (Rababah et al., 2011). Fenugreek endosperm contains 35% alkaloids, primarily trigonelline (Jani et al., 2009). Flavonoid constitutes more than 100 mg/g of fenugreek seed (Naidu et al., 2011). All these compounds are classified as biologically active as these have pharmacological effects on the human body when ingested. Their use should, therefore, be promoted in daily diet to manage hypercholesterolemia, cancer and diabetes mellitus as they possess hypoglycemic, antilipidemic, anticarcinogenic and cholagogic properties (Meghwal and Goswami, 2012). However, volatile oils and alkaloids are the two major constituents that cause bad odor and bitter taste, and may therefore be removed before use.

Table 5 Biologically active constituents of fenugreek and their classifications.

Chemical Group	Compounds	References
Alkaloids	Trigonelline, choline, carpaine	Lee et al. (2005) Kaviarasan et al. (2007) Rababah et al. (2011)
Amino Acids	Lysine, histidine, 4-hydroxyisoleucine, tryptophan, tyrosine, cystine, arginine	Gupta et al. (2001) Ruby et al. (2005) El Nasri and El Tinay (2007)
Coumarins	Methyl coumarin, trigocoumarin, trimethyl coumarin	Raju et al. (2001)
Flavonoids	Naringenin, lilyn, kaempferol, vecenin-1, tricrin 7-O-D glucopyranoside, saponaretin, isovitexin, isoorientin. Orientin, vitexin, luteolin, quercetin	Blumenthal et al. (2000) Sauvare et al. (2000) Meghwal and Goswami (2012)
Saponins	Fenugrin, foenugracin, glycoside, yamogenin, trigonoesides, smilagenin, gitogenin, sarsasapogenin, yuccagenin, hederagin, diosgenin, tigononin, neotigogenin	Gupta et al. (2001)
Others	Vitamin A, folic acid, ascorbic acid, thiamin, riboflavin, biotin, nicotinic acid, gum	Hamden et al. (2010) Chatterjee et al. (2010)

Table 6 Some food and non-food applications of fenugreek.

Applications/ Uses	Plant Parts	References
Bread making	Seeds	Meghwal and Goswami (2012) Raju et al. (2001)
Vegetable Food (General)	Leaves and stems Seed and leaves (mixed with wheat and maize flour)	Balch (2003) Srinivasan (2006)
Functional food	Galactomannan, fiber and extract	Meghwal and Goswami (2012)
Food gum	Seed	Sowmya and Rajyalakshmi (1999) Srinivasan (2006)
Flavoring agents	Seeds, leaves (condiments, pickles, curries)	Srinivasan (2006)
Forage	Leaves, straw	Sowmya and Rajyalakshmi (1999)
Cosmetics	Leaves, seeds	Meghwal and Goswami (2012)
Dyes	Seeds	Meghwal and Goswami (2012)
Paper industries	Seeds and leaves	
Alcoholic beverages	Seeds	Jani et al. (2009)
Perfumes	Seed oil	Srinivasan (2006)
Emulsifying agent	Seeds	Jani et al. (2009)
Stabilizer and adhesive	Seeds	
Insect repellent	Seed oil	Meghwal and Goswami (2012)
Paints	Seeds and leaves extract	
Fumigant	Leaves	Srinivasan (2006)
Syrups	Trigonelline	Meghwal and Goswami (2012)

4. Uses

4.1. Ethno-historical uses

Fenugreek is one of the oldest medicinal plants, its seeds, leaves and even the whole plant are used to prepare powders and extracts for medicinal use. Fenugreek had been applied to embalm mummies and in incense in ancient Egypt. In modern Egypt, it is still being used as wheat and maize flour supplement for bread making while one of the staple foods in Yemen (Mehrafarin et al., 2011). In Indian subcontinent, fenugreek was being consumed as lactation stimulant and condiment (Betty, 2008). In ancient Rome, it was purportedly used in labor pain and delivery; while in traditional Chinese medicine, fenugreek seeds were used as tonic and in treatment of edema and legs weakness (Yoshikawa et al., 2000). Seeds of fenugreek were traditionally used as a remedy for diabetes in many Asian and African civilizations (Miraldi et al., 2001; Basch et al., 2003). Numerous other folkloric uses of fenugreek are verified by the primary results of human and animal trials (Basch et al., 2003).

4.2. General uses

Both ripened and unripened seeds as well as green leaves have been used as vegetable, food additive, medicinal plant and

fodder in South and Central Asian countries (Petropoulos, 2002). However, it is well known as flavor, curry powder and spice, and has also been used in tea and as food preservative in sauces and pickles (Betty, 2008). Fenugreek is also being used in paper industry, cosmetics, pharmacology, beverages, perfume, paints and some of the food oriented implications (Table 6).

5. Therapeutic/pharmacological claims

Food is undoubtedly a major determinant of human health under his own control. Apart from helping the normal body functioning and metabolism, food constituents such as antioxidants, vitamins, minerals, fiber, proteins, fat and carbohydrates also contribute to prevent overall aging and the onset of chronic diseases, in particular, metabolic disorders and oxidative damage (Mullaicharam et al., 2013). Plant-based natural antioxidants are getting popularity among the researcher, industry and users as cure from cancer, artherosclerotic heart disorders and other epidemics (Rababah et al., 2011). The secondary metabolites of plants origin may provide a wide range of biological and pharmacological compounds, which have been used extensively as food additives, flavorants, colorants, and as drugs and insecticides (Priya et al., 2011).

Fenugreek possesses pharmacological properties such as antimicrobial, anticholesterolemic, carminative, emollient, febrifuge, laxative, restorative, uterine tonic, expectoral, galactagogue, anti-carcinogenic, anti-inflammatory, antiviral, antioxidant, demulcent and hypotensive (Moradi kor and Moradi, 2013). In addition, it regulates several enzymatic activities, relieves fever, reduces body pain and fat, alleviates swelling, augments appetite and promotes lactation and sex hormones. Compounds isolated from fenugreek have remarkable biological activities including protection against cancer, malaria, allergies, bacteria and viruses (Naidu et al., 2011; Priya et al., 2011). Fenugreek, in particular, is abundant in polyphenolics that inhibit peroxidation and remarkably reduce oxidative hemolysis in human erythrocytes (Rayyan et al., 2010; Belguith-Hadriche et al., 2013). Moreover, their optimal consumption may lower triglycerides and cholesterol concentrations in the blood (Afef et al., 2000), prevent cancer (Raju et al., 2004) and control diabetes mellitus (Broca et al., 2000). The oral intake of ethyl acetate extract of fenugreek seeds has been tested to reduce triglycerides and low-density lipoprotein cholesterol (LDL-C) while increasing high-density lipoprotein cholesterol (HDL-C); hence had a noteworthy antioxidant and hypocholesterolemic effects (Belguith-Hadriche et al., 2013). Furthermore, it exhibits scavenging of free hydroxyl radical (-OH) and discourages hydrogen peroxide induced peroxidation in liver mitochondria and protects cellular organelles from oxidative damage (Kaviarasan et al., 2007). However, hypoglycemic effect of fenugreek is likely due to the inhibitory effect of mucilaginous fiber and galactomannan gum. Currently, fenugreek is being used in pharmacology and disease treatments. A few medicinal benefits of fenugreek have been summarized in Table 7.

6. Crop prospectives

6.1. Potential to marginal lands and adverse conditions

Though fenugreek cultivation is concentrated mainly in some countries of Africa and Asia; however, it is being grown

Table 7 Pharmacological and therapeutic benefits of fenugreek as recurrently reported.

Disease/ Disorders	Description	References
Diabetes	4-hydroxyisoleucine (amino acid) stimulates insulin production thereby control blood sugar level	Gupta et al. (2001) Zia et al. (2001) Vats et al. (2002)
	Polyphenolic compounds exhibit anti-diabetic effects	Kaviarasan et al. (2007) Broca et al. (2000)
	Curative effects of fenugreek seed powder is a potential neuropathic medicine in diabetes	Nanjundan et al. (2009)
Cancer	Polyphenolic compounds from seed possess anti-carcinogenic activities	Raju et al. (2004) Yoshinari and Igarashi (2010) Mohamed et al. (2015)
Hypercholesterolemia	Anti-oxidants from seeds control high blood cholesterol	Sowmya and Rajyalakshmi (1999) Srinivasan (2006)
	Flavonoids from ethyl acetate extracts of seeds exhibit hypocholesterolemic abilities	Belguith-Hadriche et al. (2013)
Myocardial infarction	Trigonelline (anti-oxidant) detoxification of free radicals, high lipid peroxidation and enzymes prevents Myocardial injuries	Panda et al. (2013)
Skin irritation	Seeds extracts reduces the skin irritation and pain	Sauvare et al. (2000)
	Seed powder paste produces skin healing, moisturizing, smoothening, whitening	Meghwal and Goswami (2012)
Indigestion and flatulence	Fenugreek has been used as laxative	Sauvare et al. (2000)
	It stimulates appetite and act as laxative	Petit et al. (1993)
Inflammation	Reduces swelling and pain	Thakur et al. (1994) Sauvare et al. (2000)
	Mucilage from seed detoxify the oxidants and free radicals to reduce inflammation	Ahmadiani et al. (2001)
Anemia	Prevents red blood cell oxidation	Kaviarasan et al. (2004) Kaviarasan et al. (2007)
	Being rich in iron (Fe) seeds are valuable to reduce anemia	James et al. (2002)
	Restoration and Fe nutrition in iron deficiency patients	Mahmoud et al. (2012)
Immunodeficiency	Natural antioxidants help to strengthen immune system Immunomodulatory and Immune stimulatory effects	Kaviarasan et al. (2004) Bin-Hafeez et al. (2003)
Aging	Antioxidants improves reduces cell death and aging	Kaviarasan et al. (2004)
Kidney disorders	Protects functional and histopathologic abnormalities of kidney in diabetic patients	Thakran et al. (2004) Hamden et al. (2010)
	Reduces catalase (CAT) contents and superoxide dismutase (SOD) activity in hypercholesterolemia patients	Belguith-Hadriche et al. (2013)
	Inhibit accumulation of oxidized DNA to prevent kidney injuries	Xue et al. (2011)
Others	Respiratory disorders, bacterial infection, epilepsy, gout, chronic cough, paralysis, dropsy, piles, heavy metal toxicity, liver disorders and arthritis	Ahmadiani et al. (2001) Tayyaba et al. (2001) Kaviarasan et al. (2004) Amin et al. (2005) Belguith-Hadriche et al. (2013)

throughout the world under different environmental conditions. This extensive scattering of fenugreek around the globe is the individuality of its adaptation to variable climates. Ranging from dry tropical zones to temperate forests, fenugreek may grow well in areas receiving 300–1500 mm annual precipitation and annual mean temperature of 7.8–27.5 °C (Petropoulos, 2002).

Being a legume, fenugreek may fix about 283 kg N ha⁻¹ year⁻¹, and may therefore be grown as a potential crop on marginal lands to improve health (Petropoulos, 2002; Ali

et al., 2012; Solorio-Sánchez et al., 2014). This potential can be further increased by symbiotic Rhizobium. However, the use of effective Rhizobium inoculums with fenugreek crop still lacks sound research (Abdelgani et al., 1999). Fenugreek has been successfully adapted to dry lands under both irrigated and rain-fed conditions, and it can produce a high quality forage even more efficiently than alfalfa. In addition, the crop contains animal growth promoting substances and encourages feed concentrate. Fenugreek as “fodder bank” may provide not only a fodder in off seasons but can also promote the main

fodder growth by continuous N supply (Solorio-Sánchez et al., 2014).

It may grow well during summer conditions with low night temperature (Billaud and Adrian, 2001). Although, yields low seed, successful cultivation of fenugreek on sandy soil in arid environment with limited fertilizer input is profitable (Deora et al., 2009). As its water requirements are low, use of this legume crop can reduce the irrigation as well as fertilizer cost. In addition, it can limit eutrophication of surface water and reduce underground water contamination. Above mentioned properties also make it a useful green manuring crop, particularly for short term rotations (Basu, 2006; Acharya et al., 2008). Fenugreek has also been adapted to slightly alkaline soils or marginal saline lands. Though salt affected soils exist throughout the world under almost all climatic zones, and a wide exploration on salt effects have also been reported; unfortunately only a fraction of fenugreek potential to saline soils has been revealed (Acharya et al., 2006). Garg (2012) reported that some of the fenugreek genotypes are capable of tolerating higher exchangeable sodium percentage (ESP). The results depicted that plant had a sodium inclusion mechanism, and showed a narrow Ca/Na and K/Na ratios portraying the potential of this crop to withstand a range of sodicity. Elleuch et al. (2013) have reported survival of fenugreek under copper stress, even higher up to 10 mM (CuSO₄).

6.2. Allelopathic potential

Like humans and animals, flora have to face numerous competitions in their ecosystem while being sessile, they cannot skip or manipulate this competitive environment. Hence, many of the plants produce secondary metabolites to cope with limitations; some of these compounds exhibit allelopathic properties, growth inhibition of surrounding plants (Duke et al., 2000). These compounds provide excellent weed control in intercropping and have herbicidal potential or templates for new herbicides (Duke et al., 2000; Caamal-Maldonado et al., 2001). Fenugreek species possesses weedicidal, insecticidal and antifungal potentials (Evidente et al., 2007; Haouala et al., 2008a,b).

7. Research advances and crop improvement

Fenugreek is one of the potential candidates to be acclimatized under stress regions or on However; Garg (2012) reported successful cultivation of fenugreek under saline sodic soils followed by Farahmandfar and his team (2013) who made efforts to facilitate fenugreek cultivation by seed priming. In addition, Ahari et al. (2009, 2010) made several experiments to check fenugreek's drought tolerance potential and genotypic screening of available landraces for drought stress. One step ahead, Ali et al. (2012) advocated the efficient use of rhizobial inoculation for fenugreek and claimed a fruitful improvement in its adoption to arid and semiarid soils, but unfortunately no further research was made for rhizobial inoculations. Moreover, in the last decade fenugreek was investigated for heavy metal toxicity (Sinha et al., 2007; Elleuch et al., 2013), sowing date (Nandre et al., 2011), intercropping (Shirzadi et al., 2011), phosphorous fertilizer doses (Khan et al., 2005; Jat et al., 2012), fodder bank (Solorio-Sánchez et al., 2014) and response

to exogenous application of plant growth regulators (Danesh-Talab et al., 2014). More recently, Pouryousef et al. (2015) have recently introduced fenugreek as intercrop, a living mulch, to suppress weeds and found significant results. Dar and his team has promoted growth performance, biomass production and grain yield of fenugreek using Co-60 gamma irradiated chitosan and phosphorus fertilizer. They further claimed that fenugreek could potentially withstand high radiation stress. Hence its genetic potential and chemical feedback might be the feature of natural gamma radiation protection cosmetics.

Estimation of genetic variability is important for improvement of any crop, but in spite of fenugreek's diverse importance and applications, genetic diversity among fenugreek genotypes has rarely been estimated (Harish et al., 2011). For instance, Najafi et al. (2013) explored the karyotype of fenugreek, Banerjee and Kole (2004) analyzed the genetic variability in twenty-two genotypes. Prajapati et al. (2010) and his co-scientists accessed genetic variability and character association in 94 fenugreek genotypes. Furthermore, genetic variability and its association with yield and yield component characters were studied by Fufa (2013) and Jain et al. (2013). Harish et al. (2011) and his team used RAPD (random amplified polymorphic DNA) and ISSR (inter-simple sequence repeat) for molecular and biochemical characterization of ten accessions. In recent times, mutagens have become important tools in crop improvement. These mutagens are being used to produce resistance in various crops to improve their yield and quality traits. Ethidium bromide and UV radiations were used as mutagenic agents, and Gadge et al. (2012) recommended ethidium bromide an effective mutagenic agent for fenugreek. Basu (2006) initiated mutation facilitated breeding in fenugreek through EMS (ethylmethane sulfonate) for seed quality and production. More specifically, gamma rays, EMS and sodium azide efficiency and effectiveness for chlorophyll targeted mutations were evaluated for fenugreek (Bashir et al., 2013) (Table 8).

8. Research gaps

By inference, fenugreek is although well explored by medical science for its potential contribution to human health. However, unquestionably it is only a fraction of this multipotential medicinal plant. As fenugreek is well distributed in various climatic conditions geographically, it is supposed to have a wide genotypic variability. Furthermore, being a least bred (artificial selection) crop hence possibility is there to have a multiple and potential allelic system against environmental stresses. Science is unstoppable and currently expanding much faster than any other stage of its history; however, unfortunately no particular attention was paid to fenugreek. It is the need of time to consider this crop in massive research projects not only to explore its potential, but improvements as well, and fenugreek deserves to be entertained. An extensive genomic and agronomic characterization/clustering is needed to identify the potential genes which could further help in breeding programs followed by targeted mutation and genetic improvement for abiotic stress tolerance. Furthermore, fenugreek as green manuring and fodder crop, and for soil reclamation must be explored and encouraged especially in arid agricultural systems.

Table 8 Crop potential exploration and improvements made in the last decade for fenugreek.			
Category	Main objectives	Techniques/instruments/design	References
Molecular and genetics	Analysis of genetic divergence in fenugreek (22 genotypes)	Cluster analysis	Banerjee and Kole (2004)
	Genetic variability and character association in fenugreek (94 genotypes)	Path coefficient analysis	Prajapati et al. (2010)
	Extent of variability among the 10 accessions	Molecular and Biochemical Characterization by RAPD and ISSR	Harish et al. (2011)
	Correlation studies on yield and yield components of fenugreek (<i>Trigonella foenum-graecum</i> L.) lines evaluated in South-Eastern Ethiopia (23 genotypes)	Correlation analysis	Fufa (2013)
Karyotype	Estimation of genetic variability and association among seed yield and its contributing traits. Determination of direct and indirect effects of the yield contributing traits on seed yield. (50 genotypes)	Path coefficient analysis	Jain et al. (2013)
	Chromosome type and identification	Stained with aceto-iron-hematoxylin Olympus BH-2 microscopes	Najafi et al. (2013)
Mutagens	Genetic improvement of fenugreek through EMS induced mutation breeding for higher seed yield	Seed qualitative and quantitative measures	Basu (2006)
	Effect of magnets (UV and ethidium bromide) on morphology of fenugreek	Morphological screening	Gadge et al. (2012)
	Mutagenic (gamma rays, EMS) and sodium azide effectiveness and efficiency in Fenugreek	Chlorophyll mutations	Bashir et al. (2013)
Salinity	Effect of sodicity on growth, yield and cation composition of fenugreek	Germination characteristics and Yield attributes K, Ca, Mg, Na estimation	Garg (2012)
	Effect of seed priming on morphological and physiological parameters of fenugreek seedlings under salt stress	Physiological and morphological parameters	Farahmandfar et al. (2013)
Drought tolerance	Assessment of drought tolerance in Iranian fenugreek landraces (20)	Screening based on quantitative stress tolerance parameters	Ahari et al., 2009
	Genetic variability of some agronomic traits in the Iranian Fenugreek landraces under drought stress and non-stress conditions (20 landraces)	Cluster analysis	Ahari et al. (2010)
Metallic toxicity	Effect of metals (Fe, Zn, Mn, Cu, Cr, Pb) translocation on antioxidant contents	Atomic Absorption Spectrophotometer (AAS)	Sinha et al. (2007)
	Morphological and biochemical behavior under copper stress (CuSO ₄)	Germination characteristics, chlorophyll, enzymes and secondary metabolites assay, copper by Atomic Absorption Spectrophotometer	Elleuch et al. (2013)
Agronomic management	Effect of phosphorus levels on growth and yield of <i>Trigonella foenum graecum</i> L. grown under different spatial arrangements	Quantitative data recordation on growth and yield	Khan et al. (2005)
	Effect of sowing dates and nutrient management on growth and seed yield fenugreek	Split plot design	Nandre et al. (2011)
	Evaluation of fenugreek and lentil intercropping proportion and performance	Yield, land equivalent ration and economic analysis	Shirzadi et al. (2011)
	Ecotypes of some Iranian fenugreek based on seed and agronomic traits	Quantitative analysis	Soori and Mohammadi-Nejad (2012)
Fodder	Effect of Phosphorus and Sulfur levels on growth and yield of fenugreek.	Quantitative measurements	Jat et al. (2012)
	Introduction of fenugreek to Sylvopastoral System of Mexico	Fodder bank intercropping	Solorio-Sánchez et al. (2014)
Growth regulators	Effect of plant growth promoting rhizobia on seed germination, growth promotion and suppression of Fusarium wilt of fenugreek	DNA sequencer Scanning electron microscope Bacterial assay	Kumar et al. (2011)
	Response of fenugreek to exogenous application of plant growth regulators (PGRs)	Mucilage and trigonelline extraction and quantification. HPLC and chromatography	Danesh-Talab et al. (2014)
Symbiotic association	Possibilities and potential of Rhizobial inoculants in organic production of fenugreek in arid and semiarid	Strategic review	Ali et al. (2012)

(continued on next page)

Table 8 (continued)

Category	Main objectives	Techniques/instruments/design	References
Antifungal potential	Assessment of in vitro antifungal activity of diploid and mixoploid <i>Trigonella foenum graecum</i> L. aqueous extracts, harvested at three developmental stages against <i>Fusarium oxysporum</i> f and <i>Fusarium oxysporum</i> f	Phytochemical screening Antifungal assay	Omezzine et al. (2014)
Nutraceutical	Improvement in the nutraceutical properties of fenugreek (148 accessions)	Screening EMS mutation breeding	Acharya et al. (2006)

9. Conclusion

Fenugreek is traditionally assumed and purportedly consumed as a medicinal plant since prehistoric time and is undoubtedly considered safe to human health. Its nutritional value and biologically active compound profile are unquestionably appreciated by medical science. Moreover, drought, saline and heavy metal tolerability, wide adaptability to various climatic regions and marginal lands are the potentialities of this crop to hold a righteous place in agricultural systems. However, unfortunately just a few advances have been made for crop improvement yet. Hence, a huge gap is still existing particularly in varietal development and more specifically in biotechnologically facilitated breeding.

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