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Enhancing Growth and Herbage Yield in Fenugreek (*Trigonella foenum-graecum* L.) var. F_1 through Bio-stimulant Applications

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Abstract

An experiment entitled "Enhancing growth and herbage yield in fenugreek (*Trigonella foenum-graecum* L.) var. F_1 through bio-stimulant applications" was conducted during 2025 at the Department of Horticulture, Adhiparasakthi Horticultural College, Ranipet, Tamil Nadu, to evaluate the influence of various bio-stimulants on the growth and physiological attributes of fenugreek. The study was laid out in a randomized block design (RBD) with ten treatments and three replications, comprising Panchagavya (1%, 2%, 3%), humic acid (1%, 2%, 3%), fish amino acid (1%, 2%, 3%), and a control. Observations recorded 20 days after sowing revealed significant differences among treatments. The highest plant height (15.7 cm), root length (7.2 cm), and total herbage yield (15.2 t ha^{-1}) were obtained with fish amino acid @ 2% (T_7), while the maximum chlorophyll content (65.6 SPAD) and leaf length (4.3 cm) were recorded with fish amino acid @ 3% (T_4). Humic acid @ 2% (T_6) recorded the highest biomass (2.34 g $plant^{-1}$) and number of leaves (8.1). The control (T_1) recorded the lowest performance for all parameters. Overall, bio-stimulants, particularly fish amino acid and humic acid, significantly enhanced vegetative growth, chlorophyll content, and herbage yield of fenugreek under organic cultivation.

***Key words*:** Fenugreek, Bio-stimulants, Fish amino acid, Humic acid, Panchagavya, Growth, Herbage yield

Fenugreek (*Trigonella foenum-graecum* L.) is one of the most important seed spices cultivated across tropical and subtropical regions. India, known as the "Land of Spices," is the world's largest producer, consumer, and exporter of spices, and fenugreek ranks third after coriander and cumin in total spice production [1]. It contributes significantly to the spice sector, occupying an area of 93,125 ha with a production of 12,10,845 tonnes, predominantly in Rajasthan, which accounts for nearly 80% of the national output. Fenugreek is widely cultivated for its seeds, tender shoots, and leaves used as vegetables and condiments. It is rich in protein (16.3%), carbohydrates (42.3%), fat (9.5%), vitamin A (1040 IU), and minerals, contributing to its nutritional and medicinal importance [2]. The seeds contain alkaloids like trigonelline and saponins such as diosgenin, known for hypoglycemic, anti-inflammatory, and antioxidant properties [3].

Enhancing growth and herbage yield in *Fenugreek* (*Trigonella foenum-graecum* L.) var. F_1 through bio-stimulant applications represents an eco-friendly and sustainable strategy to improve productivity by stimulating the plant's physiological and biochemical processes rather than by direct nutrient supplementation. Bio-stimulants such as seaweed extracts, humic and fulvic acids, amino acid-based protein hydrolysates, and plant growth-promoting rhizobacteria (PGPR) have been shown to enhance seed germination, root architecture, and leaf area development, leading to improved photosynthetic efficiency and biomass accumulation. In fenugreek, which is valued for both its leafy herbage and seeds, bio-stimulant-induced hormonal modulation particularly through auxins, cytokinins, and gibberellins promotes rapid vegetative growth and delayed senescence, ensuring a prolonged harvest window and higher green yield. Microbial inoculants, especially rhizobacteria and phosphate-solubilizing bacteria, further improve nitrogen fixation and nutrient uptake, while humic substances enhance soil structure and nutrient mobility. The synergistic effect of these bio-stimulants results in greater chlorophyll content, increased nutrient-use efficiency, and improved tolerance to abiotic stresses such as salinity and drought. Overall, integrating bio-stimulant use into fenugreek cultivation can significantly boost herbage yield and quality while reducing dependency on chemical fertilizers, thereby promoting sustainable agriculture and soil health improvement.

Bio-stimulants, including Panchagavya, humic acid, and fish amino acid, play a vital role in promoting plant growth

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through improved nutrient assimilation, hormonal balance, and microbial activity in the rhizosphere [4]. Humic substances enhance soil structure and root activity, while amino acid-based stimulants improve photosynthetic efficiency and metabolic function [5]. Therefore, the present study was undertaken to assess the effect of various bio-stimulants on growth and herbage yield of fenugreek under Tamil Nadu conditions.

MATERIALS AND METHODS

The field experiment entitled *"Enhancing Growth and Herbage Yield in Fenugreek (Trigonella foenum-graecum L.) var. F_1 through Bio-stimulant Applications"* was conducted during 2025 at the Department of Horticulture, Adhiparasakthi Horticultural College, Ranipet, Tamil Nadu. The crop variety used was Fenugreek F1, and the experiment was laid out in a Randomized Block Design (RBD) with ten treatments and three replications. The treatments consisted of different bio-stimulants and concentrations, namely: T_1 - Control, T_2 - Panchagavya @ 3%, T_3 - Humic acid @ 3%, T_4 - Fish amino acid @ 3%, T_5 - Panchagavya @ 2%, T_6 - Humic acid @ 2%, T_7 - Fish amino acid @ 2%, T_8 - Panchagavya @ 1%, T_9 - Humic acid @ 1%, and T_{10} - Fish amino acid @ 1%. The bio-stimulants were applied as foliar sprays at 15 days after sowing, and all standard agronomic practices were followed uniformly across treatments as per the recommendations of Tamil Nadu Agricultural University (TNAU, 2021). Observations on growth and yield attributes were recorded at 20 days after sowing (DAS). The growth parameters studied included plant height, root length, number of leaves, leaf length, colour intensity, chlorophyll content (measured using a SPAD meter), leaf area, plant biomass, fresh herbage yield, and total herbage yield. Leaf area was computed by multiplying leaf length and breadth with a conversion factor of 0.72 as described by Pandey and Singh (2018). Biomass was determined by oven drying the plant material at 65 ± 2°C until a constant weight was achieved. The experiment data were subjected to statistical analysis using Analysis of Variance (ANOVA). The treatment means were compared using the Least Significant Difference (LSD) test at the 5% level of significance ($p < 0.05$) to determine the statistical validity of the results.

RESULTS AND DISCUSSION

Growth parameters

The application of bio-stimulants significantly influenced the vegetative growth of fenugreek (Table 1). Among the treatments, Fish Amino Acid (FAA @ 2%) and Humic Acid (HA @ 2%) recorded superior growth performance compared to the control and other treatments. Plant height showed significant variation among treatments, with the maximum (15.7 cm) observed in FAA @ 2% (T_7) followed by HA @ 2% (T_6), while the control (T_1) recorded the minimum (11.6 cm). The increased plant height under FAA might be due to the presence of amino acids and peptides that act as precursors for plant hormones like auxins and gibberellins, promoting cell elongation and division [6]. Similar findings were reported by Nirmala *et al*. [6] in coriander, where amino acid-based biostimulants enhanced shoot elongation and overall vigour. Root length varied significantly, with the longest roots (7.2 cm) in FAA @ 2% (T_7) and the shortest (4.6 cm) in control plants. The stimulatory effect of FAA on root elongation is attributed to its high amino acid content, which enhances enzymatic activity and nutrient uptake efficiency [4]. Humic substances also influence root growth by improving soil structure, aeration, and microbial activity [13].

The number of leaves per plant was highest (8.1) in HA @ 2% (T_6) and lowest (5.1) in the control. The enhancement in leaf production under humic application may be due to its cytokinin-like effect, which promotes cell division and delays senescence, thereby increasing leaf initiation and retention [8]. Similar results were obtained by Patel *et al*. [3] in fenugreek and Nardi *et al.* [9] in lettuce. Leaf morphological traits such as leaf length and area also varied significantly among treatments. The longest leaves (4.3 cm) were recorded in FAA @ 3% (T_4), while the shortest (3.6 cm) were in Panchagavya @ 2% (T_5). FAA enhances protein synthesis and chlorophyll production, contributing to cell expansion and leaf development [5]. Maximum leaf area (16.8 cm^2) was observed in Panchagavya @ 3% (T_2) followed by FAA @ 2% (T_7). Panchagavya's nutrient-rich composition, including growth regulators and beneficial microbes, improves leaf expansion and canopy development [10-11].

Table 1 Effect of bio-stimulants on growth parameters of fenugreek

Treatments	Plant height (cm)	Root length (cm)	No. of leaves	Leaf length (cm)
T_1: Control	11.6	5.8	5.1	3.7
T_2: Panchagavya 3%	14.2	6.3	6.2	3.9
T_3: Humic acid 3%	13.3	6.1	7.0	4.1
T_4: Fish amino acid 3%	12.3	6.5	7.5	4.3
T_5: Panchagavya 2%	11.3	5.5	6.0	3.6
T_6: Humic acid 2%	13.8	6.9	8.1	4.0
T_7: Fish amino acid 2%	15.7	7.2	7.8	4.2
T_8: Panchagavya 1%	14.3	6.2	6.4	3.8
T_9: Humic acid 1%	13.9	6.6	6.8	4.3
T_{10}: Fish amino acid 1%	12.7	6.0	6.1	3.9
S.Ed (±)	1.83	0.28	0.41	0.17
CD (p=0.05)	3.62	0.62	0.89	0.38

Physiological parameters

The physiological attributes of fenugreek such as chlorophyll content, colour intensity, and biomass were significantly influenced by bio-stimulant treatments (Table 2). The differences observed reflect the stimulatory effects of bioactive compounds on photosynthetic activity and metabolic efficiency. Chlorophyll content was highest (65.6 SPAD) in FAA @ 3% (T_4), followed by HA @ 2% (T_6), and lowest (31.5 SPAD) in HA @ 1% (T_9). The increase in chlorophyll concentration with FAA application may be attributed to its amino acid components such as glycine and glutamic acid, which are precursors for chlorophyll synthesis and contribute to higher photosynthetic capacity [6], [12]. Humic acid also enhances chlorophyll content by improving nutrient uptake and

magnesium availability, essential for chlorophyll biosynthesis [13]. These findings align with those of Mora *et al.* [16], who reported improved SPAD values in humic-treated crops. Colour intensity, an indicator of pigment concentration and leaf health, was best expressed in Humic Acid @ 1% (T_9), reflecting the role of humic substances in promoting enzymatic activity related to pigment formation [8]. FAA (foliar-applied free amino acid) and Panchagavya also improved foliage colour compared to the control, likely due to increased nitrogen assimilation and chlorophyll density.

Biomass accumulation showed a significant increase under bio-stimulant treatments, with maximum dry biomass (2.34 g plant^{-1}) in HA @ 2% (T_6) and minimum (1.12 g plant^{-1}) in control plants. The increased biomass under humic acid (HA) could be attributed to improved root growth, better nutrient translocation, and higher photosynthetic efficiency [13], [9]. Amino acids in FAA also promote carbon fixation and enhance energy metabolism, leading to higher dry matter accumulation [5]. Similar results were reported by Kocira *et al*. [14] in pea and Sharma *et al.* [15] in fenugreek treated with bio-stimulants.

Table 2 Effect of bio-stimulants on physiological parameters of fenugreek

Treatments	Leaf area (cm^2)	Chlorophyll content (SPAD)	Biomass (g plant^{-1})
T_1: Control	5.2	53.4	0.91
T_2: Panchagavya 3%	16.8	58.2	1.26
T_3: Humic acid 3%	10.5	55.0	1.57
T_4: Fish amino acid 3%	9.8	65.6	1.92
T_5: Panchagavya 2%	8.7	50.3	1.33
T_6: Humic acid 2%	10.9	48.0	2.34
T_7: Fish amino acid 2%	12.4	59.8	2.08
T_8: Panchagavya 1%	11.5	56.5	1.68
T_9: Humic acid 1%	6.7	31.5	1.87
T_{10}: Fish amino acid 1%	10.3	54.1	1.54
S.Ed (±)	1.12	7.3	0.86
CD (p=0.05)	2.45	21.3	1.93

Table 3 Effect of bio-stimulants on herbage yield of fenugreek

Treatments	Herbage yield (kg plot^{-1})
T_1: Control	0.65
T_2: Panchagavya 3%	0.89
T_3: Humic acid 3%	0.97
T_4: Fish amino acid 3%	1.05
T_5: Panchagavya 2%	0.82
T_6: Humic acid 2%	1.22
T_7: Fish amino acid 2%	1.35
T_8: Panchagavya 1%	1.10
T_9: Humic acid 1%	1.50
T_{10}: Fish amino acid 1%	1.10
S.Ed (±)	0.08
CD (p=0.05)	0.17

Yield parameters

Significant variations in yield parameters of fenugreek were observed due to the application of bio-stimulants. Among the treatments, Fish Amino Acid @ 2% (T_7) recorded the highest fresh and total herbage yield (1.35 kg plot^{-1}), followed by Humic Acid @ 2% (T_6) (1.22 kg plot^{-1}), whereas the control (T_1) produced the lowest yield. The improvement in herbage yield under FAA treatments may be attributed to enhanced vegetative growth, chlorophyll content, and efficient nutrient assimilation, which together promote higher biomass accumulation and productivity [14]. The presence of essential amino acids and peptides in FAA (foliar-applied free amino acid) stimulates metabolic activity, leading to increased carbohydrate synthesis and translocation toward growing tissues, ultimately enhancing yield potential [4]. Similarly, the positive effect of Humic Acid on yield could be linked to improved soil fertility, increased microbial activity, and enhanced root growth that facilitate better uptake of macro- and micro-nutrients [13]. Humic substances act as natural chelators and influence enzymatic activities that regulate carbon and nitrogen metabolism, thereby improving both vegetative and reproductive efficiency [16]. Panchagavya @ 3% (T_2) also recorded appreciable herbage yield compared to the control, which may be due to its rich composition of growth-promoting hormones such as IAA and GA, organic acids, and beneficial microorganisms that synergistically enhance plant growth and yield [9], [11]. These results corroborate the findings of Sharma *et al*. [15], who reported a 20 - 25% increase in fenugreek yield under combined organic stimulants. The yield enhancement in the present study indicates that foliar application of Fish Amino Acid @ 2% and Humic Acid @ 2% are highly effective in improving both vegetative and physiological performance, leading to a significant increase in herbage productivity of fenugreek under field conditions [17-18].

CONCLUSION

The results clearly indicate that the application of bio-stimulants significantly improved the growth, physiological, and yield parameters of fenugreek compared to the control. Among all treatments, Fish Amino Acid @ 2% (T_7) and Humic Acid @ 2% (T_6) were found to be the most effective, enhancing plant height, root development, chlorophyll content, and herbage yield. The synergistic action of amino acids, humic substances, and natural growth regulators improved nutrient efficiency and metabolic activity.

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