Journal of Wasit for Science and Medicine 2026: 19, (1), 141-151

Impact of Organic and Nano Fertilizers on Biosynthesis of Active Compounds in Fenugreek (*Trigonella Feonum-graeum L.)*

Marwa Mhaibis Thijeel, and Wasan Hmaza Mazeil

Department of Biology, College of Science, Wasit University, Wasit, Iraq.

Abstract

Fenugreek (*Trigonella foenum-graecum L*.) is a well-known medicinal and aromatic plant that contains diverse bioactive compounds such as alkaloids, flavonoids, saponins and essential vitamins. The biosynthesis of these compounds is the target of sustainable fertilization strategies to increase plant quality and therapeutic value. Field experiment was carried out at the College of Science, Wasit University, to study the effect of foliar application of organic and nano-fertilizers, alone and in combination on growth, and biochemical characteristics in fenugreek plant. Results indicated that the sprayed plants, especially those getting a simultaneous spray with nano-fertilizers and organic, presented an observable increase in vegetative height as compared to unsprayed control. Plant canopy, number of branches and leaf development significantly increased after treatment. In addition, the foliar application increased the nutrient absorption as indicated by increase in tissue NPK content and improvement of biosynthesis of major bioactive metabolites. However, concentration of vitamin C and E in plants treated with combination also was significantly increased, demonstrating an efficient activity of metabolism, antioxidant and biosynthetic capability in plants. Data indicates that the combination of nano and organic fertilizer may be an excellent and sustainable approach for enhancing growth, nutrient uptake, as well as the synthesis of medicinally important metabolites in fenugreek. These are also consistent with ecological agriculture and make contributions to high-quality medicinal plant crude drug production.

Keywords: Fenugreek, Organic Fertilizer, Nano fertilizer, and Plant height.

1. Introduction

1.1 Botanical features and nutritive value of fenugreek (Trigonella foenum-graecum L.)

Fenugreek (*Trigonella foenum-graecum L.*) is botanically a member of the leguminous family. Its genus name is derived from the Latin word Trigonos, meaning "triangle", which describes the characteristic triangular form of its flowers. The word foenum-graecum is the plant's “surname” and it was named this way to show that fenugreek has been used as forage since Ancient Greek [1]. Apart from being a feed for animals, its seeds are used as spice worldwide that provides unique characteristic flavor to various foods [2].

Fenugreek is also grown for its edible leaves, which are fresh or dried as a potherb. Fresh leaves of fenugreek contain plenty of nutritive elements and are an invaluable antidermatotic medic its high content in calcium, iron and vitamins A, B, D make fenumusk body to include them. Traditionally, fenugreek has been used in the ethnobotanical herbology of being widely found in many East Asian countries as a medicinal plant for its usefulness and properties in decreasing constipation, maintaining healthy digestion and boosting up the metabolism [3].

Fenugreek is abundant in carbohydrates, sugars and proteins and is extremely rich in nutritional levels as per its high dietary fiber. It also has several minerals, including calcium, phosphorus and iron, and several vitamins. In addition, fenugreek oil contains alkaloids like trigonelline and choline that are believed to confer medicinal properties, and seeds of which contain a mucilaginous compound, fixed oils, and volatile oils. Fenugreek is also comprised of nicotinic acid, saponins and coloring matter [4] and vitamins A B complex, E, C [5].

1.2 Fertilizer Application Management and Modern Technologies

Fertilizer integration is a key link in agricultural production management and plays a significant role in improving crop quality and yield amount [6]. Over the past, such requirement has resulted in an excessive use of numerous types of conventional chemical fertilizers, especially single-element synthetic compositions comprising the macronutrient NPK that contribute to soil and water depletion and cause environmental pollution. Thus, application with these nutrients in nano size could be an innoxious and innovative alternative.

Such applications are more attractive as low application rates are necessary, and the slow release of nutrients allows higher efficiency of applications and less environmental problems [7, 8]. Recently, in most parts of the world attention has been drawn to food quality and safety with organic farming strategies. Central to this approach is the promotion of organic fertilizers that use nutrients derived organically rather than synthetically for healthier food and less environmental load. The organic inputs include soluble compound fertilizers which contain amino acids as a source of N and proteins. Their inclusion also promotes growth and productivity of plants directly due to support in the plant protein synthesis [9]. Technology used to increase yield and lower input prices is now translating into other sectors such as using nano-fertilizers in agriculture. This has developed from soil amendment to the use of direct foliar sprays designed to enhance crop plant growth and productivity via influencing the nutrient system [10].

The Spray method might be favorable compared to other application methods due to its quick nutrient processing, higher nutrient exploitation rates and a long-term effect [11]. The objective of this research was to investigate the influence organic and nano fertilization by foliar application on average plant height, number of branches, NPK elements (N, P, K), and vitamin E & C concentration in fenugreek.

2. Materials and Methods

2. 1 Experimental Location and preparation

The experiment was held at the Department of Biology, College Science, Wasit University. Seventy-five pots with a 10 kg capacity were utilized. Pots were filled with an appropriate soil mixture. Ten seeds were sown in each pot on 1st of November 2024. The plants were watered right after planting, by using the sprinkler to wet the top 1/3 of the pot to a depth of 3-5 cm. Two weeks after germination, the seedlings were thinned to three plants per pot.

2. 2 Treatment Application (Foliar Spraying)

The research focused on the impacts of two foliar applications [nano-fertilizer (NF) and organic fertilizer (OF)] application arrays. Leaves were sprayed with different concentrations of organic fertilizer after an hour prepared by waiting Spraying the leaves with Nano fertilizer. The spraying process was repeated two weeks after first treatment.

2. 3 Data Collection and Measured Parameters

Data collection began two weeks after the second foliar application four weeks after the initial treatment, where growth and chemical parameters were both measured. Growth parameters included the average plant height, and average number of branches per plant. While chemical parameters included the percentage of NPK (Nitrogen, Phosphorus, Potassium) elements. Also, Average content of Vitamin C and Vitamin E [12-14].

2. 4 Statistical Analysis

The experiment was arranged using a Complete Randomized Design (CRD). Statistical analysis was performed using the Analysis of Variance (ANOVA) test to determine statistically significant differences among treatments. Mean comparisons were conducted using the Least Significant Difference (LSD) test at a 0.05 probability level [15].

3. Results and Discussion

3. 1 The Average of Plant Height (cm)

The mean Plant Height increased progressively from 22.55 cm in control treatment (0 ml/L organic fertilizer) to 30.52 cm at the highest level (20 ml/L organic fertilizer). This represents an increase of 35.34% compared to the control. Similarly, nano-fertilizer application resulted in a steady increase in plant height, from 23.19 cm in the control (0 ml/L nano-fertilizer) to 28.11 cm at the highest concentration (20 ml/L nano-fertilizer). This corresponds to an improvement of 21.21% over control.

Table1: Effect of Nano-fertilizer and Organic fertilizer and the interactions between them on average of the Plant Height.

Organic fertilizer (0)	Nano-fertilizer					Average of organic fertilizer (O)
	0	5 ml/L	10 ml/L	15 ml/L	20 ml/L	
0	20.17	21.47	22.43	23.77	24.90	22.55
5 ml/L	21.27	24.47	24.77	26.57	25.90	24.59
10 ml/L	23.23	24.77	26.03	24.53	26.43	25.00
15 ml/L	24.43	27.57	29.10	30.37	30.10	28.31
20 ml/L	26.83	28.87	31.17	32.50	33.23	30.52
Average of Nano fertilizer	23.19	25.43	26.70	27.55	28.11	22.55
LSD P = 0.05	0.673					LSD P = 0.05
						0.673
Two-way LSD P = 0.05	1.506					

The interaction between organic fertilizer and nano-fertilizer was also significant (LSD at P = 0.05 = 1.506), indicating that the combined application produced effects beyond the sum of their individual impacts. The smallest mean value

(20.17 cm) was observed in the absence of both fertilizers (control), while the largest value (33.23 cm) was recorded when combining the highest organic fertilizer level (20 ml/L) with the highest nano-fertilizer concentration (20 ml/L), showing an increase of 64.74% compared to the control.

3. 2 Determination Average Number of Branches (branches/ plant^{-1})

Data in table two displayed that both organic fertilizer and nano-fertilizer significantly influenced the average, Number of branches with a clear trend of increasing leaf area as the concentration of each fertilizer increased. Number of branches increased progressively from 10.200 (branches/plant^{-1}) in the control treatment (0 ml/L organic fertilizer) to 15.333 (branches/ plant^{-1}) at the highest level (20 ml\L organic fertilizer). This represents an increase of 50.32% compared to the control. Similarly, nano-fertilizer application resulted in a steady increase in number of branches, from (10.400 branches/ plant^{-1}) in control (0 ml/L nano-fertilizer) to 14.467 at the highest concentration (20 ml/L nano-fertilizer). This is due to an improvement of 39.10% over control.

Table 2: Effect of Nano-fertilizer and Organic fertilizer and the interactions between them on average Number of branches.

Organic fertilizer (0)	Nano-fertilizer					Average of organic fertilizer (O)
	0	5 ml/L	10 ml/L	15 ml/L	20 ml/L	
0	8.000	9.000	10.667	11.333	12.000	
5 ml/L	10.000	12.000	12.333	13.000	13.667	10.200
10 ml/L	10.667	12.000	11.677	13.667	13.333	12.200
15 ml/L	11.677	12.667	13.000	14.000	15.000	12.267
20 ml/L	11.677	13.000	16.333	17.333	18.333	13.267
Average of Nano-fertilizer	10.400	11.733	12.800	13.867	14.467	15.333
LSD P = 0.05	0.5602					LSD P = 0.05 0.5602
Two-way LSD P = 0.05	1.2527					

Interaction between organic fertilizer and nano-fertilizer was also significant (LSD at P = 0.05 = 1.2527). Indicating that the combined application produced effects beyond the sum of their individual impacts. The smallest mean value (8000 branches/ plant^{-1}) was observed in the absence of both fertilizers (O_0N_0), while the largest value (18.333 branches/ plant^{-1}) was recorded when combining the highest organic fertilizer level (20 ml\L) with the highest nano-fertilizer concentration (20 ml/L), showing an increase of 129.1% compared to the control.

3. 3 Nitrogen Percentage

Both nano-fertilizer and organic fertilizer significantly influenced the percentage of nitrogen in table 3. The LSD value at $P \leq 0.05$ was 0.2401 which confirms that differences greater than this value are statistically significant. As the level of nano-fertilizer increased from (0 to 20ml\L), the average number of percentages of nitrogen consistently increased across all levels of organic fertilizer. The highest percentage of nitrogen (5.280) was recorded with the combination of 20ml\L organic fertilizer and 20 ml\L nano-fertilizer, while the lowest (1.993) was observed in the control treatment (0 organic, 0 nano).

Table 3: Nano-fertilizer and organic fertilizer effects on average nitrogen percentage.

Organic fertilizer (0)	Nano-fertilizer					Average of organic fertilizer (O)
	0	5ml/L	10 ml/L	15 ml/L	20 ml/L	
0	1.993	2.457	2.827	2.933	3.603	2.763
5 ml/L	1.273	3.363	3.897	4.027	4.810	3.474
10 ml/L	2.323	3.290	3.193	3.717	4.483	3.401
15 ml/L	2.923	3.450	3.780	3.973	4.710	3.767
20 ml/L	2.917	3.910	4.363	4.807	5.280	4.255
Average of Nano fertilizer	2.286	3.294	3.612	3.891	4.577	Nano-fertilizer
LSD P = 0.05	0.2401					LSD P = 0.05
						0.2401
Two-way LSD P = 0.05	0.5370					

Average values for nano-fertilizer treatments show a clear upward trend organic similarly. The average n number of nitrogen percentage also increased with organic fertilizer application. Two interaction LSD values were 0.5370 and many combinations show differences exceeding this, confirming a significant interaction between two factors.

3. 4 Phosphorus Percentage

Nano-fertilizer and organic fertilizer significantly influenced the percentage of phosphorus as listed in table four. The LSD value at $P \leq 0.05$ was 0.01966 which confirms that differences greater than this value. As the level of nano-fertilizer increased from 0 to 20, the average number of percentages of phosphorus consistently increased across all levels of organic fertilizer. The highest number of phosphorus percentages (0.6957) was recorded with the combination of 20 ml\L organic fertilizer and 20 ml\L nano-fertilizer.

While the lowest (0.17 90) was observed in the control treatment (0 organic, 0 nano). Average values for nano-fertilizer treatments show a clear upward trend. Similarly, average number of phosphorus percentage also increased with organic fertilizer application. The two-way interaction LSD value was 0.04397, and many combinations show differences exceeding this, confirming a significant interaction between two factors.

Table 4: Effect of nano-fertilizer and organic fertilizer and the interactions between them on average of phosphorus percentage.

Organic fertilizer (0)	Nano-fertilizer					Average of organic fertilizer (O)
	0	5 ml/L	10 ml/L	15 ml/L	20 ml/L	
0	0.1790	0.2760	0.2650	0.2813	0.3110	0.2625
5 ml/L	0.3383	0.4150	0.4313	0.4483	0.4840	0.4234
10 ml/L	0.4110	0.4310	0.4560	0.4723	0.5230	0.4587
15 ml/L	0.3977	0.5277	0.5607	0.5937	0.6030	0.5365
20 ml/L	0.4203	0.4803	0.5913	0.6813	0.6957	0.5738
Average of Nano-fertilizer	0.3493	0.4260	0.4609	0.4954	0.5233	Nano-fertilizer
LSD P = 0.05	0.001966					LSD P = 0.05
						0.001966
Two-way LSD P = 0.05	0.04397					

3. 5 Potassium Percentage

Data listed in table 5 revealed both nano-fertilizer and organic fertilizer significantly influenced the percentage of potassium. The LSD value at $P \leq 0.05$ was 0.0737, which confirms that differences greater than this value are statistically significant. As the level of nano-fertilizer increased from 0 to 20, the average number of percentages of potassium consistently increased across all levels of organic fertilizer.

The highest percentages of the potassium (3.840) were recorded with the combination of 20 ml\L organic fertilizer and 20 ml\L nano-fertilizer, while the lowest (1.210) was observed in the control treatment (0 organic, 0 nano). The average values for nano-fertilizer treatments show a clear upward trend. Similarly, the average number of potassium percentage also increased with organic fertilizer application. The two-way interaction LSD value was 0.1649, and many combinations show differences exceeding this, confirming a significant interaction between the two factors.

Table 5: Effect of Nano-fertilizer and organic fertilizer and the interactions between them on average of the potassium percentage.

Organic fertilizer (0)	Nano-fertilizer					Average of organic fertilizer
	0	5 ml/L	10 ml/L	15 ml/L	20 ml/L	
0	1.210	1.380	1.447	1.510	1.810	1.471
5ml/l	1.173	1.410	1.830	1.930	1.957	1.781
10 ml/L	1.403	1.750	1.753	1.880	2.120	2.437
15 ml/L	1.980	2.040	2.377	2.830	2.957	2.437
20 ml/L	2.110	2.943	3.470	3.697	3.840	3.212
Average of Nano-fertilizer	1.575	1.905	2.175	2.369	2.537	Nano -fertilizer
LSD P = 0.05	0.0737					LSD P = 0.05
						0.0737
Two-way LSD P = 0.05	0.1649					

3.6 Percentage of Vitamin C (mg/g)

Nano-fertilizer and organic fertilizer significantly influenced the percentage of vitamin C as listed in table six. The LSD value at $P \leq 0.05$ was 1.0941, which confirms that differences greater than this value are statistically significant. As the level of nano-fertilizer increased from (0 to 20ml/L). The average percentage of vitamin C consistently increased across all levels of organic fertilizer. The highest percentage of vitamin C (12.347mg/g) was recorded with the combination of 20 ml\L organic fertilizer and 20 ml\L nano-fertilizer, while the lowest (5.280mg/g) was observed in the control treatment (0 organic, 0 nano).

Average values for nano-fertilizer treatments show a clear upward trend. Similarly, the average number of vitamin C percentage also increased with organic fertilizer application. The two-way interaction LSD value was 0.2105, and many combinations show differences exceeding this, confirming a significant interaction between two factors.

Table 6: Effect of nano-fertilizer and organic fertilizer and the average of vitamin C.

Organic fertilizer (0)	Nano -fertilizer					Average of organic fertilizer (O)
	0	5 ml/L	10 ml/L	15 ml/L	20 ml/L	
0	5.280	5.740	5.937	6.277	6.680	5.983
5 ml/L	5.840	6.380	6.780	6.923	6.987	6.582
10 ml/L	5.787	5.947	6.710	6.903	7.653	6.600
15 ml/L	.6773	6.903	7.593	8.347	8.560	7.635
20 ml/L	6.840	8.843	10.293	11.380	12.347	9.941
Average of Nano-fertilizer	6.104	6.763	7.463	7.966	8.445	Nano-fertilizer
LSD P = 0.05	0.0941					LSD P = 0.05
						0.0941
Two-way LSD P = 0.05	0.2105					

3. 7 Vitamin E Percentage (mg/g)

Nano-fertilizer and organic fertilizer significantly influenced the percentage of vitamin E as listed in table 7. The LSD value at $P \leq 0.05$ was 0.00929, which confirms that differences greater than this value are statistically significant. As the level of nano-fertilizer increased from 0 to 20, the average number of vitamin E consistently increased across all levels of organic fertilizer. The highest percentage of vitamin E (0.2767mg/g) was recorded with the combination of 20 ml\L organic fertilizer and 20 ml\L nano-fertilizer, while the lowest (0.0567mg/g) was observed in the control treatment (0 organic, 0 nano).

The average values for nano-fertilizer treatments show a clear upward trend. Similarly, the average number of vitamin E percentage also increased with organic fertilizer application. The two-way interaction LSD value was 0.02078, and many combinations show differences exceeding this, confirming a significant interaction between the two factors.

Table 7: Effect of Nano-fertilizer and organic fertilizer and the interactions between them on average of Vitamin E.

Organic fertilizer (0)	Nano-fertilizer					Average of organic fertilizer (O)
	0	5 ml/L	10 ml/L	15 ml/L	20 ml/L	
0	0.0567	0.0700	0.1233	0.1433	0.1567	0.1100
5 ml/L	0.1067	0.1500	0.1733	0.1833	0.1967	0.1620
10 ml/L	0.1100	0.1400	0.1700	0.1967	0.2033	0.1640
15 ml/L	0.1300	0.1467	0.1867	0.2267	0.2500	0.1880
20 ml/L	0.1700	0.2067	0.2333	0.2567	0.2767	0.2287
Average of Nano fertilizer	0.1147	0.1427	0.1773	0.2013	0.2167	Nano -fertilizer
Organic fertilizer (0)	0.00929					LSD P=0.05
						0.00926
Tow-way LSD P = 0.05	0.02078					

4. Discussion

The objective of the study was to assess the additive/antagonism changes in response to nano-fertilizers application in combination with organic fertilizers on fenugreek plant nutrition and synthesizing of vitamins. The results reveal a positive and consistent synergism of both types of fertilizers on all traits examined.

4. 1 Effect on Vegetative Growth Characteristics

significant differences between the average height for plants and the number of branches as affected by individual fertilizer treatments or their interaction as listed in tables one and two. These findings are in agreement with earlier work [16]. Organic manure, organic fertilizers, which contain plant growth inducing substances, especially gibberellins, are expected to enhance stem elongation resulting in an increased height of the plant. This with the presence of nitrogen from the fertilizer that increases cell division and plant biomass as it develops stronger roots.

Nano-fertilizers are highly efficient and results in substantial vegetative growth [17, 18]. Nano-formulation containing chelating agents, and high penetration ability triggers for rapid uptake, transport and distribution of major and minor nutrients in the plant body that improve photosynthesis ultimately leading to improved total biomass [19].

4. 2 Effect on Major Element Concentration (N, P, K)

Substantial enhancement of the N-P-K contents especially in the combined application case. The optimal combination of N, P and K was reported at (5.280%, 0.6957% and 3.840%) when the treatment included organic fertilizer 20 ml/L + nano-fertilizer 20 ml/L. This was much higher than that of the N, P and K (1.993%, 0.1790%, and 1.210%), indicating a remarkable positive synergy of two fertilizer types in this treatment. This enhancement is also ascribed to other findings which revealed that the application of NPK nano fertilizers increases nutrient consumption [20]. The small size of nanoparticles permits deep penetration into different plant tissues [21, 22]. Foliar fertilization increases nutrient absorption by elevating pressure in guard cells and stimulating stomata while increasing epidermal permeability for nutrient uptake.

4. 3 Effect on Vitamin C and E Content

Data in tables 6 and 7 show that there is significant variation for vitamin C and vitamin E levels, which the fertilizer treatments surpass control. The high vitamin, primarily vitamin C, content is likely induced due to accelerated nutrient absorption with the mixture of nano and organic fertilizers [23]. This global supply of nutrients provides the plant with important trace elements necessary for the metabolic pathways associated vitamin synthetic [24, 25]. In general, efficacy of treatments suggests that foliar application is well adapted for plant feeding in arid and semi-arid areas [26]. It allows nutrients to avoid soil borne obstacles and be directly absorbed by vegetative organs, which would compensate for nutrient deficiencies rapidly to continued growth and productivity [27].

5. Conclusion

According to experimental results, application of different levels of organic and nano-fertilizers alone or in various combinations significantly increased all the traits measured for fenugreek *Trigonella foenum-graecum L.* .The corresponding combined highest rates led to more pronounced effects, which reflected a strong synergistic action on the promotion of vegetative growth, nutrient uptake and C and E vitamin synthesis.

6. References

1. Martin E., Akan H., Ekici M., and Aytac Z., (2011). Karyotype analyses of ten sections of Trigonella (Fabaceae). Comparative cytogenetics. 5, 2, 105.
2. Dwivedi A. K., Singh S., and Ranjan R., (2006). Suitable varieties of fenugreek for Jharkhand spices and medicinal and Aromatic plants in eastern region.
3. Canter P. H., Thomas H., and Ernst E., (2005). Bringing medicinal plants into cultivation: opportunities and challenges for biotechnology. TRENDS in Biotechnology. 23, 4, 180-185.
4. Sulieman A. M. E., Ali A. O., and Hemavathy J., (2008). Lipid content and fatty acid composition of fenugreek (*Trigonellafoenum-graecum L.*) seeds grown in Sudan. International Journal of Food Science and Technology. 43, 2, 380-382.
5. Zandi P., Basu S. K., Cetzal-Ix W., Kordrostami M., Chalaras S. K., and Khatibai L. B., (2017). Fenugreek (*Trigonella foenum-graecum L.*): an important medicinal and aromatic crop. In Active ingredients from aromatic and medicinal plants. IntechOpen.
6. Davod T., Reza Z., Ali V. A., and Mehrdad C., (2011). Effects of nanosilver and nitroxin biofertilizer on yield and yield components of potato minitubers. International Journal of Agriculture and Biology (Pakistan). 13, 6.
7. Choudhary R. C., Singh P. K., Parmar Y. C. J., and Lakshmanan A., (2026). Novel Developments in Nano Fertilizer for Sustainable Crop Production to Promote Global Food Security. Sustainability. 18, 7, 3198.
8. Al-Juthery H. W., Lahmod N. R., and Al-Taee R. A., (2021). Intelligent, nano-fertilizers: A new technology for improvement nutrient use efficiency (article review). In IOP conference series:

Earth and environmental science. 735, 1, 012086.

9. Taiz L., and Zeiger E., (2006). Plant physiology., 4th Ed. (Sinauer Associates Inc. Publishers: Sunderland, MA).
10. Duhan J. S., Kumar R., Kumar N., Kaur P., Nehra K., and Duhan S., (2017). Nanotechnology: The new perspective in precision agriculture. Biotechnology reports. 15, 11-23.
11. Kumar Y., Tiwari K. N., Singh T., and Raliya R., (2021). Nanofertilizers and their role in sustainable agriculture. Annals of Plant and Soil Research. 23, 3, 238-255.
12. Gresser M. S., and Parsons J. M., (1979). Sulfuric-perchloric acid digestion of some nutrients. Egyptian Journal of Horticulture. 25, 55-70.
13. John M. K., (1971). The distribution of inorganic phosphorus in some soils of Western Canada and its relationship to soil characteristics. Soil Science and Plant Nutrition. 17, 1, 9-14.
14. OAC, A., (1990). Official Methods of Analysis. 15th Edition. Association of official Chemists, Washington, USA.
15. Steel R. G., and Torrie J. H., (1980). Principles and procedures of statistics mcgraw-hill book co. Inc., New York, 481.
16. Al-Saidi A. A. R. N., Al-Mohammad M. H., and Al-Juthery, H. W., (2022). Effect of spraying some nano-fertilizers and their combinations on the growth and yield of fenugreek (*Trigonella foenum-graecum L.).* In IOP Conference Series: Earth and Environmental Science. 1060, 1, 012041.
17. Alameer Madhoor H. A., and Faisal M. Z., (2020). Effect of the use of micro-nano fertilizers, normal micro fertilizer and Gibberellic acid and their interference in some growth, chemical, medicinal characteristics and yield in fenugreek (*Trigonella foenum graecum L*.). Plant Archives. 09725210, 20, 1.
18. Singh M. D., (2017). Nano-fertilizers is a new way to increase nutrients use efficiency in crop production. International Journal of Agriculture Sciences. 9, 7, 0975-3710.
19. Alalaf A. H., Alalam A. T. S., and Fekry W. M., (2020). The effect of spraying with nano-iron and zinc on improving growth and mineral content of pomelo (Citrus grandis) seedlings. International Journal of Agricultural and Statistical Science. 16, 1, 1645-1650.
20. Bameri M., Abdolshahi R., Mohammadi-Nejad G., Yousefi K., and Tabatabaie S. M., (2012). Effect of different

microelement treatments on wheat (Triticum aestivum) growth and yield. International Research Journal of Applied and Basic Sciences. 3, 1, 219-223.

21. Subramanian K. S., Manikandan A., Thirunavukkarasu M., and Rahale C. S., (2015). Nano-fertilizers for balanced crop nutrition. In Nanotechnologies in food and agriculture. 69-80. Cham: Springer International Publishing.
22. Shang Y., Hasan M. K., Ahammed G. J., Li M., Yin H., and Zhou J., (2019). Applications of Nanotechnology in Plant Growth and Crop Protection: A Review. Molecules. 24, 14, 2558.
23. Vemulakonda A. L., Saad A. A., Kumar S. S., Wani O. A., Singh L., Babu S., Khan I. M., Wani F. J., Jan S. K., Elhindi K. M., and Mattar M. A., (2024). Revealing the Nexus between Fertilizer Composition and the Performance of Common Bean (*Phaseolus vulgaris L.*) Genotypes in the Himalayan Heartland of India. Sustainability. 16, 14, 6234.
24. Abdel-Aziz H. M., Soliman M. I., Abo Al-Saoud A. M., and El-Sherbeny G. A., (2021). Waste-derived NPK nanofertilizer enhances growth and productivity of Capsicum annuum L. Plants. 10, 6, 1144.
25. Al-Burki H. A., and Al-Ajeel S. A. H. S., (2021). Effect of bio-fertilizer and nano-elements on growth and yield of two Phaseolus vulgaris L. varieties. Plant archives. 21, 1, 1191-1194.
26. Ehmke T., (2018). WATER management strategies under water-limited conditions. Crops and Soils. 51, 3, 16-19.
27. Oad R. K., (2018). Effect of foliar applied urea on growth and yield of sunflower (*Helianthus annuus L.*). Open Access Library Journal. 5, 07, 1.