

## **Effect of foliar spraying with Alpha tocopherol and nano fertilizers calcium and boron on growth of two chili pepper hybrids**

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### **Abstract**

A field experiment was carried out at research station, Horticulture and Landscape design Department, College of Agriculture, University of Diyala During the 2025-2026 growing season, a study was conducted on the effect of foliar spraying with alpha tocopherol, nano calcium and nano boron fertilizers on the growth and yield of two chili pepper hybrids. The split-plot system was used within the completely randomized block design, where the foliar spray treatments were placed in the main blocks and the hybrids in the subblocks to facilitate foliar spraying operations the following combinations were applied: (Control treatment), (alpha tocopherol at a concentration of 100 mg L<sup>-1</sup>), (Nano calcium 500 mg L<sup>-1</sup>), (Nano boron 250 mg L<sup>-1</sup>), combination (alpha tocopherol 100 + Nano calcium 500 mg L<sup>-1</sup>), combination (alpha tocopherol 100 + Nano boron 250 mg L<sup>-1</sup>), and combination (alpha tocopherol 100 + Nano calcium 500 + Nano boron 250 mg L<sup>-1</sup>).

The results showed that the treatment with the triple combination significantly and significantly improved the biochemical and vegetative growth characteristics, and gave the highest values in chlorophyll content (29.67 mg/100 g<sup>-1</sup> fresh weight), plant height (127.4 cm), stem diameter (3.600 cm), number of main branches (4.567 branches per plant), and total number of leaves per plant (2401 leaves per plant) were all significant. Among hybrids, the hybrid (BARBARIAN F1) significantly outperformed in most traits no significant superiority was observed in the two characteristics of the number of branches and the total number of leaves of the plant.

**Keywords:** Pepper, Hybrids, foliar Spray, Alpha tocopherol, Nano Calcium, Nano Boron.

### **Introduction:**

Chili peppers (*Capsicum annuum* L.) are among the most widely cultivated crops worldwide and belong to the nightshade family (Solanaceae) its fruits contain many biologically active compounds, including capsaicinoids and carotenoids, in addition,

its fruits contain proteins, carbohydrates, fiber, and fats Thanks to these properties, chili peppers are widely used in the preparation of many dishes in various countries around the world [1]. pepper fruits are also consumed in cooking, pain relief,

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weight loss, improving blood circulation, and as an antioxidant. Its fruits are characterized by containing vitamins, including vitamins C and E, as well as

capsaicinoids, which constitute about 90% of these components and are responsible for the distinctive spicy taste [2]

Foliar feeding is one of the agricultural practices followed and effective to increase crop productivity and improve its quality by supplying the plant with the necessary nutrients. It is considered a complement to soil fertilization when applied correctly due to its high efficiency in improving the quantity and quality of agricultural production [3] .

the properties of their molecules, it contributes to raising the efficiency of plants' tolerance to biotic and abiotic stresses, which leads to reducing production costs and mitigating the environmental impact. The multiple benefits of nano-fertilizers open new horizons towards sustainable agriculture and mitigating the effects of climate change [6] .

In light of recent climate changes, the use of antioxidants has become prominent, including alpha-tocopherol, a member of the vitamin E family, which is a lipophilic antioxidant that is synthesized in plants, algae, and cyanobacteria. It plays a pivotal role in many antioxidant functions, including reducing reactive oxygen species, preventing lipid peroxidation, and protecting fatty acids, thus improving the nutritional value of plants [4] .The study conducted by [5] showed that foliar spraying of tocopherol at a concentration of 100 mg/L on tomato plants led to an improvement in vegetative growth characteristics, including plant height, number of branches, and number of leaves.

Calcium is an essential nutrient for plants and has many physiological functions within plants, including plant growth and development, cell division, regulation of osmotic potential and ethylene, and it also contributes to reducing pectin breakdown in the necks of flowers, fruits, and leaves, this prevents the shedding of flowers and fruits. Calcium is also used to treat many physiological damages to fruits, including enhancing fruit firmness and reducing spoilage, because it is involved in the formation of the middle lamella of the cell wall, which gives the cell wall strength and rigidity [7] . The study conducted by [8] showed that foliar spraying of calcium on tomato plants at a concentration of 500 mg/L was superior in most vegetative growth characteristics, including plant height and number of leaves, 79.42 cm and 85.43 leaves per plant, respectively.

Nano fertilizers are hybrid nanostructures and a promising alternative to overcome the negative effects of traditional chemical fertilizers. Plants can absorb these fertilizers through the foliage or roots, depending on the methods of application and

Boron is an essential nutrient that plays an important role in the biochemical,

morphological, and physiological processes of plants. The plant absorbs it in the form of boric acid or borate. Both boron deficiency and excess in the soil cause problems for the plant, as its deficiency leads to reduced leaf growth, root elongation, inhibition of flower development, and excessive boron increase

reduce photosynthetic capacity. Optimal boron supply strongly promotes root growth, increases plant pigment content, and, as it is involved in pollen tube formation, plays a major role in improving fruit set and seed production [9]. The results of the study conducted by [10]

showed that foliar spraying of boron on chili pepper plants at a concentration of 100 mg L<sup>-1</sup> led to an increase in chlorophyll content, stem diameter, plant height, number of branches, and number of leaves, reaching (48.23 mg g<sup>-1</sup>), (21.02 mm), (70.02 cm), (4.50 plant branches<sup>-1</sup>), and (156.81 plant leaves<sup>-1</sup>), respectively.

This study aims to determine the effect of foliar spraying with tocopherol, calcium, boron nanoparticles and their combinations on some of the biochemical and vegetative growth characteristics of the chili pepper plant.

## **2. Materials and methods**

### **2.1. Experiment site**

The experiment was conducted in the open field of the Department of Horticulture and Landscape Engineering, College of Agriculture, University of Diyala, during the 2025-2026 agricultural season, with the aim of studying the effect of foliar spraying with alpha tocopherol and nano-fertilizer of calcium and boron on the growth and yield of two chili pepper hybrids.

### **2.2. Experiment design**

The experiment was carried out with (RCBD) and a split plot system with three replicates. Leaf spray treatments were in main plots and hybrids were in subplots. The experiment was conducted using experimental units of 4 m<sup>2</sup> with a drip irrigation system employing GR-type pipes arranged as two lines per bed, with 0.6 m between lines and 0.4 m between plants; plants were grown on two lines with 5 plants per line, resulting in 10 plants per unit, and the study included three replicates with 14 treatments each, giving a total of 42 treatments

### **2.3. Factors of the experiment**

**Factor I:** Foliar spray treatments(A): which included the comparison treatment      **A1:** Control (No fertilization).

**A2:** alpha tocopherol at 100 mg L<sup>-1</sup>.

**A3:** nano calcium at 500 mg L<sup>-1</sup>.

**A4:** nano boron at 250 mg L<sup>-1</sup>.

**A5:** the combination of alpha tocopherol 100 mg L<sup>-1</sup> + nano calcium at 500 mg L<sup>-1</sup>.

**A6:** the combination of alpha tocopherol 100 mg L<sup>-1</sup>+ nano boron at of 250

mg L<sup>-1</sup>. **A7:** the combination of alpha tocopherol at 100 mg L<sup>-1</sup>+ nano calcium at 500 mg L<sup>-1</sup>+ nano boron at 250 mg L<sup>-1</sup>. The plants were sprayed with four sprays: one before flowering and three after flowering, with a period of 14-15 days between each spray.

**Factor II:** It represents two chili pepper hybrids, namely: HAR F1 and BARBARIAN F1.

D represents the device reading at the specified wavelength, then the unit was converted to (mg 100g<sup>-1</sup>)  $\text{mg } 100\text{g}^{-1} = \text{mg L}^{-1} \times \text{final volume of extract (L)} \times 100 / \text{weight of sample (g)}$ .

#### **-Plant height (cm)**

The plant height was measured using a measuring tape from the soil surface level to the highest growing tip of the plant at the end of the growing season and the average was calculated.

#### **- Stem diameter (cm)**

The diameter of the main stem was measured at the end of the experiment using a (Vernier) at the last plow from the point where the stem connects to the soil.

#### **- Number of main branches (branches plant<sup>-1</sup>)**

The number of main branches of the control plants was calculated at the end of the experiment from each experimental unit, and then the average was calculated.

#### **Studied Parameters:**

##### **- Chlorophyll content (mg100g<sup>-1</sup> fresh weight)**

It was estimated according to the method described by [11] using a spectrophotometer at wavelengths of 663 and 645 nm according to the following equation:

$$\text{Total chlorophyll} = 20.2 \times D(645) + 8.02 \times D(663) \quad (\text{V/W} \times 1000) \times 100$$

##### **- Total number of leaves per plant (leaf \plant<sup>-1</sup>)**

The number of leaves for three plants at the end of the experiment was calculated for each experimental unit and the average was calculated.

#### **4.2. Statistical Analysis**

The results were analyzed using the SAS program and the means were compared according to Duncan's multiple range test at a probability level of 0.05 [12].

#### **3. Results and discussion:**

##### **Chlorophyll content in leaves (mg 100g<sup>-1</sup> fresh weight)**

The results in Table (1) showed a significant superiority of the effect of spraying treatment with the triple combination (alpha-tocopherol, calcium and boron nanoparticles) in the chlorophyll content of the leaves, as the highest content reached 29.67 mg/100g<sup>-1</sup> fresh weight, compared to the control treatment (without spraying)

which gave the lowest value of 21.95 mg/100g<sup>-1</sup> fresh weight and did not differ significantly from the rest of the spraying treatments.

As for the results of the effect of the hybrids, the results indicate that there is a significant effect between them, as the HAR F1 hybrid gave the highest concentration of chlorophyll in the leaves, reaching 29.60 mg/100g<sup>-1</sup> fresh weight, compared to the BARBARIAN F1 hybrid, which gave 25.71 mg/100g<sup>-1</sup> fresh weight.

The results in the same table showed significant interaction effects between the foliar spray treatment (nano calcium 500 mg L<sup>-1</sup>) and the HAR F1 hybrid in this trait, which reached 32.10 mg 100 g<sup>-1</sup> fresh weight, compared to the interaction treatment between the control (no spray) and the BARBARIAN F1 hybrid, which reached 22.25 mg 100 g<sup>-1</sup> fresh weight. It did not differ significantly with the treatment with the triple combination (alpha-tocopherol, calcium, and nano-boron), which reached 32.88 mg 100 g<sup>-1</sup> fresh weight.

**Table (1) Effect of foliar spraying with alpha-tocopherol and nano-fertilizer of calcium and boron and the interaction between them on the total concentration of chlorophyll in leaves (mg100 g<sup>-1</sup> fresh weight) of two chili pepper hybrids.**

| Hybrids<br>Transactions                                                                                                                   | HAR F1       | BARBARIAN<br>F1 | Average impact<br>of spray<br>treatments |
|-------------------------------------------------------------------------------------------------------------------------------------------|--------------|-----------------|------------------------------------------|
| Comparison (without spraying)                                                                                                             | 21.66<br>D   | 22.25<br>d      | 21.95<br>B                               |
| Alpha-tocopherol 100 mg/L <sup>-1</sup>                                                                                                   | 30.18<br>a b | 25.04<br>c d    | 27.61<br>A                               |
| Nano Calcium 500 mg L <sup>-1</sup>                                                                                                       | 32.10<br>A   | 26.97<br>b c    | 29.53<br>A                               |
| Nano-boron 250 mg L <sup>-1</sup>                                                                                                         | 30.46<br>B   | 24.63<br>c d    | 27.55<br>A                               |
| Alpha-tocopherol 100 mg L <sup>-1</sup> +<br>Nano Calcium 500 mg L <sup>-1</sup>                                                          | 29.88<br>Ab  | 28.26<br>b c    | 29.07<br>A                               |
| Alpha-tocopherol 100 mg L <sup>-1</sup> +<br>Nano-boron 250 mg L <sup>-1</sup>                                                            | 30.01<br>a b | 26.37<br>b c    | 28.19<br>A                               |
| Alpha-tocopherol 100 mg L <sup>-1</sup> +<br>Calcium nanoparticles 500 mg L <sup>-1</sup><br>+ Boron nanoparticles 250 mg L <sup>-1</sup> | 32.88<br>a   | 26.45<br>b c    | 29.67<br>A                               |
| Average impact of hybrids                                                                                                                 | 29.60<br>A   | 25.71<br>B      |                                          |

**Similar letters within the same column indicate no significant difference between the means at a significance level of 0.05.**

### **Plant height (cm)**

The results in Table (2) showed that there was a significant superiority of the effect of the triple combination treatment (alpha tocopherol, calcium and boron nanoparticles), as it gave the highest plant height of 127.4 cm plant<sup>-1</sup> compared to the control treatment (without spraying), which gave the lowest plant height of 77.33 cm plant<sup>-1</sup>. This treatment also outperformed the rest of the other treatments, but it did not

differ significantly from the combination of alpha tocopherol + boron nanoparticles.

The results of the same table showed significant differences between the hybrids in the plant height trait, as the BARBARIAN F1 hybrid gave the highest height of 108.7 cm plant<sup>-1</sup> compared to the HAR F1 hybrid, which recorded the lowest height of 101.9 cm plant<sup>-1</sup>.

As for the interaction, it had a significant effect, as the foliar spray treatment with the triple combination (alpha-tocopherol, calcium, and boron nanoparticles) and the BARBARIAN F1 hybrid was superior, as it

gave the highest plant height of 128.3 cm plant<sup>-1</sup> compared to the interaction between the control treatment (without spraying) and the HAR F1 hybrid, which showed the lowest plant height of 74.20 cm plant<sup>-1</sup>.

**Table (2) Effect of foliar spraying with alpha-tocopherol and nano-fertilizer of calcium and boron and the interaction between them on the plant height characteristic of two chili pepper hybrids (cm).**

| Hybrids<br>Transactions                                                                                                             | HAR F1       | BARBARIAN F1 | Average impact of spray treatments |
|-------------------------------------------------------------------------------------------------------------------------------------|--------------|--------------|------------------------------------|
| Comparison (without spraying)                                                                                                       | 74.20<br>f   | 80.47<br>e   | 77.33<br>D                         |
| Alpha-tocopherol 100 mg/L <sup>-1</sup>                                                                                             | 96.00<br>d   | 98.93<br>c d | 97.47<br>C                         |
| Nano Calcium 500 mg L <sup>-1</sup>                                                                                                 | 100.1<br>c d | 100.2<br>c d | 100.2<br>C                         |
| Nano-boron 250 mg L <sup>-1</sup>                                                                                                   | 97.63<br>c d | 124.6<br>a b | 111.1<br>B                         |
| Alpha-tocopherol 100 mg L <sup>-1</sup> + Nano Calcium 500 mg L <sup>-1</sup>                                                       | 97.13<br>c d | 102.5<br>c   | 99.83<br>C                         |
| Alpha-tocopherol 100 mg L <sup>-1</sup> + Nano-boron 250 mg L <sup>-1</sup>                                                         | 121.5<br>b   | 125.8<br>a b | 123.6<br>A                         |
| Alpha-tocopherol 100 mg L <sup>-1</sup> + Calcium nanoparticles 500 mg L <sup>-1</sup> + Boron nanoparticles 250 mg L <sup>-1</sup> | 126.5<br>a b | 128.3<br>a   | 127.4<br>A                         |
| Average impact of hybrids                                                                                                           | 101.9<br>B   | 108.7<br>A   |                                    |

**\*Similar letters within the same column indicate no significant difference between the means at a significance level of 0.05.**

### **Stem diameter (cm)**

The results of Table (3) indicated a significant superiority of the treatment with the triple combination (alpha-tocopherol,

calcium, and boron nanoparticles), as it gave the highest stem diameter of 3.600 cm compared to the control treatment (without

spraying), which showed the lowest stem diameter of 2.318 cm. It also outperformed the other treatments, but it did not differ significantly from the binary combination (alpha-tocopherol and calcium nanoparticles).

The same table shows significant effects between the hybrids, as the BARBARIAN

F1 hybrid showed the highest stem diameter of 3.242 cm compared to the HAR F1 hybrid, which recorded the lowest diameter of 3.107 cm.

As for the interaction, it had a significant effect, as the foliar spray treatment with the triple combination (alpha-tocopherol, calcium, and nano-boron) with the BARBARIAN F1 hybrid was superior and gave the highest diameter of 3.620 cm. It did not differ significantly with the dual combination (alpha-tocopherol and nano-boron) and the combination (alpha-tocopherol and nano-calcium) compared to the interaction between the control treatment (without spraying) and the HAR F1 hybrid, which gave the lowest stem diameter of 2.273 cm.

**Table (3) Effect of foliar spraying with alpha-tocopherol and nano-fertilizer of calcium and boron and the interaction between them on the stem diameter characteristic of two chili pepper hybrids (cm).**

**\*Similar letters within the same column indicate no significant difference between the**

| Hybrids<br>Transactions                                                                                                                   | HAR F1       | BARBARIAN<br>F1 | Average impact of<br>spray treatments |
|-------------------------------------------------------------------------------------------------------------------------------------------|--------------|-----------------|---------------------------------------|
| Comparison (without spraying)                                                                                                             | 2.273<br>e   | 2.363<br>e      | 2.318<br>D                            |
| Alpha-tocopherol 100 mg/L <sup>-1</sup>                                                                                                   | 3.243<br>cab | 3.320<br>cab    | 3.282<br>B                            |
| Nano Calcium 500 mg L <sup>-1</sup>                                                                                                       | 3.033<br>cd  | 3.100<br>cd     | 3.067<br>C                            |
| Nano-boron 250 mg L <sup>-1</sup>                                                                                                         | 3.180<br>cd  | 3.153<br>cd     | 3.167<br>BC                           |
| Alpha-tocopherol 100 mg L <sup>-1</sup> + Nano<br>Calcium 500 mg L <sup>-1</sup>                                                          | 3.520<br>ab  | 3.573<br>a      | 3.547<br>A                            |
| Alpha-tocopherol 100 mg L <sup>-1</sup> +<br>Nano-boron 250 mg L <sup>-1</sup>                                                            | 2.920<br>d   | 3.563<br>a      | 3.242<br>BC                           |
| Alpha-tocopherol 100 mg L <sup>-1</sup> +<br>Calcium nanoparticles 500 mg L <sup>-1</sup> +<br>Boron nanoparticles 250 mg L <sup>-1</sup> | 3.580<br>a   | 3.620<br>a      | 3.600<br>A                            |
| Average impact of hybrids                                                                                                                 | 3.107<br>B   | 3.242<br>A      |                                       |

**means at a significance level of 0.05.**

#### **Number of main branches (branch\ plant<sup>-1</sup>)**

The results in Table (4) showed that the spraying treatments were significantly superior to the control treatment, while the spraying treatments did not differ significantly between them. The spraying treatment with the triple combination (alpha-tocopherol, calcium and boron nanoparticles) gave the highest average of 4.567 plant branches<sup>-1</sup> compared to the control treatment (without spraying), which

gave the lowest average of 3.317 plant branches<sup>-1</sup>.

The results of the same table also showed that there were no significant differences between the hybrids in the trait of the number of branches, as the BARBARIAN F1 hybrid gave the highest number of branches, reaching 4,329 plant<sup>-1</sup> branches, while the HAR F1 hybrid reached 4,200 plant<sup>-1</sup> branches.

Regarding the interaction, the foliar spray treatment with the triple combination (alpha-tocopherol, calcium, and boron nanoparticles) with the BARBARIAN F1 hybrid showed the highest number of branches, reaching 4,633 plant<sup>-1</sup> branches. It

did not differ significantly with the other treatments compared to the interaction between the control treatment (without spraying) and the HAR F1 hybrid, which gave the lowest number of branches, reaching 3,167 plant<sup>-1</sup> branches.

**Table (4) Effect of foliar spraying with alpha-tocopherol and nano-fertilizer of calcium and boron and the interaction between them on the number of branches trait of two chili pepper hybrids.**

| Hybrids<br>Transactions                                                                                                                      | HAR F1     | BARBARIAN<br>F1 | Average impact<br>of spray<br>treatments |
|----------------------------------------------------------------------------------------------------------------------------------------------|------------|-----------------|------------------------------------------|
| Comparison (without spraying)                                                                                                                | 3.167<br>b | 3.467<br>b      | 3.317<br>B                               |
| Alpha-tocopherol 100 mg/L <sup>-1</sup>                                                                                                      | 4.300<br>a | 4.433<br>a      | 4.367<br>A                               |
| Nano Calcium 500 mg L <sup>-1</sup>                                                                                                          | 4.467<br>a | 4.367<br>a      | 4.417<br>A                               |
| Nano-boron 250 mg L <sup>-1</sup>                                                                                                            | 4.200<br>a | 4.367<br>a      | 4.283<br>A                               |
| Alpha-tocopherol 100 mg L <sup>-1</sup> +<br>Nano Calcium 500 mg L <sup>-1</sup>                                                             | 4.333<br>a | 4.500<br>a      | 4.417<br>A                               |
| Alpha-tocopherol 100 mg L <sup>-1</sup> +<br>Nano-boron 250 mg L <sup>-1</sup>                                                               | 4.433<br>a | 4.533<br>a      | 4.483<br>A                               |
| Alpha-tocopherol 100 mg L <sup>-1</sup> +<br>Calcium nanoparticles 500 mg<br>L <sup>-1</sup> + Boron nanoparticles 250<br>mg L <sup>-1</sup> | 4.500<br>a | 4.633<br>a      | 4.567<br>A                               |
| Average impact of hybrids                                                                                                                    | 4.200<br>A | 4.329<br>A      |                                          |

\*Similar

ar letters within the same column indicate no significant difference between the means at a significance level of 0.05.

### **Total number of leaves per plant (leaf\ plant<sup>-1</sup>)**

The results in Table (5) proved that there was a significant superiority of the effect of the triple combination treatment (alpha

tocopherol, calcium and boron nanoparticles), as it gave the highest total number of leaves, reaching 2041 plant

leaves<sup>-1</sup>, compared to the control treatment (without spraying), which gave the lowest total number of leaves, reaching 970.5 plant leaves<sup>-1</sup>. It also outperformed the rest of the other treatments, but it did not differ significantly from the binary combination (alpha tocopherol and boron nanoparticles) and the (boron nanoparticles) treatment.

We did not observe any significant differences between the hybrids, and the highest value was for the BARBARIAN F1 hybrid, which reached 1875 plant leaves<sup>-1</sup>, compared to the HAR F1 hybrid, which had a total of 1843 plant leaves<sup>-1</sup>.

The results of the interaction had a significant effect, as the foliar spray treatment (250 mg/L nano-boron) with the BARBARIAN F1 hybrid was superior, as it gave the highest total number of leaves, reaching 2490 leaves per plant<sup>-1</sup>, and it did not differ significantly with the dual combination (alpha-tocopherol and nano-boron) compared to the interaction between the control treatment (without spraying) and the HAR F1 hybrid, which showed the lowest total number of leaves, reaching 923.7 leaves per plant<sup>-1</sup>.

**Table (5) Effect of foliar spraying with alpha-tocopherol and nano-fertilizer of calcium and boron and the interaction between them on the number of leaves trait of two chili pepper hybrids.**

| Hybrids<br>Transactions                                                                                                                   | HAR F1     | BARBARIAN<br>F1 | Average<br>impact of<br>spray<br>treatments |
|-------------------------------------------------------------------------------------------------------------------------------------------|------------|-----------------|---------------------------------------------|
| Comparison (without spraying)                                                                                                             | 923.7<br>g | 1017<br>g       | 970.5<br>E                                  |
| Alpha-tocopherol 100 mg/L <sup>-1</sup>                                                                                                   | 1311<br>f  | 1417<br>ef      | 1364<br>D                                   |
| Nano Calcium 500 mg L <sup>-1</sup>                                                                                                       | 1501<br>e  | 1520<br>e       | 1511<br>C                                   |
| Nano-boron 250 mg L <sup>-1</sup>                                                                                                         | 2097<br>c  | 2490<br>a       | 2293<br>A                                   |
| Alpha-tocopherol 100 mg L <sup>-1</sup> +<br>Nano Calcium 500 mg L <sup>-1</sup>                                                          | 2384<br>ab | 1811<br>d       | 2097<br>B                                   |
| Alpha-tocopherol 100 mg L <sup>-1</sup> +<br>Nano-boron 250 mg L <sup>-1</sup>                                                            | 2287<br>b  | 2472<br>a       | 2380<br>A                                   |
| Alpha-tocopherol 100 mg L <sup>-1</sup> +<br>Calcium nanoparticles 500 mg L <sup>-1</sup><br>+ Boron nanoparticles 250 mg L <sup>-1</sup> | 2401<br>ab | 2400<br>ab      | 2401<br>A                                   |
| Average impact of hybrids                                                                                                                 | 1843<br>A  | 1875<br>A       |                                             |

\*Similar letters within the same column indicate no significant difference between the means at a significance level of 0.05.

Table (1) shows significant differences in foliar spray treatments, with the triple combination treatment (alpha-tocopherol, calcium, and boron nanoparticles) yielding the highest concentration of chlorophyll in the leaves this superiority is attributed to the role of alpha-tocopherol, which is a powerful antioxidant that protects chloroplast membranes and maintains the efficiency of the photosynthetic system, thus promoting chlorophyll accumulation [13], Calcium plays a role in stabilizing the cell wall and middle lamella membranes, and also contributes to increasing the activity of some enzymes associated with photosynthesis [14], in addition, boron plays an important role in improving metabolic processes and sugar transport, which causes a significant increase in the chlorophyll content of the leaves and improves the physiological state of the plant [15].

The results in Tables (2, 3, 4, and 5) also showed a significant advantage for foliar spray treatments, where the treatment with the triple combination (alpha-tocopherol, calcium, and boron nanoparticles) was superior in terms of plant height, stem diameter, number of main branches, and total number of leaves This superiority is due to the complementary role of foliar spray treatments (alpha-tocopherol, calcium, and boron nanoparticles), as alpha-tocopherol contributed to raising the efficiency of photosynthesis and protecting

chloroplast membranes [13]. These results are consistent with what was found by (5) When tocopherol was sprayed on tomato plants, it significantly affected vegetative growth characteristics, while nano-calcium and boron enhanced cell division and elongation processes, strengthened cell walls, improved the transport of photosynthesis products and sugars, and regulated hormonal balance, these results are consistent with [16] [17] and also with what [18] concluded when spraying boron on sweet pepper plants led to an improvement in vegetative growth characteristics.

As for the effects of hybridization, the BARBARIAN F1 hybrid outperformed the HAR F1 hybrid in most of the studied traits. This is due to the genetic and physiological differences between them. Hybrids also vary in their absorption and metabolic efficiency and their ability to regulate environmental stresses this is reflected in the concentration of elements and vital compounds in the leaves. Researchers [19] indicated that the genetic differences of hybrids play an important role in adapting to different environmental conditions, which affects the plant's growth and production performance, this is consistent with these results which showed that the BARBARIAN F1 hybrid has broader genetic capabilities to withstand environmental stresses and this is reflected positively in physiological and agricultural traits.

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