



Comparative Analysis of Morphological and Biochemical Profiles in Different Fenugreek (*Trigonella foenum-graecum* L.) Biotypes

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Fenugreek (*Trigonella foenum-graecum* L.), an annual plant of the Fabaceae family, widely recognized for its medicinal and nutritional value, is cultivated for its seeds and leaves that are rich in bioactive compounds such as phenol, alkaloid, saponin and tannin. In this study, seven fenugreek genotypes—Hisar Sonali, Rajendra Kranti, Gujarat Methi-1, Pusa Early Bunching, RMT-1, CO-1, and Pant Ragini—were evaluated under a completely randomized design to assess their morphological, physiological, and biochemical characteristics. The scientific analysis showed that the biotypes had significant variations in timing of flowering, fresh and dry weight, water relations traits, and phyto-biochemical content. The average days to 50% flowering was early in the Rajasthan Methi-1 (50.10). The fresh weight of the stem ranged from 12.85 g in Rajasthan Methi-1

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to 17.95 g in Pant Ragini, while the dry weight in Pant Ragini reached 6.55 g. Water relations also differed as indicated by relative water content (RWC) and water saturation deficit (WSD). Pant Ragini displayed the highest RWC (88.96%), indicating better water retention, while Rajasthan Methi-1 recorded the highest relative water deficit (RWD) of 22.37%, indicating greater sensitivity to water stress. Total carbohydrate content (TCC) was highest in Hisar Sonali (32.57%) and lowest in Coimbatore-1 (24.94%), with all genotypes having significant carbohydrate and phenolic contents. These findings provide the basis for further breeding and selection programs aimed at enhancing the medicinal and agronomic value of fenugreek.

Keywords: Fenugreek; Morphological; bioactive compounds; water relation traits; phytochemical analysis.

1. INTRODUCTION

Fenugreek (*Trigonella foenum-graecum* L.), a member of the Fabaceae family, has been cultivated for millennia due to its important nutritional and therapeutic properties. According to the World Health Organization [1], fenugreek is a historically important plant consumed internationally as a traditional medicinal and food ingredient. Fenugreek is known for its complex phytochemical composition, which provides anticancer, antidiabetic, antioxidant, hypocholesterolemic, antibacterial and immunomodulatory activities, making it a valuable plant in culinary and medicinal applications [2]. In the *Trigonella* genus, which includes about 260 species, *T. foenum-graecum* is the most cultivated species all over [3], which originates from the Mediterranean region but is now cultivated in Asia, Africa and Europe [4]. The plant is an aromatic herb known for its aromatic seeds and nutrient-rich leaves, grown in moderate to low rainfall and cool environments, often prefers dry or semi-arid soils with high saline levels [5].

Fenugreek has trifoliate leaves, white flowers, and yellowish-brown oblong seeds. The seeds, usually 2–3 mm in length, are a distinctive feature and feel slightly sandy [6]. The plant itself grows to a height of 30–60 cm, with branches, hairy stems, and lanceolate leaves [4]. These morphological properties promote its wide use as a healthy vegetable, a spice, and herbal medicine, and as a valuable item in traditional diets. Fenugreek seeds provide a rich range of nutrients, containing about 25% fiber, 0.9% fat, 23–26% protein, and 58% carbs. The leaves supply large levels of protein (6%), fiber (4.4%), and carbs (1.1%), as well as important minerals such as potassium, calcium, magnesium, and iron [7]. These seeds and leaves contain not only macronutrients but also bioactive substances, including vitamins C and A, beta-

carotene, and flavonoids, which contribute to their antioxidant capacity [8]. Fenugreek is rich in flavonoids such as quercetin, kaempferol, and luteolin, which are known for their anti-inflammatory and antioxidant properties [9]. The seeds of the plant are also rich in alkaloids, especially trigonelline and choline, which have antibacterial and antifungal activities, justifying the traditional medical use of this herb [4].

Relative amount of water and water saturation deficit is the most important physiological factors for assessing plant water status under varying environmental conditions and yield contribution [10]. These parameters directly influence plant physiological (photosynthesis, chlorophyll content and accumulation of biomass) and biosynthesis of primary and secondary metabolites, which are vital for the plant's adaptive responses and medicinal value [11,12]. Fenugreek seeds and leaves contain phenolic compounds such as phenols, alkaloids and saponin and tannins which are responsible for antioxidant, anti-inflammatory and hypoglycaemic activity [13, 14]. Due to high content of protein and bioactive compound in fenugreek it a good functional food and can serve as a potential component in nutraceuticals [15]. Flavonoids, the group of compounds found in fenugreek, shows the free radical scavenging activity while the alkaloids and saponins displays the hypolipidaemic and antidiabetic effect [16].

Studies conducted on the phytochemical activity of fenugreek have revealed that it contains steroidal saponins, phenolic acids, and various glycosides that enhance its medicinal properties [17]. These bioactive compounds provide significant health benefits, making fenugreek a natural cure for diabetes, cancer, hypercholesterolemia, and inflammatory disorders [7]. The phytochemistry of the plant varies greatly with genotype and environmental

conditions, resulting in diverse profiles of bioactive chemicals depending on regional and climatic parameters [6]. Understanding these variations is important in designing standardized herbal preparations that enhance the therapeutic value of fenugreek.

2. MATERIALS AND METHODS

2.1 Materials

Plant material and study location: In this study, seven different fenugreek genotypes—Hisar Sonali, Rajendra Kranti, Gujrat Methi-1, Pusa Early Bunching, RMT-1, Co-1, and Pant Ragini—were used for evaluating their phytochemical and bioactive compounds.

2.2 Methods

Raising of crop & experimental design: To avoid contamination during the experiment, the seeds were surface sterilized for five minutes using mercuric chloride (HgCl_2 ; 0.1%). 10 kgs of rich agricultural soil and five sterilized seedlings were placed in clay pots. Complete randomization design (CRD) was applied to triplicated pots in the experimental area of Department of Life Science, Baba Mastnath University, Rohtak.

2.3 Observations Recorded

The observation of various morphological, physiological, and biochemical parameters was recorded. The data was recorded on three plants per genotype.

Number of Days to 50% flowering: The days to 50% flowering were calculated by counting the number of days between the date of planting and the day that 50% of the plants in each experimental plot bloomed.

Leaf Fresh and Dry Weight (g): The leaf's fresh and dried weights were recorded. Ten fully grown leaves of about identical size were collected and given a DDW wash. The extra water was soaked in tissue paper. After room drying, fresh weights were obtained, and after drying, dry weights were obtained.

Stem Fresh and Dry weight (g): The stem's fresh and dried weights were recorded. Ten fully grown stems of about identical size were collected and given a DDW wash. The extra water was soaked in tissue paper. After room drying, fresh weights were obtained, and after drying, dry weights were obtained.

Relative Water Content (RWC; %): The relative water content is a measure of the plant's water status and hydration level. To determine RWC, fresh leaf samples are weighed (fresh weight, FW), then floated in distilled water for 4–6 hours to reach full turgidity. The samples are gently blotted and weighed again (turgid weight, TW). Finally, the samples are dried in an oven at 80°C for 24 hours to obtain the dry weight (DW). The relative water content was calculated using the Bars and Weatherly technique [18] and expressed in the percentage (%).

$$\text{RWC (\%)} = (\text{FW} - \text{DW}) / (\text{TW} - \text{DW}) \times 100$$

Water Saturation deficit (WSD): The difference between the quantity of water that a soil or substance can store at full saturation and the amount that it now contains is known as the water saturation deficit.

$$\text{Water Saturation Deficit (\%)} = 100\% - \text{RWC}$$

Total carbohydrate content (TCC): The total carbohydrate content was quantified using the anthrone method according to Hege and Hofreiter [19]. Weigh an 1g of the powdered sample (from dry leaf) and extract the carbohydrates by boiling in 80% ethanol (v/v) and centrifuge to remove the pellets. Collect the supernatant and 1 mL was mixed with 4 mL of 2Molar H_2SO_4 and placed in a boiling water bath for 3 h, then cooled to room temperature and centrifuged. The supernatant was used to calculate TCC based on glucose as a standard reference. The results were expressed on percentage (%) basis of total carbohydrate.

Total phenolic content (TPC): The Folin-Ciocalteu method established by Swain and Hillis [20] was used to determine TPC. To the extract of a sample of 1 mg/mL, 2.5 mL of 10% Folin-Ciocalteu reagent and 2 mL of 2% Na_2CO_3 were added. This mixture was left to react for 15 min at room temperature, and the absorbance was measured at 765 nm using a UV-VIS spectrophotometer. A standard calibration curve was constructed with gallic acid at a concentration of 0.1–0.5 mg/mL, and TPC results were expressed as mg gallic acid equivalent per gram of dry weight extract (GAE/g DWE).

Lipid content: Lipid content was estimated using the Folch method [21], which involved a mixture of chloroform and methanol (2:1, v/v). The microalgal suspension pellet was mixed with the solvent mixture, vortexed, and methanol and

water were added to obtain a final ratio of 1:1:0.9 for methanol, chloroform, and water, respectively. The mixture was transferred to a separating funnel and stirred, then incubated to form two phases. The lipid content in the lower phase was separated and quantified by gravity after solvent evaporation using a rotary evaporator.

Phytochemical tests: For anthocyanin analysis, the spectrophotometric method of Swain and Hillis [22] was used. Anthocyanins were extracted and measured at 520 nm. Alkaloids were detected by heating the methanolic and aqueous extracts with 2% H₂SO₄ for two minutes, then filtering and adding Mayer's reagent; a yellow precipitate confirmed their presence. Saponins were tested by mixing 1 mL of the extract with 20 mL of distilled water, followed by vigorous stirring in a graduated

cylinder; the appearance of stable froth indicated the presence of saponins.

3. RESULTS

The study assessed the morphological, physiological, and biochemical characteristics of different biotypes in terms of days till 50% flowering, leaf fresh weight, leaf dry weight, stem fresh weight, stem dry weight, relative water content (RWC), water deficit (RWD), water saturation deficit (WSD), lipid content, total phenolic content, total carbohydrate content (TCC), anthocyanins, saponins and alkaloids. The data presented in the Tables and Figures shows the mean values with standard errors (S.E.) for each parameter across biotypes: Coimbatore-1, Gujarat Methi-1, Hisar Sonali, Pusa Early Bunching, Pant Ragini, Rajendra Kranti, and Rajasthan Methi-1.

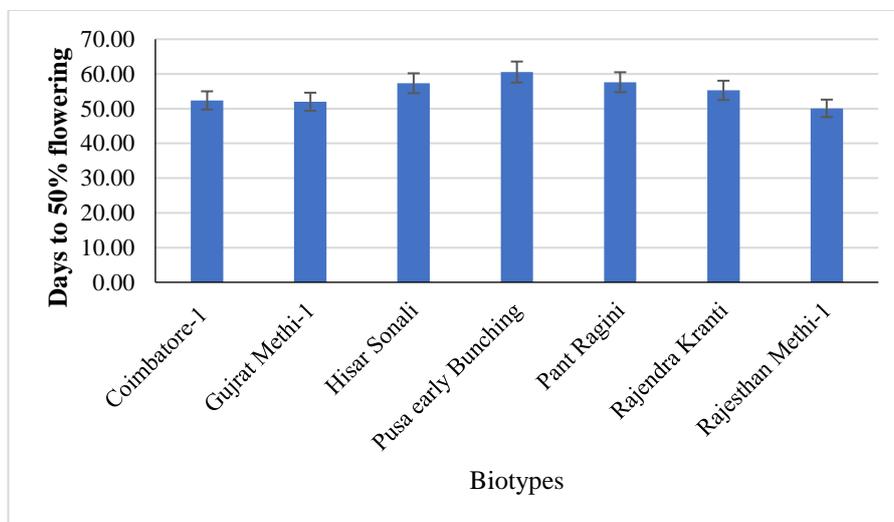


Fig. 1. Number of days to 50% flowering of different biotypes of *Trigonella foenum graecum* L.

Table 1. Morphological characteristics of different biotypes of *Trigonella foenum graecum* L.

Biotypes	LFW		LDW		SFW		SDW	
	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.
Coimbatore-1	4.69	±0.078	1.95	±0.015	14.68	±0.244	4.92	±0.000
Gujrat Methi-1	4.32	±0.098	0.73	±0.006	13.35	±0.255	3.63	±0.089
Hisar Sonali	5.12	±0.092	1.63	±0.015	16.25	±0.110	5.98	±0.042
Pusa early Bunching	5.26	±0.089	1.55	±0.012	17.63	±0.348	6.25	±0.104
Pant Ragini	5.42	±0.050	1.95	±0.050	17.95	±0.134	6.55	±0.170
Rajendra Kranti	4.86	±0.054	1.55	±0.012	15.85	±0.182	5.73	±0.045
Rajasthan Methi-1	3.94	±0.068	0.65	±0.003	12.85	±0.300	2.85	±0.068
C.D.	0.24		0.07		0.73		0.27	
SE(m)	0.08		0.02		0.24		0.09	
SE(d)	0.11		0.03		0.34		0.13	

LFA: Leaf Fresh Weight, LDW: Leaf Dry Weight, SFW; Stem Fresh Weight, SDW: Stem Dry Weight

Days to 50% flowering: The number of days required till 50% flowering was significantly different across biotypes. Pusa Early Bunching showed the longest time to 50% flowering (60.54 ± 0.946 days), indicating a slow flowering response. In contrast, Rajasthan Methi-1 reached 50% flowering (50.10 ± 0.806 days) the fastest, indicating a faster reproductive cycle. This variation may be associated with genetic or environmental adaptation differences among biotypes. The significant difference (C.D.) of 2.23 days confirms a statistically significant difference in flowering time, which is relevant for selecting biotypes with specific flowering responses.

Fresh and dry weight of leaves: Significant variation in fresh weight of leaves was observed among biotypes. Pant Ragini showed the highest average leaf fresh weight (5.42 ± 0.050 g), followed by Pusa Early Bunching (5.26 ± 0.089 g) and Hisar Sonali (5.12 ± 0.092 g). Rajasthan Methi-1 recorded the lowest fresh leaf weight of 3.94 ± 0.068 g. The significant difference (C.D.) value for fresh leaf weight was 0.24, indicating a statistically significant difference between biotypes. A similar trend was observed in leaf dry weight, with both Pant Ragini and Coimbatore-1 recording the highest values (1.95 ± 0.015 g for Coimbatore-1 and 1.95 ± 0.050 g for Pant Ragini). Hisar Sonali also displayed a relatively high leaf dry weight (1.63 ± 0.015 g), while Rajasthan Methi-1 had the lowest dry leaf weight

of 0.65 ± 0.003 g. The CD for dry leaf weight was 0.07, which further confirms the statistically significant differences observed.

Stem fresh and dry weight: Pant Ragini (17.95 ± 0.134 g) and Pusa Early Bunching (17.63 ± 0.348 g) had the highest stem fresh weight, indicating robust stem development of these biotypes. Hisar Sonali had a stem fresh weight of 16.25 ± 0.110 g. Rajasthan Methi-1 displayed the lowest stem fresh weight (12.85 ± 0.300 g), with a CD of 0.73. The C.D. value for stem dry weight was 0.27, which proves the statistical significance of difference between biotypes.

Leaf Relative Water Content (RWC; %): Leaf relative water content, a measure of water-holding capacity, showed notable differences among biotypes. Pant Ragini recorded the highest RWC ($88.96 \pm 2.527\%$), followed by Pusa Early Bunching ($87.05 \pm 0.800\%$). In contrast, Rajasthan Methi-1 had the lowest RWC ($73.38 \pm 5.792\%$), suggesting low water holding capacity under the measured conditions. The C.D. value of 9.22 supports significant variation in RWC among biotypes, indicating potential differences in drought tolerance and water-use efficiency. The coefficient of variation (C.V.) of 6.36 indicates moderate variability within this parameter, suggesting that leaf water content is relatively stable across measurements but still shows variation among biotypes.

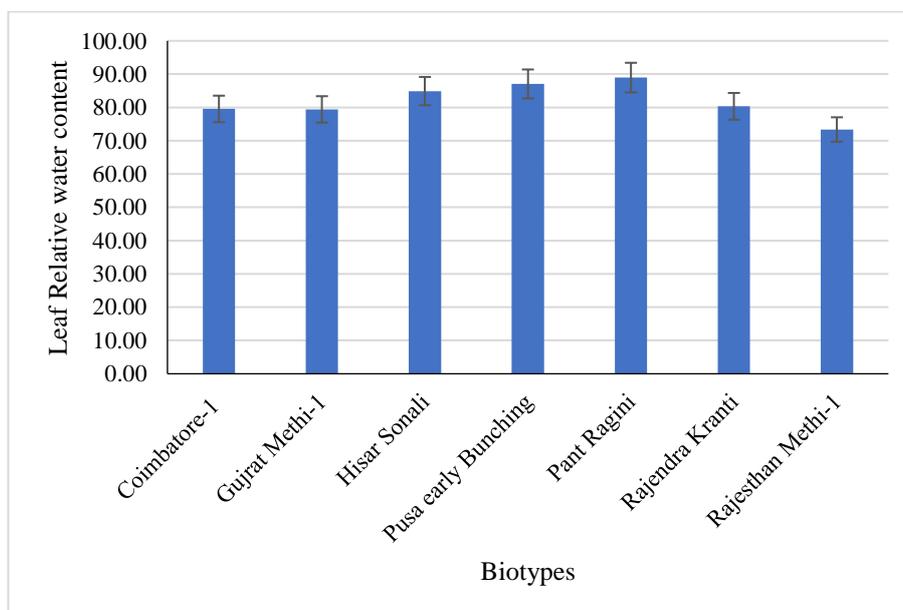


Fig. 2. Leaf Relative Water Content (RWC; %) of different biotypes of *Trigonella foenum graecum* L.

Table 2. Physiological characteristics of different biotypes of *Trigonella foenum graecum* L.

Biotypes	RWD		WSD		TCC	
	Mean	S.E.	Mean	S.E.	Mean	S.E.
Coimbatore-1	16.97	±1.572	20.59	±2.755	24.94	±0.154
Gujrat Methi-1	17.14	±2.243	20.45	±1.728	31.45	±0.720
Hisar Sonali	12.59	±2.397	15.09	±2.802	32.57	±0.428
Pusa early Bunching	10.51	±0.745	12.95	±0.800	30.43	±0.333
Pant Ragini	9.32	±1.720	11.04	±2.527	29.98	±0.467
Rajendra Kranti	16.37	±1.725	19.67	±2.106	25.31	±0.016
Rajasthan Methi-1	22.37	±5.259	26.62	±5.792	32.25	±0.770
C.D.	7.97		9.22		1.49	
SE(m)	2.60		3.01		0.49	
SE(d)	3.68		4.26		0.69	

RWD: Relative Water Deficit, WSD: Water Saturation Deficit, TCC: Total Carbohydrate Content

Relative Water Deficit (RWD; %): The relative water deficit (RWD) differed significantly among biotypes. Rajasthan Methi-1 displayed the highest RWD at $22.37 \pm 5.259\%$, indicating greater water stress, while Pant Ragini displayed the lowest RWD ($9.32 \pm 1.720\%$), suggesting its resilience under water-limited conditions. Other biotypes, including Coimbatore-1 ($16.97 \pm 1.572\%$) and Gujarat Methi-1 ($17.14 \pm 2.243\%$), had moderate RWD levels. The critical difference (C.D.) value of 7.97 confirms the significant difference in RWD among biotypes.

Water saturation deficit (WSD): In terms of water saturation deficit (WSD), Rajasthan Methi-1 again recorded the highest average ($26.62 \pm 5.792\%$), followed by Coimbatore-1 ($20.59 \pm 2.755\%$) and Gujarat Methi-1 ($20.45 \pm 1.728\%$), indicating greater sensitivity to water saturation deficit. In contrast, Pant Ragini and Pusa Early Bunching displayed lower WSD values ($11.04 \pm 2.527\%$ and $12.95 \pm 0.800\%$, respectively), suggesting a more favourable water holding capacity. The C.D. of 9.22 supports the statistical significance of the difference in WSD across biotypes.

Total Carbohydrate Content (TCC): Significant variation was also observed in total carbohydrate content (TCC), with Hisar Sonali ($32.57 \pm 0.428\%$) and Rajasthan Methi-1 ($32.25 \pm 0.770\%$) showing the highest carbohydrate levels, which may indicate greater photosynthetic capacity or carbohydrate storage capacity. Gujarat Methi-1 ($31.45 \pm 0.720\%$) and Pusa Early Bunching ($30.43 \pm 0.333\%$) also had high TCC. In contrast, Coimbatore-1 had the lowest carbohydrate content at $24.94 \pm 0.154\%$. The C.D. value for TCC (1.49) validates the statistical relevance of these observed differences.

Lipid Content: Lipid content analysis showed that Hisar Sonali had the highest lipid concentration (91.46 ± 1.046 mg/g), followed by Rajasthan Methi-1 (91.21 ± 0.619 mg/g) and Gujarat Methi-1 (89.19 ± 0.651 mg/g). Coimbatore-1, with a lipid content of 75.72 ± 1.062 mg/g, had the lowest value among biotypes, suggesting a comparatively low lipid reserve. The CD of 3.05 confirms significant variation in lipid content across biotypes, and the CV of 2.04% indicates that lipid content is one of the most stable traits within this dataset.

Total Phenolic Content: Phenolic content showed great variation across biotypes, with Rajasthan Methi-1 exhibiting the highest concentration (62.05 ± 1.130 mg/g), followed by Gujarat Methi-1 (61.15 ± 1.463 mg/g). Rajendra Kranti had the lowest phenolic content (59.03 ± 0.091 mg/g), suggesting lower antioxidant capacity compared to other biotypes. The absence of a CD value for phenolic content implies that the variation observed may not be statistically significant. However, with a CV of 2.534%, phenolic content is generally stable across biotypes, although minor variations are observed in this trait.

Anthocyanin Content: Anthocyanin content varied across biotypes, with Hisar Sonali exhibiting the highest average anthocyanin level (7.98 ± 0.057 mg/g), followed by Rajasthan Methi-1 (7.55 ± 0.158 mg/g) and Gujarat Methi-1 (7.15 ± 0.119 mg/g). Coimbatore-1 had the lowest anthocyanin content (5.75 ± 0.131 mg/g), indicating significant differences in pigmentation and possibly antioxidant capacity among biotypes. The significant difference (C.D.) of 0.35 highlights the statistically significant variation observed in anthocyanin content.

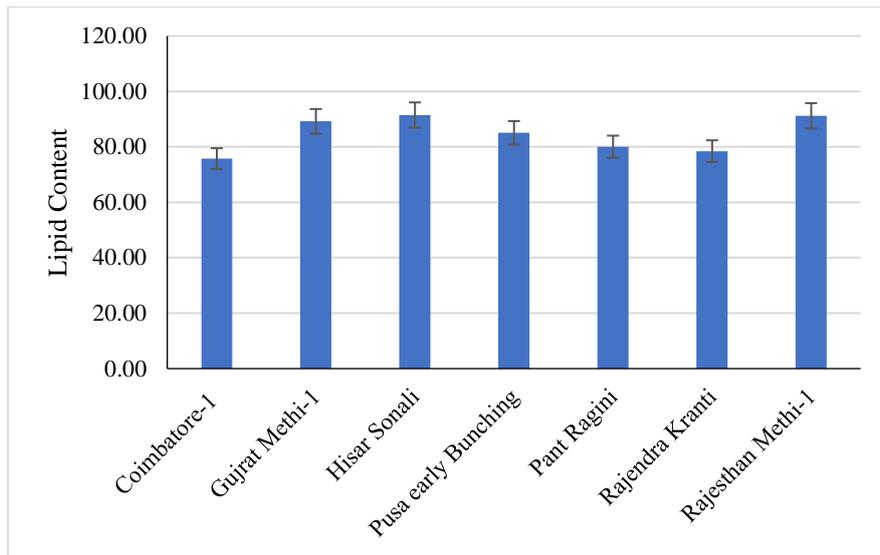


Fig. 3. Lipid content of different biotypes of *Trigonella foenum graecum* L.

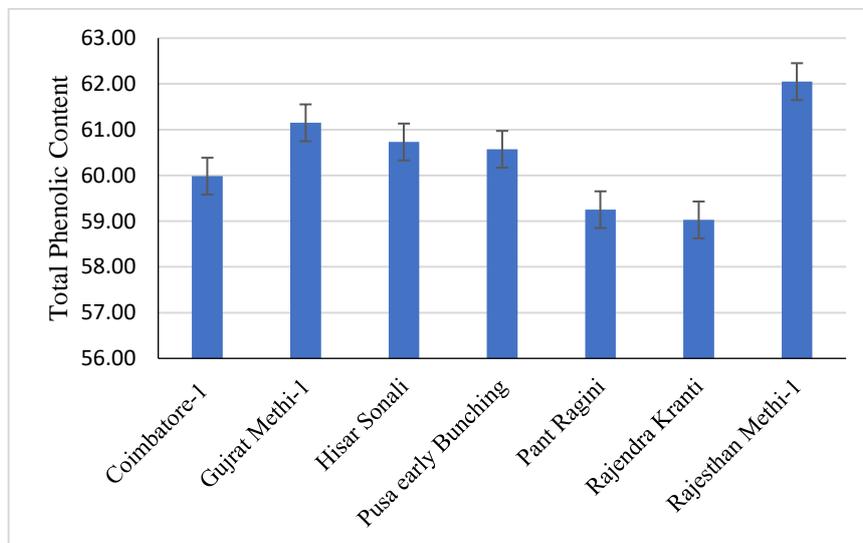


Fig. 4. Total Phenolic content of different biotypes of *Trigonella foenum graecum* L.

Table 3. Estimation of Phytochemical compounds of different biotypes of *Trigonella foenum graecum* L.

Biotypes	Anthocyanin		Saponin		Alkaloids	
	Mean	S.E.	Mean	S.E.	Mean	S.E.
Coimbatore-1	5.75	±0.131	3.15	±0.003	18.23	±0.172
Gujrat Methi-1	7.15	±0.119	4.58	±0.059	22.34	±0.348
Hisar Sonali	7.98	±0.057	5.65	±0.134	37.78	±0.178
Pusa early Bunching	6.92	±0.137	4.37	±0.000	21.23	±0.395
Pant Ragini	6.45	±0.095	4.25	±0.071	20.23	±0.318
Rajendra Kranti	6.15	±0.062	3.35	±0.080	19.34	±0.271
Rajasthan Methi-1	7.55	±0.158	5.35	±0.116	36.45	±0.588
C.D.	0.35		0.25		1.07	
SE(m)	0.11		0.08		0.35	
SE(d)	0.16		0.12		0.50	

Saponin content: Saponin levels were also variable, with Hisar Sonali showing the highest concentration (5.65 ± 0.134 mg/g), followed by Rajasthan Methi-1 (5.35 ± 0.116 mg/g). Gujarat Methi-1 recorded medium saponin levels (4.58 ± 0.059 mg/g), while Coimbatore-1 showed the lowest saponin content (3.15 ± 0.003 mg/g). The CD value of 0.25 indicates that these differences are statistically significant, indicating diversity in biochemical traits among biotypes.

Alkaloid Content: In terms of alkaloid content, Hisar Sonali displayed the highest concentration (37.78 ± 0.178 mg/g), followed by Rajasthan Methi-1 (36.45 ± 0.588 mg/g), suggesting the potential of these biotypes as a source of bioactive compounds. On the other hand, Coimbatore-1 showed the lowest alkaloid levels (18.23 ± 0.172 mg/g). With a CD of 1.07, these differences in alkaloid content are statistically significant, indicating substantial variability in secondary metabolite production among biotypes.

Statistical Interpretation: The statistical parameters CD, SE(M), and SE(D) are important in validating the differences among biotypes. The CD values for each parameter highlight significant differences in leaf and stem weights across biotypes. The standard errors (SE) for each mean provide information about the precision and variability of the data within each biotype. The SE(m) and SE(d) values confirm the consistency of the observed trends.

4. DISCUSSION

This investigation gives the values of morpho-physiological parameters no. of days to 50% flowering, fresh and dry weight of leaves and stem, leaf relative water content, relative water deficit and water saturation deficit. Analysis of the result showed that the Pusa Early Bunching is superior from all the biotypes in number of days to 50% flowering. In fresh and dry weight of leaves and stem Pant ragini is uppermost in all biotypes. Greater branches and fresh weight may be positively impacted by the maximum plant height, and the large variance in the treatment combination may be the result of changes in the genetic composition of the types. According to Latye et al. [23] and Aggarwal et al. [24], fenugreek genotypes influenced similar findings under various sets. Fenugreek genotypes vary in their morphologies, growth patterns, biomass, and seed-producing abilities. Steroid sapogenins (Diosgenin), complex

carbohydrates (Galactomannan), and the amino acid isoleucine are the three most important parts of the seed and, to a lesser extent, the leaves [25].

The most crucial factor for a crop is yield. However, the factors that contribute to yield vary across pulses, seeds, spices, and cereals [26]. As plants mature, photosynthesis becomes more efficient in producing the sugar required for plant growth, increasing the amount of stored carbohydrates that may be used for plant growth and development. The results were consistent with the findings of Duwal et al. [27] in coriander and Latye et al. [23] and Aggarwal et al. [24] in fenugreek. In both acetone and methanol extracts, flavonoids, alkaloids, phenolics, and carbohydrates were discovered in fenugreek seeds [28].

Total phenolic content of fenugreek in different biotypes ranged from (59.03 ± 0.091) to (62.05 ± 1.130) mg/g in our study. In another study the total phenolic content was ranged from 83.46 ± 0.24 to 139.88 ± 0.38 mg GAE/g DW [29]. Crop saponin levels may depend on the plant type, geographic area, and stage of growth [30]. In our study total saponin content ranged from 3.15-5.65 g/100g. Total saponin content in the leaves of *T. foenum-graecum* from Tunisia at the maturity stage have been reported as 0.33 g/100 g DW [31]. Scientists have found and extracted the bioactive components in fenugreek using a variety of techniques. Chromatography combined with mass spectrophotometry is one of the most widely used techniques for isolation and characterization [32].

5. CONCLUSION

Examination of different biotypes showed environmental variability with each other all tested parameters such as morphological, physiological and biochemical. Environmental factors such as temperature, moisture, and light directly influence the plant's biochemical characteristics clearly displayed in results. This study shows that seven fenugreek genotypes differ in morphological, physiological, and biochemical features, highlighting their breeding and selection potential. Rajasthan Methi-1 bloomed early, whereas Pant Ragini had high RWC and excelled in fresh and dry biomass and water retention. Hisar Sonali had the most total carbohydrate, indicating nutritional value. These findings can be used to generate fenugreek cultivars with improved medicinal, nutritional,

and agronomic properties to increase yield and water stress resistance. Furthermore, utilizing the advanced analytical techniques viz., HPLC or GC-MS used to enhance the accuracy of bioactive compounds quantification and identification.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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