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Response of Fenugreek (*Trigonella Foenum-Graecum* L.) to Bacterial Inoculum, Zeolite and Organic Fertilizer and its Effect on Growth, Yield and its Components.

M Y K Al-Nuaimi and A N A Almohammedi

Department: Field Crops College of Agriculture- Tikrit University/ Iraq.
Corresponding Author E-mail / mohammed.y.k005@st.tu.edu.iq

Abstract. The effects of bacterial inoculants, zeolites and organic fertilizers on the growth characteristics, yield and composition of fenugreek (Trigonella foenum-graecum L.) were studied in a field trial conducted in Talmiyah city (soil loam-sandy) in the north-central region of Baghdad Governorate, Iraq, during the winter of 2022-2023 and 2023-2024. The trial included 24 treatments based on a combination of zeolites and organic fertilizers (sheep manure) with the addition of bacterial inoculants (Sinorrhiza meliloti) and without inoculants (0, 200 ml and 400 ml/25 kg seeds). The experiment was based on a randomized controlled trial (RCBD) design with a split-plot factorial system (factorial) and three replications. The main plot contained a combination of zeolites and organic fertilizers, while the secondary plot contained bacterial inoculants (Sinorrhiza meliloti). The results of the study showed that the treatment with bacterial inoculants (S. meliloti) at a concentration of 400 ml performed better in terms of vegetative growth, yield and composition. The combination of 100 kg of zeolite per hectare and 24 tons of organic fertilizer per hectare performed well in terms of plant growth, yield and composition.

1. Introduction

Trigonella foenum -graecum L: It is an annual medicinal plant of the Fabaceae family. [1] Fenugreek is often used as a medicinal and edible plant in folk culture. The seeds of this plant contain (11)% triadenosine, (3.7)% essential oil, (4)% essential oil and (6.20)% protein [2]. Fenugreek seeds also contain many active ingredients, including alkaloids diosgenin, triadenosine, fatty oil, gum and protein [3]. Triadenosine is one of the most important alkaloids in plants and has the effect of treating and preventing diabetes, cancer, inflammation, high cholesterol and headaches [4]. There are about 260 species of plants in the genus Trigonella L., which are widely distributed throughout the world, including Europe, West Asia, North America, southern Australia, southern and northern Africa and the Mediterranean region [5, 6]. Excessive use of chemical fertilizers has led to environmental problems such as water and soil resource pollution in many countries around the world. [7]. While the use of chemical fertilizers is an important management practice in agricultural production, continued use can reduce soil fertility and have negative effects on soil microorganisms [8]. Therefore, there is a need to experiment with environmentally friendly biological, natural and organic compounds, including

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bacterial vaccines combined with zeolites and organic fertilizers. This has prompted researchers to turn to clean cultivation of fenugreek to meet its nutritional needs and reduce production costs. Rhizobium inoculants are one of the best technologies for sustainable agricultural production and a potential solution to support environmental stability and global food security issues [9, 10].

Rhizobium inoculants can meet the nutritional needs of plants, especially nitrogen, by about 50-100 $kg.ha^{-1}$. It has also been proven to be environmentally friendly. When the bacterial inoculant is introduced into the soil, it either contaminates the seeds or changes the biological environment around the roots. This can improve soil fertility and increase nutrient availability to plants, thereby promoting growth, yield and plant active ingredients. [11,12]. One modern technology in agriculture is the use of natural soil treatment agents such as zeolites [13]. Zeolites are used as soil conditioners, humus for treating contaminated soils, and slow-release fertilizers [14]. The important role of zeolites is to slowly release the adsorbed nutrients and prevent their leaching, thereby ensuring a continuous supply of nutrients to the crop [15]. One of the most important factors that play an important role in plant growth is the use of organic fertilizers, as the addition of organic matter to the soil improves soil structure and increases its water retention capacity, improves soil properties, increases the ability of the soil to absorb nutrients, increases the cation exchange capacity of the soil, and also increases the nitrogen, carbon, potassium, and phosphorus content of the soil, as well as the carbon dioxide requirement of the plant [16, 17, and 18]. Therefore, the use of organic fertilizers in sustainable agriculture is a successful step towards improving plant growth and increasing yields. [19] Given the limited information on its medicinal value and the effects of the addition of bacterial inoculants, zeolites, and organic fertilizers on the growth and yield of fenugreek, this study aimed to investigate the effects of the addition of bacterial inoculants, zeolites, and organic fertilizers on the growth and yield of fenugreek.:

1. Demonstrate The impact of bacteria inoculum on growth characteristics, yield, and its components of fenugreek.
2. Determine the optimal level of zeolite and organic fertilizer for optimal growth and yield of fenugreek.
3. Demonstrate the effect of seasonal variations on fenugreek's growth traits, yield, and constituents.

2. Materials and Methods

2.1 The experiment's location.

A field experiment was conducted for the winter seasons of 2022-2023 and 2023-2024 in Al-Abayji district, which is situated north of the Baghdad Governorate's core, which is situated at longitudes -15, -26, 440, -50, -5, 440 degrees east, and latitudes -15, -31, 330, -45, -48, 330 degrees north.

2.2 Preparing the soil for planting.

The test soil was plowed vertically twice. The soil was then leveled to provide a suitable foundation for the seeds. According to the field plan, the test plot was divided into 72 test units with dimensions of 4 x 4.8 m and an area of 19.2 m^2. A distance of 0.5 m was maintained between the test units and a distance of 1 m was maintained between the sectors. There were a total of twelve lines, each with sixteen holes. All experimental units were disinfected with formaldehyde (2%) and covered with transparent polyethylene for three days, after which the covers were removed from the floor[20]. Superphosphate and potash fertilizers were added once at 120 kg per hectare[21]. Nitrogen fertilizer was added in the form of urea (46%) at a rate of 90 kg dun-1. Half of the amount was applied at planting and the other half after thirty days.. [22].

2.3 Experimental design and treatments.

A factorial experiment was conducted using this system (split panel) and completely randomized block design. The combinations were randomly distributed in the experimental units. The main plots contained the second factor (zeolite + organic fertilizer (sheep manure)) with the following combinations: (0) control treatment, 100 $kg.ha^{-1}$ zeolite, 16 $t.ha^{-1}$ organic fertilizer, 24 $t.ha^{-1}$ organic fertilizer, 8 $t.ha^{-1}$ organic fertilizer, 100 $kg.ha^{-1}$ zeolite + 24 t/ha organic fertilizer, 100 $kg.ha^{-1}$ zeolite + 16 $t.ha^{-1}$ organic fertilizer, 100 $kg.ha^{-1}$ zeolite + 8 t. ha^{-1} organic fertilizer, while the secondary plots (subplots) contained the first factor, the bacterial inoculum (S. meliloti) at the following concentrations.: (without inoculation 0, 200 ml and 400 ml/25 kg seeds).

2.4 Preparing seeds for planting.

Inoculated and non-inoculated fenugreek seeds were planted and the first irrigation of both seasons

was carried out on May 11, 2022 and 2023. Subsequently, the hollows were patched and when the plants reached a height of (10) cm, they were thinned so that they remained on one plant in the hole. Cultivation work was also carried out according to the needs of the plants. The trial planting was carried out on 11.05. winter of 2022-2023 and 2023-2024. Regarding the preparation of bacterial inoculum (S. meliloti): Before starting the trial planting, samples of (10) flowering fenugreek plants were collected from the fields of the research station attached to the Department of Field Crops, Faculty of Agriculture, University of Tikrit. The roots of the fenugreek plants were then carefully washed with running water to remove the remaining dirt and clay adhering to them. The active, mature nodules (identified by pink or red color) were removed, washed thoroughly with water again, and then immersed in a 1% solution of mercuric chloride (HgCl2) for five minutes. They were then placed in 95% ethanol for three minutes and in sterile water for five minutes. They were then supplemented with crushed nodules. A portion of the bacterial suspension was transferred to a Petri dish containing yeast extract medium (YEMA) for propagation via a wire conveyor (loop), and sterile water drops were added during the crushing process to form a bacterial suspension. The Petri dishes were incubated at 28 °C for 72 hours[23]. After confirming bacterial growth in the Petri dishes, the best isolates were selected and, after sterilization, Sinorhizobium was injected into flasks. They were then incubated at 28 °C for 48 hours[24]. Natural zeolite was added to the test unit in the above amount depending on the area of the test unit and the depth and density of the test soil. It was mixed with the soil in the planting row 7 days before planting to a depth of 20 cm. It was obtained from the Agricultural Green Zeolite Company in Amman, Jordan. Organic fertilizer was produced from sheep manure by building an underground tank with dimensions of 3 x 1.5 meters and a depth of 0.5 meters. The waste is layered in tanks and immersed in water until saturated with water. Every 10 days, the mixture is constantly stirred and humidified if necessary. The aim is to provide moisture and good aeration to the compost layers in order to activate the decomposition process of microorganisms and create suitable conditions for their growth. The manufacturing process takes 7 months to mature the organic compost before adding it to the soil. Signs of maturity can be observed by the dark brown color of the compost, its earthy smell and its humus-like consistency. [25].

2.5 Study indicators:

2.5.1 Plant height (cm. plant $^{-1}$)
5 plants were randomly selected from each experimental unit of the intermediate planting lines during the plant maturity stage. The plant height was calculated from the soil surface level to the top of the plant using a measuring tape and the average of the five plants was taken.

2.5.2 Number of branches (branch. plant $^{-1}$)
When the plant achieved full maturity, this characteristic was measured. Five plants were chosen from each experimental unit, and the branches that connected to the main stem were counted and their average was determined.

2.5.3 Number of pods in the plant (pod .plant^{-}).
This trait was calculated for five plants randomly taken from the experimental units and the number of pods per plant was calculated and the average was taken.

2.5.4 Number of seeds per pod (seed. pod $^{-1}$).
I counted the seeds of 5 pods taken from the five plants representing the experimental units, extracted the number of seeds from them, and took the average.

2.5.5 Seed yield (kg. ha $^{-1}$).
t was calculated after harvest by weighing the seeds produced by the plants of each experimental unit, then converted into kg. h $^{-1}$ according to the following equation:
Total seed yield (kg. h $^{-1}$) = Yield of experimental unit (g) ÷ Area of experimental unit (m^2) × 10,000

2.5.6 Harvest index (%).
The harvest index is one of the indicators that demonstrates the efficiency of crops in distributing

metabolic products between economic and biological yields. Estimate the harvest index using the equation mentioned by [26] as follows:
Harvest index (%) = Total seed yield (kg. ha $^{-1}$) ÷ Biological yield (kg. ha $^{-1}$) × 100

2.6 Statical Analysis:

Most of the average data were analyzed using the statistical program (SAS) for the two study seasons using the cluster analysis method, for a factorial experiment within split plots. with three replicates according to the (RCBD) design. At the five percent significance level, Duncan's multiple range test was used to compare the averages of the qualities under study. [27].

3. Results and Discussion

3.1. Plant height (cm. plant $^{-1}$).
The test results in Table (1) show that inoculation with rhizobia had a significant effect on the mean values of the above-examined characteristics. The greatest significant difference was achieved with an inoculum of 400 ml of bacteria, with an average of 71.361 cm² plant^{-1}, while the lowest mean value was achieved for uninfected plants (54.664 cm² plant^{-1}). The reason for the above-mentioned increase in performance is the ability of the microorganisms contained in the bacterial inoculum to fix atmospheric nitrogen. The role of nitrogen in cell division and the production of growth regulating hormones leads to an increase in plant height, in addition to the production of auxins, gibberellins, cytokinins and enzymes. The sum of these data leads to an increase in plant growth. This result is consistent with [28,29]. The differences between the zeolite and organic fertilizer treatments were also the greatest, with the treatment with 100 kg of zeolite having the best effect. ha^{-1} + 24 tons of organic fertilizer. ha^{-1} reached the highest value with an average of 83.039 cm plant^{-1}, which was lower than that of the other treatments; the control treatment had the lowest average plant height of 43.872 cm plant^{-1}. The reason for the increase in fenugreek plant growth is that the addition of zeolite helps retain elements in the soil, prevents them from leaching from the root zone, and improves soil fertility during the plant growth stage. In addition, zeolite is a strong and highly absorbent material that prevents the loss of water and nutrient ions and improves root absorption, thereby improving and increasing plant growth. This has a positive impact on the improvement of the properties examined above. This result is consistent with [30]. When organic fertilizer (sheep manure) was added, the plants grew taller. This can be explained by the fact that organic fertilizers can improve various aspects of the soil, stimulate plant growth and provide important nutrients to plants. These results are consistent with the findings of [31]. The highest average value of was 67.865 cm Plant^{-1} and the lowest average value was 58.138 cm Plant^{-1} in the second season compared to the first season, which also showed a significant advantage over the first season. The combination of bacterial inoculation and (zeolite and organic) treatments clearly outperformed all other interactions, as the treatment with 400 ml of bacterial inoculum per ha with 100 kg of zeolite plus organic fertilizer per ha^{-1} had the highest mean value, 92.773 cm. Plant^{-1} in contrast to the mean value of 35.310 cm Plant^{-1} achieved by the control treatment and the treatment with uninoculated plants. The treatment with Plant-1 inoculated with 400 ml of bacteria plus the second season had the highest mean value, (76.080) cm Plant^{-1} although the interaction between the inoculated bacterial treatment and season was significant compared to the other treatments. Plant-1 had the lowest difference of 49.635 cm Plant^{-1} compared to the treatment with uninoculated plants in the first season + Plant^{-1}. As with the 100 kg zeolite treatment, the mean values of this function varied greatly depending on the season and the interaction between the combination (zeolite + organic matter) per ha^{-1} + 24 tons of organic fertilizer per ha^{-1}.The second season had the highest mean value, reaching 87.885 cm. Plant^{-1} had the lowest mean of 39.990 cm Plant^{-1} in the first season compared to the zeolite and organic + control treatments.The triple interactions of bacterial inoculation, combination (zeolite + organic) and seasons also recorded a significant difference with the highest value being with the treatment (400 ml bacterial inoculation with combination of 100 kg. ha^{-1} zeolite + 24 tons. ha^{-1} organic fertilizer + the second season) which amounted to (97.576 cm. plant-1), while the triple interaction between the uninoculated treatments + the comparison treatment of zeolite and organic + the 1 season

recorded the lowest value of (31.300 cm. plant^{-1}).

Table 1. The effect of bacterial inoculum, zeolite, organic fertilizer and their interactions on the on average plant height (cm. plant $^{-1}$)

seasons	first season2022-2023			second season2023-2024			interaction		
Bacterial inoculum treatments	Without adding bacterial Inoculum	Add (200) ml bacterial inoculum	Add (400) ml bacterial inoculum	Without adding bacterial inoculum	Add (200) ml bacterial inoculum	Add (400) ml bacterial inoculum	average treatments	treatments and seasons first season1	second season2
Control treatment	31.300 z	39.990 yz	48.680 wxy	39.320 yz	47.493 y	56.450 t	43.872 h	39.990 n	47.754 m
100kg. h $^{-1}$ zeolite + 24 ton . h $^{-1}$ organic	68.750 jk	77.860 ef	87.970 b	78.340 e	87.740 b	97.576 a	83.039 a	78.193 b	87.885 a
100kg. h $^{-1}$ zeolite + 16 tons. h $^{-1}$ organic	59.533 pqr	67.740 jkl	75.930 g	69.470 j	77.480 efg	85.140 c	72.548 b	67.734 d	77.363 b
100kg. h $^{-1}$ zeolite + 8 ton . h $^{-1}$ organic	54.600 u	63.860 o	72.120 i	65.660 mn	73.880 h	82.310 d	68.738 c	63.526 f	73.950 c
100kg. h^{-1} Zeolite	50.226 vw	58.440 rs	66.660 lm	60.460 pq	68.520 jk	76.200 fg	63.417 d	58.442 i	68.393 d
24ton . h^{-1} organic	48.116 xy	56.330 t	64.550 no	58.760 qrs	66.360 lm	74.133 h	61.375 e	56.332 j	66.417 e
16ton . h^{-1} organic	43.253 wyz	51.400 v	59.550 pqr	53.780 u	61.280 p	69.380 j	56.440 f	51.401 k	61.480 g
8ton . h^{-1} organic	41.300 yz	49.490 wx	57.680 st	51.760 v	59.826 pqr	67.453 kl	54.585 g	49.490 l	59.680 h
Bacterial inoculum averages	54.664 c	62.980 b	71.361 a				average seasons	58.138 b	67.865 a

Interaction between Bacterial inoculum and treatments	Without adding bacterial inoculum	Add (200) ml bacterial inoculum	Add (400) ml bacterial inoculum	Interaction between compost and seasons	first season	second season
Control treatment	35.310 r	43.741 q	52.565 n	Without adding bacterial inoculum	49.635 f	59.693 d
100kg. h $^{-1}$ zeolite + 24 ton . h $^{-1}$ organic	73.545 e	82.800 b	92.773 a	Add (200) ml bacterial inoculum	58.138 e	67.822 b
100kg. h $^{-1}$ zeolite + 16 ton . h $^{-1}$ organic	64.501 h	72.610 e	80.535 c	Add (400) ml bacterial inoculum	66.642 c	76.080 a
100kg. h $^{-1}$ zeolite + 8 ton . h $^{-1}$ organic	60.130 k	68.870 g	77.215 d			

100kg. h^{-1} Zeolite	**55.343 lm**	**63.480 hi**	**71.430 f**
24ton . h^{-1} organic	**53.438 n**	**61.345 j**	**69.341 g**
16ton . h^{-1} organic	**48.516 o**	**56.340 l**	**64.465 h**
8ton . h^{-1} organic	**46.530 p**	**54.658 m**	**62.566 i**

**The means of the coefficients and their interactions, which are symbolized by different letters, are significantly different from each other according to Duncan's multiple range test at the probability level (5%).*

3.2 Number of branches (branch. plant $^{-1}$).

The results presented in Table (2) indicate that bacterial inoculation (rhizobia) resulted in significant differences in the mean values of the above traits, since the 400 ml bacterial inoculation produced the highest mean value of 8.017 branches. The mean number of branches of the non-inoculated plants was 5.831 branches per plant^{-1}, which was the least different from plant -1. The production of growth regulators (auxins and gibberellins) by the bacterial inoculum (S. meliloti bacteria) may be responsible for the increase in the above traits studied. These growth regulators improve nitrogen fixation, which is essential for the formation of growth substances and promote cell division and development. This leads to increased plant growth and thus inhibits the formation of branches. However, the experimental factors played a role in enhancing the stimulation of the production of cytokinins and phytohormones in the roots. This ensured a balance between the activity of hormones that interrupt apical dominance and the increased branch production. This is consistent with the positive effect of the experimental factors on increasing plant height and, therefore, the incidence of the above traits studied. This result is consistent with the results of [32,28]. The addition of zeolite and organic fertilizers had a significant effect on the mean values of the above traits. The combination of 100 kg zeolite.ha^{-1} and 24 t organic fertilizer.ha^{-1} showed the best effect, with an average of 8.940 branches per plant^{-1}, while the control treatment showed the least difference, with an average of (4.710 branches per plant^{-1}).

The increase in the number of branches may be due to the role of zeolite in improving the nutrient status of the root zone, especially the selective retention of (NH_4 and K_2 ions), which significantly contributes to the vegetative growth of plants [33]. These results are consistent with [34]. In addition to promoting plant growth by improving plant growth conditions, increasing the biological fertility of the soil, enriching the main and minor elements available to the rhizosphere, organic fertilizers also help to improve the efficiency of physiological processes such as respiration and carbon metabolism, promote the production of growth substances, cell division and the formation of new cells, and the production of growth regulators cytokinins. This can also be attributed to the beneficial effects of the factors studied (bacterial inoculum, zeolite and organic fertilizer), which stimulate the plants to produce more vegetative growth and more lateral shoots, thereby increasing the number of branches of the plants, or because it plays a vital role in stimulating the growth of lateral shoots and reducing apical dominance. These results are consistent with those of [35]. In terms of season, the most significant differences were found in the second season, with an average of 7.464 branches .plant^{-1}. This was compared to the lowest average of 6.379 branches. Plant $^{-1}$ in the first season for Plant -1. The treatment with the combination of 400 ml + zeolite 100 kg.ha^{-1} + organic fertilizer 24 t.ha^{-1} produced the highest average of 9.975 branches Plant $^{-1}$, indicating that the binary interaction between bacterial inoculation and (zeolite + organic) treatments significantly outperformed all other binary interactions. contrasted with the average of 3.630 branches Plant $^{-1}$ obtained for the uninoculated plant treatment and the control treatment combined. The highest significant differences in the means of the above

traits were obtained for the two-way interaction of 400 ml bacterial inoculation + second season treatment, reaching a mean of (8.572) branches. Plant $^{-1}$ had an average of 5.295 branches compared to the lowest difference for the uninoculated plant + first season treatment. The effect of the interaction between the treatments (zeolite + organic) and the seasons, as the treatment of zeolite 100 kg. ha $^{-1}$ + organic fertilizer 24 ton. ha $^{-1}$ + the second season outperformed with the highest average of 9.437 branch. plant $^{-1}$ compared to the comparison treatment of zeolite and organic + the first season, which achieved the lowest average of 4.200 branch. plant $^{-1}$. The treatment of bacterial inoculation 400 ml + zeolite combination 100 kg. ha^{-1} + organic fertilizer 24 ton. ha^{-1} + the second season with an average of 10.530 branches Plant $^{-1}$ produced the highest significant difference among the triple interaction between bacterial inoculation, (zeolite + organic) treatments, and seasons, but the triple interaction of the first season, zeolite and organic comparison treatments, and non-inoculated plants showed the least amount of variation, averaging 3,200 branches. plant $^{-1}$.

Table 2. The effect of bacterial inoculum, zeolite, organic fertilizer and their interactions on the on average *Number of branches (branch. plant $^{-1}$).*

seasons	first season2022-2023			second season2023-2024				interaction treatments and seasons	
Bacterial inoculum treatments	Without adding bacterial Inoculum	Add (200) ml bacterial inoculum	Add (400) ml bacterial inoculum	Without adding bacterial inoculum	Add (200) ml bacterial inoculum	Add (400) ml bacterial inoculum	average treatments	first season1	second season2
Control treatment	3.200 n	4.200 lmn	5.200 jklm	4.060 mn	5.293 ijklm	6.310 fghij	4.710 f	4.200 g	5.221 fg
100kg. h $^{-1}$ zeolite + 24 ton . h $^{-1}$ organic	7.460 cdefg	8.446 bcd	9.420 ab	8.446 bcd	9.336 ab	10.530 a	8.940 a	8.442 ab	9.437 a
100kg. h $^{-1}$ zeolite + 16 ton . h $^{-1}$ organic	6.360 fghij	7.420 cdefg	8.480 bcd	7.460 cdefg	8.440 bcd	9.500 ab	7.943 b	7.420 bcd	8.466 ab
100kg. h $^{-1}$ zeolite + 8 ton . h $^{-1}$ organic	6.200 ghij	7.200 defgh	8.200 bcde	7.310 defg	8.440 bcd	9.450 ab	7.800 bc	7.200 cd	8.400 ab
100kg. h $^{-1}$ Zeolite	5.340 ijklm	6.550 fghij	7.760 cdef	6.470 fghij	7.660 cdefg	8.870 bc	7.108 cd	6.550 cde	7.666 bc
24ton . h $^{-1}$ organic	5.200 jklm	6.400 fghij	7.600 cdefg	6.310 fghij	7.393 cdefg	8.600 bcd	6.917 d	6.400 de	7.434 bcd
16ton . h $^{-1}$ organic	4.600 klmn	5.600 ijkl	6.600 fghij	5.740 hijk	6.750 efghi	7.780 cdef	6.178 e	5.600 ef	6.756 cd
8ton . h $^{-1}$ organic	4.000 mn	5.220 jklm	6.440 fghij	5.140 jklm	6.316 fghij	7.540 cdefg	5.776 e	5.220 fg	6.332 def
Bacterial inoculum averages	5.831 c	6.916 b	8.017 a				average seasons	6.379 b	7.464 a

Interaction between Bacterial inoculum and treatments	Without adding bacterial inoculum	Add (200) ml bacterial inoculum	Add (400) ml bacterial inoculum	Interaction between compost and seasons	first season	second season
Control treatment	3.630 l	4.746 k	5.755 ij	Without adding bacterial inoculum	5.295 d	6.367 c
100kg. h $^{-1}$ zeolite + 24 ton . h $^{-1}$ organic	7.953 cdef	8.891 bc	9.975 a	Add (200) ml bacterial inoculum	6.379 c	7.453 b

100kg. h $^{-1}$ zeolite + 16 ton . h $^{-1}$ organic	6.910 gh	7.930 cdef	8.990 b	Add (400) ml bacterial inoculum	7.462 b	8.572 a
100kg. h $^{-1}$ zeolite + 8 ton . h $^{-1}$ organic	6.755 hi	7.820 defg	8.825 bcd			
100kg. h^{-1} Zeolite	5.905 ij	7.105 efgh	8.315 bcd			
24ton . h^{-1} organic	5.755 ij	6.896 gh	8.100 bcde			
16ton . h^{-1} organic	5.170 jk	6.175 hij	7.190 efgh			
8ton . h^{-1} organic	4.570 k	5.768 ij	6.990 fgh			

**The means of the coefficients and their interactions, which are symbolized by different letters, are significantly different from each other according to Duncan's multiple range test at the probability level (5%).*

3.3. Number of pods in the plant (pod. plant $^{-1}$).

The results in Table (3) show that the bacterial inoculum (Rhizobium) had a significant effect on the mean values of the above studied traits. The most significant difference was achieved in the 400 ml bacterial inoculum treatment, with an average of 65.236 pods per plant $^{-1}$, while the lowest number of pods was achieved in the uninoculated plants, with an average of 49.411 pods per plant $^{-1}$. The increase in the number of pods after treatment with the bacterial inoculum (S. meliloti) is due to the supply of nitrogen to the plant throughout its life cycle by fixing atmospheric nitrogen. This leads to a slower rate of leaf aging. Thus, an increase in the balanced supply of nitrogen stimulates flowering and fruiting in the plant, releases sufficient amounts of primary and secondary nutrients, and releases organic matter from sources in the root environment and increases its uptake by the plant, resulting in an increase in photosynthetic products from the source (leaves), and as a result, the vegetative growth indicators of the plant are improved, thereby improving the mean characteristics studied above. This result is consistent with the results of [36,37]. Among the zeolite and organic treatments, the zeolite treatment (100 kg.ha^{-1}) and organic fertilizer (24 t.ha^{-1}) performed better than the other treatments. The control treatment had the least difference, with an average of 35.255 pods per plant^{-1}. Zeolite acts by increasing water uptake in the root zone, thereby reducing interference with plant biological processes, which may be the reason for the increase in the average number of pods per plant. Therefore, zeolite leads to an increase in various biological processes in the plant. In addition, it helps to reduce competition within the plant, thereby increasing metabolites. These effects are positively reflected in the improved average performance of fenugreek plants in the above study. Zeolite also helps in nutrient supply and increases chlorophyll content in leaves, thereby improving the carbon metabolism efficiency of plants. This result is consistent with the results of the study [38]. The addition of organic fertilizer (sheep manure) can increase the number of pods per plant. This is because it contains essential nutrients that can effectively accelerate plant growth and increase carbohydrate production in plants, thereby increasing the amount of nutrients in the plant and its transportation to the pods. This result is consistent with the results of both studies [39]. Furthermore, the number of pods in the second study season exceeded that in the first study season, which had the least difference with an average of 53.846 pods per plant^{-1}, while the highest average number of pods per plant was 60.883 in the second study season. Compared to the interaction between the treatment with uninoculated plants and the control treatment (zeolite and organic), the treatment recorded the lowest average of 26.780 pods per plant^{-1}, while the combined treatment of bacterial inoculation + 100 kg zeolite per hectare + 24 tons of organic fertilizer per hectare reached the highest average of 94.200 pods per plant^{-1}. This interaction significantly outperformed all other interactions. While the two-way interaction between bacterial inoculation treatment and season had a significant effect on the above trait means, the 400 ml bacterial inoculation + second season treatment reached the highest average of 68.649 pods. Plant^{-1} had the least difference compared to the treatment with uninoculated plants in the first season + plant reaching an average of 45.870 pods. Plant^{-1}. The interaction between treatment (zeolite + organic matter) and season proved to be significantly better

on average for the property. The combination of 100 kg of zeolite per hectare plus 24 tons of organic fertilizer per hectare plus the second season produced the highest average of 86,083 pods per plant-1, while the comparison treatment of zeolite and organic plus the first season produced the lowest average of 32,520 pods per plant^{-1}.The results also showed that the triple interaction between bacterial inoculation and (zeolite + organic) treatments and seasons significantly increased the average number of pods for fenugreek plants, as the highest significant difference was achieved with the bacterial inoculation treatment 400 ml + zeolite combination 100 kg. ha $^{-1}$ + organic fertilizer 24 ton. ha $^{-1}$ + the second season, which averaged 98.520 pod. plant $^{-1}$, while the triple interaction between (non-inoculated plants + comparison treatment of zeolite and organic + the first season) recorded the lowest significant difference, which averaged 24.330 pod. plant $^{-1}$.

Table 3. The effect of bacterial inoculum, zeolite, organic fertilizer and their interactions on the on average *Number of pods in the plant (pod. plant $^{-1}$).*

seasons	first season2022-2023			second season2023-2024				interaction	
Bacterial inoculum treatments	Without adding bacterial Inoculum	Add (200) ml bacterial inoculum	Add (400) ml bacterial inoculum	Without adding bacterial inoculum	Add (200) ml bacterial inoculum	Add (400) ml bacterial inoculum	average treatments	treatments and seasons first season1	second season2
Control treatment	24.330 f	32.520 d	40.710 za	29.230 e	38.560 b	46.180 x	35.255 h	32.520 p	37.990 o
100kg. h $^{-1}$ zeolite + 24 tons . h $^{-1}$ organic	65.640 jk	77.760 d	89.880 b	73.460 f	86.270 c	98.520 a	81.921 a	77.760 b	86.083 a
100kg. h $^{-1}$ zeolite + 16 ton . h $^{-1}$ organic	57.240 pq	64.360 kl	71.480 g	64.360 kl	71.240 g	78.476 d	67.859 b	64.360 e	71.358 c
100kg. h $^{-1}$ zeolite + 8 ton . h $^{-1}$ organic	52.640 st	60.790 mn	68.946 hi	60.550 no	67.320 ij	75.513 e	64.293 c	60.792 g	67.794 d
100kg. h $^{-1}$ Zeolite	48.270 vw	55.430 qr	62.590 lm	55.440 qr	62.740 lm	69.340 h	58.968 d	55.430 i	62.506 f
24ton . h $^{-1}$ organic	44.120 y	51.550 tu	58.983 nop	51.380 tu	58.656 op	65.490 jk	55.030 e	51.551 k	58.508 h
16ton . h $^{-1}$ organic	39.320 ab	46.290 x	53.260 st	46.633 wx	53.720 rs	60.416 no	49.940 f	46.290 m	53.590 j
8ton . h $^{-1}$ organic	35.400 c	42.070 z	48.740 v	42.576 yz	49.883 uv	55.256 qr	45.654 g	42.070 n	49.238 l
Bacterial inoculum averages	49.411 c	57.447 b	65.236 a				average seasons	53.846 b	60.883 a

Interaction between Bacterial inoculum and treatments	Without adding bacterial inoculum	Add (200) ml bacterial inoculum	Add (400) ml bacterial inoculum	Interaction between compost and seasons	first season	second season
Control treatment	26.780 u	35.540 t	43.445 r	Without adding bacterial inoculum	45.870 f	52.953 e
100kg. h $^{-1}$ zeolite + 24 ton . h $^{-1}$ organic	69.550 e	82.015 b	94.200 a	Add (200) ml bacterial inoculum	53.846 d	61.048 c

100kg. h $^{-1}$ zeolite + 16 ton . h $^{-1}$ organic	60.800 j	67.800 f	74.978 c	Add (400) ml bacterial inoculum	61.823 b	68.649 a
100kg. h $^{-1}$ zeolite + 8 ton . h $^{-1}$ organic	56.595 l	64.055 h	72.230 d			
100kg. h $^{-1}$ Zeolite	51.855 n	59.085 k	65.965 g			
24ton . h $^{-1}$ organic	47.750 p	55.103 m	62.236 i			
16ton . h $^{-1}$ organic	42.976 r	50.005 o	56.838 l			
8ton . h $^{-1}$ organic	38.988 s	45.976 q	51.998 n			

**The means of the coefficients and their interactions, which are symbolized by different letters, are significantly different from each other according to Duncan's multiple range test at the probability level (5%).*

3.4. Number of seeds per pod (seed .pod $^{-1}$).

Table (4) shows that the bacterial inoculum (rhizobium) had a significant effect on the mean values of the above-examined traits, given that the 400 ml bacterial inoculum treatment produced the largest significant difference, with an average of 16.495 seed pods, while the non-inoculated plants had the lowest mean value of 13.875 seed pods. The effectiveness of the S. meliloti bacteria in the secretion of phytohormones (cytokinins) helps transport carbon metabolites from the initial production site of the plant (leaves) to the downstream storage sites (flowers and fruits), and the role of cytokinins produced by the bacterial inoculum in the growth and development of eggs and ovaries, thereby improving pollination rates, leading to faster germination, and, in turn, increasing the number of seeds in the capsule. These factors could be responsible for the effects of the bacterial inoculum treatment on the above-examined traits. This result is consistent with the findings of [40]. Although the zeolite and organic fertilizer treatments had a significant effect on the mean values of the above-examined traits, the most significant differences were seen in the treatments containing 100 kg zeolite per hectare and 24 tons of organic fertilizer per hectare, with an average of 18.990 seeds per pod. The lowest average number of seeds per pod was 11.884 in the other treatments. The addition of zeolite and organic fertilizers to fenugreek plants improved root mass growth and improved physiological and vegetative growth indicators, which may be the reason for the increase in the above-mentioned studied traits. This may be because zeolite participates in plant growth and development, provides important nutrients (potassium, phosphorus and nitrogen), increases the amount of carbohydrates produced by the leaves and transferred to the seeds, and supports plant growth. All of these contribute to the improvement of this characteristic. Since more nutrients are available for absorption, the leaves may contain more synthetic substances. In addition, enzymes that promote the transport of carbohydrates from the production site in the leaves to the storage site in the fruit part may play a greater role. As a result, the number of seeds in the pods increased, reflecting these facts, and this result is consistent with [41]. The number of seeds in the pods increased when organic fertilizers (sheep manure) were applied. This may be because organic fertilizers promote better flowering and fruit formation, thereby increasing the number and length of pods. In addition, this leads to a more efficient division of photosynthesis and protein synthesis processes, thereby increasing the number of grains formed in the pods. This result is consistent with [39,42]. The second season had the highest number of seed pods with an average of 16.677, while the first season had the lowest number of with an average of 13.697 seed .pod $^{-1}$, with the second season performing significantly better. The treatment with 400 ml bacterial inoculation + 100 kg zeolite per hectare combination + 24 tonnes of organic fertilizer per hectare achieved the highest significant difference in the means of the above studied traits with an average of 21.130 seed .pod $^{-1}$, while the treatment with the control treatment of uninoculated plants + zeolite and organic fertilizer achieved the lowest significant difference with an average of 9.320 seed .pod $^{-1}$. This means that the binary interaction between the bacterial inoculation and (zeolite + organic) treatments was significantly better than all other binary

interactions. Pods -1. The results also showed that the bacterial inoculation treatment interacted significantly better with the season, with the 400 ml + second season bacterial inoculation treatment having the highest mean number of seeds with an average of 18.053 seed .pod $^{-1}$.compared to the non-inoculated plants treatment + the first season, which averaged 12.472 seed. pod $^{-1}$The combination of 100 kg of zeolite and the seasons produced the highest average for this feature in the two-way interaction between the treatments (zeolite + organic). 24 tons of organic fertilizer per hectare. Compared to the zeolite and organic control treatments plus the first season, which had the lowest average of 10.480 seeds per pod, + the second season produced 20.606 seeds per pod. The study's findings demonstrated that the greatest significant variation in the average number of seeds per pod was observed in the triple interaction between bacterial inoculation, treatments (zeolite + organic), and seasons. This was done using a 400 cc bacterial inoculation therapy and a 100 kg zeolite combination. 24 tons of organic fertilizer per hectare. hectare $^{-1}$ + with an average of 22,950 seeds during the second season. pod -1 However, with an average of 8.220 seed .pod $^{-1}$, the triple interaction between non-inoculated plants + the comparison treatment of zeolite and organic + the first season produced the smallest difference.

Table 4. The effect of bacterial inoculum, zeolite, organic fertilizer and their interactions on the on average *Number of seeds per pod (seed. pod $^{-1}$).*

seasons	first season2022-2023			second season2023-2024				interaction treatments and seasons	
Bacterial inoculum treatments	Without adding bacterial Inoculum	Add (200) ml bacterial inoculum	Add (400) ml bacterial inoculum	Without adding bacterial inoculum	Add (200) ml bacterial inoculum	Add (400) ml bacterial inoculum	average treatments	first season1	second season2
Control treatment	8.220 y	10.480 x	12.740 tuvw	10.420 x	13.640 qrstu	15.806 ghijklmn	11.884 g	10.480 j	13.288 ghi
100kg. h $^{-1}$ zeolite + 24 tons . h $^{-1}$ organic	15.550 hijklmnop	17.260 defgh	19.310 bc	18.660 bcd	20.210 b	22.950 a	18.990 a	17.373 b	20.606 a
100kg. h $^{-1}$ zeolite + 16 ton . h $^{-1}$ organic	13.990 opqrstu	14.976 jklmnopqr	15.956 fghijklm	16.740 efghij	17.860 cde	18.936 bcd	16.410 b	14.974 ef	17.845 b
100kg. h $^{-1}$ zeolite + 8 ton . h $^{-1}$ organic	13.593 qrstu	14.530 lmnopqrs	15.430 ijklmnop	16.780 efghi	17.750 cde	18.756 bcd	16.140 bc	14.517 efg	17.762 b
100kg. h $^{-1}$ Zeolite	12.833 stuvw	13.880 pqrstu	14.890 klmnopqr	15.763 hijklmno	16.823 efghi	17.526 defg	15.286 cd	13.867 fgh	16.704 bc
24ton . h $^{-1}$ organic	12.320 uvw	13.220 rstuv	14.116 nopqrst	15.240 ijklmnopq	16.420 efghijk	17.680 cdef	14.832 de	13.218 ghi	16.446 bcd
16ton . h $^{-1}$ organic	11.840 vwx	12.850 stuvw	13.823 pqrstu	14.376 mnopqrst	15.576 hijklmnop	16.550 efghijk	14.169 ef	12.837 hi	15.501 cde
8ton . h $^{-1}$ organic	11.433 wx	12.266 uvw	13.240 rstuv	14.240 mnopqrst	15.340 ijklmnopq	16.220 efghijkl	13.790 f	12.313 i	15.266 def
Bacterial inoculum averages	13.875 c	15.192 b	16.495 a				average seasons	13.697 b	16.677 a

Interaction between Bacterial inoculum and treatments	Without adding bacterial inoculum	Add (200) ml bacterial inoculum	Add (400) ml bacterial inoculum	Interaction between compost and seasons	first season	second season
Control treatment	9.320 m	12.060 l	14.273 hi	Without adding bacterial inoculum	12.472 e	15.277 c

100kg. h $^{-1}$ zeolite + 24 ton . h $^{-1}$ organic	17.105 cd	18.735 b	21.130 a	Add (200) ml bacterial inoculum	13.682 d	16.702 b
100kg. h $^{-1}$ zeolite + 16 ton . h $^{-1}$ organic	15.365 efgh	16.418 cde	17.446 c	Add (400) ml bacterial inoculum	14.938 c	18.053 a
100kg. h $^{-1}$ zeolite + 8 ton . h $^{-1}$ organic	15.186 fgh	16.140 def	17.093 cd			
100kg. h $^{-1}$ Zeolite	14.298 hi	15.351 efgh	16.208 def			
24ton . h $^{-1}$ organic	13.780 ijk	14.820 ghi	15.898 efg			
16ton . h $^{-1}$ organic	13.108 jkl	14.213 hij	15.186 fgh			
8ton . h $^{-1}$ organic	12.836 kl	13.803 ijk	14.730 ghi			

**The means of the coefficients and their interactions, which are symbolized by different letters, are significantly different from each other according to Duncan's multiple range test at the probability level (5%).*

3.5. Seed yield (kg. ha $^{-1}$).

The bacterial inoculation (rhizobium) treatment with an inoculum size of 400 ml obtained the highest mean value of 1631.61 kg. ha^{-1}, while the lowest mean value of 913.73 kg. ha^{-1} was obtained for the uninoculated plants. The results in Table (5) show that there were significant differences on average between the experimental factors and their binary and ternary interactions for the above-mentioned studied characteristics. Inoculation of plants with S. meliloti bacteria may increase total seed yield because bacteria produce plant hormones such as auxins, cytokinins, gibberellins and vitamins that promote microbial activity, plant growth, water uptake and nutrients important for plant growth, as well as the ability of roots to absorb them. As a result, the weight of root growth signs increased, resulting in an increase in vegetative growth markers. In addition, the bacterial inoculum (rhizobium) improved physiological growth indicators, each of which contributes to the ability of seeds to store proteins and carbohydrates and to efficiently transport photosynthetic products. As a result, the average characteristics of the above-mentioned studies were improved. These results are consistent with the results of the study by [43]. The treatment of 100 kg zeolite.ha^{-1} + 24 tons of organic fertilizer.ha^{-1} had a significant effect on the mean values of the above-mentioned studied traits, with the maximum significant difference reaching an average of 2055.48 kg.ha^{-1} compared to the other treatments, among which the control treatment had the smallest difference, with an average of 528.13 kg.ha^{-1}. Zeolite not only improves the utilization of nitrogen by plants by preventing the loss of nitrogen required for chlorophyll production in plant leaves, but also helps to establish a root system that absorbs water and important nutrients, which has a positive effect on improving physiological activities (efficiency of photosynthesis and respiration). These factors can help the soil retain more water and increase the availability of nutrients. All these factors contribute to the improvement of the average characteristics of the above-mentioned studies. These results are consistent with the results of [44]. When treated with organic fertilizer (sheep manure), the total seed yield increased. This may be because organic fertilizers improve the physical and chemical properties of the soil., These include root respiration, aeration, water movement, and removal of gases that are harmful to microorganisms and essential for root activity. In addition, the decomposition of organic fertilizers releases organic acids and minerals such as fulvic acid and humic acid, which change the soil pH and N-P-K availability. By combining all these indicators, the studied characteristics of the mulch were ultimately improved, and these results are consistent with [45]. The highest significant difference in the mean value of this trait was in the second season, reaching 1414.58 kg.ha^{-1}, while the lowest significant difference was in the first season, with an average value of 1143.22 kg.ha^{-1}. The interaction of the treatment of 400 ml of the inoculant + 100 kg.ha^{-1} of zeolite combination + 24 tons.ha-1 of organic fertilizer was significantly superior to all interactions, with the highest average value of 2557.71 kg. ha^{-1} compared to the interaction of the treatment of uninoculated plants + the control

treatment of zeolite and organic matter, which had the lowest average value of 255.00 kg. ha^{-1}. The interaction of the treatment of 400 ml + bacterial inoculation in the second season had a significant effect on the mean values of the above traits, with the highest mean value of 1439.49 kg. ha^{-1}, while the treatment of uninoculated plants + the first season had the smallest difference, with an average of 803.81 kg. ha^{-1}. The combination of 100 kg of zeolite per hectare and 24 tons of organic fertilizer per hectare plus the second season had the highest yield of 2210.51 kg per hectare^{-1}, while the control treatment of zeolite and organic fertilizer plus the first season had the lowest yield of 447.91 kg per hectare^{-1}. In addition, compared with the interaction of uninoculated plants + zeolite and organic fertilizer control treatment + the first season, the interaction showed the smallest difference, with an average of 203.12 kg.ha^{-1}, while the interaction of the treatment of bacterial inoculation rate 400 ml + the combination of zeolite 100 kg.ha^{-1} + organic fertilizer 24 tons.ha^{-1} + the second season showed the largest significant difference in the average total seed yield trait, which was 2716.12 kg.ha^{-1}.

Table 5. The effect of bacterial inoculum, zeolite, organic fertilizer and their interactions on the on average *Seed yield (kg. ha $^{-1}$).*

seasons	first season2022-2023			second season2023-2024				interaction	
Bacterial inoculum treatments	Without adding bacterial Inoculum	Add (200) ml bacterial inoculum	Add (400) ml bacterial inoculum	Without adding bacterial inoculum	Add (200) ml bacterial inoculum	Add (400) ml bacterial inoculum	average treatments	treatments and seasons first season1	second season2
Control treatment	203.12 z	447.91 y	692.70 v	306.88 xy	636.68 wx	881.46 t	528.13 h	447.91 l	608.34 k
100kg. h $^{-1}$ zeolite + 24 ton . h $^{-1}$ organic	1402.77 kl	1899.30 f	2399.30 b	1699.81 h	2215.59 d	2716.12 a	2055.48 a	1900.46 b	2210.51 a
100kg. h $^{-1}$ zeolite + 16 ton . h $^{-1}$ organic	994.79 rs	1444.23 k	1894.09 f	1418.48 kl	1843.48 g	2292.76 c	1647.97 b	1444.37 e	1851.57 b
100kg. h $^{-1}$ zeolite + 8 ton . h $^{-1}$ organic	960.07 s	1328.12 m	1694.44 h	1074.59 q	1673.84 h	2039.85 e	1461.82 c	1327.54 f	1596.09 c
100kg. h $^{-1}$ Zeolite	869.79 t	1229.16 no	1588.54 i	1155.68 p	1538.44 j	1897.54 f	1379.86 d	1229.16 g	1530.55 d
24ton . h $^{-1}$ organic	776.04 u	1079.86 q	1385.41 l	959.83 s	1257.87 n	1580.82 i	1173.30 e	1080.44 h	1266.17 g
16ton . h $^{-1}$ organic	614.58 x	906.25 t	1197.91 o	906.61 t	1216.28 no	1504.77 j	1057.73 f	906.25 i	1209.22 g
8ton . h $^{-1}$ organic	609.37 x	810.76 u	1008.76 r	667.33 vw	1133.80 p	1331.38 m	926.89 g	809.60 j	1044.17 h
Bacterial inoculum averages	913.73 c	1291.34 b	1631.61 a				average seasons	1143.22 b	1414.58 a

Interaction between Bacterial inoculum and treatments	Without adding bacterial inoculum	Add (200) ml bacterial inoculum	Add (400) ml bacterial inoculum	Interaction between compost and seasons	first season	second season
Control treatment	255.00 t	542.30 s	787.08 q	Without adding bacterial inoculum	803.81 f	1023.65 e

100kg. h $^{-1}$ zeolite + 24 ton . h $^{-1}$ organic	1551.29 g	2057.44 c	2557.71 a	Add (200) ml bacterial inoculum	1143.19 d	1439.49 c
100kg. h $^{-1}$ zeolite + 16 ton . h $^{-1}$ organic	1206.63 k	1643.86 f	2093.43 b	Add (400) ml bacterial inoculum	1482.63 b	1780.60 a
100kg. h $^{-1}$ zeolite + 8 ton . h $^{-1}$ organic	1017.33 n	1500.98 h	1867.14 d			
100kg. h $^{-1}$ Zeolite	1012.74 n	1383.80 i	1743.04 e			
24ton . h $^{-1}$ organic	867.93 p	1168.86 l	1483.12 h			
16ton . h $^{-1}$ organic	760.60 q	1061.27 m	1351.34 j			
8ton . h $^{-1}$ organic	638.35 r	972.28 o	1170.03 l			

**The means of the coefficients and their interactions, which are symbolized by different letters, are significantly different from each other according to Duncan's multiple range test at the probability level (5%).*

3.6. Harvest index (%).

The results in Table (6) show that the bacterial inoculum has a significant effect on the mean values of the above-mentioned studied traits, since the mean value of the treatment with 400 ml of bacterial inoculum (rhizobium) reached 47.562%, while the lowest mean value of the treatment with uninfected plants was 41.520%. In addition to increasing the chlorophyll content in plant leaves and nutrients, inoculation with S. meliloti bacteria can also accelerate plant growth and development, thereby improving plant growth indicators, promoting biochemical processes, increasing the efficiency of plant water and nutrient absorption, activating carbon metabolism, accumulating products of proteins, minerals, sugars, amino acids and other organic substances, thereby increasing the mean values of the above-mentioned studied traits, the content of which is reflected in the mean values of the above-mentioned studied traits. The results of the two studies are consistent with these findings [46]. In addition, zeolite and organic treatments have a significant effect on the mean value of this characteristic. Among them, the combination of zeolite 100 kg.ha^{-1} + organic fertilizer 24 tons.ha^{-1} has a significant difference, with an average of 50.264%, while the remaining treatments have the smallest difference, with an average of 36.535%. The positive ability of zeolites to store nutrients (nitrogen, phosphorus and potassium) in the root environment and use them when needed may be the reason for the increase in the harvest index. As a result, nutrient utilization becomes more efficient, as evidenced by the increase in yield components and indicators. Alternatively, this increase may be explained by the role of zeolites in increasing plant biomass, which in turn increases photosynthesis and plant maintenance. As a result, the average performance of the study was improved due to all these facts. These results are in line with the results of the study by [47]. The addition of organic fertilizers (sheep manure) can increase the harvest area index, which may be due to the fact that the fertilizer provides the plants with essential nutrients such as nitrogen, phosphorus and potassium, while improving soil properties and absorption capacity. This is reflected in the significant improvement of the above characteristics. This result is consistent with the results of [25]. Although the above characteristics in the second season achieved the highest average value of 46.184%, it was significantly higher than the lowest average value of 43.004% in the first season. The results also showed that the interaction between bacterial inoculation and (zeolite + organic) treatment was significantly better than all interactions, such as the interaction between bacterial inoculation 400 ml + zeolite combination 100 kg. ha^{-1} + organic fertilizer 24 tons. ha^{-1}, with an average value of 53.666% higher than the interaction between uninoculated plant treatment + zeolite and organic fertilizer control treatment, which had the lowest difference, with an average of 31.560%. The results also showed that the two-way interaction between bacterial inoculation and uninoculated plants + first season treatment produced the lowest significant difference, with an average of 39.840%, while the 400 ml bacterial inoculation + second season treatment produced the highest

significant difference, with an average of 49.001%. In addition to the interaction between season and treatment (zeolite + organic fertilizer), the combination of 100 kg zeolite per hectare plus 24 tons of organic fertilizer per hectare plus the second season produced the highest mean value of 51.856%, while zeolite and organic fertilizer plus the control treatment in the first season produced the lowest mean value of 34.844%. The results also showed that the triple interaction between bacterial inoculation and treatment (zeolite + organic) and season significantly exceeded the mean harvest index. The mean difference of the triple interaction of uninoculated plants + zeolite and organic fertilizer control treatment + bacterial inoculation treatment (100 kg zeolite per hectare + 24 tons of organic fertilizer per hectare) in the first season was 29.330%, while the mean difference of the bacterial inoculation treatment (100 kg zeolite per hectare^{-1} + 24 tons of organic fertilizer per hectare^{-1}) in the second season was higher at 52.880%.

Table 6. The effect of bacterial inoculum, zeolite, organic fertilizer and their interactions on the on average *Harvest index (%).*

seasons	first season2022-2023			second season2023-2024				interaction treatments and seasons	
Bacterial inoculum treatments	Without adding bacterial Inoculum	Add (200) ml bacterial inoculum	Add (400) ml bacterial inoculum	Without adding bacterial inoculum	Add (200) ml bacterial inoculum	Add (400) ml bacterial inoculum	average treatments	first season1	second season2
Control treatment	29.330 w	34.797 v	40.407 stu	33.790 v	38.410 u	42.480 pqrst	36.535 e	34.844 i	38.227 h
100kg. h $^{-1}$ zeolite + 24 tons . h $^{-1}$ organic	46.110 hijklmn	48.990 cdefg	50.920 bcd	47.637 fghijk	51.517 bc	52.880 a	49.675 a	48.673 ab	50.678 a
100kg. h $^{-1}$ zeolite + 16 ton . h $^{-1}$ organic	42.560 pqrst	45.643 jklmno	48.227 defghi	49.487 bcdef	48.877 cdefgh	50.523 bcde	47.552 b	45.477 cde	49.629 a
100kg. h $^{-1}$ zeolite + 8 ton . h $^{-1}$ organic	42.337 pqrst	45.183 jklmnop	48.043 efghij	44.923 klmnop	47.017 fghijkl	49.113 cdefg	46.102 bc	45.188 cde	47.018 bc
100kg. h $^{-1}$ Zeolite	40.910 stu	43.813 nopqr	46.710 fghijklm	43.917 mnopqr	46.453 ghijklmn	48.567 defgh	45.061 cd	43.811 def	46.312 bcd
24ton . h $^{-1}$ organic	40.220 tu	43.120 opqrs	46.030 hijklmn	42.893 opqrst	45.207 jklmnop	48.117 defghi	44.264 d	43.123 efg	45.406 cde
16ton . h $^{-1}$ organic	38.780 u	41.670 qrst	44.587 lmnop	47.803 efghij	42.740 pqrst	44.817 klmnop	43.399 d	41.679 fg	45.120 cde
8ton . h $^{-1}$ organic	38.480 u	41.163 rstu	44.070 mnopq	35.150 v	50.583 bcde	51.983 b	43.571 d	41.238 g	45.906 cd
Bacterial inoculum averages	41.520 c	44.699 b	47.342 a				average seasons	43.004 b	46.037 a
Interaction between Bacterial inoculum and treatments									

Control treatment	**31.560 o**	**36.603 n**	**41.443 m**	**Without adding bacterial inoculum**	**39.840 d**	**43.200 c**
100kg. h $^{-1}$ zeolite + 24 ton .h $^{-1}$ organic	**46.873 defg**	**50.253 b**	**51.900 a**	**Add (200) ml bacterial inoculum**	**43.047 c**	**46.350 b**
100kg. h $^{-1}$ zeolite + 16 ton . h $^{-1}$ organic	**46.023 fghi**	**47.260 def**	**49.375 bc**	**Add (400) ml bacterial inoculum**	**46.124 b**	**48.560 a**
100kg. h $^{-1}$ zeolite + 8 ton . h $^{-1}$ organic	**43.630 jkl**	**46.100 efgh**	**48.578 bcd**			
100kg. h $^{-1}$ Zeolite	**42.413 klm**	**45.133 ghij**	**47.638 cdef**			
24ton . h $^{-1}$ organic	**41.556 m**	**44.163 ijk**	**47.073 def**			
16ton . h $^{-1}$ organic	**43.291 jklm**	**42.205 lm**	**44.701 hij**			
8ton . h $^{-1}$ organic	**36.815 n**	**45.873 fghi**	**48.026 cde**			
	Without adding bacterial inoculum	**Add (200) ml bacterial inoculum**	**Add (400) ml bacterial inoculum**	**Interaction between compost and seasons**	**first season**	**second season**

4. Conclusion

Statistical analysis of the data means showed significant differences in all studied traits, with the treatment with 400 ml of bacterial inoculum (Sinorhizobium rhizobium) and the combined treatment (100 kg/ha of zeolite + 24 t/ha of organic fertilizer) being more effective, with the second season also showing advantages in vegetative growth, yield and its component traits.

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