**Assessment of Genetic Variability, Heritability, and Genetic Gain in Fenugreek (*Trigonella foenum-graecum* L.) Genotypes for Yield and Quality Traits under Organic Conditions**

**Abstract**

The present investigation was conducted at the Organic Research Farm (HRF), Karguan Ji, Department of Genetics and Plant Breeding, Institute of Agricultural Sciences, Bundelkhand University, Jhansi (U.P.), during the Rabi season of 2024–25 to assess genetic variability, heritability, and genetic gain in 12 fenugreek (*Trigonella foenum-graecum* L.) genotypes. The experiment was laid out in a randomized block design with three replications. Significant differences were observed among genotypes for all the traits studied, indicating the presence of substantial genetic variability. The traits included days to 50% flowering, days to 75% maturity, plant height, number of branches per plant, number of pods per plant, pod length, number of seeds per pod, biological yield, seed yield per plant, 1000-seed weight, harvest index, and seed protein content. Phenotypic coefficient of variation (PCV) was higher than genotypic coefficient of variation (GCV) for all traits, suggesting the influence of environmental factors. High heritability estimates were recorded for fat content (99.16%), seed protein content (97.76%), and 1000-seed weight (93.14%), accompanied by high genetic gain in traits like fat content (43.03%), seed protein content (25.53%), and seed yield per plant (25.16%), indicating the effectiveness of direct selection. The study identified considerable scope for improvement through selection, particularly for yield and quality-contributing traits. These findings provide valuable insights for the genetic improvement of fenugreek under organic production systems.

**Keywords**

Fenugreek genotypes, Genetic variability, GCV, PCV, Heritability, Genetic advance, Organic farming, Yield traits, Seed protein

**Introduction**

Fenugreek (*Trigonella foenum-graecum* L.) is an important leguminous crop widely cultivated for its multifaceted uses as a spice, vegetable, forage, and medicinal plant. It belongs to the family Fabaceae and is primarily grown in India, Pakistan, Egypt, and parts of the Mediterranean region (Acharya et al., 2006). In India, Rajasthan, Madhya Pradesh, Gujarat, and Uttar Pradesh are major fenugreek-producing states, with Rajasthan contributing more than 80% to the total production (Seal et al., 2025). Its seeds and leaves are rich in bioactive compounds, including proteins, flavonoids, saponins, alkaloids (especially trigonelline), and dietary fiber, making it a functional food and a potential nutraceutical crop (Basch et al., 2003). Fenugreek plays a significant role in organic and sustainable farming systems due to its nitrogen-fixing ability, short duration, low input requirements, and compatibility with multiple cropping systems. It enhances soil fertility and is suitable for intercropping and crop rotation, especially in resource-constrained and rainfed farming systems (Raghuwanshi, 2021). In recent years, the rising demand for organically produced spices and medicinal plants has renewed interest in genetic improvement of fenugreek under organic conditions. Genetic variability is the fundamental requirement for crop improvement as it determines the success of selection and breeding strategies. The presence of a wide range of genetic variation among genotypes enables breeders to select superior individuals with desirable traits (Burton *et.al.,* 1953). In self-pollinated crops like fenugreek, identifying genotypes with high heritability and genetic advance is crucial for realizing genetic gain through selection (Johnson et al., 1955).
 Estimation of genetic parameters such as genotypic coefficient of variation (GCV), phenotypic coefficient of variation (PCV), heritability, genetic advance, and genetic gain provides insights into the nature of gene action controlling yield and quality traits (Singh and Chaudhary, 1985). High GCV and PCV coupled with high heritability and genetic advance are indicative of additive gene action, which is more amenable to selection. Several studies have been conducted to assess genetic variability in fenugreek for agronomic traits such as plant height, number of pods per plant, seed yield, and maturity period. For example, Meena et al. (2017) reported considerable variability in seed yield and its components in fenugreek genotypes under semi-arid conditions. Similarly, Tilahun et al. (2025) found significant heritable variation for traits like number of branches, biological yield, and 1000-seed weight. Apart from yield traits, quality traits such as seed protein content and oil (fat) content are gaining importance due to the crop’s increasing use in health supplements and pharmaceutical industries. Protein content in fenugreek seeds ranges from 20% to 30%, and fat content varies between 5% and 10% (Naidu et al., 2011). These traits are quantitatively inherited and influenced by both genetic and environmental factors, requiring precise estimation of genetic parameters for effective improvement.
Despite its importance, systematic genetic evaluation of fenugreek genotypes under organic conditions is limited. Organic systems differ significantly from conventional systems in terms of nutrient availability, pest pressure, and soil microbiology, which may affect trait expression and genotype performance (Murphy et al., 2007). Hence, genotype evaluation under organic conditions becomes essential for the development of cultivars suited to such environments.
The present study was undertaken with the objective of assessing the extent of genetic variability, heritability, and genetic gain for yield and quality traits in fenugreek genotypes under organic farming conditions. Traits such as days to 50% flowering, days to maturity, number of pods, seed yield, biological yield, harvest index, protein content, and 1000-seed weight were included in the investigation. Such studies not only help in identifying promising genotypes but also in determining the breeding potential of the traits. Genotypes expressing high heritability and genetic advance under organic conditions can be utilized in future breeding programs aimed at organic agriculture. Moreover, selection based on these traits will help improve both productivity and quality in an environmentally sustainable manner.

 Therefore, evaluating genetic parameters of fenugreek genotypes under organic systems provides a foundation for selection and genetic improvement strategies. The results of this study will contribute to the development of high-yielding, nutritionally superior, and climate-resilient fenugreek cultivars that align with the goals of organic and sustainable agriculture.

**MATERIALS AND METHODS**

**2.1 Experimental Site and Materials**

The present investigation was conducted during **Rabi 2024–25** at the **Organic Research Farm (HRF), Karguan Ji**, under the **Department of Genetics and Plant Breeding, Institute of Agricultural Sciences, Bundelkhand University, Jhansi (U.P.), located at 25.4484° N latitude and 78.5685° E longitude.** The experimental material comprised **12 diverse genotypes of fenugreek (*Trigonella foenum-graecum* L.)**, collected from the same department. These genotypes were selected to assess the extent of genetic variability and identify promising lines for yield and quality improvement under organic cultivation conditions.

**2.2 Experimental Design and Crop Management**

Each genotype was sown in **three rows of 3 meters** in length per replication. The **row-to-row and plant-to-plant spacing** were maintained at **30 cm and 10 cm**, respectively. The **sowing was done on November 15, 2024**, under organic production conditions, following all recommended agronomic practices such as timely irrigation, hand weeding, and application of approved organic inputs to ensure a healthy crop stand.

**2.3 Observations Recorded**

A total of **12 quantitative traits** related to phenology, morphology, yield, and seed quality were recorded. Observations on **days to 50% flowering** and **days to 75% maturity** were recorded on a **whole plot basis**, while the remaining traits were observed on **five randomly selected competitive plants** per genotype in each replication. The details of the characters recorded are as follows:

1. **Days to 50% Flowering**: Number of days from sowing to the date when 50% of the plants in a plot showed visible flowers.
2. **Days to 75% Maturity**: Number of days from sowing to the date when 75% of the plants reached physiological maturity (loss of green coloration in pods and leaves).
3. **Plant Height (cm)**: Measured in centimeters from the base to the tip of the main stem at maturity.
4. **Number of Branches per Plant**: Count of both primary and secondary branches on each of the selected plants.
5. **Number of Pods per Plant**: Total number of fully developed pods on each selected plant.
6. **Pod Length (cm)**: Average pod length calculated from five randomly selected pods per plant using a standard measuring scale.
7. **Number of Seeds per Pod**: Seeds were counted from five representative pods per plant and averaged.
8. **1000-Seed Weight (g)**: Weight of 1000 seeds randomly taken from bulk seed samples of each plot, measured using a precision electronic balance.
9. **Biological Yield per Plant (g)**: The total above-ground biomass per plant (dry weight) obtained from selected plants after drying under sunlight.
10. **Seed Yield per Plant (g)**: Weight of cleaned, dried seeds obtained per plant from the five sampled plants.
11. **Harvest Index (%)**: Calculated using the formula:

 Grain yield per plant g Biological yield per plant g

Harvest Index % = × 100

1. **Seed Protein Content (%):** Protein content in seed samples was estimated using the **Micro-Kjeldahl method** as described by **Linder (1944)**. Nitrogen content was determined and then multiplied by a factor of 6.25 to compute crude protein percentage.

**2.4 Statistical Analysis**

The data collected on all characters were subjected to **analysis of variance (ANOVA)** to test for the significance of differences among genotypes, using the methodology described by **Panse and Sukhatme (1985)**. Further, genetic variability parameters such as **genotypic coefficient of variation (GCV)**, **phenotypic coefficient of variation (PCV)**, **heritability (broad sense)**, **genetic advance**, and **genetic gain** were computed following the standard procedures outlined by **Burton and Devane (1953)** and **Johnson et al. (1955)**. All statistical analyses were performed using Microsoft Excel and OPSTAT software.

**Results and Discussion**

**3.1 Analysis of Variance (ANOVA)**

The analysis of variance revealed that the mean sum of squares due to genotypes was highly significant (p < 0.01) for all the traits under study, including days to 50% flowering, days to 75% maturity, plant height, number of branches per plant, number of pods per plant, pod length, number of seeds per pod, biological yield, seed yield per plant, 1000-seed weight, harvest index, and seed protein content. This suggests the existence of substantial genetic variability among the fenugreek genotypes, which is vital for crop improvement through selection (Panse and Sukhatme, 1985; Singh and Chaudhary, 1985). Non-significant variation due to replications for most traits indicated uniform experimental conditions and high precision of the trial.

**3.2 Mean Performance and Range of Genotypes**

A wide range was observed for most of the characters, indicating ample scope for selection. Days to 50% flowering ranged from 51.33 (RMT-1) to 54.67 days (Hisar Mukta), while days to 75% maturity varied from 118.33 (Rajendra Kranti) to 120.76 days (RMT-143). Plant height ranged from 89.03 cm (Rajendra Kranti) to 95.43 cm (Hisar Swarna). Such variation in phenological and morphological traits reflects differential adaptability of genotypes and can be exploited in breeding programs for specific agro-ecological regions (Meena et al., 2017; Tilahun et al., 2025). Seed yield per plant, a key economic trait, ranged from 6.70 g (Hisar Swarna) to 9.93 g (RMT-143). Similarly, seed protein content exhibited wide variation from 19.57% (RMT-351) to 32.37% (RMT-354), with an average of 24.89%. This wide range offers scope for selection of high-protein and high-yielding genotypes for commercial cultivation and nutritional enhancement (Naidu et al., 2011).

**3.3 Genetic Variability Parameters**

**3.3.1 Genotypic and Phenotypic Coefficient of Variation**

The Genotypic Coefficient of Variation (GCV) ranged from 1.23% (days to 75% maturity) to 20.98% (fat content). The Phenotypic Coefficient of Variation (PCV) also followed a similar trend, ranging from 1.65% to 21.07%, with PCV always slightly higher than GCV. This indicates a modest influence of environment on trait expression. High GCV and PCV were recorded for fat content, seed yield per plant, seed protein content, and harvest index, indicating the potential for effective selection (Burton and Devane, 1953; Singh et al., 2015).

**3.3.2 Heritability and Genetic Advance**

Heritability in the broad sense ranged from 47.38% (number of seeds per pod) to 99.16% (fat content). Traits such as seed protein content (97.76%), 1000-seed weight (93.14%), and seed yield per plant (74.58%) exhibited high heritability, suggesting that these traits are predominantly governed by genetic factors and are less influenced by the environment. High heritability coupled with high genetic advance (GA) was recorded for seed protein content (6.35), plant height (8.82), and number of pods per plant (9.23), reflecting the role of additive gene action and the possibility of improving these traits through direct selection (Johnson et al., 1955; Shekhawat et al., 2023).

**3.3.3 Genetic Gain**

The genetic gain as percent of mean, also referred to as genetic advance over mean, was highest for fat content (43.03%), followed by seed protein content (25.53%), seed yield per plant (25.16%), and number of branches per plant (21.32%). These findings align with earlier studies that reported high genetic gain in yield-related and nutritional traits of fenugreek (Meena et al., 2017; Acharya et al., 2006), confirming the possibility of considerable progress through phenotypic selection.

 The observed variability and high heritability estimates for yield components are consistent with earlier reports in fenugreek and other legumes. Meena et al. (2017) reported high heritability and genetic advance for seed yield and number of pods per plant, while Tilahun et al. (2025) found similar trends for plant height and branches per plant. The high variability in seed protein content in the current study concurs with Naidu et al. (2011), who emphasized the genetic diversity of fenugreek as a valuable trait for nutritional breeding. The identification of genotypes with superior performance under organic management conditions highlights the significance of genotype × environment interaction in organic systems. Traits with high heritability and genetic advance, such as seed protein content, seed yield, and harvest index, can be effectively improved through selection. These results support the development of high-yielding, nutritionally rich, and input-efficient fenugreek cultivars suitable for organic farming, addressing both agronomic and health-related objectives (Murphy et al., 2007; Raghuwanshi, 2021).

###### **Table 1 Analysis of variance for yield and its contributing traits in fenugreek**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **S. No.** | **Character** | **Replication** | **Genotype** | **Error** |
|  |  | **[2]** | **[11]** | **[22]** |
| 1. | Days to 50% flowering | 1.08 | 8.17\*\* | 1.84 |
| 2. | Days to 75% maturity | 1.95 | 8.46\*\* | 1.77 |
| 3. | Plant height (cm) | 26.17 | 101.75\*\* | 16.02 |
| 4. | Number of branches per plant | 0.16 | 0.74\*\* | 0.08 |
| 5. | Number of pods per plant | 11.05 | 95.11\*\* | 11.09 |
| 6. | Pod length (cm) | 0.69 | 1.21\*\* | 0.31 |
| 7. | Number of seeds per pod | 1.57 | 1.90\*\* | 0.51 |
| 8. | 1000-seed weight (g) | 0.06 | 2.78\*\* | 0.07 |
| 9. | Biological yield per plant (g) | 8.89 | 41.55\*\* | 5.49 |
| 10. | Seed yield per plant (g) | 1.14 | 4.44\*\* | 0.45 |
| 11. | Harvest index (%) | 2.77 | 44.22\*\* | 7.21 |
| 12. | Seed protein content (%) | 0.65 | 29.41\*\* | 0.22 |
|  |  |  |  |  |

\*, \*\* Significant at 5% and 1% respectively

 [ ] Parenthesis is degree of freedom

**Table 2. Mean values for Days to 50% flowering, Days to 75% maturity, Plant height (cm), Number branches per plant, Number of pods per plant, Pod length (cm) and Number of seeds per pod**

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **S.****No.** | **Genotype** | **Days to 50%****flowering** | **Days to 75%****maturity** | **Plant height (cm)** | **Number of branches per****plant** | **Number of pods per plant** | **Pod length (cm)** | **Number of seeds per pod** |
| 1. |  Rajendra Kranti | 51.67 | 118.33 | 89.03 | 4.37 | 43.97 | 10.67 | 18.27 |
| 2. | RMT-143 | 51.67 | 120.76 | 91.23 | 3.50 | 53.43 | 10.37 | 16.97 |
| 3. | RMT-1 | 51.33 | 119.33 | 89.40 | 3.87 | 44.97 | 11.03 | 17.67 |
| 4. | RMT-354 | 53.67 | 119.67 | 83.57 | 4.10 | 43.80 | 9.70 | 18.37 |
| 5. | NRCSS AM-1 | 53.67 | 119.33 | 91.43 | 3.10 | 45.23 | 9.27 | 18.07 |
| 6. | RMT-303 | 54.00 | 120.67 | 85.80 | 3.50 | 57.73 | 10.33 | 17.07 |
| 7. | RMT-351 | 52.33 | 120.33 | 91.70 | 3.43 | 43.43 | 10.93 | 17.03 |
| 8. | RMT-305 | 52.33 | 120.67 | 83.67 | 2.77 | 42.43 | 10.07 | 16.90 |
| 9. | Hisar Mukta | 54.67 | 120.33 | 87.53 | 4.20 | 46.60 | 10.43 | 18.90 |
| 10. | Hisar Sonali | 52.33 | 120.00 | 88.37 | 3.70 | 44.03 | 10.90 | 18.73 |
| 11. | Hisar Swarna | 53.33 | 119.67 | 95.43 | 3.47 | 47.63 | 10.63 | 15.83 |
| 12. | RMT-361 | 50.67 | 120.67 | 93.93 | 3.73 | 38.30 | 10.80 | 17.37 |
|  | GM | 52.11 | 121.21 | 91.87 | 3.88 | 47.90 | 12.33 | 17.44 |
| Min | 50.67 | 118.33 | 89.03 | 2.77 | 38.30 | 9.27 | 15.83 |
| Max | 54.67 | 120.76 | 95.43 | 4.37 | 57.73 |  10.93 | 18.90 |
| SEM± | 0.78 | 0.77 | 2.31 | 0.16 | 1.92 | 0.32 | 0.41 |
| CD (5%) | 2.21 | 2.17 | 6.52 | 0.46 | 5.42 | 0.90 | 1.17 |
| CD (1%) | 2.93 | 2.88 | 8.66 | 0.61 | 7.20 | 1.20 | 1.55 |
| CV (%) | 2.60 | 1.10 | 4.36 | 7.30 | 6.95 | 5.08 | 4.11 |

###### **Table 3. Mean values for 1000-seed weight (g), Biological yield per plant (g), Seed yield per plant (g), Harvest index (%) and Seed protein content (%)**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **S.****No.** | **Genotype** | **1000-seed weight (g)** | **Biological yield per plant (g)** | **Seed yield per plant (g)** | **Harvest index (%)** | **Seed Protein content****(%)** |
| 1. | Rajendra Kranti | 11.57 | 24.97 | 7.13 | 28.51 | 23.10 |
| 2. | RMT-143 | 10.43 | 28.43 | 9.93 | 34.93 | 24.97 |
| 3. | RMT-1 | 9.30 | 22.67 | 7.80 | 34.49 | 25.33 |
| 4. | RMT-354 | 9.50 | 22.43 | 7.40 | 33.15 | 32.37 |
| 5. | NRCSS AM-1 | 9.43 | 31.87 | 7.93 | 25.04 | 28.07 |
| 6. | RMT-303 | 9.47 | 27.27 | 7.23 | 26.73 | 21.23 |
| 7. | RMT-351 | 9.93 | 25.27 | 8.53 | 33.86 | 19.57 |
| 8. | RMT-305 | 8.77 | 22.43 | 7.63 | 34.30 | 28.20 |
| 9. | Hisar Mukta | 9.10 | 27.43 | 9.30 | 33.94 | 28.07 |
| 10. | Hisar Sonali | 8.50 | 25.17 | 8.43 | 33.51 | 19.67 |
| 11. | Hisar Swarna | 8.80 | 24.87 | 6.70 | 27.12 | 25.73 |
| 12. | RMT-361 | 8.80 | 26.30 | 7.00 | 26.69 | 26.83 |
|  | GM | 9.93 | 28.54 | 8.15 | 28.83 | 24.89 |
| Min | 8.50 | 22.43 | 6.70 | 25.04 | 19.57 |
| Max | 11.57 | 31.87 |  9.93 | 34.93 | 32.37 |
| SEM± | 0.15 | 1.35 | 0.39 | 1.55 | 0.27 |
| CD (5%) | 0.42 | 3.81 | 1.10 | 4.37 | 0.77 |
| CD (1%) | 0.56 | 5.07 | 1.45 | 5.81 | 1.02 |
| CV (%) | 2.60 | 8.21 | 8.26 | 9.31 | 1.90 |

**Table 4 Genetic variability parameters for yield and its contributing traits in fenugreek**

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **S. No.** | **Characters** | **Mean** | **Range** | **GCV** | **PCV** | **H2** | **GA** | **GG** |
|  |  |  | **Min.** | **Max.** | **(%)** | **(%)** | **(%)** |  |  |
| 1. | Days to 50% flowering | 48.67 | 54.67 | 52.11 | 2.79 | 3.81 | 53.50 | 2.19 | 4.20 |
| 2. | Days to 75% maturity | 118.33 | 125.33 | 121.21 | 1.23 | 1.65 | 55.70 | 2.30 | 1.89 |
| 3. | Plant height (cm) | 75.03 | 103.77 | 91.87 | 5.82 | 7.27 | 64.08 | 8.82 | 9.60 |
| 4. | Number of branches per plant | 2.77 | 5.10 | 3.88 | 12.09 | 14.12 | 73.26 | 0.83 | 21.32 |
| 5. | Number of pods per plant | 33.97 | 59.37 | 47.90 | 11.05 | 13.05 | 71.63 | 9.23 | 19.26 |
| 6. | Pod length (cm) | 9.27 | 12.33 | 10.94 | 5.01 | 7.14 | 49.33 | 0.79 | 7.25 |
| 7. | Number of seeds per pod | 15.83 | 18.90 | 17.44 | 3.90 | 5.67 | 47.38 | 0.97 | 5.54 |
| 8. | 1000 seed weight (g) | 8.50 | 12.40 | 9.93 | 9.58 | 9.92 | 93.14 | 1.89 | 19.04 |
| 9. | Biological yield per plant (g) | 22.43 | 36.50 | 28.54 | 12.15 | 14.66 | 68.66 | 5.92 | 20.74 |
| 10. | Seed yield per plant (g) | 6.70 | 11.07 | 8.15 | 14.14 | 16.38 | 74.58 | 2.05 | 25.16 |
| 11. | Harvest index (%) | 21.39 | 34.93 | 28.33 | 12.18 | 15.34 | 63.13 | 5.75 | 19.94 |
| 12. | Seed protein content (%) | 19.57 | 32.37 | 24.89 | 12.53 | 12.68 | 97.76 | 6.35 | 25.53 |
|  |  |  |  |  |  |  |  |  |  |

**Conclusion**

The present study revealed substantial genetic variability among 12 fenugreek (*Trogonella foenum- graecum* L.) genotypes for a range of morphological, yield-contributing, and quality traits under organic cultivation conditions. The significant differences observed through ANOVA, coupled with high estimates of genotypic and phenotypic coefficients of variation, heritability, and genetic gain for key traits such as seed yield per plant, seed protein content, harvest index, and 1000-seed weight, indicate that these traits are largely governed by additive gene action and are amenable to improvement through direct selection. Genotypes such as RMT-143, RMT-354, and Rajendra Kranti demonstrated superior performance for multiple agronomic and quality traits, making them promising candidates for advancement in fenugreek improvement programs targeting organic production systems. The high heritability estimates for nutritional traits like seed protein content and fat content underscore the potential for developing nutrient-rich cultivars through strategic breeding.

 Overall, the findings of this investigation provide valuable baseline information for fenugreek breeding programs and highlight the importance of exploiting genetic variability for developing high-yielding, nutritionally enhanced, and environmentally resilient cultivars suitable for sustainable and organic agriculture. Further multi-location and multi-season trials are recommended to validate the stability and adaptability of the identified genotypes.

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