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**Prawal PS Verma**

1. Integral Institute of  
Agricultural Science &  
Technology Agricultural  
Block, Integral University,  
Kursi Road, Lucknow, Uttar  
Pradesh, India

2. CSIR-Central Institute of  
Medicinal and Aromatic  
Plants, P.O.-CIMAP, Near  
Kukrail Picnic Spot, Lucknow,  
Uttar Pradesh, India

**Md. Abu Nayyer**

Integral Institute of Agricultural  
Science & Technology  
Agricultural Block, Integral  
University, Kursi Road,  
Lucknow, Uttar Pradesh, India

**Saudan Singh**

CSIR-Central Institute of  
Medicinal and Aromatic Plants,  
P.O.-CIMAP, Near Kukrail  
Picnic Spot, Lucknow, Uttar  
Pradesh, India

**Dipender Kumar**

CSIR-Central Institute of  
Medicinal and Aromatic Plants,  
P.O.-CIMAP, Near Kukrail  
Picnic Spot, Lucknow, Uttar  
Pradesh, India

**Saba Siddiqui**

Integral Institute of Agricultural  
Science & Technology  
Agricultural Block, Integral  
University, Kursi Road,  
Lucknow, Uttar Pradesh, India

**Corresponding Author:**

**Md. Abu Nayyer**

Integral Institute of Agricultural  
Science & Technology  
Agricultural Block, Integral  
University, Kursi Road,  
Lucknow, Uttar Pradesh, India

## Genetic diversity and distribution of fenugreek (*Trigonella foenum-graecum* Linn): A review

**Prawal PS Verma, Md. Abu Nayyer, Saudan Singh, Dipender Kumar and  
Saba Siddiqui**

### Abstract

Fenugreek (*Trigonella foenum-graecum* Linn) is an important leafy vegetable crop and is also used as a spice crop in the world which is belonging to Fabaceae family. India is the top producer of fenugreek in the world. Fenugreek is an herb which is commonly found to be growing in the Mediterranean region. Fenugreek has the highest genetic diversity in the Indian subcontinent compared to the rest of the world, and is widely grown in these regions. Knowledge of genetic variability, heredity, genetic progression, correlation, and path coefficient is very essential as well as genetic diversity of various quantitative and qualitative traits and their effects on herb and seed yield in order to keep progressing in fenugreek crop. Studies in this area cannot be predicted for every genetic variation and environmental circumstance. Therefore, the details given below can facilitate in creating a strong fenugreek breeding plan.

**Keywords:** Fenugreek, genetic variability, correlation, path coefficient, genetic diversity, taxonomy, distribution

### Introduction

Fenugreek (*Trigonella foenum-graecum* Linn) can be easily cultivated in tropical and temperate regions in India (Singh *et al.*, 2003) [46]. It is easily cultivated from sea level up to an altitude of 2000 MSL. Most of the *Trigonella* species are found in the Mediterranean region. *Trigonella foenum-graecum* is also known as "methi," and *Trigonella corniculata* popularly referred as "kasurimethi," are the two species of the genus that are economically significant. Fenugreek is an annual plant that grows 30 to 90 cm tall. It has pinnately trifoliate (Fig 1), light green leaves (Jhanavi *et al.*, 2018) [18]. Fenugreek was formerly cultivated as a forage crop in areas of Mediterranean Eurasia, Russia, North Africa, and the Middle East. Later, it migrated to other regions of the world, such as the wide Indian subcontinent or to major portions of South Asia. Fenugreek, also referred to as "Queen of Forages," is an annual forage legume that is a member of the Fabaceae (Leguminosae) genus of legumes (Zandi *et al.*, 2011) [56].

It belongs to the Fabales order and family and is a dicotyledonous angiospermic annual leguminous plant. Additionally, fenugreek is similar to the famous fodder crop alfalfa (*M. sativa*). It is a self-pollinated crop has an indeterminate growth habit which means it continues to spread throughout the growing season (Zandi *et al.*, 2011; Solorio-Sanchez F *et al.*, 2014) [56, 49]. Fine branches and sub branches are produced by fenugreek, which also has terminal or axillary small papilionaceous flowers that range in colour from red to pale yellow to white and complex trifoliate leaves of a pale green color. The plant can grow to a height of 10-42 cm. The height of plants that are grown on dry land and are dependent on rainfall is lower than that of irrigated plants. The plant produces numerous, long and single pods that range in length from 8 to 14 cm and contain, on average, 18 to 20 seeds (Acharya *et al.*, 2007; Acharya *et al.*, 2011) [2, 1]. The pods have little hairs on them and are long and curved. When the pods are immature, they are green to light purple in colour; when they are mature, they turn brown. The colour of the immature seeds are green (Fig 1-2), but they mature to become hard and brown or golden brown in colour (Basu *et al.*, 2007a; Basu *et al.*, 2007b; Zandi *et al.*, 2015) [7, 8, 55].

The level and scope of population diversity have a significant impact on the effectiveness of any breeding operation. To improve both qualitative and quantitative traits in vegetable breeding programmes, it is also essential to have a thorough grasp of the genetics underpinning various characteristics (Yadav *et al.*, 2018) [52]. A wide range of diversity provides more opportunities for selecting profitable genotypes.

The type and degree of genetic diversity, degree of transmission of desirable traits, and actual expected genetic advantage to characteristics in a population can influence whether effective selection works (Solanki *et al.*, 2006) [48]. Correlation and path coefficient analysis are helpful tools for determining the true components of yield. Each crop improvement objective to increase yield while taking into account all other relevant elements that either directly or indirectly contribute to it. An understanding of genetic variation, including its type and degree, is fruitful for any heritable crop development plan. Correlation studies and path coefficient analyses are thus effective tools for scrutinize character associations and their effects on yield, which aid in the selection process (Kole and Goswami, 2015) [23]. Fenugreek crop is significant to the economy of our country and to fulfil domestic and export demand its production must increase by three to four times.

India is the second largest vegetable producer in the world

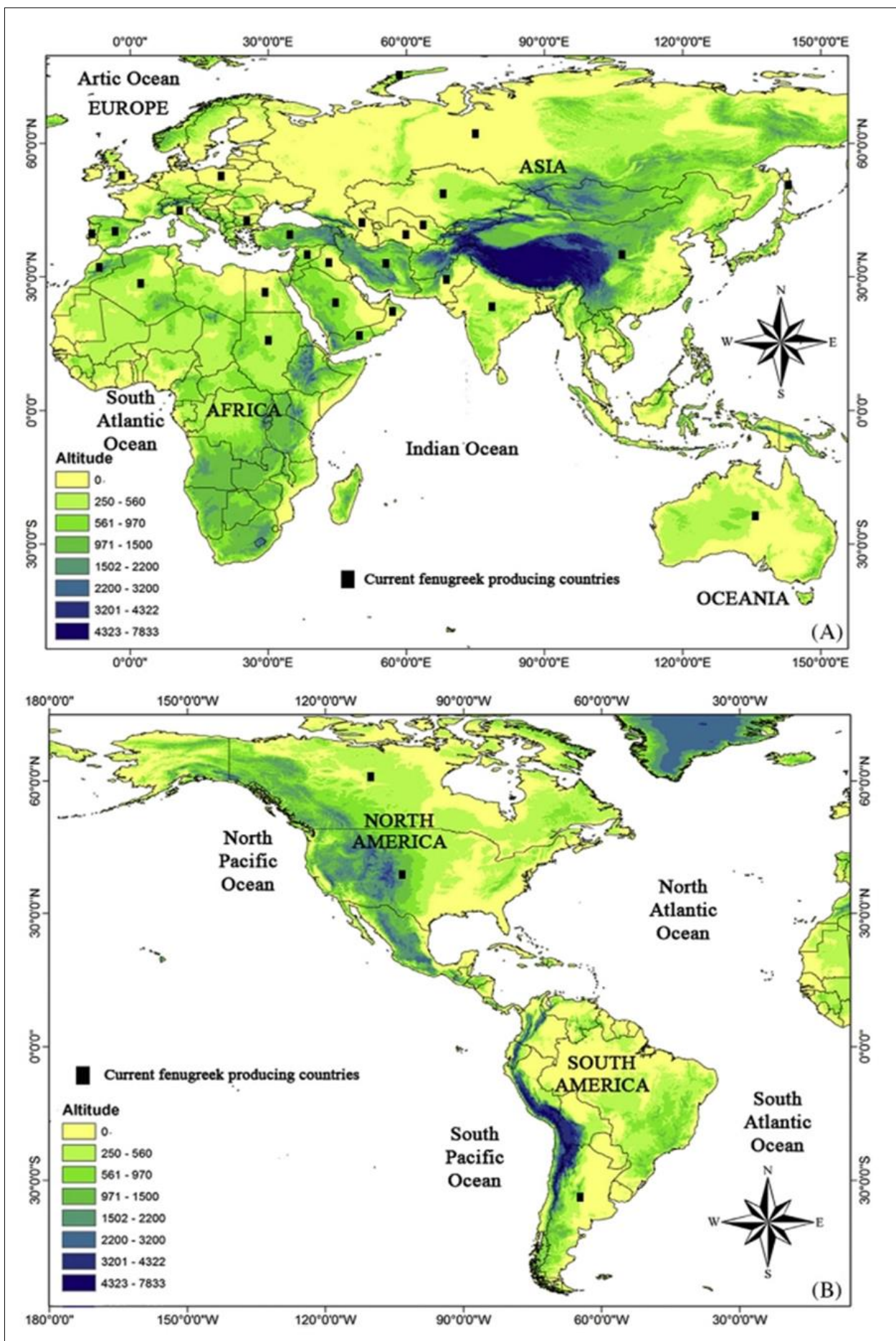
after China. We have a lot of opportunity to increase the export capacity by increasing the vegetable production. Simultaneously, there is immense potential for the production of fenugreek in these areas, if fenugreek is produced using improved varieties, then the farmers can get more yield and higher return. However, minimal research on *Trigonella foenum-graecum* L. has been conducted to improve crop improvement. It is imperative to conduct breeding work to create new and improved varieties of fenugreek for these regions. But before the breeding work, it is necessary to have all the information related to the characterization of *Trigonella foenum-graecum* L varieties/strain. So that the data of all the varieties is available with us before studying the breeding/hybridization work. The main purpose of writing this review paper is to provide important data related to genetic diversity of fenugreek crop for breeding to the researchers working on the breeding program of fenugreek.



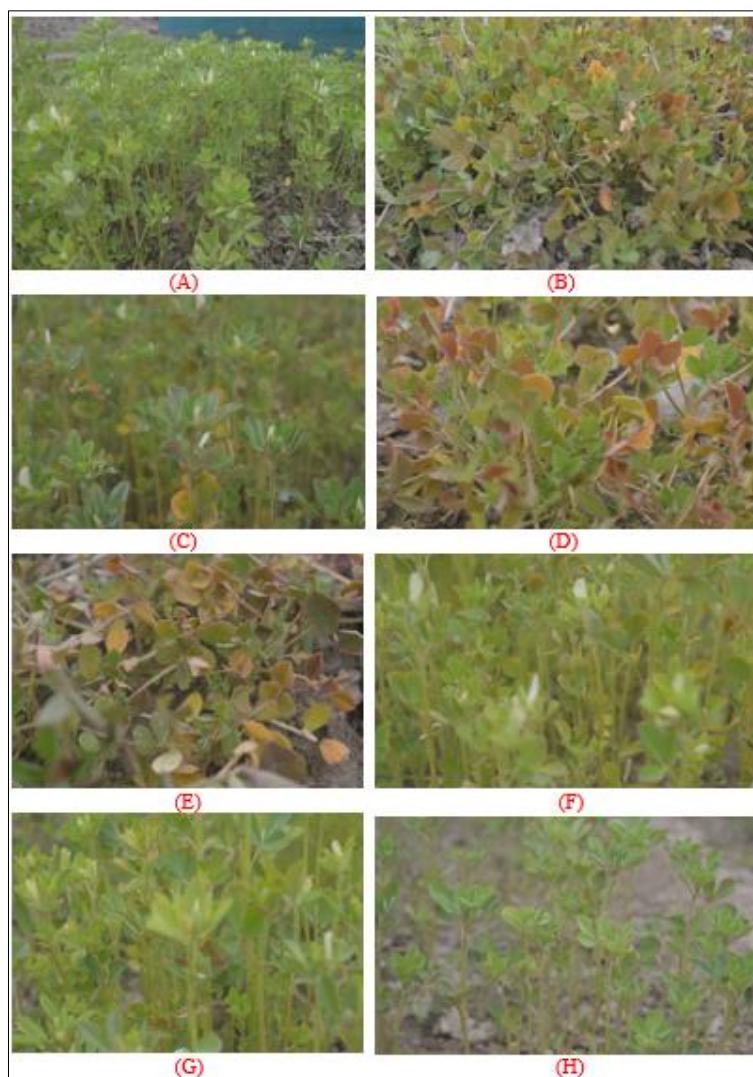
**Fig 1:** (A) Seed germination; (B) Mature Fenugreek seed; (C) Standing crop; (D) Seedling in pot; (E) Fenugreek naturally grown in forests in the Western Himalayan region; and (F) Fenugreek cultivation under irrigated area.



**Fig 2:** (A) Healthy crop of fenugreek collected from western Himalayan region; (B) Trifoliate compound of fenugreek leaf; (C) Primary branch of fenugreek; (D) fenugreek seeds sprouts; and (E) Experiment conducted for genetic diversity assessment of fenugreek under district Bageshwar, Uttarakhand.



**Fig 3:** Fenugreek crop distribution. (A) Continents of Europe, Asia, Africa, and Oceania; and (B) Continents of North and South Americas.



**Fig 4:** Genotypes collected from different regions of Uttarakhand for the study of Genetic Variability Assessment; (A) Dangoli, Gwaldam, UK; (B) Ghodakhal, Bageshwar, UK; (C) Kichha, US Nagar, UK; (D) Silati, Bageshwar, UK; (E) Khatima, US Nagar, UK; (F) Garur, Bageshwar, UK; (G) Kaflogair, Bageshwar, UK; and (H) Wajyula, Bageshwar.

**Table 1:** Comparative frequency of fenugreek diversity across several nations of the world.

Name of country	Genetic diversity	Name of country	Genetic diversity
Iran	4.22	Taiwan	0.09
Iraq	0.64	Turki	3.67
Israel	0.28	Tunisia	3.85
Italy	0.37	Turkmenistan	0.09
Jordan	0.46	USA	0.28
Kanya	0.09	Ukraine	0.09
Libya	0.46	Yemen	0.28
Nepal	0.18	Afghanistan	2.48
Oman	7.06	Algeria	0.18
Morocco	0.46	Australia	0.64
Pakistan	3.76	Austria	0.09
Poland	0.18	Azerbaijan	0.09
Portugal	0.09	Canada	4.95
Romania	1.38	China	4.04
Russia	0.28	Egypt	1.47
Slovenia	0.37	England	1.56
South Africa	0.09	Eritrea	0.09
Spain	0.73	Ethiopia	13.94
Sudan	0.92	France	0.28
Sweden	0.28	Germany	0.37
Switzerland	0.18	Greece	0.55
Syria	1.38	Hungary	0.28
		India	36.78

**Table 2:** Potential fenugreek production areas and current global distribution of fenugreek crop

Distribution areas	Name of countries	Reference
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	[38, 53-55]
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	[40]
Oceania	Pacific Islands, Australia	[39, 41]
South, Central and South East 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	[42, 45]
Sub Saharan Africa, Horn of Africa and North Africa	Western Sahara, Africa (Somalia and Djibouti), Algeria, Egypt, Morocco, Sudan, Libya, Kenya and Tunisia	[46, 48-50]
Middle East	Saudi Arabia, Qatar, UAE, Turkey, Israel, Lebanon, Jordan, Syria and Iraq	[50, 53]

**Table 3:** Description of the genetic diversity of fenugreek species with different economic uses.

Taxa	Uses	References
<i>Trigonella anguina</i> Delile	Leafy vegetable, insect repellent and nutraceuticals,	[40]
<i>Trigonella calliceris</i> Fischer ex M. Bieb.	Pharmaceutical	[41]
<i>Trigonella caerulea</i> (L.) Ser.	Insect repellent, medicinal and pharmaceutical	[41, 45, 55]
<i>Trigonella cretica</i> (L.) Boiss.	Pharmaceutical	[40]
<i>Trigonella maritima</i> Poir	Pharmaceutical	[40]
<i>Trigonella spruneriana</i> Boiss	Leafy vegetable, insect repellent and nutraceuticals,	[38]
<i>Trigonella glabra</i> subsp. <i>uncata</i> (Boiss. & Noe)	Medicinal	[55]
<i>Trigonella foenum-graecum</i> L.	Leafy vegetable, insect repellent, medicinal, nutraceuticals and pharmaceutical	[42, 38, 39]
<i>Trigonella stellata</i> Forssk.	Leafy vegetable, insect repellent and nutraceuticals	[37]
<i>Trigonella spicata</i> Sm.	Leafy vegetable, insect repellent, nutraceuticals and pharmaceutical	[33, 40]
<i>Trigonella suavissima</i> Lindl.	Insect repellent	[41]
<i>Trigonella lilacina</i> Boiss.	Pharmaceutical	[42]
<i>Trigonella hamosa</i> Del. ex Smith	Leafy vegetable, insect repellent, and nutraceuticals	[45]
<i>Trigonella glabra</i> Thunb.	Leafy vegetable, insect repellent and nutraceuticals	[46]
<i>Trigonella laciniata</i> L.	Leafy vegetable, insect repellent, Nutraceuticals	[45]
<i>Trigonella occulta</i> Ser.	Leafy vegetable, insect repellent, medicinal, nutraceuticals and pharmaceutical	[45, 50, 51]
<i>Trigonella spinosa</i> L.	Leafy vegetable, insect repellent, Nutraceuticals, pharmaceutical	[37]
<i>Trigonella arabica</i> Delile	Leafy vegetable, insect repellent and nutraceuticals	[35]
<i>Trigonella corniculata</i> Sibth. & Sm.	Leafy vegetable, insect repellent, nutraceuticals and pharmaceutical	[41, 43, 44]
<i>Trigonella baccarinii</i> Chiov.	Leafy vegetable, insect repellent and nutraceuticals	[31]
<i>Trigonella coerulescens</i> Halácsy	Leafy vegetable, insect repellent and nutraceuticals	[36]
<i>Trigonella balansae</i> Boiss. & Reut.	Leafy vegetable, insect repellent, nutraceuticals and pharmaceutical	[42, 39]

### Taxonomy of genus *Trigonella*

The genus presently has 62 species (Hardman, 1969) [14], according to the most recent assessment (Small, 1987) [47]. Other than this in the plant List (Dangi *et al.*, 2016) [10], listed 26 accepted synonyms, 96 accepted taxa, three misapplied names, and 97 accepted taxa with accepted names. Numerous *Trigonella* species have commercial potential with *T. foenum-graecum* being the most well-known species in the genus due to its many desirable characteristics. Additionally, several authors assigned various potential uses for different fenugreek species (Table 1). Although, several are presently synonyms or comes under different genera. For example *Medicago monspeliaca* (L.) Trautv, *Medicago orthoceras* (Kar. & Kir.) Trautv. (Hidvegi, 1984) [15] and *Medicago radiata* L. are all represented by the synonyms *T. monspeliaca*, *T. polycerata*, and *T. radiata* Boiss, respectively (Hardman, 1969) [14]; Hardman *et al.*, 1972 [13]; Mehra *et al.*, 1996 [33]; Hidvegi *et al.*, 1984) [15].

*Trigonella uncata*, *Trigonella polycerata* and *Trigonella occulta*, are considered as an Indian herb together with *Trigonella foenum-graecum*. Some of these species are also

utilized in traditional medicine system (Hardman *et al.*, 1972) [13]. Most species have well-developed endosperms that are rich in galactomannan, a polysaccharide mucilage that has several industrial applications, particularly in pharmaceuticals and cosmetics industries. *T. corniculata* is employed for a variety of functions in various regions of Pakistan and India. Its aerial part is consumed as a green leafy vegetable, the dried herb is used as a seasoning, (Allen *et al.*, 1981) [4].

### Genetic diversity and distribution of fenugreek

Fenugreek is a very old worldwide crop and is also known for its wide global distribution (Table 1-2 & fig 3). It is very important to have high degree of genetic diversity, only by this long-term quantitative and qualitative yield improvement of a crop can be achieved. It is also possible to introduce the crop to new climatic conditions through genetic diversity as well as selection and screening of high yielding and early maturing species. Through this, commercially suitable disease resistant species can be developed by studying genetically desirable traits and incorporating breeding activities (Basu *et al.*, 2014) [9]. The diversity of genetic variations found in

different populations or different families of plant are important characteristics for genetic diversity screening. In order to find varieties that are appropriate to a particular region or to create cultivars through multi-location studies, high genetic diversity is very important. Furthermore, any crop development program requires a high genetic diversity or huge genetic variability (Acharya *et al.*, 2006<sup>[3]</sup>; Basu *et al.*, 2007a<sup>[7]</sup>; Basu *et al.*, 2007b<sup>[8]</sup>; Hardman *et al.*, 1972<sup>[13]</sup>; Petropoulos, 2002<sup>[38]</sup>; Allen *et al.*, 1981<sup>[4]</sup>). There is an urgent need to develop locally adapted varieties of fenugreek to meet the challenges of high genetic environmental impact (Sindhu *et al.*, 2017)<sup>[44]</sup>. Fenugreek is widespread in many countries of the major continents and is essential for significant genetic diversity (Provorovl *et al.*, 1996)<sup>[41]</sup>. Table 3 shows the wide genetic diversity in fenugreek germplasms. In this context, economically vulnerable countries of Asia, Africa, America seeking minimum agricultural practices and genetically diverse fenugreek varieties can be released commercially (Makai *et al.*, 2004)<sup>[32]</sup>. The major objective of the plant breeding organizations that are working on fenugreek development program around the world is to release locally adapted cultivars for different climatic conditions with sustainable forage and herb yield as well as enriched active compounds beneficial for human health (Allen *et al.*, 1981<sup>[4]</sup>; Basu *et al.*, 2007a<sup>[7]</sup>).

The data that is being given indicates that there are 1080 different varieties of the fenugreek crop, which are spread over 45 countries in the world. Also a straight pattern is shown in the Table 1, which clearly shows the percentage of genetic diversity and richness of Fenugreek in different countries. India has the largest abundance and diversity (Nagendra, 2002)<sup>[34]</sup> of fenugreek (36.79%), followed by Ethiopia (13.94%), and Oman has the lowest relative abundance (7.06%). The Indian subcontinent, which has a remarkable range of climatic zones ranging from tropical in the south to temperate and alpine in the north of the Himalayas (Fig 4), is considered to have the highest diversity richness of fenugreek.

### Genetic variability

The success of a breeding program is ensured only when the extent and amount of variability existing in the germplasm is accurately assessed. In order to study variability, the genotypic coefficient of variability (GCV) and phenotypic coefficient of variability (PCV) are typically measured. The following is the literature related to the study of genetic variability on fenugreek. A study involving one hundred-two genotypes was conducted by Singh *et al.* in 2015<sup>[25]</sup>. According to the investigation, there is a sizable amount of genetic variability was presented, and the mean values for every character showed a wide range of variability for every traits. The highest number of primary and secondary branches per plant were found in the genotype UM-117. In various fenugreek germplasm lines, number of seeds/pod varied from 7.3 to 22.2. Prajapati *et al.* in 2010<sup>[39]</sup> investigated the genetic diversity of *Trigonella foenum-graecum* L. using sixty-four genotypes. They found that both the PCV and GCV of primary branches/plant, number of pods/plant, and grain yield/plant were high. Forty-eight *Trigonella foenum-graecum* L. genotypes were used to study genetic variability by Dashora *et al.* in 2011<sup>[28]</sup>. They revealed that genotype differences that were highly significant have been noted for each character under study. High PCV and GCV were found

for harvest index, pods/plant, biological yield, and seed yield/plot, demonstrating the significance of additive gene effects for these traits. It was discovered that fenugreek seed yield can be increased by selection for biological yield/plot, harvest index, branches/plant, length of pod, and test weight. The number of branches/plants, number of pods/plant, number of pods/axes, seed yield/plant, seed yield/plot, number of primary branches/plant, chlorophyll content, and vegetative yield of fenugreek crop have the highest PCV & GCV values, according to the conclusion of Singh *et al.* in 2012<sup>[45]</sup>. Fenugreek (*Trigonella foenum-graecum* L.) germplasms were used in an experiment by Jain *et al.* in 2013<sup>[17]</sup> along with five standard checks. The discovery of these research workers revealed that the number of pods on the main axis and seed yield/plant both had high estimates of the phenotypic and genotypic co-efficient of variance. Kumar *et al.* in 2020<sup>[27]</sup> estimates of genetic variability of fenugreek were examined with one hundred twenty-three accessions. They found that the number of pods/plant showed low coefficients of variation, whereas the days until 50% flowering, primary branch/plant, and pod length were estimated to have high coefficients of variation. The best traits that can be used for selection for hybridization and improvement may be the day to 50% flowering and pod length since these traits exhibit high variability when variability is considered as a whole. Thirty genotypes of fenugreek (*Trigonella foenum-graecum* L.) were studied by Yadav *et al.* in 2013<sup>[54]</sup> for the estimation of genetic variability. They concluded that for each character under study, genotype differences that were highly significant were noted. For the seed yield/plant, high estimates of the phenotypic and genotypic coefficients of variance were made. Pathak *et al.* in 2014<sup>[36]</sup> investigated the genetic variability of forty genotypes of fenugreek (*Trigonella foenum-graecum* L.). They find out the higher phenotypic coefficient of variances value on seed yield/plant (g) followed by number of pods/plant. Thirty genotypes of fenugreek (*Trigonella foenum-graecum* L.) were used by Mahendra *et al.* in 2016<sup>[31]</sup> to estimate genetic variability and they concluded that the dry weight/plant at the onset of flowering followed by dry herb yield/plant, had the highest genotypic and phenotypic coefficients of variance.

### Heritability and genetic advance

Heritability is the ability of traits to be passed down from parents to offspring and genetic advance is the potential improvement over the base population that can result from selection for traits. Reviews on heritability and genetic advance are presented below. One hundred twenty-two strains of fenugreek were analysed by Prakash *et al.* in 2020<sup>[40]</sup>, they observed very high GA in percent of mean revealed that seed yield which was 45.19% followed by branches per plant (51.26%), and heritability estimates for seed output were high (99.57%) followed by estimates for number of branches/plant (99.30%). For heritability and genetic advance, Pathak *et al.* in 2014<sup>[36]</sup> investigated forty fenugreek genotypes. They concluded that the number of branches/plant, number of pods/plant, protein content/plant, days to flowering, and weight of 100 seeds (gm) were found to have the highest GA and heritability. In an experiment by Pushpa *et al.* in 2012<sup>[42]</sup>, twenty-five genotypes of fenugreek were used for assessment. They found that all traits such as number of branches/plant, plant diameter (cm), pod length (cm), and harvesting index

exception of plant height (cm) has high heritability and GA estimates. In order to assessment of heritability and genetic advance, Kumar *et al.* in 2018 [26] did an analysed one hundred twenty-four fenugreek genotypes and they find out the plant height (cm), branches/plant, pods/plant, and pod length were found to have the highest heritability estimations. Plant height, days to 50% flowering, seeds/pod and seed weight, and pods/plant showed moderate GA, while the remaining attributes showed poor GA. The genetic heritability study by Lodhi *et al.* in 2015 [29] used 28 fenugreek genotypes across eleven quantitative variables and they found high heritability in plant height and dry matter content. The dry matter content (DMC) and dry weight during flowering were shown to have the highest GA as a percentage of the mean. Mori *et al.* in 2015 [22] investigated the forty genotypes under conditions of timely and late sowing and they evaluate morphological characteristics such as seed herb yield, number of pods/plant, number of branches/plant, fresh herb yield/plant, and harvesting index. They observed that the percentage of mean seed yield/plant in both scenarios indicated, strong heritability was associated by high GA, suggesting the potential for increasing these qualities through simple selection.

### Correlation study

Character association has economic significance, which can be measured scientifically using the correlation coefficient. This makes it easier to choose the individual characters, which is a good starting point. The characters' contributions to yield are revealed through correlation studies between production and its constituents, which will help in developing and putting any crop improvement programme into practise. The reviews of the correlations between various characteristics are presented below. In order to determine the correlation between seed output and seven plant parameters, Ayanoglu F. *et al.* in 2004 [12] evaluated 35 fenugreek lines and they revealed that the number of pods/plant and the number of days before flowering were both positively linked with the seed output. Based on correlations and path coefficient analysis, Kailash *et al.* in 2000 [19] evaluated seventy-two germplasms of fenugreek (*Trigonella foenumgraecum* L.) for quality and they find out the number of pods per plant, test weight, and plant height were determined to be the most important variable since they had a favourable direct impact as well as a positive association with seed yield. KC Sharma and Sastry in 2008 [21] examined over two hundred forty lines of a large fenugreek germplasm as well as five promising cultivars and local check. As per the correlation study they find out traits like biological yield, pods per plant, and primary branches/ plant were important for the selection of high-yielding genotypes because they had a positive direct effect and a positive correlation with seed yield at both the genotypic and phenotypic levels. Twenty genotypes of fenugreek were used in an experiment by Kole and Mishra in 2006 [24] to determine the correlation coefficient. And they found that plant height and days from flowering to maturity had negative connections with seed yield/plant, while branches/plant, pods/plant, seeds/plant, biological yield/plant, seed weight/plant, husk weight/plant, straw yield/plant, and biological yield/plant all showed high positive associations with seed output. Thirty different fenugreek genotypes were examined by PC Kole and Saha in 2012 [37] by altering the date of sowing, spacing, fertilizer doses, and

other crop management strategies, they are cultivated in six (E1 to E6) distinct habitats under high input and low input settings. Analysis of the correlations showed that the substantial and favourable genotypic and phenotypic relationships between seed production and pod number, husk weight, stem weight, and harvest index did not alter when the environmental circumstances changed. For the correlation coefficient, DB Prajapati *et al.* in 2010 [11] assessed sixty-four genotypes of fenugreek (*Trigonella foenum-graecum* L.) and they concluded that the number of pods/plant, number of seeds/pod, and the weight of 1000 seeds were positively correlated with grain output.

### Path coefficient analysis

Economically significant character association is quantitatively quantified by the correlation coefficient. This provides a solid foundation for choice and makes selecting the component characters easier. When creating and implementing crop development techniques, studies that examine the relationship between yield and its component elements can indicate how specific features affect production. Reviews on correlations between various traits are presented below. J. Mahey *et al.* in 2003 [16] assessed the seed production and its constituent parts in thirty F3 varieties. In this study, as per path coefficient analysis, plant height, number of pods/plant, and length of the pods all positively influenced the genotypic and phenotypic levels of seed yield/plant. Path coefficient analysis in fenugreek was conducted by S. Datta *et al.* in 2005 [43], they discovered that the number of pods/plant, followed by the number of leaves/plant and the number of seeds/pod, had the highest direct influence on seed output. The number of secondary branches/plant significantly reduced seed production directly. Kailash C and Sastry in 2000 [19] evaluated seventy-two fenugreek strains. After accomplishing their analysis for path coefficient analysis, they discovered that the number of pods per plant, test weight, and plant height were the most associated that either directly or indirectly affected seed yield. In their study, KC Sharma and Sastry in 2008 [21] investigated at two hundred-forty germplasms, five varieties and local check. The analysis of the path coefficient showed that traits like biological yield, number of pods/plant, and primary branches/plant were important for the selection of genotypes that produced high yields because they had a favourable direct effect. For a path co-efficient analysis, Balai *et al.* in 2006 [5] analysed the thirty-six genotypes including checks/local selection and they discovered highly significant traits such as number of seeds/pod, number of pods/plant and test weight because they have a positive direct effect.

### Genetic diversity

Knowledge of the genetic divergence of many factors, particularly those impacting yield and quality, would be very beneficial when creating any crop improvement programme. Mahalanobis's (1928) [30] D2 statistics give a numerical indication of how diverse the genotypes being compared. When selecting eligible parental germplasms for a heterosis breeding programme, it will be helpful to group genotypes based on D2 analysis. This grouping can also aid in the production of superior open pollinated varieties for commercial cultivation. Reviews of the genetic diversity are presented below. UK Jain *et al.* in 2006 [51] investigated the genetic divergence of thirty-six fenugreek genotypes using D2



analysis. The study revealed that there was no equality between genetic and geographic diversity and that the genotypes were divided into six clusters. The highest intra-cluster distances were found in clusters I and II. Clusters IV and II had the highest inter cluster distance followed by clusters III and II. Fat content contributed the highest to the genetic divergence among the ten characters examined, accounting for 70.3% of the total divergence followed by plant height (8.6%). According to the study, inter-mating between genotypes of different clusters can be done in breeding programmes to improve yield and quality traits in order to obtain heterotic response as well as improved segregants. Using Mahalanobis' D2 statistic, Banerjee and Kole in 2004 [6] estimated genetic divergence for eight quantitative characters across twenty-two genotypes of fenugreek, and the genotypes were divided into six clusters following cluster I, which had a maximum of thirteen genotypes, were clusters II and III, which had four and two genotypes, respectively. Three clusters contained only one genotype. Geographic differentiation was unrelated to the genotype clustering pattern. The highest intra-cluster distance was found in cluster III, while the highest inter-cluster distance was found between clusters III and VI and lowest between clusters II and VI. The main factors causing divergence were plant height, pods per plant, days to flowering, and test weight. Based on the similarities of the D2 values that Yadav P. *et al.* in 2018 [52] evaluated sixty genotypes were divided into eight different clusters. They discovered that in most cases, the clustering pattern of the genotypes under study did not correspond to their geographic distribution. Eight clusters were found to have significant diversity both within and between them. With accordance to the eight clusters, cluster V had the most genotypes (16), followed by cluster III (12), cluster I (9) and cluster VII (7), clusters VI (6), cluster IV (5), cluster II (4), and cluster VIII, which had a single genotype. Cluster IV was followed by cluster VII in terms of intra-cluster distance. The highest intercluster distance was seen between clusters IV and VIII, followed by cluster II and VIII, and the least distance was seen between clusters I and III. In order to estimate genetic divergence, Kakani *et al.* in 2015 [20] evaluated fifty fenugreek (*Trigonella foenum-graecum* L.) germplasm samples along with five checks were divided into five clusters. Cluster III had an intra cluster distance ranging from 18.89 to 35.88. (Cluster IV). The distance between clusters was highest between cluster V and others, whereas it was lesser between cluster IV and III. However, cluster IV had the highest intra-cluster distance. Fenugreek (*Trigonella foenum-graecum* L.) genotypes were studied by Pathak *et al.* in 2014 [36] for their genetic divergence after D2 analysis. The research revealed that the genotypes could be divided into nine clusters. Cluster III have highest intra-cluster distance, followed by clusters IV and II. Cluster IV and cluster V had the maximum distance between them, followed by clusters I and IV. Protein content, one of the eleven traits examined for genetic divergence, contributed the most 53.85% of the total divergence followed by days to 50% flowering (16.41%) and seed yield/plant (15.90%). The study demonstrated that in breeding programmes for enhancing yield and quality traits, inter-mating between genotypes of various clusters may be undertaken to obtain heterotic response as well as better segregants. Twenty genotypes of fenugreek were studied by Tariyal *et al.* in 2017 [50] to estimate the degree of genetic

divergence. The research of the study entire genotype collection are divided into four clusters. The analysis of genotypes cluster revealed that for these characters, hybridization between genotypes from cluster III and cluster IV can result in better segregants in segregating populations. In order to measure genetic divergence, Panwar A. *et al.* 2017 [35] conducted a biometric analysis on various varieties of Indian fenugreek (*Trigonella foenum-graecum* L.) for seed yield and yield-contributing traits. The seventeen varieties were divided into two clusters based on diversity analysis, and there was no similarity between genetic and geographic diversity. Cluster I had the highest intra-cluster distance compared to Cluster II. Plant height came in second with a maximum contribution to total divergence of 37.5%.

## Conclusion

Currently young plant breeders face a problem in producing adequate genetic diversity to continuously increase genetic yield potential. In order to find new genotypes that will protect and enhance genetic gain through selection, plant breeders may use exotic non-adapted material or existing dominant germplasm. To feed the growing population on dwindling arable land, plant breeding faces challenges. In this aspect, success has been achieved in modern plant breeding. However, because of the limited genetic diversity of cultivated types in many crops, it has led to genetic fragility. Therefore, a fundamental change in plant breeding that concentrates on a variety of genetic resources is required. Genetic variability can play important role in maintaining the security of food and nutrition. Determining what to protect and where to conserve it will be easier with a good understanding of genetic variety. The long-term development of new cultivars is based on the genetic diversity of plants. Therefore, it is necessary to use various statistical approaches evaluating the various genetic resources and utilising them in the breeding programme. For accurate characterisation of germplasm resources, morphological and molecular data are used. High throughput molecular marker technologies have made it possible to characterise more germplasm with a limited amount of time and money. In conclusion, crop diversity in India has a tremendous wealth of genetic diversity in the fenugreek crop. This genetic diversity needs to be adequately collected and preserved before it is overwhelmed and destroyed by enhanced uniform strains and emerging technologies.

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## Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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