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Exploration of Industrial, Traditional, and Pharmaceutical Applications of Diversity Rich Genus Trigonella: A Comprehensive Review

PRAWAL P S VERMA[1,2], SABA SIDDIQUI[1]*, MD ABU NAYYER[1], SAUDAN SINGH[2], DIPENDER KUMAR[2] and RC PADALIA[2]

[1]Department of Agriculture, Integral Institute of Agricultural Sciences and Technology (IIAST), Integral University, Lucknow, Uttar Pradesh, India.
[2]CSIR-Central Institute of Medicinal and Aromatic Plants Research Centre Purara, PO Gagrigole, Bageshwar (Uttarakhand) India.

Abstract

The Trigonella genus, encompassing *Trigonella foenum gracum* L. and other species, exhibits annual growth patterns and thrives in arid and semiarid environments worldwide. India stands at the forefront of Trigonella diversity, showcasing its adaptability to challenging climatic conditions. This meticulous review consolidates existing scientific literature to provide a comprehensive evaluation of the Trigonella genus, emphasizing its nutritional value, traditional uses, and therapeutic applications. Particularly, its significance in traditional medicine systems such as Indian Ayurveda, Tibetan, and Chinese medicine is highlighted, shedding light on its profound cultural and medicinal implications. Morphological distinctions, etymology, vernacularity, and habitat preferences specific to the Trigonella genus are also discussed. Additionally, this study explores the economic potential of Trigonella, underscoring its pivotal role in ensuring food security and healthcare within local communities. Furthermore, it emphasizes the importance of safeguarding traditional healthcare practices and fostering biodiversity conservation efforts by examining the traditional knowledge and utilization of endemic plants worldwide. By offering insights into the diverse species within the Trigonella genus, their cultural significance, and medicinal potential, this review significantly contributes to our comprehension of these invaluable resources and their far-reaching implications for human well-being.

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CONTACT Saba Siddiqui 27.sabasiddiqui@gmail.com Department of Agriculture, Integral Institute of Agricultural Sciences and Technology (IIAST), Integral University, Lucknow, Uttar Pradesh, India.

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Introduction

The Trigonella genus comprises annual legumes distributed across the globe. Particularly noteworthy is fenugreek (*Trigonella foenum-graecum* L.), cultivated in different parts of the world, including the Indian Subcontinent, North Africa, the Middle East, Mediterranean Europe, China, Southeast Asia, Australia, the United States, Argentina, and Canada (Table 1). India leads in fenugreek production, although its significant domestic consumption limits international trade. This versatile crop thrives in arid and semiarid environments, making it ideal for cultivation in Asia, Africa, and Latin America. Moreover, fenugreek holds an integral role in traditional medicine, with its use prominent in Indian Ayurvedic practices and esteemed traditional medicinal systems of Tibet and China, showcasing its enduring cultural and therapeutic importance.[1] India is renowned for its rich biodiversity, encompassing a wide array of plant species with significant contributions to both food sources and traditional medicine. Among the notable plant genera in this region, Trigonella species hold a prominent position.

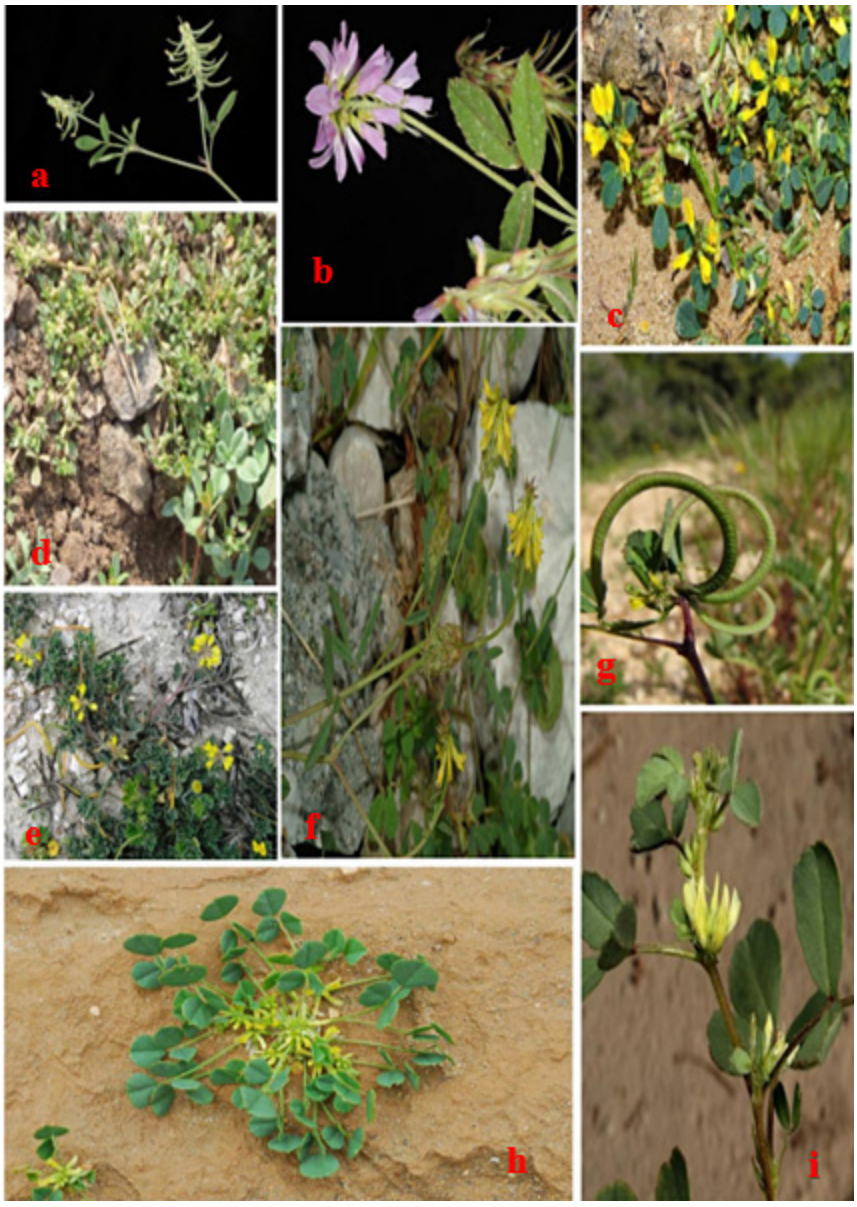

Fig. 1: A collection of diverse species of the Trigonella genus *(a) Trigonella laciniata L.; (b) Trigonella lilacina Boiss.; (c) Trigonella balansae Boiss. & Reut.; (d) Trigonella occulta Ser.; (e) Trigonella spruneriana Boiss; (f) Trigonella spicata Sm.; (g) Trigonella spinosa L.; (h) Trigonella stellata Forssk.; (i) Trigonella suavissima Lindl.; (j) Trigonella anguina Delile; (k) Trigonella arabica Delile; (l) Trigonella balansae Boiss. & Reut.; (m) Trigonella caerulea (L.) Ser.; (n) Trigonella calliceras Fischer ex M. Bieb.; (o) Trigonella coerulescens Halácsy.; (p) Trigonella corniculata Sibth. & Sm.; (q) Trigonella glabra subsp. uncata (Boiss. & Noe).; (r) Trigonella glabra Thunb.; (s) Trigonella foenum-graecum L. (t) Trigonella hamosa* Del. ex Smith

Trigonella is a genus within the Fabaceae family and comprises numerous species (Fig 1), including *Trigonella anguina Delile, Trigonella calliceras Fischer ex M. Bieb., Trigonella caerulea (L.) Ser., Trigonella cretica (L.) Boiss., Trigonella maritima Poir, Trigonella spruneriana Boiss, Trigonella glabra subsp. uncata (Boiss. & Noe), Trigonella foenum-graecum L., Trigonella stellata Forssk.,*

Trigonella spicata Sm., Trigonella suavissima Lindl., Trigonella lilacina Boiss., Trigonella hamosa Del. ex Smith, Trigonella glabra Thunb., Trigonella laciniata L., Trigonella occulta Ser., Trigonella spinosa L., Trigonella arabica Delile, Trigonella corniculata Sibth. & Sm., *Trigonella baccarinii Chiov.*, *Trigonella coerulescens* Halácsy, and *Trigonella balansae* Boiss. & Reut.[2] Trigonella species, commonly known as fenugreek, have been extensively utilized in both culinary and medicinal practices throughout history. These plants are characterized by their aromatic leaves, delicate flowers, and small, angular seeds. In the Western Himalayan region, Trigonella species have gained recognition as staple food sources due to their nutritional composition and culinary versatility. Additionally, these plants possess various bioactive compounds, including alkaloids, flavonoids, saponins, and sterols, which contribute to their medicinal potential.[3] The medicinal properties of Trigonella species have been well-documented. *Trigonella foenum-graecum* L. has garnered significant attention for its anti-diabetic effects, demonstrated through its ability to enhance insulin sensitivity, regulate blood glucose levels, and alleviate associated complications. Other Trigonella species have also exhibited promising pharmacological activities, such as anti-inflammatory, antioxidant, antimicrobial, and anticancer effects.[4] These properties make Trigonella species valuable resources for developing therapeutic interventions and natural remedies.

This comprehensive review aims to provide a detailed assessment of the contribution of Trigonella genus to major food sources and the medicinal potential of endemic plants in the western Himalayan region of India. By synthesizing the available scientific literature, this review intends to enhance our understanding of the diverse species within the Trigonella genus, their nutritional value, traditional uses, and therapeutic applications. Additionally, the review will shed light on sustainable cultivation practices and the economic potential associated with Trigonella species and endemic plants, emphasizing the importance of these resources for food security and healthcare in the local communities.

Botanical Characteristics

The genus Trigonella is a member of the subtribe Trifolieae of the family Fabaceae. Notable species of this subgenus are Medicago Inc., Trifolium L., Melilotus L., and Trigonella. The leaves of these species are divided into three leaflets (trifoliate) and are attached to the stem.[5] Trigonella is a monophyletic genus within the subtribe Trifolieae and is of high economic importance. It includes annual or perennial aromatic herbs with distinctive morphological characteristics, including campanulate or tubular sepals with two large and three small equal lobes, didadelphous stamens, uniform anthers, terminal stigma, and an ovary with many ovules. Trigonella species exhibit a widespread distribution across arid regions encompassing the Mediterranean, Europe, Western Asia, North and South Africa, North and South Australia. Additionally, Trigonella genus is also found in lower altitude regions of the Himalayas, spanning countries such as India, Pakistan, Afghanistan, China, Bhutan, and Nepal. These regions serve as thriving habitats for various Trigonella genus. The Trigonella genus has a variable number of accepted species due to naming uncertainties, synonyms, and differing author viewpoints. Linnaeus listed 260, while other authors acknowledged a range of 62 to 128. A recent study identifies 62 species, but the plant list records 98 accepted taxa, 97 unresolved names, 3 misapplied names, and 27 synonyms (Table 2). Notably, T. *foenum-graecum* (fenugreek) is a widely recognized and utilized species. Some previously classified Trigonella species are now considered synonyms of other genera, such as *T. monspeliaca* being synonymous with *Medicago monspeliaca* (L.) Trautv, *T. polycerata* aligning with *Medicago orthoceras* (Kar. & Kir) Trautv, and *T. radiata* being recognized as *Medicago radiata* L.[6-7] The Trigonella genus exhibits a wide range of economic uses. Many of these species are rich in proteins, vitamins, and amino acids. The seeds and fresh herb of Trigonella are used in the eastern Mediterranean region, especially as fodder for cattle. Some species, such as *T. arabica* and T. stelata, are grazed by animals in desert regions like the Sahara, Palestine. Some Trigonella genus are also used in traditional and veterinary medicine for treating different ailments. For instance, *T. occulta, T. polycerata*, and T. *uncata* are included in Indian herbals alongside T. *foenum-graecum*. The endosperm of most Trigonella species is rich in mucilage (galactomannan), which finds wide applications in industries including pharmaceuticals and cosmetics. In certain regions of India and

Pakistan, T. *corniculata* is used as a green vegetable, flavoring agent, and for treating swellings and bruises.[8] In Switzerland, T. *caerulea* (sweet trefoil) is used to flavor green cheeses, bread, soups, and potatoes. It is also employed in herbal medicine in Switzerland.[9] Trigonella species, including fenugreek and others, have diverse etymologies and vernacular names reflecting cultural significance. "*Foenum-graecum*" means "Greek hay," highlighting its historical association. Fenugreek is known by various names globally, like "Methi" in Hindi and "Hulba" in Arabic. *Trigonella caerulea*, Blue Fenugreek, has blue flowers, while Trigonella corniculata, Yellow Trefoil, has horn-shaped seedpods. Trigonella stellata, Starry Fenugreek, has star-shaped flowers, and Trigonella suavissima, Sweet Fenugreek, signifies a pleasant taste. Trigonella spruneriana honors botanist Carl Spruner von Merz, and Trigonella anguina, Snake Clover, suggests a snakelike form. These names showcase the rich historical usage and local knowledge tied to Trigonella species.

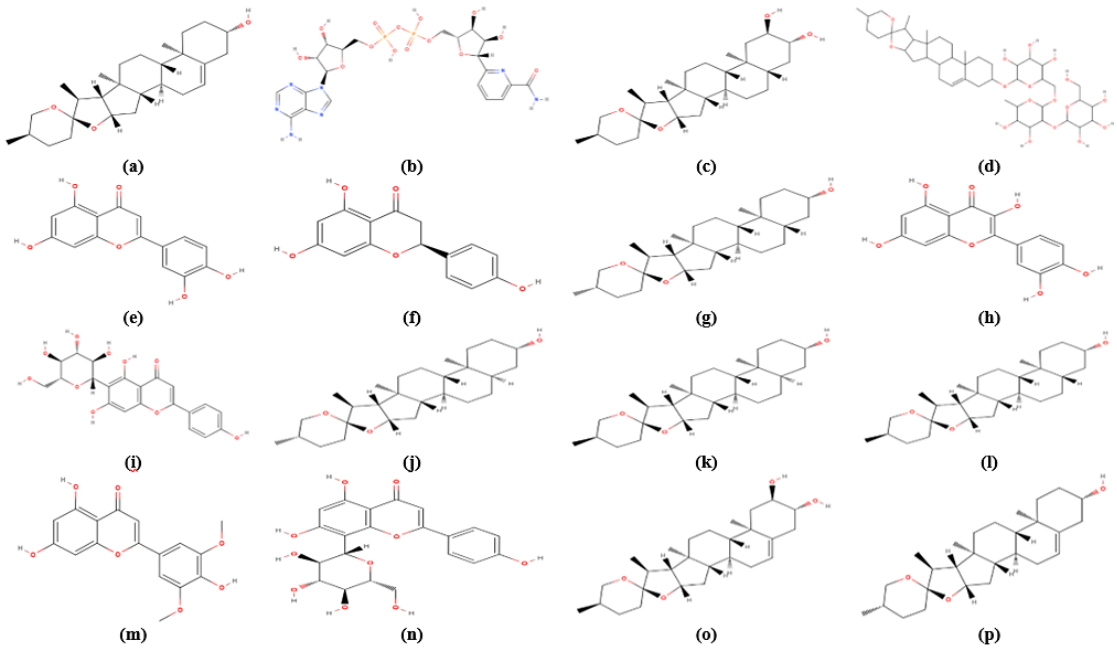

Fig 2: The chemical structures of (a) Diosgenin; (b) Fenugreekine; (c) Gitogenin; (d) Graecunins g; (e) Luteolin; (f) Naringenin; (g) Neotigogenin; (h) Quercetin; (i) Saponaretin; (j) Sarsasapogenin; (k) Smilagenin; (l) Tigogenin; (m) Tricin; (n) Vitexin; (o) Yaccagenin and (p) Yamogenin

Phytochemistry

Fenugreek (*Trigonella foenum-graecum* L.) is a plant known for its diverse chemical constituents, including steroidal sapogenins (Table 4 & fig 2). Among these compounds, diosgenin holds particular significance and is chiefly located in the oily embryo of fenugreek seeds. Additionally, fenugreek contains furastanol glycosides and hederagin glycosides, both of which serve as precursors to diosgenin. The plant's stem contains alkaloids like trigocoumarin, nicotinic acid, trimethyl coumarin, and trigonelline.[10] Fenugreek seeds are remarkable for their high mucilage content, around 28% of their composition. The stem contains alkaloids like trigonelline and choline, proteins (22%), and a distinct yellow coloring substance. The seeds provide 23-26% protein, 6-7% fat, 58% carbohydrates, and 25% dietary fiber. They are also rich in iron, with 33 mg/100 g dry weight. Fenugreek leaves hold seven saponins called graecunins, stemming from diosgenin. The leaves comprise 86.1% moisture, 4.4% protein, 0.9% fat, 1.5% minerals, 1.1% fiber, and 6% carbohydrates.[11] Fenugreek is rich in minerals and vitamins like calcium, zinc, iron, and vitamins like riboflavin, carotene, thiamine, niacin, and vitamin C. Fresh leaves have high ascorbic acid and β-carotene,

preserved through proper storage methods. Fenugreek seeds are widely used in cooking for their unique taste, appearing in curry powders, teas, and spice blends. Fenugreek seeds possess a unique composition, featuring a central robust and yellow embryo encased by a substantial, white, and semi-transparent endosperm layer. These seeds contain diosgenin in concentrations ranging from 0.1% to 0.9%, a compound commercially extracted from them. Saponins like fenugrin B, diverse coumarin compounds, and alkaloids such as trigonelline, gentianine, and carpaine are also present. Additionally, fenugreek seeds offer polyphenol compounds like rhaponticin and isovitexin, which display antioxidant attributes. Although present in small amounts, volatile and fixed oils are found in the seeds. The distinctive scent of fenugreek arises from various odor-active elements, including diacetyl, 1-octene-3-one, sotolon, acetic acid, 3-isobutyl-2-methoxypyrazine, butanoic acid, isovaleric acid, 3-isopropyl-2-methoxypyrazine, caproic acid, eugenol, 3-amino-4,5-dimethyl-3, linalool, (Z)-1,5-octadiene-3-one, and 4-dihydro-2(5H)-furanone. These compounds contribute to buttery, roasty/earthy, metallic, pungent, paprika-like, sweaty/rancid, flowery, musty, spicy aromas, respectively. Sotolon, particularly in its (5s)-enantiomeric form, is the most predominant volatile compound found in fenugreek.

Pharmacology

Fenugreek, renowned for its seeds and leaves, showcases robust antioxidant properties, effectively restoring enzyme activity, reducing oxidative stress, and enhancing the antioxidant system in tissues affected by conditions such as diabetes.[12] The germinated seeds exhibit heightened antioxidant activity attributed to polyphenols, making fenugreek a natural source of non-toxic antioxidants with therapeutic potential against oxidative stress-related diseases. In addressing lipid regulation, fenugreek demonstrates significant antilipidemic effects by lowering serum triglycerides, total cholesterol, and hepatic lipid concentrations in experimental models.[13] Supplementation in patients with coronary artery disease and type-2 diabetes results in substantial reductions in blood lipids without affecting HDL-cholesterol levels. Active components like saponins, alkaloids, flavonoids, and polyphenols contribute to modifying lipid metabolism, with fenugreek-derived saponins like diosgenin inhibiting lipid accumulation and the expression of lipogenic genes in hepatic cells. Fenugreek emerges as a potential anticancer agent, exhibiting inhibitory effects on cancer cell growth and promoting apoptosis, especially against breast, colon, pancreatic, and prostate cancer.14 However, further research is essential to unravel the full mechanisms and therapeutic applications of fenugreek in cancer prevention and treatment. In the realm of anti-inflammatory effects, fenugreek showcases its prowess by inhibiting inflammatory cytokine production and reducing paw edema in arthritis models. The anti-inflammatory and antioxidant properties, combined with flavonoids in fenugreek seeds, position it as a promising antiarthritic agent (Fig 3). Key phytochemicals isolated from fenugreek seed extracts hold potential therapeutic applications in inflammatory disorders. Fenugreek's antibacterial and antifungal effects further underscore its versatility, inhibiting the growth of various fungal strains and demonstrating efficacy against Helicobacter pylori bacteria.15 Trigonella-derived peptides exhibit potent antifungal activity, while the plant extract displays nematicidal effects against nematodes, hinting at Trigonella's potential for developing new drugs. In terms of hepatoprotection, fenugreek proves instrumental in shielding the liver from damage caused by alcoholism and medications. *Trigonella foenum-graecum* L. extracts enhance liver function, reduce enzyme levels, restore antioxidant balance, and mitigate alcohol-induced hepatic injury. Additionally, Trigonella supplementation is linked to a decrease in triglyceride accumulation in the liver, addressing hepatic steatosis. Nephroprotective effects of *Trigonella* are evident in its ability to ameliorate kidney abnormalities and restore function in diabetic rats. Fenugreek seeds exhibit antiulcer effects akin to omeprazole, with flavonoids protecting the mucosa and preventing lesions caused by necrotic agents. Furthermore, dietary fenugreek seeds display an antilithogenic effect, lowering cholesterol levels, and improving bile composition.

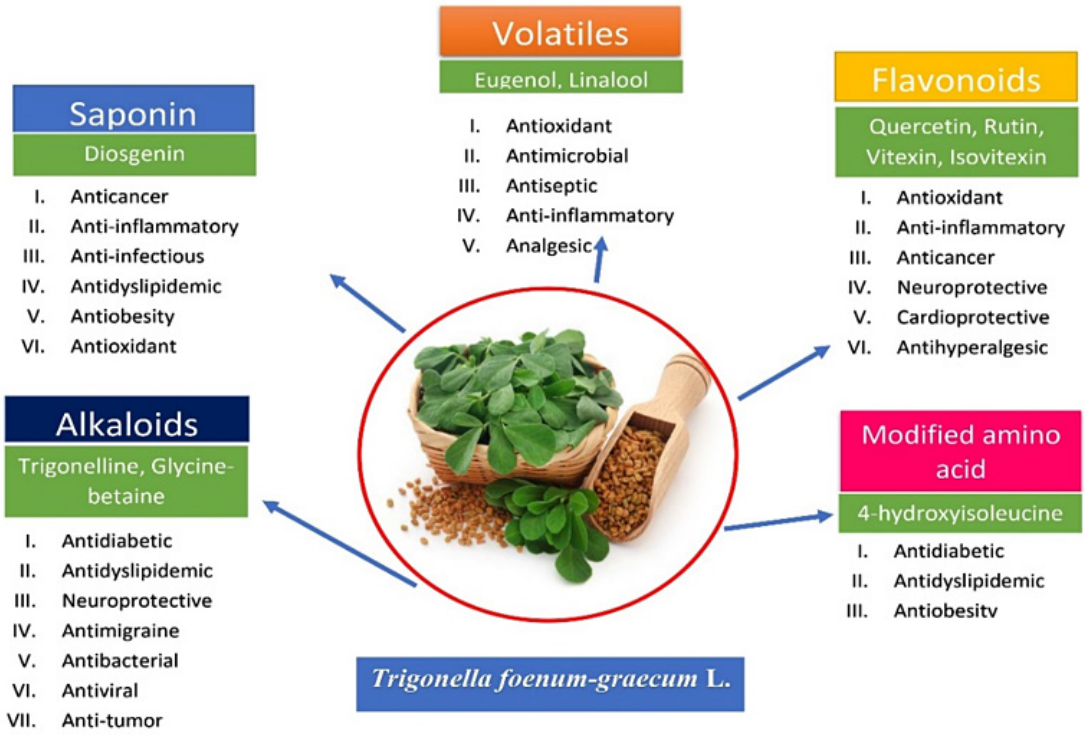

Fig 3: Illustrates a visual representation featuring a selection of secondary metabolites synthesized by *Trigonella foenum-graecum* L

Traditional Uses

Fenugreek, an herb deeply ingrained in the traditional medicinal practices of various countries including India, Middle Eastern countries, the Mediterranean region, China, Ethiopia, Egypt, Iran, Pakistan, Morocco, Greece, Nigeria, Sri Lanka, Bangladesh, and Sudan, possesses remarkable potential for various therapeutic applications (Table 3). This versatile herb has been harnessed for generations in these regions to address a wide array of health concerns. One notable traditional use of *Trigonella foenum-graecum* L. lies in its ability to promote optimal digestive health. Consuming fenugreek seeds is associated with improved digestion, alleviation of indigestion, and relief from discomfort linked to bloating and stomach issues. The carminative properties of fenugreek are highly esteemed for their effectiveness in reducing gas and enhancing overall digestive function.[16] Furthermore, fenugreek has a longstanding tradition of easing joint and muscle pain. Both internal consumption and topical application of fenugreek seeds are attributed to their anti-inflammatory properties, which provide relief from conditions such as arthritis and muscle strains. The significance of fenugreek in women's health should not be underestimated. It is believed to possess estrogen-like properties that contribute to regulating menstrual cycles, alleviating menstrual cramps, and mitigating menopausal symptoms.17 Moreover, fenugreek is commonly employed to support lactation in nursing mothers, stimulating milk production, and enhancing the breastfeeding experience. Respiratory ailments find effective remedies in fenugreek within the traditional medicine practices of these countries. The seeds are utilized to address conditions such as cough, bronchitis, and congestion due to their expectorant properties. Fenugreek is renowned for its ability to loosen and expel mucus from the respiratory tract, thereby promoting easier breathing. Additionally, fenugreek holds significant value as a component of traditional skincare remedies. Its antimicrobial properties have been harnessed to treat various skin issues including acne, eczema, and infections. Topical application of fenugreek paste or oil is believed to possess anti-inflammatory effects,

combat microbial infections, and facilitate the healing process of the skin.18 While the traditional uses of fenugreek in these countries are deeply rooted in historical knowledge and practices, further research is essential to substantiate its efficacy and explore its active compounds. Given the immense potential of fenugreek as a natural remedy, collaboration between traditional medicine practitioners and modern scientific researchers can pave the way for evidence-based insights and open up new avenues for therapeutic applications.

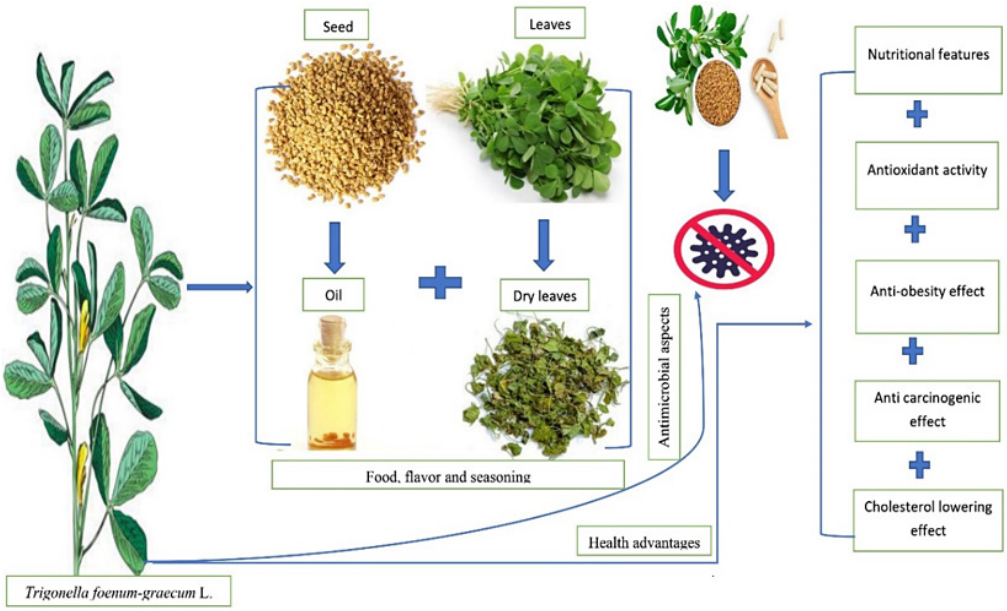

Fig 4: Visual representation of industrial, traditional, and pharmaceutical applications of *Trigonella foenum-graecum* L

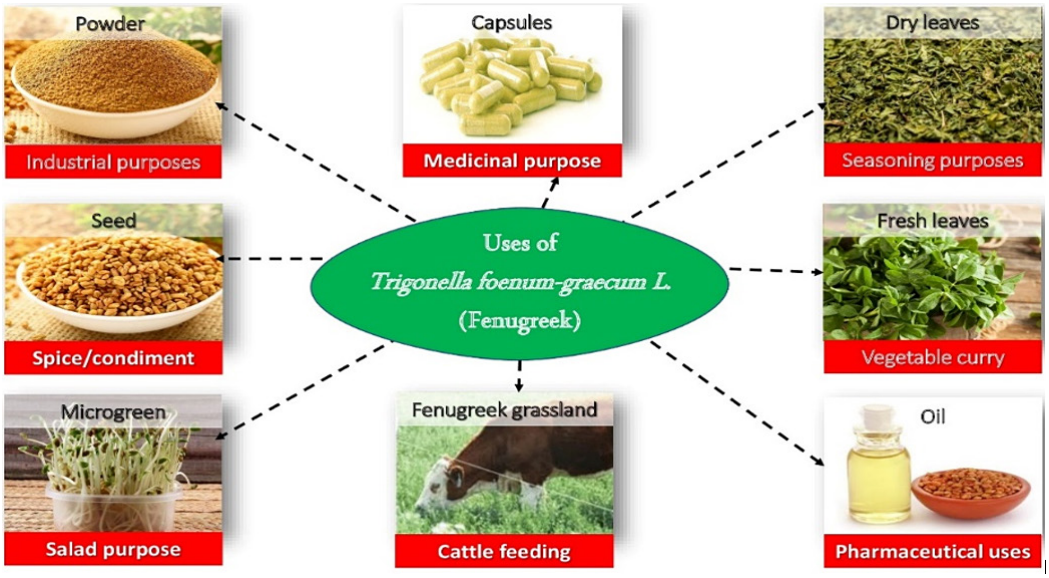

Fig 5: Depicts the various applications of Trigonella foenum-graecum L., including its seeds, fresh herb, dried herb, and oil

Culinary uses and other Applications

Fenugreek, with its rich culinary heritage, is widely used across different cuisines and has various applications worldwide (Fig 4-5). This versatile herb adds a distinct flavor and aroma to dishes, making it a popular choice in kitchens around the globe. In Indian cuisine, fenugreek is a fundamental ingredient, contributing to the flavors of curries, dals (lentil soups), and vegetable dishes.19 Fenugreek leaves are commonly used to enhance the taste of dishes like methi paratha (fenugreek flatbread) and methi chicken. Additionally, fenugreek seeds are used in the preparation of pickles, chutneys, and spice pastes, adding a unique tanginess and complexity. Middle Eastern cuisine also makes ample use of fenugreek.20 It is a key component in spice blends like za'atar, providing an earthy and aromatic note. Dishes like falafel and hummus benefit from the flavor-enhancing properties of fenugreek. In Ethiopian cuisine, fenugreek plays a vital role. It is a crucial ingredient in the spice blend called berbere, which is used to season stews and sauces. Fenugreek is also added to the batter of injera, a traditional Ethiopian sourdough flatbread, giving it a distinctive taste. The Mediterranean culinary tradition incorporates fenugreek as well. It is used in spice blends and marinades for meats and fish, imparting a savory and slightly bitter flavor. Fenugreek is also sprinkled on breads and pastries to enhance their taste and aroma. Asian cuisines, such as Indian, Chinese, and Thai, rely on fenugreek for its unique flavor profile. It is commonly used in curries, stir-fries, and spice pastes, lending depth and complexity to the dishes. Fenugreek sprouts are also popular as a garnish or ingredient in salads. Beyond its culinary uses, fenugreek holds significance in various other applications. It has a long history of medicinal use, being employed as a traditional remedy for digestive issues, lactation support in nursing mothers, and potentially aiding in diabetes management and cholesterol reduction. Fenugreek tea is consumed for its antioxidant properties, while fenugreek oil finds use in hair and skincare products. Furthermore, fenugreek seeds serve as a valuable animal feed supplement, promoting growth and improving feed conversion efficiency in livestock and poultry.[21] Fenugreek's widespread culinary uses and diverse applications make it an integral part of global cuisine. Its distinct flavor, aroma, and potential health benefits have garnered appreciation and admiration in kitchens worldwide.

Conservation Status and Future Prospects

Trigonella species display diverse conservation statuses, wherein the cultivation of certain species, like *Trigonella foenum-graecum* L., has emerged as a stabilizing force owing to their culinary and medicinal significance. However, the wild counterparts of these species confront formidable threats stemming from habitat loss, climate change, and overharvesting. The imperative for sustainable cultivation and habitat preservation is underscored, and achievable strategies encompass the establishment of protected areas, adoption of agroforestry practices, and the promotion of well-informed research initiatives. While not presently classified as endangered, proactively addressing these challenges is indispensable to secure the ecological and cultural importance of Trigonella species. The future trajectory for these species holds promising prospects across multiple domains, including agriculture, medicine, sustainability, and biodiversity. Unveiling the medicinal potential through research stands to significantly contribute to pharmaceutical and nutraceutical advancements. The adaptability of Trigonella species positions them as pillars of sustainable agriculture and agents of climate resilience. Simultaneously, safeguarding traditional knowledge not only enriches innovation but also contributes to the conservation cause. Emphasizing conservation efforts, such as protecting genetic diversity and preserving habitats, becomes paramount in maintaining enduring ecological balance. In harnessing the diverse potentials of Trigonella species, an opportunity arises to address challenges related to food security, health, and environmental sustainability. This holistic approach propels advancements that span a spectrum of disciplines, marking Trigonella as a crucial player in the dynamic interplay between human activities and the environment.

Extraction Methods and Medicinal Formulations

Industrial methods employed for fenugreek extraction include solvent extraction, steam distillation, and cold pressing. These techniques are vital for extracting fenugreek's beneficial compounds on a large scale, ensuring consistency in the quality and potency of fenugreek products for pharmaceutical and commercial use.[22] Solvent Extraction involves using solvents such as ethanol or methanol to extract fenugreek's bioactive constituents. The seeds are

typically ground into a fine powder and then mixed with the solvent, followed by filtration to obtain the extract. Solvent extraction is often preferred for its efficiency in extracting a wide range of compounds from fenugreek seeds, including polyphenols, alkaloids, and saponins. Steam distillation is a traditional method used to extract fenugreek essential oil, which contains potent aromatic compounds such as fenugreekene and sotolon. In this process, steam is passed through the fenugreek seeds, causing the volatile oils to evaporate. The steam-oil mixture is then condensed, and the essential oil is separated from the water.[23] Steam distillation is valued for its ability to preserve the fragrance and therapeutic properties of fenugreek oil. Cold pressing, also known as expeller pressing, is a mechanical method used to extract fenugreek oil without the use of heat. The fenugreek seeds are crushed or pressed to release the oil, which is then filtered to remove impurities. Cold pressing is preferred for its ability to retain the nutritional integrity and natural flavor of fenugreek oil, making it suitable for culinary and medicinal use. Additionally, it is essential to delve into medicinal formulations containing fenugreek extracts, as these formulations serve as vital conduits for delivering its benefits in a standardized and readily accessible manner to patients. Examples of such formulations include fenugreek capsules, tinctures, and extracts, which are used in traditional and modern medicine practices for various therapeutic purposes. Fenugreek extracts are commonly formulated into capsules or tablets for oral consumption. These formulations provide a convenient and standardized way to deliver fenugreek's therapeutic benefits, such as supporting digestive health, regulating blood sugar levels, and promoting lactation in nursing mothers. Capsules and tablets are popular choices for individuals seeking the health benefits of fenugreek in a convenient and controlled dosage form. Fenugreek tinctures are concentrated liquid extracts made by soaking fenugreek seeds or powder in alcohol or glycerin.[24] Tinctures are valued for their high potency and rapid absorption, making them ideal for addressing acute health issues such as indigestion, inflammation, and respiratory congestion. Fenugreek tinctures are often used in traditional herbal medicine practices for their ability to deliver fenugreek's medicinal properties in a concentrated form. Topical formulations incorporating fenugreek extracts, such as creams and ointments, are used for skincare applications. These formulations treat various skin conditions, including acne, eczema, and fungal infections, due to fenugreek's antimicrobial and anti-inflammatory properties. Topical fenugreek preparations are valued for their natural and gentle approach to skincare, providing relief from irritation and promoting skin healing.

Diverse Range of Fenugreek-Based Pharmaceutical Products

In India, numerous pharmaceutical companies have developed a variety of fenugreek-based products catering to diverse health needs. Some notable formulations include FenuLife Capsules by Himalaya Wellness, which contain standardized fenugreek seed extract and are utilized as dietary supplements for supporting digestive health, regulating blood sugar levels, and promoting lactation in nursing mothers.[25] Dabur India Ltd. offers Fenugreek Plus Syrup, which incorporates fenugreek extract and is formulated to support digestive health and overall wellness.[26] Indus Biotech Pvt Ltd. produces Fenugreek Extract Tincture, known as IBHB, in tincture form to promote various health benefits.[27] Charak Pharma Pvt. Ltd. manufactures Fenu-Pro Topical Ointment, containing fenugreek extract for skincare applications to treat conditions such as acne, eczema, and fungal infections.[28] AOS Products Pvt. Ltd. produces Fenugreek Essential Oil for various therapeutic applications.[29] Additionally, herbal toothpaste containing fenugreek extracts is offered by Vicco Laboratories and Himalaya Wellness for promoting oral health and hygiene.[30] Face masks with fenugreek extracts are available from Khadi Natural and Forest Essentials for skincare purposes.[31] Lactation supplements containing fenugreek extracts are provided by Zandu and Dabur to support breastfeeding mothers, while herbal syrups for children with fenugreek extracts are offered by Baidyanath and Hamdard to alleviate common childhood ailments.[32-33] Patanjali Ayurved and Sri Sri Tattva produce herbal juices enriched with fenugreek extracts for detoxifying and health-promoting properties.[34] These fenugreek-based pharmaceutical products from India provide standardized and regulated options for individuals seeking the medicinal benefits of fenugreek extract, manufactured by reputable pharmaceutical companies in compliance with quality standards.

Additionally, fenugreek is incorporated into various other products in India, including hair oils, herbal teas, dietary supplements, skincare creams, cooking oils, herbal supplements, and fortified cereals and snacks. These diverse offerings cater to different health needs and preferences, offering consumers a wide array of options to incorporate fenugreek into their daily wellness routines.

Table 1: Worldwide distribution and cultivation areas of the Trigonella genus.

Distribution areas	Name of countries	References
Europe	Serbia, Belorussia, United Kingdom, France, Spain, Ukraine, Moldavia, Bulgaria, Macedonia, Serbia, Russia, Portugal, Greece, Germany Italy, Switzerland, Sweden, Austria, Hungary, Poland, Romania, Croatia and Slovenia	35
North America and South America	Guyana, Ecuador, Colombia, Brazil, Uruguay, Guatemala, Belize, Nicaragua, Panama, Mexico, Honduras, Costa Rica Suriname, Venezuela, Canada, Argentina and United States	35
Oceania	Pacific Islands, Australia	36
South, Central and Southeast Asia	Vietnam, Cambodia, Brunei-Darussalam, Indonesia, Malaysia, Papua, New Guinea, Bhutan, Bangladesh, Maldives, Myanmar, Thailand, Sri Lanka, Singapore, Philippines, India, Pakistan, Nepal, China, Taiwan, Afghanistan, Turkmenistan, and Azerbaijan	37
Far East	Japan, S. Korea	38
Sub Saharan Africa, Horn of Africa and North Africa	Western Sahara, Africa (Somalia and Djibouti), Algeria, Egypt, Morocco, Sudan, Libya, Kenya and Tunisia	39
Middle East	Saudi Arabia, Qatar, UAE, Turkey, Israel, Lebanon, Jordan, Syria and Iraq	39

Table 2: Description of the genetic diversity of Trigonella genus with different economic uses.

Taxa	Uses	References
Trigonella anguina Delile	Leafy vegetable, insect repellent and nutraceutics,	40
Trigonella calliceras Fischer ex M. Bieb.	Pharmaceutical	41
Trigonella caerulea (L.) Ser.	Insect repellent, medicinal and pharmaceutical	42
Trigonella cretica (L.) Boiss.	Pharmaceutical	42
Trigonella maritima Poir	Pharmaceutical	42
Trigonella spruneriana Boiss	Leafy vegetable, insect repellent and nutraceutics,	43
Trigonella glabra subsp. uncata (Boiss. & Noe)	Medicinal	43
Trigonella foenum-graecum L.	Leafy vegetable, insect repellent, medicinal, nutraceutics and pharmaceutical	44
Trigonella stellata Forssk.	Leafy vegetable, insect repellent and	45

	nutraceutics	
Trigonella spicata Sm.	Leafy vegetable, insect repellent, nutraceutics and pharmaceutical	46
Trigonella suavissima Lindl.	Insect repellent	47
Trigonella lilacina Boiss.	Pharmaceutical	47
Trigonella hamosa Del. ex Smith	Leafy vegetable, insect repellent, and nutraceutics	48
Trigonella glabra Thunb.	Leafy vegetable, insect repellent and nutraceutics	48
Trigonella laciniata L.	Leafy vegetable, insect repellent, Nutraceutics	49
Trigonella occulta Ser.	Leafy vegetable, insect repellent, medicinal, nutraceutics and harmaceutical	50
Trigonella spinosa L.	Leafy vegetable, insect repellent, Nutraceutics, pharmaceutical	50
Trigonella arabica Delile	Leafy vegetable, insect repellent and nutraceutics	51
Trigonella corniculata Sibth. & Sm.	Leafy vegetable, insect repellent, nutraceutics and pharmaceutical	51 52
Trigonella coerulescens Halácsy	Leafy vegetable, insect repellent and nutraceutics	

Table 3: Demonstrates the utilization of *Trigonella foenum*-graecum L. throughout history, from the 1st century to the 20th century.

Period	The utilization of fenugreek throughout history.	References
In the 1st century BC, Fenugreek was employed by the Romans	1. Adding flavor to wine. 2. Stimulating childbirth.	53
n 1060 BC, In China, fenugreek was utilized in traditional Chinese medicine for	1. Addressing leg weakness and edema (swelling caused by an accumulation of lymphatic fluid). 2. Dispelling cold and alleviating pain. 3. Treating hyperlipidemia, hypertension, and immune disorders.	54
In 1333 BC–1324 BC, Fenugreek was employed by the Egyptian Pharaoh	1. Burning Kuphi incense to create sacred smoke for fumigation and embalming rituals. 2. Cultivating in the tomb of Egyptian Pharaoh Tuthankhamun.	54
In 2000–1700 BC, In India, fenugreek had been utilized	1. Fenugreek serves as a primary ingredient in Indian spices and is also a valuable source of dietary fiber and protein.	55
In the 15th century, in Africa, fenugreek had been utilized	1. Employed as a fragrance and seasoning. 2. Utilized as a coffee substitute to prevent insect infestations in grain storage, and as an ingredient in cosmetics and traditional herbal remedies. 3. The dried seeds and leaves were used to treat various conditions such as eczema, rashes, and inflammatory ailments, by creating a paste with ground fenugreek seeds.	55

	4. Fenugreek was also commonly used for ethnove -terinary purposes.	
In 16th century, Fenugreek was grown in England.	1. There are records of fenugreek being employed for various purposes in the 16th century.	56
In the 17th century, powde -red fenugreek seeds were utilized for	1. To remove the placenta following childbirth.	57
In the 19th century, fenugreek had been utilized for	1. Relieving symptoms related to dysmenorrhea and postmenopausal syndrome, reducing blood glucose levels, and aiding lactation.	58
At present, fenugreek is used for diverse medicinal purposes.	1. Fenugreek is employed to decrease blood sugar levels in diabetic individuals and regulate plasma. cholesterol levels 2. Fenugreek has been recently utilized for its various medicinal properties, including antidiabetic, hypocho -lesterolemic, antilipidemic, hepatoprotective, antiulcer, antilithigenic, antioxidant, anti-inflammatory, antibacterial, antifungal, anticarcinogenic, and neuroprotective activities. 3. To date, the bioactive compounds of fenugreek (saponins and sapogenins) have demonstrated their efficacy in treating diabetes mellitus.	58

Table 4: Chemical components found in *Trigonella foenum-graecum* L.

Main group	Subgroup	References
Pyridine alkaloid	Trimethylamine Minerals Iron, Neurin, Zinc, Choline, Phosphorus, Gentianine Magnesium, Capaine, Manganese, Betaine Selenium, Trigonelline	59
Flavonoids	Vitexin, Tricin, Naringenin, Quercetin, Luteolin	60
Saponins	Graecunins G, Fenugrin B, Fenugreekine, Trigofoenosides A-G	61
Steroidal sapogenins	Diosgenin, Yamogenin, Sarsasapogenin, Smilagenin, Gitogenin, Yaccagenin, Saponaretin, Tigogenin, Neotigogenin	62
Minerals	Iron, Zinc, Phosphorus, Magnesium, Manganese, Selenium, Calcium	63
Vitamins	Vitamin A, Vitamin C, Niacin, Pyridoxine, Thiamine, Riboflavin, Nicotinic acid, Folate	64
Protein and amino acids	Globulin, Albumin, Lecithin, Histidine, lysine, 4-hydroxyi -soleucine	65
Volatile oils	n-hexanol, Heptanoic acid, Dihydroactiniolide, Dihydrobenzofuran	66

Conclusion

Trigonella genus, especially fenugreek (*Trigonella foenum gracum* L.), stands out as a crucial contributor to both food sources and traditional medicine. With rich bioactive compounds and significant nutritional value, these plants support culinary and medicinal purposes. Their adaptability allows widespread cultivation, contributing to food security and sustainable local diets. Extensive research highlights fenugreek's anti-diabetic effects,

while other Trigonella species show promise in various pharmacological activities. Maximizing health benefits requires exploring cultivation, processing, and culinary applications. Preserving traditional knowledge is vital for biodiversity conservation and healthcare practices. Recognizing Trigonella's importance promotes sustainable cultivation, benefiting human health, local communities, and conservation efforts. Continued research and conservation are essential for fully realizing the potential of Trigonella species, enhancing overall well-being.

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Conflict of Interest
The authors declare no conflict of interest.

Authors' contribution
The review paper was a collaborative effort involving contributions from several authors. Prawal P. S. Verma played a key role in conceptualizing the study, devising the methodology, conducting investigations, curating the data, and preparing the original draft of the manuscript. Saba Siddiaqi contributed to the methodology, conducted investigations, and played a pivotal role in reviewing and editing the manuscript, as well as in visualizing the data. Md Abu Nayyer provided valuable input in conceptualizing the study, supervising the work. Saudan Singh was responsible for visualizing key findings and providing critical input during the review and editing stages. Dipender Kumar contributed extensively to the review and editing process. Finally, R. C. Padalia played a crucial role in conceptualization, supervision, validation of findings, and contributed significantly to the review and editing process.

Data Availability Statement
Not applicable

Ethics Approval Statement
As this is a review paper and does not involve any experiments on humans or animals, no specific ethics approval was required for this study.

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