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# Effect of using *Pseudomonas fluorescens* bacteria, *Glomus mosseae* fungus and liquid organic fertilizer on soil available nitrogen and phosphorus and some characteristics of fenugreek (*Trigonella foenum graecum L.*) and choline seed content

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**Abstract.** A factorial pot experiment was conducted during the fall season of 2023–2024 in the fields of the College of Agriculture/University of Wasit, according to a randomized complete block design (RCBD) with three factors and three replicates. The first factor is the bacterial inoculum *Pseudomonas fluorescens* at two levels (addition B1 and without addition B0), the second factor is the fungal fertilizer *Glomus mosseae* at two levels (addition M1 and without addition M0), and the third factor is the liquid organic fertilizer at two levels as well (addition O1 and without addition O0) added in two batches, thus we have eight treatments with three replicates so that the number of experimental units is 24 experimental units (pots). Available nitrogen and phosphorus in the soil, plant height, number of branches, number of pods, number of seeds per pod, seed content of active substance choline, and biological yield were measured. The triple interaction treatment of the three factors (B1M1O1) gave the best results for the mentioned traits, followed by the dual interaction treatment between bacteria and fungi (B1M1), then the dual interaction treatments between bacteria and liquid organic fertilizer B1O1 and between fungi and liquid organic fertilizer M1O1, then the single treatments B1, M1, and O1, and finally the control treatment without additives (B0M0O0), which gave the lowest results. The mycorrhizal reliability was calculated for each of the plant heights, number of pods, and biological yield and was 22.2, 68.25, and 33.00%, respectively.

**Key words:** soil content, water management, biofertilizer, biological yield.

# INTRODUCTION

In light of the development and scientific progress that the world has witnessed today, humans must create an environmental balance, take into account the cleanliness of the environment, protect it from production waste, and benefit from it on the agricultural and industrial levels. Therefore, the use of organic and biological fertilizer technologies in agriculture has recently been resorted to. Biofertilizers and organic fertilizers have proven their worth in restoring the environmental balance and obtaining a clean, healthy environment, in addition to producing crops with good and healthy specifications free of chemical pollutants. Biofertilizers, whether bacterial or fungal, are beneficial microscopic organisms that improve the physical, chemical, fertility, and biological properties of the soil by fixing some elements, such as nitrogen, and dissolving some compounds, such as phosphorus and potassium compounds, and facilitating some major and minor elements necessary for plant nutrition and by secreting a number of enzymes, organic acids, growth regulators, chelating materials, and biological inhibitors for some microscopic diseases (Mohammed & Alkobaisy, 2024; Al-Silmawy & Abdul-Ratha, 2023).

Fenugreek (*Trigonella foenum-groeum*) is a leguminous plant of the Fabaceae family, of which there are many species (about 70 species) in the world, of which about 17 species are widespread in Iraq. Fenugreek is of great importance, both from an agricultural and medical perspective, as it is used as food and a source of protein and has a high nutritional value, as its seeds are rich in a group of nutritional components such as proteins, fats, carbohydrates, and vitamins, in addition to containing many effective medical and pharmaceutical compounds, including choline, which is used in the treatment and prevention of many diseases such as diabetes, cholesterol, atherosclerosis, and stomach ulcers. It is also described as being a better green fodder than alfalfa because it contains phosphorus, protein, and fatty acids. Because of this importance, it is imperative to increase the production of the green group and seeds from fenugreek (Ghazal & Al-Jahshi, 2017; Hassan, 2017). Matevosyan et al., (2024a) determine the removal and usage rates of nitrogen, phosphorus, and potassium from soil and fertilizers by tomatoes and peppers in the Ararat Plain of Armenia. Results showed varying nutrient uptake, with nitrogen utilization ranging from 27–45% for tomatoes and 6–14% for peppers. The researchers concluded that organic fertilizers were more effective than microbiological concentrates. Matevosyan et al., (2024b) evaluated the agro-biological properties of different groundnut varieties (Lia, Virginia, Mocket, TMV 3, Sevahatik, and Chinese) in Armenia's semi-desert soil zones. Field experiments (2020–2022) revealed high germination rates (77.5–81.0%) and average yields of 2.77–3.33 t $ha^{-1}$. The varieties Mocket and Chinese stood out for their superior yield and quality, making them recommended for cultivation in the region. Almamori & Abdul-Ratha (2020), Hamid (2025) assessed the interaction between bio-fertilizers (nitrogen and phosphate) and vermicompost types under different NPK levels. Results showed that bio-fertilizers significantly increased available nitrogen and phosphorus in the soil, tuber count, and total yield, with the tri-interaction treatments showing the highest overall effectiveness.

The yield of fenugreek seeds and its active components are affected by many growth conditions, such as soil, fertilization, and its type. The use of biofertilizers such as fungi like arbuscular fungi AMF, especially the *Glomus mosseae*, which is suitable for Iraqi soil conditions, and plant growth-promoting bacteria PGPR such as *Pseudomonas fluorescens*, can be one of the important methods to improve the growth and production of fenugreek, especially with some components and organic materials that play an important role with organic fertilizers in maintaining soil fertility and its sustainability in the long term by fixing and preparing large and small nutrients, including nitrogen and phosphorus for plants. In addition, they are inexpensive and healthy compared to economically expensive chemical fertilizers. They also improve the physical and chemical properties of the soil and help provide organic humic acids such as humic and fulvic acids when organic matter decomposes.

Many studies have indicated that bio- and organic fertilizers can replace about half of the added mineral NPK fertilizers, which reduces the use of mineral fertilizers and leads to a reduction in environmental pollution that occurs with high additions of mineral fertilizers. Therefore, integrated fertilization of organic, bio-, and mineral fertilizers achieves a balanced nutrition system for the plant, which improves its qualities in quantity and quality (Abd-Al-Hadi et al., 2018; Jafaar et al., 2023). Benlahrech et al. (2018) examine the effects of inoculation and phosphorus regimes on symbiotic nitrogen fixation and phosphorus use efficiency in Algerian cowpea landraces. The results showed that inoculation with *Mesorhizobium sp.* (S1) increased shoot dry weight by 22%, total phosphorus content by 20%, and phosphorus use efficiency by 18%. Landraces from northern Algeria, particularly NE4, NE10, and NE11, exhibited better growth than those from the Sahara, making them potentially valuable for improving nitrogen fixation and promoting sustainable farming by reducing reliance on fertilizers. The research aims to study the effect of using bacterial and fungal bio-fertilizers and organic fertilizers, whether as a single addition or combinations, in improving the readiness of major elements in the soil and some characteristics of the vegetative group and yield and the content of fenugreek seeds of choline to serve humans as a treatment or animals as fodder.

## MATERIALS AND METHODS

This study was conducted during the fall season of 2023–2024 in the fields of the College of Agriculture/UUniversity of Wasit as a factorial pot experiment (pot capacity 20 kg soil) according to the randomized complete block design RCBD with three factors and three replicates. The treatments were randomly distributed within the sectors (replicates). The first factor is the bacterial vaccine at two levels (addition and without addition) symbolized by (B1, B0), which was obtained from a graduate student. The isolates were activated and grown on nutrient agar medium added at a rate of 10 mL per pot. The second factor is the mycorrhizal fungal fertilizer at two levels (addition and without addition) symbolized by (M1, M0) type *Glomus mosseae*, which was obtained from the Agricultural Research Department of the Ministry of Science and Technology. It consists of (soil + infected root + fungal spores) which were grown and propagated in pots by planting fenugreek, 20 g of vaccine was added to each pot, while the third factor is liquid organic fertilizer, also at two levels (addition and without addition) and symbolized by (O1, O0) and its type is AgriM40, Spanish origin, 100%

natural plant origin, containing 40% humic acids with a recommendation of 40 liters hectare$^{-1}$, as it was diluted with distilled water and added in two batches to each pot, one batch before planting and one batch at the vegetative growth stage (flowering stage), thus we have eight treatments with three replicates, so the number of experimental units is 24 experimental units. Fenugreek seeds were planted at a rate of 10 seeds per pot on 11/20/2023. Crop service and irrigation operations were carried out using the weight method when 50% of the field capacity was depleted, and weeding and patching operations were carried out throughout the growth period, then the plants were decreased to 7 plants. The physical and chemical properties of the experimental soil were analyzed before planting, as shown in Table 1.

**Table 1.** Some chemical and physical properties of soil before planting

| Property | Value | Unit |
|---|---|---|
| Electrical Conductivity EC(1:1) | 2.82 | dS. m$^{-1}$ |
| Soil pH(1:1) | 7.84 | ------- |
| Organic matter | 6.90 | g kg$^{-1}$ |
| Cation Exchange Capacity CEC | 11.36 | cmol km$^{-1}$ soil |
| Major available elements | | |
| Available Nitrogen | 29.4 | mg kg$^{-1}$ |
| Available Phosphorus | 12.50 | |
| Available Potassium | 139 | |
| Soil separates | | |
| Sand | 505 | g kg$^{-1}$ |
| Silt | 482 | |
| Clay | 13 | |
| Texture | Sandy loam | |

**Some soil and plant characteristics were studied after planting as follows:**

**Soil content of available major elements:**

1 – Soil content of available nitrogen: Available nitrogen was extracted from the soil with potassium chloride solution (2N) using the (Micro Kjeldahl) device and according to the method of Page et al. (1982), Mohammed & Suliman, (2023), Hassan et al. (2023a), Al-Salihi & Salim (2023).

2 – Soil content of available phosphorus: The method of Olsen et al. (1954), Jaafer et al. (2020) and Shahad et al. (2025) was used for extraction with sodium bicarbonate solution (0.5N) using the Spectrophotometer device according to the method of (Page et al., 1982) Hassan et al., (2022) and Hassan et al., (2023b).

**Plant characteristics: By taking five plants from each experimental unit:**

1 – Plant height (cm): Using a measuring tape from the area of contact of the stem with the soil to the highest peak.

2 – Number of branches. Plant$^{-1}$: The number of branches was calculated and divided by the number of the five random plants.

3 – Number of pods Plant$^{-1}$: The number of pods was calculated and divided by the number of the five random plants.

4 – Number of seeds Pod$^{-1}$: The total number of seeds was calculated and divided by the number of pods for the five random plants.

5 – Seed content of the active substance choline (microgram mL$^{-1}$): 100 g of seeds were taken from each experimental unit and milled and sifted, then 80 g of the milled seeds were taken to remove fats and prepare them for the purpose of extracting the alkaloid compounds. After removing the fat from the seeds according to the method of Wagner et al. (1984), Khudhair & Abdulrasool (2023). the compounds were separated

and purified by taking 40 g of the residue of the defatted seeds. The alkaloids were extracted and purified according to the method of (Tugrul & Ozer, 1985).

6 – Biological yield (gm plant$^{-1}$): The biological yield was calculated at harvest, the plants were cut from the soil surface level (the whole plant with the pods) and placing them in perforated paper bags, they were placed in an electric oven at a temperature of 70 °C for 72 hours and then weighed.

7 – Mycorrhizal reliability: The relative mycorrhizal reliability was estimated by the following equation:

Mycorrhizal reliability = the measured trait of the mycorrhizal plant - the same measured trait of the non-mycorrhizal plant / the measured trait of the mycorrhizal plant X100.

Its value ranges from (0–100%) according to what was stated in Shi et al. (2016), Akol et al. (2023) and Akol et al. (2024).

Statistical analysis was carried out by comparing the averages using the least significant difference (LSD) at a significance level of 0.05 using SAS (1992) SAS.

## RESULTS AND DISCUSSION

### Soil content of available nitrogen (mg kg$^{-1}$)

Fig. 1 shows adding bacterial, fungal and liquid organic fertilizers individually or in a double and triple interaction had a significant effect on the soil content of available nitrogen, as adding *Pseudomonas fluorescens* bacteria alone led to an increase in the concentration of available nitrogen in the soil, which reached 22.2 mg kg$^{-1}$, and adding mycorrhizal fertilizer also led to a significant increase in the soil content of available nitrogen, which reached 20.5 mg kg$^{-1}$, and using liquid organic fertilizer led to an increase in the soil content of available nitrogen, which reached 21.4 mg kg$^{-1}$, and the double interactions in all cases had a significant effect on the soil concentration of available nitrogen, which reached 22.7 mg kg$^{-1}$ when adding biofertilizer and fungal fertilizer together, and reached 22.6 mg kg$^{-1}$ by adding bacteria with organic fertilizer, while when adding mycorrhizal and organic fertilizer, the available nitrogen concentration reached 21.8 mg kg$^{-1}$, and there were significant effects of the triple interactions, reaching their highest level when adding bacteria, fungi and liquid organic fertilizer, giving 23.0 mg kg$^{-1}$ of available nitrogen compared to the control sample (without any addition) which gave the lowest average soil content of available nitrogen 11.9 mg kg$^{-1}$ and an increase rate of 93.27%.

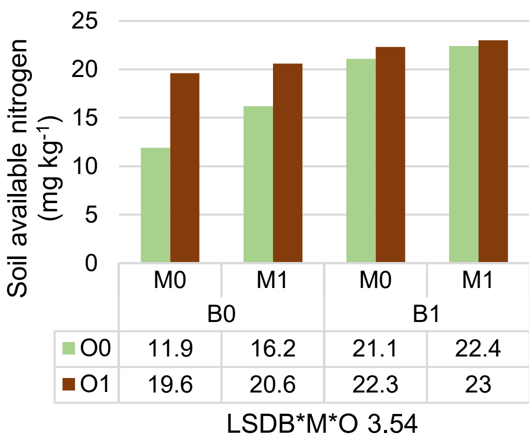


**Figure 1.** Effect of adding bacterial, fungal and liquid organic fertilizer on the soil content of available nitrogen (mg kg$^{-1}$).

**Soil content of available phosphorus (mg kg$^{-1}$)**

Fig. 2 shows the addition of *Pseudomonas fluorescens* bacteria and *Glomus mosseae* fungus individually had a significant effect on the soil content of available phosphorus, which reached 14.0 mg kg$^{-1}$ and 14.2 mg kg$^{-1}$, respectively, while the addition of organic fertilizer alone did not affect the average concentration of available phosphorus in the soil, which reached 13.4 mg kg$^{-1}$. The dual interactions had a significant effect on the soil content of available phosphorus, as by adding bacterial and fungal fertilizer together, the available phosphorus reached 14.9 mg kg$^{-1}$, and it reached 14.1 mg kg$^{-1}$ when adding bacterial biofertilizer and liquid organic fertilizer, while its value was 14.6 mg kg$^{-1}$ when adding mycorrhizal fertilizer and liquid organic fertilizer. As for the triple interactions, they had a significant effect on the soil content of available phosphorus, recording the highest average of 15.3 mg kg$^{-1}$ when adding bacterial, fungal and liquid organic fertilizers, compared to the comparison (control) sample, which gave the lowest average of 11.2 mg kg$^{-1}$ for available phosphorus in the soil, with an increase rate of 36.6%.

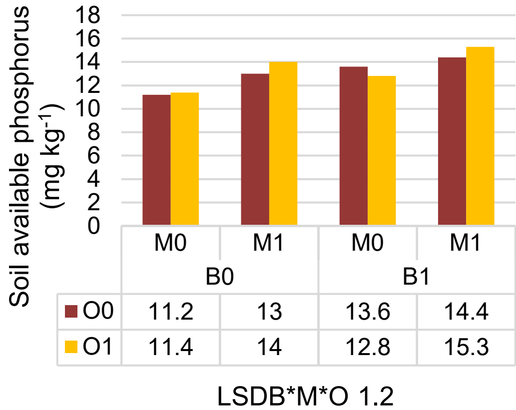


**Figure 2.** Effect of adding bacterial, fungal and liquid organic fertilizer on the soil content of available phosphorus (mg kg$^{-1}$).

**Plant height (cm):**

Fig. 3 that there is a significant effect of adding bacterial, fungal and organic fertilizers individually on plant height, as plant height reached 43.8, 43.7 cm and 43.4 cm respectively. There was also a significant effect in the case of dual interactions, as plant height reached 46.8 cm when adding *Pseudomonas fluorescens* bacteria with mycorrhizal fungi, and the height reached 47.0 cm when adding biofertilizer with organic fertilizer, and the height reached 44.6 cm when adding fungal fertilizer with liquid organic fertilizer, while the highest average significant height reached 47 cm in the case of triple interaction when adding the three fertilizers together compared to the comparison (control) sample, which was the lowest height, which reached 34.1 cm, recording an increase in height of 37.8%.

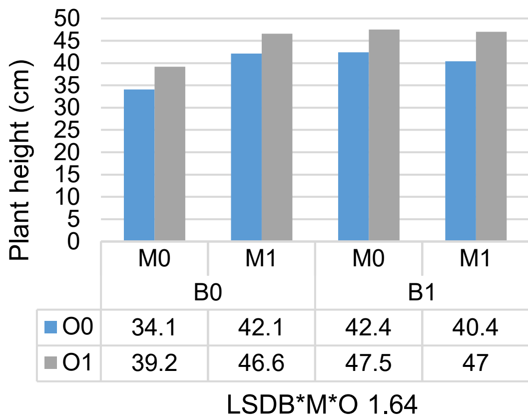


**Figure 3.** Effect of adding bacterial, fungal and liquid organic fertilizer on plant height (cm).

**Number of branches plant$^{-1}$:**

Fig. 4 shows a significant effect of the treatments added individually or in double or triple combination, on the number of branches per plant. It was found that adding bacterial fertilizer alone gave the highest number of branches, reaching 6.64 branches plant$^{-1}$, and the number of branches when adding fungal fertilizer reached 6.52 branches per plant. When adding liquid organic fertilizer alone, the number of branches reached 6.14 branches plant$^{-1}$. As for the case of double combination, it had a significant effect on the number of branches, as the number of branches when adding bacterial fertilizer with fungal fertilizer reached 7.15 branches plant$^{-1}$. The average of the branches number when adding bacterial fertilizer with organic fertilizer reached 7.03 branches plant$^{-1}$, while it reached 6.87 branches plant$^{-1}$ when adding fungal fertilizer with liquid organic fertilizer. The triple combination had a significant effect, which was the highest when adding the three fertilizers, bacterial, fungal, and liquid organic, it reached 8.20 branches per plant, which is the highest value compared to the lowest value recorded by the comparison (control) treatment without any addition, which gave 4.32 branches per plant$^{-1}$.

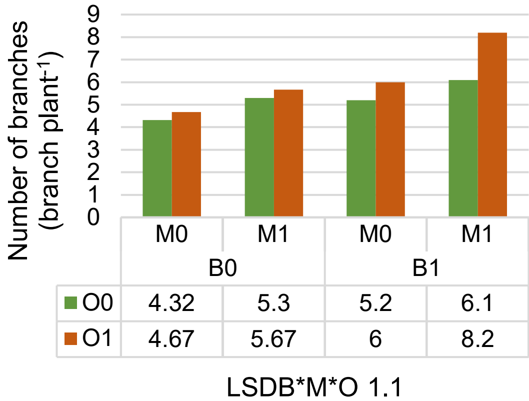


**Figure 4.** Effect of adding bacterial, fungal and liquid organic fertilizer on the number of branches (branch plant$^{-1}$).

**Number of pods (pod plant$^{-1}$):**

Fig. 5 shows that adding fertilizer individually had a significant effect on the number of pods in each plant, as adding *Pseudomonas fluorescens* alone gave a number of pods of 16.25 pods plant$^{-1}$, and adding mycorrhizae alone gave an average number of pods of 15.75 pods plant$^{-1}$, while the liquid organic fertilizer alone gave 14.75 pods plant$^{-1}$, and the binary combination also gave significant differences in the number of pods, as the bacterial fertilizer with fungi, the bacterial fertilizer with organic, and the fungal fertilizer with organic gave averages for the number of pods of 17.83, 16.67, and 17.0 pods plant$^{-1}$, respectively, and there was also a significant difference for the triple combination, which was at its maximum when adding the three fertilizers, as it gave the highest average

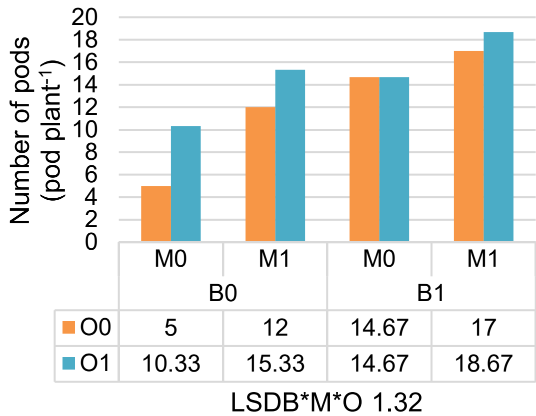


**Figure 5.** Effect of adding bacterial, fungal and organic liquid fertilizers on the number of pods (pod plant$^{-1}$).

number of pods per plant, which amounted to 18.67 pods plant$^{-1}$, while the comparison treatment gave the lowest average was 5 pods Plant$^{-1}$, with an increase rate of 273%.

**Number of seeds Pod$^{-1}$:**

Fig. 6, it is clear that adding fertilizers individually had a significant effect on the number of seeds per pod compared to the comparison treatment, as adding the biofertilizer of *Pseudomonas fluorescense* bacteria, *Glomus mosseae* mycorrhizal fungus and liquid organic fertilizer gave the highest average number of seeds per pod, reaching 10.33, 9.50 and 9.33 seed pod$^{-1}$, respectively. For the binary combinations, all of them had a significant effect on the average number of seeds per pod, as adding the bacterial biofertilizer with fungal, adding the bacterial biofertilizer with organic fertilizer and adding fungal fertilizer with organic fertilizer gave averages of the number of seeds of 11.00, 11.17 and 10.17 seed Pod$^{-1}$, respectively. Adding the three fertilizers together in a triple combination had a significant effect on the number of seeds per pod and gave the highest average of 11.67 seed. Pond$^{-1}$ compared to the control treatment, which gave the lowest average of 6 seed Pond$^{-1}$, with an increase rate of 94.5%.

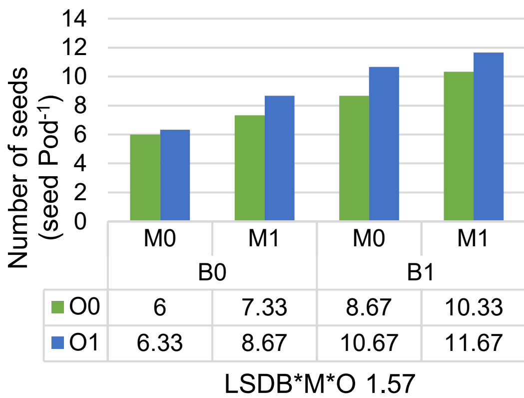


**Figure 6.** Effect of adding bacterial, fungal and liquid organic fertilizer on the number of seeds (seed Pod$^{-1}$).

**Seed content of active ingredient choline (µg mL$^{-1}$):**

Fig. 7 shows that there are significant differences in adding fertilizers, whether individually or in double or triple combinations, in the seed content of active ingredient choline, as adding bacterial fertilizer alone gave an average concentration of choline of 127.6 µg mL$^{-1}$, and the seed content of choline when adding mycorrhizae alone was 129.6 µg mL$^{-1}$ and reached 134.5 µg mL$^{-1}$ when adding liquid organic fertilizer. There were significant differences in the case of double combinations, as the seed content of choline when adding bacteria and mycorrhizae was 140.0 µg mL$^{-1}$, and it reached 146.4 µg mL$^{-1}$ when adding bacteria with liquid organic, while it reached 154.2 µg mL$^{-1}$ when adding fungal and organic fertilizers. As for the

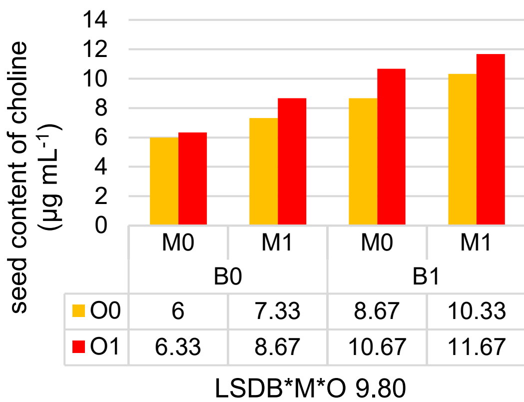


**Figure 7.** Effect of adding bacterial, fungal and liquid organic fertilizer on the seed content of choline (µg mL$^{-1}$).

case of triple combination, the effect was significant in the content of the seeds of choline, which reached the highest average of 160.3 µg $mL^{-1}$ compared to the control treatment, which gave the lowest average of 78.2 µg $mL^{-1}$, with an increase rate of 105%.

**Biological yield (g $plant^{-1}$):**

Fig. 8. shows that adding bacterial, fungal and liquid organic fertilizers individually had a significant effect on the biological yield of fenugreek plant (g $plant^{-1}$). The biological yield was recorded as 66.76, 67.23 and 63.62 g $plant^{-1}$ when adding bacterial, fungal and liquid organic fertilizers respectively. The double combinations also recorded significant differences, as the biological yield of adding bacteria with fungi was 71.30 g $plant^{-1}$, and when adding bacteria with liquid organic fertilizer it was 66.76 g $plant^{-1}$, while when adding fungi with liquid organic fertilizer, the biological yield was 67.23 g $plant^{-1}$. The triple combination by adding bacteria, fungi and liquid organic fertilizers gave the highest significant rate of biological yield, recording 73.12 g $plant^{-1}$, while the comparison treatment without any additives recorded the lowest rate of biological yield of 45.0 g $plant^{-1}$, with an increase rate of 62.5%.

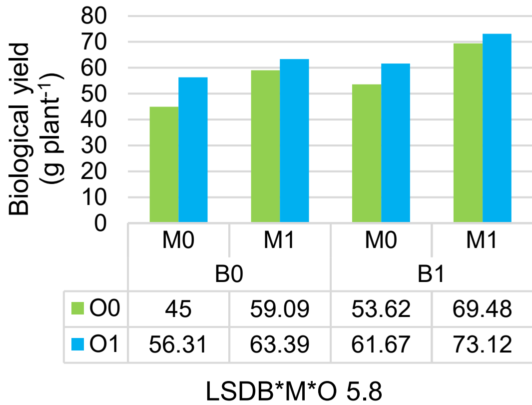


**Figure 8.** Effect of adding bacterial, fungal and liquid organic fertilizer on the biological yield (g $plant^{-1}$).

The figures show that adding biofertilizers represented by *Pseudomonas fluorescens* bacteria and *Glomus mosseae* mycorrhizae fungi and using liquid organic fertilizer sprayed on fenugreek plants gave a significant increase in the soil content of available nitrogen and available phosphorus, plant height, number of branches, number of pods per plant, number of seeds per pod, seed content of active choline and biological yield of the plant characteristics. The triple treatment was significantly superior to the dual treatment, which in turn was also significantly superior to the single treatment; the reason for this increase may be due to the increase in soil fertility through the use of some beneficial microorganisms as biofertilizers. The reason for the increase in the soil content of nutrients and then in the growth of the plant and its vegetative and root group and its yield when infected with mycorrhizae comes from many factors, perhaps the most important of which is the role of mycorrhizae in encouraging the absorption of nutrients, especially phosphorus, by exploring areas far from the reach of the root, as the fungal hyphae extend to long distances outside the root system of the plant, which leads to an increase in the used volume of soil and thus an increase in the absorption of water and the elements necessary for plant growth, whether major or minor elements, this is consistent with Alkobaisy et al., (2020), Khuit et al.,(2021) and Al-Wardy et al., (2022).

*Pseudomonas* bacteria also work as biofertilizers to improve and encourage plant growth by increasing the availability of elements, especially phosphorus and potassium, as well as nitrogen, which it provide to the plant, in addition to producing a number of vital compounds that have a stimulating effect on plant growth, such as growth regulators such a indole, cytokinin, gibberellin, organic and amino acids, and vitamins such as vitamin B. Pseudomonas bacteria also characterized by its ability to produce antibiotics that are considered a biological control against fungi and pathogenic bacteria Khuit et al. (2020), Al-Khafagi et al. (2020) and (Tajalee et al., 2022). This may be due to the effect of the added biofertilizer that contains a combination of bacteria and fungi that work through different mechanisms through which they improve plant growth, including dissolving some nutrients from their insoluble compounds in the soil, and their role in secreting growth regulators that play a role in cell division, stimulating plant growth, and secreting some organic acids, this is positively reflected in increasing the vegetative mass, photosynthesis, and transporting manufactured materials to their storage sites in plant Kumar et al. (2012) and Al-Silmawy & Abdul-Ratha (2023), in addition to the secretion of plant hormones and some growth regulators responsible for cell division and elongation that contribute to the growth, development and increase of the root system and the surface of the absorption area, which in turn increases the rate of water and nutrient absorption as well as protecting the plant from biotic and abiotic stresses Rahma et al. (2022). The liquid organic fertilizer used as a spray on the plant is one of the important organic fertilizers because it contains an amount of nutrients necessary for the plant as well as growth regulators, enzymes, vitamins, organic and amino acids. All of these specifications gave the plant better growth and higher production that was evident through the use of this organic fertilizer, which was more effective and positive when combined with biofertilizers. These results are consistent with (Levinsh et al., 2017, Giovannini et al., 2020; Alkobaisy et al., 2021; Jafaar et al., 2022; Jafaar & Abdulrasool, 2023).

The addition of organic fertilizer by spraying on the plant led to increased plant growth, increased number of branches, and increased availability of major and minor nutrients, which is reflected in increased vegetative growth indicators and yield (Kirk et al., 2019), this may be due to the role of organic fertilizer in increasing the effectiveness of vital processes such as respiration, increased permeability of cell membranes, increased conductivity of stomata, and photosynthesis, which leads to increased vegetative growth, as it works to increase the division of the cells of the growing tip, which is positively reflected in the growth and characteristics of the plant and increases the total yield. Also, the presence of beneficial microorganisms, especially fungi and bacteria, makes it suitable for plant growth, and this is consistent with what was stated by (Lamessa, 2016; Ramesh et al., 2020; Sindhuja et al., 2021; Shahad et al., 2021; Manjesh et al., 2022).

**Mycorrhizal dependence %**

Table 2 shows the mycorrhizal dependence % for plant height (cm), number of pods (pod plant$^{-1}$) and biological yield (g plant$^{-1}$). The height of the fenugreek plant inoculated with mycorrhizal was 43.7 cm compared to 34.1 cm for the uninoculated plant (comparison treatment without any addition), thus, the mycorrhizal dependence for the height of the fenugreek plant is 22.2%. For the number of pods, it gave results of 15.75, 5.00 (pods plant$^{-1}$) and 68.25% for each of the inoculated, uninoculated plants, and the mycorrhizal dependence, respectively, the biological yield was 67.23 g plant$^{-1}$ for the inoculated plant and 2.04 and 45.00 g plant$^{-1}$ for the uninoculated plant., while the plant depended on mycorrhizal in the biological yield by a percentage of 33.0% compared to unpollinated plant. This is consistent with Arty & Budi (2021), who stated that mycorrhizal dependence varies depending on the plant type, soil type, genus and type of mycorrhizae, as well as the surrounding environmental conditions, which ranged in their study between 15 and 80% according to the mentioned factors. Shi et al. (2016) also stated that the mycorrhizal dependence of the mulberry plant depended on the genus and type of mycorrhizae, and the species *F. mosseae*, followed by *A. scrobiculata*, then *R. intraradices* gave the best results in terms of physiological characteristics, plant growth, and qualitative characteristics of the mulberry plant yield, which agreed with Al-Rawi & Alkobaisy (2023) who reported that the mycorrhizal dependence of the cucumber plant increased when inoculated with mycorrhizae, especially for the yield.

**Table 2.** Mycorrhizal dependency % for plant height, number of pods and biological yield of fenugreek plant

| Plant treatment | Plant height (cm) | Number of pods (pod plant$^{-1}$) | Biological yield (g plant$^{-1}$) |
|---|---|---|---|
| Pollinated Plant | 43.7 | 15.75 | 67.23 |
| Non-Pollinated Plant | 34.1 | 5 | 45 |
| Mycorrhizal Dependency | 22.20% | 68.25% | 33.00% |

## CONCLUSIONS

The addition of bacterial and fungal biofertilizers and liquid organic fertilizer sprayed on the plant as an integrated application led to an increase in the availability of nutrients in the soil and gave better results in increasing the indicators of vegetative growth, biological yield, and active substance (choline) of the fenugreek plant. The addition of mycorrhizae also played a major role in increasing vegetative growth, biological yield, and yield, which increased the percentage of mycorrhizal dependence, which is the extent of the plant's dependence on mycorrhizae for the mentioned characteristics. Therefore, it can be recommended to fertilize fenugreek plants with biofertilizers, whether bacterial or fungal, in integration with organic fertilizers.

Since this research was conducted in pot experiments, the results need to be validated under broader field conditions. We recommend conducting field-scale trials to evaluate the effectiveness of *Pseudomonas fluorescens* bacteria, *Glomus mosseae* fungus, and liquid organic fertilizer in enhancing soil available nitrogen and phosphorus, as well as their effects on fenugreek growth and biological yield. These field studies will help assess the applicability of these treatments in diverse agricultural conditions.

Also To further enhance the findings of this research, we recommend conducting similar studies on other crops such as wheat, barley, and maize, to investigate the effects of these treatments on different crops in varying agricultural environments. Additionally, exploring the impact of these factors on different soil types (such as sandy and clay soils) will help determine the versatility of the treatments and their potential for sustainable agricultural practices.

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