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# IMPACT OF BRASSINOLIDE, NANO-SILICON, AND MYCORRHIZAE ON THE NUTRIENT COMPOSITION AND PRODUCTIVITY OF OLIVE TREES BASHIKA CV

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## ABSTRACT

A field experiment was conducted during the 2024 growing season on 15-year-old Bashika olive trees planted in a private orchard in the village of Kasara, Duhok city, Iraqi Kurdistan, to investigate the effect of foliar spraying with three concentrations of Brassinolide (0, 2.5, and 5 mg $L^{-1}$) and nano-silicon fertilizer (0, 200, and 400 mg $L^{-1}$). The third factor involved the addition of a bio-fertilizer (mycorrhizal fungus) at three concentrations (0, 50, and 100 g $tree^{-1}$). The experiment used a Randomized Complete Block Design (R.C.B.D) with three factors, three replicates, and one tree per experimental unit. Therefore, the total number of trees used in the experiment was 81). The results showed that high concentrations of the three factors (5 mg $L^{-1}$ Brassinolide, 400 mg $L^{-1}$ nano-silicon, and 100 g $tree^{-1}$ mycorrhizae), both individually and in all binary and triple interactions, resulted in the highest significant values for traits such as nitrogen, phosphorus, and potassium concentrations, total yield, oil percentage, and anthocyanin content in the fruits. The study recommends using these concentrations for optimal results, especially for yield quantity and oil percentage in the fruits.



## INTRODUCTION

Olives (*Olea europaea L.)* are among the oldest fruit trees cultivated by humans since four thousand years BC. They are evergreen fruit trees that last for hundreds of years and belong to the olive family, Oleaceae, which includes many genera, approximately 30 main genera, the most important of which is the genus Olea, which in turn includes various types, the most important of which is the olive. The eastern Mediterranean regions of northwestern Iraq, southern Turkey, Syria, Lebanon, and Palestine are among the most important areas that historical data indicate are the original home of this blessed tree. At present, the most widespread areas for olive cultivation are concentrated between latitudes (27-44)° in the Northern Hemisphere and between latitudes (15-44)° in the Southern Hemisphere (Breton *et al*., 2012; Hegazi et al., 2024; Al-Din and Alalaf, 2025).

The areas planted with olive trees worldwide are estimated at 10,578,246 hectares, with an estimated production of about 19,464,495 tons. In Iraq, the number of fruit trees is estimated at 1,329,191, with an estimated productivity of about 33,912 tons and an average productivity per tree of 25.52 kg. Olives are one of the most important food security crops in many regions, especially where they are widely cultivated. Their fruits are used as food, their leaves are used to extract medicinal preparations, and their oil is used in cooking, soap making, and cosmetics. Olives are a good source of nutrition, as they are rich in fats and contain proteins, sugars, pectins, salts, and vitamins. In addition, olive oil remains at the forefront of vegetable oils regarding nutritional value and significant therapeutic properties. Olive trees are also used to decorate gardens and parks due to their beautiful appearance (Kritioti *et al*., 2019 and Al-*Asmari et al*., 2020).

Fertilization is one of the most important horticultural practices, affecting the growth and productivity of fruit trees, including olive trees (Abdulqader, 2024). However, using chemical fertilizers negatively affects the environment and sustainable agriculture. It also harms the agricultural economy through wasteful costs associated with chemical fertilizers, which require the purchase of large and expensive quantities. Therefore, it is recommended that nano fertilizers be used as an alternative to traditional chemical fertilizers (Al-Hchami and Alrawi, 2020).

Plant hormones, or natural and synthetic growth regulators, are considered one of the most important agricultural applications due to their significant benefits and advantages for plant growth, especially after the emergence of synthetic fertilizers, their uses, and breeding methods, and their results in improving the productivity of most horticultural crops (Sharma, 2021).

Nanotechnology is defined as applying theoretical concepts of natural sciences at the microscopic level. The use of nanomaterials in fertilization programs is an effective alternative to the use of conventional fertilizers, offering numerous advantages due to their use in smaller quantities (Mahdi *et al*., 2022; Abobatta, 2023) and their high stability under various conditions, which increases the ability to store them for longer periods. The addition of nanofertilizers brings many benefits to plants and the environment by spraying them on the vegetative system. The plant benefits from them quickly, as they are rapidly absorbed, allowing them to be used at the required times according to the plant's actual needs (Akshay and Maneesha, 2023, and Aljubori *et al.,* 2024). The use of nanofertilizers also helps reduce environmental stress conditions to which plants are exposed, such as heat stress, drought, and salinity, as well as overcoming soil and water pollution problems and reducing carbon emissions from conventional fertilizer plants, which cause severe climate change (Abd *et al.,* 2020 and Sohby *et al*., 2023 and Rashid and Al-Atrushy, 2025).

Due to the significant increase in the world's population, coupled with a severe shortage of food resources and the increasing costs of chemical fertilizers, some of which cause soil and environmental pollution, a large number of countries around the world have turned to the use of biofertilizers to increase crop production at the lowest possible cost compared to other fertilizers. Biofertilizers are environmentally friendly fertilizers whose role is linked to several living organisms that contribute to enriching the soil with plant nutrients. Fungi, bacteria, and blue-green algae are among the most important sources of biofertilizers added to plants in general and to fruit crops in particular (Abobatta and El-Azazy, 2020; Alalaf *et al.,* 2023 and Abdulkadhim, 2024 and AL-Marsoumi and AL-Hadethi, 2025).

This study aimed to improve the yield and mineral content of Baashika olive trees by adding Brassinolide, nano silicon, and biofertilization with mycorrhizal fungi, and to determine the appropriate level of these factors. In addition, it was possible to reduce the amount of chemical fertilizers added to the trees by adding friendly fertilizers, biofertilizer (mycorrhizal fungi), nano fertilizers, and growth regulators at low concentrations, to reduce production costs and reduce environmental pollution.

## MATERIALS AND METHODS

The study was conducted during the growing season of 2024 in a private orchard near the village of Kasara in the city of Duhok in Iraqi Kurdistan on 15-year-old olive trees of the Bashika variety, planted at a distance of 4 x 6 meters. The orchard soil was a clay mixture, the components shown in Table 1). (81) trees were selected, as homogeneous in size and growth as possible. All maintenance operations were carried out, including removing weeds, developing cankers, pest control, and continuing regular irrigation throughout the study. The study included three factors: the first was foliar spraying with three concentrations of each of Brassinolide (0, 2.5, and 5 mg $L^{-1}$) and nano-silicon fertilizer (0, 200, and 400 mg $L^{-1}$). The third factor included the addition of bio-fertilizer (mycorrhizal fungus) at three concentrations (0, 50, and 100 g .$tree^{-1}$). Brassinolide and nano-silicon were added at three times: (The first was at the beginning of vegetative growth in April, the second was a month after the first application, and the third was a month after the second application). The mycorrhizal fertilizer was added to the soil at the same time at the end of March. The experiment used a randomized complete block design (R.C.B.D.) with three factors, three replicates, and one tree per experimental unit. Thus, the number of trees used in the experiment was 81 trees (3 x 3 x 3 x 3). At the end of the experiment, the following traits were measured (nitrogen, phosphorus, and potassium concentrations in leaves, total tree yield (kg), oil content in fruit flesh (%), and anthocyanin content in the fruit (mg/100g fresh weight). Duncan's multiple range test was used to analyze the results statistically.

Table (1): Some physical and chemical properties of the cultivation medium

| Characteristic | Measurement unit | Valua |
|---|---|---|
| Electrical conductivity | disysimns.$m^{-1}$ | 0.369 |
| pH | ----------- | 7.57 |
| Organic matter | % | 3.21 |
| Calcium carbonate, CaCO3 | **%** | 35.11 |
| Sand | % | .2618 |
| Caly | % | 31. 53 |
| Silt | % | 49.91 |
| Texture | -------------- | Silty clay loam |
| Available Nitrogen N | mg $kg^{-1}$ | 40.33 |
| Available Potassium K | mg $kg^{-1}$ | 19.7 |
| Available Phosphorus P | mg $kg^{-1}$ | 5.69 |

*The soil was analyzed in the laboratories of the College of Agriculture and Forestry.

## RESULTS AND DISCUSSION

The results presented in Table 2 show that foliar spraying with Brassinolide significantly affected the nitrogen concentration in the leaves. Spraying with a concentration of 5 mg $L^{-1}$ resulted in the highest nitrogen concentration, which was significantly superior to the other concentrations. Regarding foliar spraying with nano-silicon, the results indicated that spraying with 200 and 400 mg $L^{-1}$ significantly outperformed the control treatment. Additionally, adding mycorrhizal fertilizer at a concentration of 100 g $tree^{-1}$ resulted in the highest nitrogen concentration in the leaves, significantly surpassing the other concentrations. The findings also show that all binary and triple interactions between the study factors significantly influenced the nitrogen concentration. In the binary interaction between Brassinolide and nano-silicon, the combination of 2.5 and 5 mg $L^{-1}$ of Brassinolide with 400 mg $L^{-1}$ of nano-silicon resulted in the highest significant values of this trait compared to the other interactions. For the binary interaction between Brassinolide and mycorrhizal biofertilizer, the treatment with 5 mg $L^{-1}$ of Brassinolide and 100 g $tree^{-1}$ of mycorrhizal fertilizer gave the highest significant values.

Table (2): Effect of Brassinolide, nano-silicon, mycorrhizae, and the interaction between them on the nitrogen percentage in olive leaves Bashika cv

| Biofertilizer levels Mycorrhizal fungi (g $tree^{-1}$) | Brassinolide (mg $l^{-1}$) | | | | | | | | | Means levels of biofertilizer |
|---|---|---|---|---|---|---|---|---|---|---|
| | 0 | | | 2.5 | | | 5.0 | | | |
| | Nano silicon (mg $l^{-1}$) | | | | | | | | | |
| | 0 | 200 | 400 | 0 | 200 | 400 | 0 | 200 | 400 | |
| 0 | 1.29 r | 1.50 op | 1.67 f-h | 1.63 h-k | 1.68 e-h | 1.65 g-j | 1.73 de | 1.63 h-k | 1.65 g-j | 1.56 c |
| 50 | 1.44 q | 1.54 no | 1.60 j-m | 1.66 g-i | 1.66 g-i | 1.75 cd | 1.59 k-n | 1.72 d-f | 1.88 b | 1.62 b |
| 100 | 1.48 p q | 1.58 l-n | 1.59 k-n | 1.70 e-g | 1.61 i-l | 1.78 c | 1.56 mn | 1.68 e-h | 1.94 a | 1.72 a |
| Means Brassinolide | 1.52c | | | 1.68b | | | 1.71a | | | |
| Means Nano silicon | | | | 1.66 b | 1.65 a | 1.60 a | | | | |

| Brassinolide X Nano silicon | | | | BrassinolideX Biofertilizer | | | | Nano siliconX Biofertilizer | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Brassinolide (mg $l^{-1}$) | Nano silicon ( mg $l^{-1}$) | | | Brassinolide (mg $l^{-1}$) | Mycorrhizal fungi (g $tree^{-1}$) | | | Nano silicon (mg $l^{-1}$) | Mycorrhizal fungi (g $tree^{-1}$) | | |
| | 0 | 200 | 400 | | 0 | 50 | 100 | | 0 | 50 | 100 |
| 0 | 1.48 e | 1.65 c | 1.67 bc | 0 | 1.40 h | 1.66 cd | 1.62 ef | 0 | 1.55 g | 1.60 de | 1.66 b |
| 2.5 | 1.53 d | 1.69 b | 1.73 a | 2.5 | 1.54 g | 1.65 de | 1.68 c | 200 | 1.56 fg | 1.64 bc | 1.74 a |
| 5.0 | 1.55 d | 1.70 B | 1.72 a | 5.0 | 1.62 f | 1.73 b | 1.82 a | 400 | 1.58 ef | 1.62 cd | 1.77 a |

*The averages followed by different letters indicate the presence of significant differences between them according to the Duncan multinomial test at the 5% probability level.

In the interaction between nano-silicon and mycorrhizal fertilizer, the treatments with 200 and 400 mg $L^{-1}$ of nano-silicon combined with 100 g $tree^{-1}$ of mycorrhizal fertilizer resulted in the highest significant values for this trait compared to the other interactions. In the case of the triple interaction between the study factors, the combination of 5 mg $L^{-1}$ of Brassinolide, 400 mg $L^{-1}$ of nano-silicon, and 100 g tree⁻¹ of mycorrhizae resulted in the highest significant values for this trait compared to the other triple interactions.

The results in Table 3 indicate that foliar spraying with 5 mg $L^{-1}$ of Brassinolide resulted in the highest significant phosphorus concentration in the leaves compared to the other concentrations. Similarly, spraying with 400 mg $L^{-1}$ of nano-silicon led to a significant increase in phosphorus concentration compared to the other treatments. Additionally, the application of mycorrhizae at a concentration of 100 g tree$^{-1}$ significantly enhanced phosphorus concentration in the leaves compared to the other mycorrhizal treatments.

Table (3): Effect of Brassinolide, nano-silicon, mycorrhizae and the interaction between them on the phosphorous percentage in olive leaves Bashika cv.

| Biofertilizer levels Mycorrhizal fungi (g tree$^{-1}$) | Brassinolide (mg l$^{-1}$) 0 | | | 2.5 | | | 5.0 | | | Means levels of biofertilizer |
|---|---|---|---|---|---|---|---|---|---|---|
| Nano silicon (mg l$^{-1}$) | 0 | 200 | 400 | 0 | 200 | 400 | 0 | 200 | 400 | |
| 0 | 0.149 n | 0.160 mn | 0.184 f-k | 0.181 h-k | 0.183 g-k | 0.194 e-g | 0.175 i-l | 0.196 ef | 0.210 cd | 0.169 c |
| 50 | 0.156 mn | 0.164 lm | 0.180 h-k | 0.175 i-l | 0.187 f-j | 0.208 cd | 0.180 h-k | 0.203 de | 0.242 b | 0.185 b |
| 100 | 0.154 mn | 0.174 kl | 0.189 f-h | 0.175 j-l | 0.188 f-i | 0.217 c | 0.175 i-l | 0.211 cd | 0.267 a | 0.210 a |
| Means Brassinolide | 0.168 c | | | 0.190 b | | | 0.207 a | | | |
| Means Nano silicon | | | | 0.181 c | 0.188b | 0.194a | | | | |

Brassinolide X Nano silicon

| Brassinolide (mg l$^{-1}$) | Nano silicon (mg l$^{-1}$) 0 | 200 | 400 |
|---|---|---|---|
| 0 | 0.164 f | 0.186 d | 0.194 c |
| 2.5 | 0.167 ef | 0.190 cd | 0.208 b |
| 5.0 | 0.172 e | 0.193 c | 0.218 a |

BrassinolideX Biofertilizer

| Brassinolide (mg l$^{-1}$) | Mycorrhizal fungi (g tree$^{-1}$) 0 | 50 | 100 |
|---|---|---|---|
| 0 | 0.153 f | 0.177 d | 0.177 d |
| 2.5 | 0.166 e | 0.186 c | 0.203 b |
| 5.0 | o.184 c | 0.206 b | 0.240 a |

Nano siliconX Biofertilizer

| Nano silicon (mg l$^{-1}$) | Mycorrhizal fungi (g tree$^{-1}$) 0 | 50 | 100 |
|---|---|---|---|
| 0 | 0.168 f | 0.180 e | 0.196 c |
| 200 | 0.170 f | 0.185 de | 0.210 b |
| 400 | 0.168 f | 0.191 cd | 0.224 a |

*The averages followed by different letters indicate the presence of significant differences between them according to the Duncan multinomial test at the 5% probability level.

For the binary interaction between Brassinolide and nano-silicon, 5 mg $L^{-1}$ of Brassinolide and 400 mg $L^{-1}$ of nano-silicon resulted in the highest significant phosphorus concentration. In the interaction between Brassinolide and mycorrhizal fertilizer, the treatment combining 5 mg $L^{-1}$ of Brassinolide with 100 g tree$^{-1}$ of mycorrhizae showed the highest values and significantly outperformed all other treatments. Similarly, for the interaction between nano-silicon and mycorrhizae, the combination of 400 mg $L^{-1}$ of nano-silicon with 100 g tree$^{-1}$ of mycorrhizae recorded the highest significant phosphorus concentration in the leaves compared to the other interactions.

Regarding the triple interaction between the study factors, the combination of 5 mg L$^{-1}$ of Brassinolide, 400 mg L$^{-1}$ of nano-silicon, and 100 g tree$^{-1}$ of mycorrhizae resulted in the highest phosphorus concentration, significantly surpassing all other triple interaction treatments.

The results in Table 4 indicate that the potassium concentration in the leaves increased significantly with higher concentrations of the studied factors. Specifically, treatments with 5 mg L$^{-1}$ of Brassinolide, 200 and 400 mg L$^{-1}$ of nano-silicon, and 100 g tree$^{-1}$ of mycorrhizae significantly outperformed the other concentrations, particularly the control treatment, which recorded the lowest values.

Table (4): Effect of Brassinolide, nano-silicon, mycorrhizae and their interaction on the potassium percentage in olive leaves Bashika cv.

| Biofertilizer levels Mycorrhizal fungi (g tree$^{-1}$) | Brassinolide (mg l$^{-1}$) | | | | | | | | | Means levels of biofertilizer |
|---|---|---|---|---|---|---|---|---|---|---|
| | 0 | | | 2.5 | | | 5.0 | | | |
| | Nano silicon (mg l$^{-1}$) | | | | | | | | | |
| | 0 | 200 | 400 | 0 | 200 | 400 | 0 | 200 | 400 | |
| 0 | 1.00 I | 1.19 gh | 1.23 fg | 1.27 fg | 1.33 ef | 1.40 de | 1.48 cd | 1.53 bc | 1.63 b | 1.28c |
| 50 | 1.12 h | 1.19 gh | 1.27 fg | 1.26 fg | 1.38 de | 1.52 c | 1.48 cd | 1.50 c | 1.83 a | 1.36 b |
| 100 | 1.18 gh | 1.23 fg | 1.28 fg | 1.24 fg | 1.39 de | 1.52 c | 1.51 c | 1.54 bc | 1.53 bc | 1.47 a |
| Means Brassinolide | 1.19 c | | | 1.37 b | | | 1.56 a | | | |

| Means Nano silicon | 0 | 200 | 400 |
|---|---|---|---|
| | 1.34 b | 1.38 a | 1.39 a |

| Brassinolide X Nano silicon | | | | BrassinolideX Biofertilizer | | | | Nano siliconX Biofertilizer | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Brassinolide (mg l$^{-1}$) | Nano silicon (mg.l$^{-1}$) | | | Brassinolide (mg l$^{-1}$) | Mycorrhizal fungi (g tree$^{-1}$) | | | Nano silicon (mg l$^{-1}$) | Mycorrhizal fungi (g tree$^{-1}$) | | |
| | 0 | 200 | 400 | | 0 | 50 | 100 | | 0 | 50 | 100 |
| 0 | 1.14 e | 1.33 c | 1.54 b | 0 | 1.10 f | 1.25 de | 1.49 b | 0 | 1.25 g | 1.35 de | 1.42 bc |
| 2.5 | 1.19 de | 1.39 c | 1.60 a | 2.5 | 1.20 e | 1.37 c | 1.52 b | 200 | 1.28 fg | 1.36 de | 1.54 a |
| 5.0 | 1.23 d | 1.38 c | 1.52 b | 5.0 | 1.26 d | 1.48 b | 1.66 a | 400 | 1.31 ef | 1.38 cd | 1.44 b |

*The averages followed by different letters indicate the presence of significant differences between them according to the Duncan multinomial test at the 5% probability level.

The results confirm that the binary interaction between Brassinolide and nano-silicon had a significant impact on potassium concentration, with the combination of 2.5 mg L$^{-1}$ of Brassinolide and 400 mg L$^{-1}$ of nano-silicon yielding the highest significant values. Similarly, in the binary interaction between Brassinolide and mycorrhizae, the combination of 5 mg L$^{-1}$ of Brassinolide with 100 g tree$^{-1}$ of mycorrhizae resulted in the highest potassium concentration. Regarding the interaction between nano-silicon and mycorrhizae, the treatment with 200 mg L$^{-1}$ of nano-silicon and 100 g tree$^{-1}$ of mycorrhizae significantly outperformed all other interaction treatments.

The results also indicate that the triple interaction between the studied factors had a significant effect on potassium concentration, with the highest values recorded in the combination of 5 mg L⁻¹ of Brassinolide, 400 mg L⁻¹ of nano-silicon, and 50 g tree⁻¹ of mycorrhizae, which outperformed all other triple interaction treatments.

The results in Table 5 indicate that the three studied factors significantly impacted the total yield, particularly at higher concentrations. Specifically, treatments with 5 mg L⁻¹ of Brassinolide, 400 mg L⁻¹ of nano-silicon, and 100 g tree⁻¹ of mycorrhizae recorded the highest significant values for total yield compared to the lower concentrations.

Furthermore, the results demonstrate that all binary and triple interactions among Brassinolide, nano-silicon, and mycorrhizae significantly influenced the total yield. The binary interactions at higher concentrations (5 mg L⁻¹ of Brassinolide, 400 mg L⁻¹ of nano-silicon, and 100 g tree⁻¹ of mycorrhizae) resulted in the highest significant values. Similarly, the ternary interaction among these factors also yielded the highest significant values for total yield compared to the control treatment.

Table (5): Effect of Brassinolide, nano-silicon, mycorrhizae and their interaction on the yield (kg tree$^{-1}$) of olive leaves Bashika cv.

| Biofertilizer levels Mycorrhizal fungi (g tree$^{-1}$) | Brassinolide (mg l$^{-1}$) | | | | | | | | | Means levels of biofertilizer |
|---|---|---|---|---|---|---|---|---|---|---|
| | 0 | | | 2.5 | | | 5.0 | | | |
| | Nano silicon (mg l$^{-1}$) | | | | | | | | | |
| | 0 | 200 | 400 | 0 | 200 | 400 | 0 | 200 | 400 | |
| 0 | 35.26 p | 39.81 n | 41.06 kl | 40.92 l | 42.96 i | 44.53 g | 41.47 k | 43.22 I | 45.75 f | 40.82 c |
| 50 | 37.17 o | 40.24 m | 41.31 kl | 42.31 j | 45.43 f | 46.37 e | 43.86 h | 48.87 c | 49.71 b | 43.94 b |
| 100 | 39.75 n | 40.36 m | 41.35 kl | 42.83 i | 45.57 f | 47.26 d | 43.79 h | 49.02 c | 50.24 a | 45.29 a |
| Means Brassinolide | 39.59 c | | | 44.24 b | | | 46.21 a | | | |
| Means Nano silicon | | | | 41.66 c | 43.92 b | 44.46a | | | | |

Brassinolide X Nano silicon

| Brassinolide (mg l$^{-1}$) | Nano silicon (mg.l$^{-1}$) 0 | 200 | 400 |
|---|---|---|---|
| 0 | 38.71 h | 42.80 e | 43.48 d |
| 2.5 | 39.57 g | 44.70 c | 47.48 a |
| 5.0 | 40.49 f | 45.22 b | 47.68 a |

BrassinolideX Biofertilizer

| Brassinolide (mg l$^{-1}$) | Mycorrhizal fungi) g tree$^{-1}$( 0 | 50 | 100 |
|---|---|---|---|
| 0 | 37.39 i | 42.02 f | 43.04 e |
| 2.5 | 40.14 h | 44.65 d | 47.04 b |
| 5.0 | 41.24 g | 46.05 c | 48.57 a |

Nano siliconX Biofertilizer

| Nano silicon (mg l$^{-1}$) | Mycorrhizal fungi (g tree$^{-1}$) 0 | 50 | 100 |
|---|---|---|---|
| 0 | 39.22 g | 42.00 e | 43.78 d |
| 200 | 41.11 f | 44.84 c | 45.80 b |
| 400 | 42.12 e | 44.98 c | 46.28 a |

*The averages followed by different letters indicate the presence of significant differences between them according to the Duncan multinomial test at the 5% probability level.

The results in Table 6 confirm that foliar spraying with Brassinolide and nano-silicon, along with the addition of mycorrhizal biofertilizer, significantly impacted oil percentage values. This effect was particularly evident when applying 5 mg L⁻¹ of

Brassinolide, 400 mg $L^{-1}$ of nano-silicon, and 100 g $tree^{-1}$ of mycorrhizae, which recorded the highest significant values. Additionally, the results indicate that the binary and triple interactions involving these concentrations yielded the highest significant values for oil percentage compared to other binary and triple interaction treatments.

Table (6): Effect of Brassinolide, nano-silicon, mycorrhizae and the interaction between them on the oil percentage of olive fruits Bashika cv.

| Biofertilizer levels Mycorrhizal fungi (g $tree^{-1}$) | Brassinolide ( mg $l^{-1}$) | | | | | | | | | Means levels of biofertilizer |
|---|---|---|---|---|---|---|---|---|---|---|
| | 0 | | | 2.5 | | | 5.0 | | | |
| | Nano silicon ( mg $l^{-1}$) | | | | | | | | | |
| | 0 | 200 | 400 | 0 | 200 | 400 | 0 | 200 | 400 | |
| 0 | 19.38 J | 23.22 hi | 23.59 h | 23.35 h | 24.68 g | 24.58 g | 24.68 g | 24.54 g | 27.57 e | 23.98 c |
| 50 | 23.14 i | 25.32 f | 25.42 f | 25.34 f | 27.23 e | 29.10 cd | 25.62 f | 28.72 d | 30.87 a | 26.22 b |
| 100 | 23.23 hi | 25.44 f | 25.42 f | 25.65 f | 27.26 e | 29.13 c | 25.42 f | 29.59 b | 30.94 a | 27.40 a |
| Means Brassinolide | 23.79 c | | | 26.25 b | | | 27.55 a | | | |
| Means Nano silicon | | | | 23.95 c | 26.75 b | 26.90a | | | | |

| Brassinolide X Nano silicon | | | | BrassinolideX Biofertilizer | | | | Nano siliconX Biofertilizer | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Brassinolide (mg $l^{-1}$) | Nano silicon (mg.$l^{-1}$) | | | Brassinolide (mg $l^{-1}$) | Mycorrhizal fungi) g.$tree^{-1}$( | | | Nano silicon (mg $l^{-1}$) | Mycorrhizal fungi (g $tree^{-1}$) | | |
| | 0 | 200 | 400 | | 0 | 50 | 100 | | 0 | 50 | 100 |
| 0 | 22.06 g | 24.20 f | 25.60 d | 0 | 21.91 f | 24.78 e | 25.24 d | 0 | 22.47 g | 24.15 f | 25.24 d |
| 2.5 | 24.63 e | 27.22 c | 28.40 b | 2.5 | 24.66 e | 26.39 c | 27.61 b | 200 | 24.70 e | 27.09 c | 28.46 a |
| 5.0 | 24.70 e | 27.34 c | 28.65 a | 5.0 | 24.81 e | 27.60 b | 29.79 a | 400 | 24.76 e | 27.43 b | 28.50 a |

*The averages followed by different letters indicate the presence of significant differences between them according to the Duncan multinomial test at the 5% probability level.

The results in Table 7 clearly show that the anthocyanin pigment content in the fruits was significantly influenced by foliar spraying with Brassinolide and nano-silicon and the addition of mycorrhizae. Individually, treatments with 5 mg $L^{-1}$ of Brassinolide, 400 mg $L^{-1}$ of nano-silicon, and 100 g $tree^{-1}$ of mycorrhizae recorded the highest significant values for this trait.

In the binary interaction between Brassinolide and nano-silicon, trees sprayed with 2.5 mg $L^{-1}$ of Brassinolide combined with 400 mg $L^{-1}$ of nano-silicon, as well as those treated with 5 mg $L^{-1}$ of Brassinolide combined with 200 or 400 mg $L^{-1}$ of nano-silicon, showed the highest significant values for anthocyanin content. Similarly, in the binary interaction between Brassinolide and mycorrhizae, the combination of 5 mg $L^{-1}$ of Brassinolide with 100 g $tree^{-1}$ of mycorrhizae resulted in the highest significant values. In the binary interaction between nano-silicon and mycorrhizae, treatments with 200 or 400 mg L$^{-1}$ of nano-silicon combined with 100 g tree$^{-1}$ of mycorrhizae also led to a significant increase in anthocyanin content.

The triple interaction among all three factors significantly impacted anthocyanin content, with the highest values observed in the combination of 5 mg L$^{-1}$ of Brassinolide, 400 mg L$^{-1}$ of nano-silicon, and 100 g tree$^{-1}$ of mycorrhizae.

Table (7): Effect of Brassinolide, nano-silicon, mycorrhizae and their interaction on the anthocyanin content (mg/100g) of olive fruits Bashika cv.

| Biofertilizer levels Mycorrhizal fungi (g tree$^{-1}$) | Brassinolide (mg l$^{-1}$) | | | | | | | | | Means levels of biofertilizer |
|---|---|---|---|---|---|---|---|---|---|---|
| | 0 | | | 2.5 | | | 5.0 | | | |
| | Nano silicon (mg l$^{-1}$) | | | | | | | | | |
| | 0 | 200 | 400 | 0 | 200 | 400 | 0 | 200 | 400 | |
| 0 | 12.10 n | 15.06 kl | 15.26 k | 15.10 kl | 17.80 e | 17.74 ef | 15.90 j | 17.66 ef | 17.85 e | 15.79 c |
| 50 | 14.57 m | 16.07 J | 16.92 h | 16.99 h | 18.56 d | 19.62 b | 17.50 fg | 18.85 c | 19.87 ab | 17.53 b |
| 100 | 14.90 l | 16.39 I | 16.85 h | 17.69 ef | 18.64 cd | 19.72 ab | 17.37 g | 18.74 cd | 19.93 a | 18.19 a |
| Means Brassinolide | 15.35 c | | | 17.98 b | | | 18.18 a | | | |
| Means Nano silicon | | | | 16.05 c | 17.66 b | 17.80a | | | | |

| Brassinolide X Nano silicon | | | |
|---|---|---|---|
| Brassinolide (mg l$^{-1}$) | Nano silicon (mg l$^{-1}$) | | |
| | 0 | 200 | 400 |
| 0 | 14.14 g | 16.88 d | 17.13 c |
| 2.5 | 15.85 f | 18.39 b | 18.74 a |
| 5.0 | 16.05 e | 18.68 a | 18.68 a |

| BrassinolideX Biofertilizer | | | |
|---|---|---|---|
| Brassinolide (mg l$^{-1}$) | Mycorrhizal fungi) g tree$^{-1}$( | | |
| | 0 | 50 | 100 |
| 0 | 13.85 h | 16.59 e | 16.92 d |
| 2.5 | 15.84 g | 18.33 c | 18.41 c |
| 5.0 | 16.34 f | 19.03 b | 19.22 a |

| Nano siliconX Biofertilizer | | | |
|---|---|---|---|
| Nano silicon (mg l$^{-1}$) | Mycorrhizal fungi (g tree$^{-1}$) | | |
| | 0 | 50 | 100 |
| 0 | 14.36 f | 16.84 c | 16.95 c |
| 200 | 16.35 e | 17.83 b | 18.80 a |
| 400 | 16.65 d | 17.92 b | 18.84 a |

*The averages followed by different letters indicate the presence of significant differences between them according to the Duncan multinomial test at the 5% probability level.

The superiority of the study treatments of 5 mg L$^{-1}$ of Brassinolide in increasing the concentrations of nitrogen, phosphorus and potassium in the leaves is consistent with what Hamdullah *et al*. (2018) found when spray olive trees. This may be due to the fact that Brassinolide, when sprayed on the leaves, increases growth as a result of increasing cell division and elongation, increasing the levels of internal hormones, and thus improving the characteristics of vegetative growth, which leads to an increase in the ability of trees to absorb mineral elements from the soil and transfer them to the vegetative system, thus increasing the content of these elements in the leaves (Al-Kanani, 2024). As for the superiority of the treatment of 400 mg L-1 of nano-silicon in increasing the concentrations of elements in the leaves, it was similar to the results of Elsheery *et al*. (2020) in their study on mango, and may be due to the positive role of silicon in most physiological processes in the plant, such as hormonal balance and increasing the efficiency of photosynthesis as a result of its role in increasing the size of chloroplasts, which leads to encouraging the plant and increasing its ability to absorb elements. And its transfer to the leaves increases its concentration (Fekry *et al.,* 2022 and Mohammed and Majeed, 2024).

The results were similar to the results of Abd El-Hamid and El-Shazly (2019) on mango trees and Astiari *et al*. (2021) on mandarin trees, that biofertilization with mycorrhizae achieved a significant superiority in the values of mineral element concentrations in the leaves (nitrogen, phosphorus, and potassium). This is due to the importance of mycorrhizae in improving the characteristics of the root system and its efficiency in absorbing nutrients by increasing the availability of these elements in the soil and their transfer to the vegetative system, which increases the accumulation of these elements in the leaves and increases their concentration (Meddad-Hamza *et al.,* 2010). As for the superiority of the same treatments in the total yield, oil percentage, and anthocyanin content in the fruits, it was similar to the results of El-Boray *et al.* (2015) when spraying Brassinolide on orange trees, the yield increased, and this was attributed to the role of Brassinolide in increasing the growth of the pollen tube, which consequently leads to an increase in the percentage of fruit set and its number, which increases the total yield of the trees (Mostafa and Hatem, 2018).

Also, foliar spraying with Brassinolide led to an increase in the content of leaves of nutritional elements, which have an important role in the physiological processes in the plant, especially photosynthesis and the synthesis of sugars, enzymes, and amino acids, which is positively reflected in improving the characteristics of vegetative growth and thus increasing the total yield and oil percentage in the fruits (Shamkhi and Ayada, 2016). As for the superiority of the 400 mg $L^{-1}$ treatment of nano-silicon in increasing the total yield, it was similar to the results of Hassan *et al.* (2022) on olive trees and Abobatta *et al.* (2024) on lemon trees, and it may be due to The role of silicon in improving vegetative growth indicators, increasing the efficiency of the root system, reducing the rate of transpiration, as well as increasing the effectiveness of antioxidant enzymes, in addition to its importance in increasing plant hormones that encourage growth, as well as its role in increasing the efficiency of trees in absorbing the elements necessary for growth (nitrogen, phosphorus, and potassium) (Shayal Alalam *et al.,* 2022).

These combined roles led to positive effects in increasing the yield and the percentage of oil in the fruits (Rahmani *et al.,* 2017). The results were similar to those of Merwad *et al.* (2014) and Shaimaa and Massoud (2017) on orange trees, that biofertilization with mycorrhizae achieved a significant superiority in the total yield values. This is due to the importance of mycorrhizae in improving the characteristics of vegetative growth by increasing the efficiency of the photosynthesis process and the accumulation of manufactured nutrients in the leaves as a result of its role in increasing the availability of nutrients in the soil, their absorption, and their transfer to the leaves, which affects nutritional metabolism, which leads to an increase in the number and weight of fruits and thus an increase in the total yield and oil percentage. In the fruits (Ameen and AL- Hamdan, 2022).

## CONCLUSIONS

Foliar spraying with 5 mg $L^{-1}$ of Brassinolide and 400 mg $L^{-1}$ of nanosilicon, along with the addition of 100 g of mycorrhizae per tree, increased leaf mineral content, yield, oil percentage, and anthocyanin content in Bashika olives. Therefore, the study recommends using these concentrations of these agents, with the possibility of increasing them in future studies to achieve optimal results.

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## CONFLICT OF INTEREST

The authors state that there are no conflicts of interest with the publication of this work.

## تأثير Brassinolide والنانو سيليكون والمايكورايزا في المحتوى المعدني وانتاجية اشجار الزيتون صنف بعشيقة

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**الخلاصة**

أُجريت تجربة حقلية خلال موسم النمو لعام 2024 على أشجار زيتون بعشيقة عمرها 15 عامًا مزروعة في بستان خاص في قرية قسارة، مدينة دهوك، كردستان العراق، لدراسة تأثير الرش الورقي بثلاثة تراكيز من براسونولايد (0، 2.5، و5 ملغم لتر−1) وسماد نانو سيليكون (0، 200، و400 ملغم لتر−1). أما العامل الثالث، فتضمن إضافة سماد حيوي (فطر المايكورايزا) بثلاثة مستويات (0، 50، و100 غرام شجرة −1) صُممت التجربة باستخدام تصميم القطاعات العشوائية الكاملة (R.C.B.D) بثلاثة عوامل، وثلاث مكررات، وشجرة واحدة لكل وحدة تجريبية. وبالتالي، بلغ إجمالي عدد الأشجار المستخدمة في التجربة 81 شجرة. أظهرت النتائج أن التركيزات العالية من العوامل الثلاثة (5 ملغم لتر براسونولايد، 400 ملغم لتر نانو سيليكون، و100 غرام فطر المايكورايزا) سواءً بشكل فردي أو في جميع التداخلات الثنائية والثلاثية، أدت إلى تسجيل أعلى القيم المعنوية للصفات مثل تراكيز النيتروجين والفوسفور والبوتاسيوم، والمحصول الكلي، ونسبة الزيت، ومحتوى الأنثوسيانين في الثمار. توصي الدراسة باستخدام هذه التركيزات لتحقيق أفضل النتائج، وخاصةً لكمية المحصول ونسبة الزيت في الثمار.

الكلمات المفتاحية: أشجار الزيتون، الحاصل، المايكورايزا، براسونولايد، فطريات، نانو سيليكون، نسبة الزيتان.

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