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Effects of Boron Foliar Application on Growth Performance and Yield of Pepper (*Capsicum annuum* L.)

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Abstract: The study was conducted in 2024 at the Faculty of Agricultural Engineering farm, Idlib University, Syria, using a hybrid pepper variety of Turkish origin. The research aimed to evaluate the effect of foliar application of boron on the growth and yield performance of pepper plants. A boron solution at a concentration of 200 ppm was applied as a foliar spray, while the control plants were sprayed with water only. The experiment was arranged in a completely randomized design (CRD). Results revealed that boron foliar application significantly increased the number of fruit set compared to the control, with a gradual increase over time, reaching 26 fruits per plant under boron treatment versus 16 fruits per plant in the control. Furthermore, boron application positively affected vegetative growth, as evidenced by significant increases in plant height and leaf area, indicating enhanced physiological activity. In terms of productivity, boron-treated plants exhibited significant improvements in all evaluated yield attributes, including fruit weight, size, length, and diameter. Consequently, total yield increased to 118.73 g per plant in the boron-treated plants, compared to 66.72 g per plant in the control, representing a 177.95% increase in productivity.

Keywords: Pepper, Foliar Application, Boron, Growth, Productivity

I. INTRODUCTION

Capsicum annuum L., commonly known as pepper, is one of the most important agricultural crops cultivated widely across various regions of the world. It is characterized by its high nutritional content, including vitamins (particularly vitamin C), minerals, and carbohydrates, making it a healthy and beneficial food. Moreover, it is extensively used in the food industry as a spice or as an ingredient in processed foods (Srinivasan, 2017; Al-Khalifah, 2020).

Nevertheless, the cultivation of pepper encounters numerous challenges that could impact its productivity and quality. One such challenge is the lack of specific micronutrients in the soil, including boron, which is a crucial element for enhancing growth and productivity in various agricultural crops. Although plants need boron in minimal amounts, it is essential for several biological processes, including cell formation, cell division regulation, vegetative growth enhancement, and flowering (Shorrocks, 1997; Huang and Zhang, 2013).

Foliar fertilization is a widely adopted technique to provide essential nutrients directly to plants, particularly in situations where soil nutrient levels are inadequate. In this regard, the present research seeks to explore the impact of boron foliar application on the growth and productivity of pepper plants. This investigation aims to offer valuable insights for farmers to improve crop productivity and quality through the strategic application of boron foliar spraying (Cakmak, 2008; Zhao et al., 2017).

Micronutrients, including boron, are crucial for plant development, as boron is involved in numerous essential biological processes, rendering it vital for crop growth and achieving optimal yields. Boron is necessary for the stabilization of plant hormones, such as auxins, which govern cell growth (Smith & Johnson, 2023). Moreover, it significantly contributes to the transport of carbohydrates within plant tissues, facilitating metabolism and supplying the energy needed for growth and development (Liu, 2020). Additionally, boron plays a critical role in root development, promoting the formation of lateral roots and enhancing the plant's capacity to absorb nutrients and water from the soil (Zhao & Zhang, 2019).

Boron also has a beneficial impact on the processes of pollination and fertilization, which in turn enhances the productivity of flowering plants, including pepper and tomato (Lee & Lee, 2022).Prior research has indicated that a deficiency in boron can result in considerable challenges for plant growth, such as diminished fruit set and inferior fruit quality. For example, Kumar et al. (2014)

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noted that a lack of boron leads to smaller fruit sizes and higher rates of fruit drop in certain sensitive species.

Moreover, recent investigations have shown that the application of boron via foliar methods can promote plant growth and improve the quality of crops. A study conducted by Chen and Li (2021) demonstrated that treating plants with boron enhances the nutrient content of fruits and increases their firmness, which contributes to a longer post-harvest shelf life.Another research effort by Wimmer et al. (2005) discovered that the application of boron can bolster plant resistance to environmental stresses, such as drought, thereby enhancing the adaptability of plants to varying climatic conditions and improving overall productivity.

While boron is a vital micronutrient that significantly contributes to the enhancement of growth traits and the increase of agricultural productivity, numerous studies have established that excessive application can negatively impact plants. Research has indicated that high concentrations of boron in the soil can induce plant toxicity, manifesting as symptoms such as leaf chlorosis, stunted growth, and decreased yields (Shorrocks, 1997; Marschner, 2012).

Furthermore, studies suggest that an overabundance of boron can impede the absorption of other essential nutrients, such as calcium and magnesium, thereby worsening toxicity symptoms (Brown &Shelp, 1997).Consequently, it is imperative to ascertain the optimal rate of boron application to maximize its advantages for plant growth while avoiding detrimental effects on plant health. This optimal rate can be established through meticulous scientific investigations that consider the specific plant species and soil characteristics (Ng &Sadiq, 2013).

Multiple investigations into the influence of boron on pepper cultivation have underscored its role in enhancing fruit quality and boosting yield. In research conducted by Cakmak et al. (2000), a boron solution was administered to pepper plants, resulting in a notable increase in both fruit size and quantity when compared to the control group. Additionally, a study by Khalid et al. (2011) revealed that the application of boron elevated the vitamin content in peppers, including vitamin C, thus improving their nutritional profile. A plethora of scientific research has confirmed the beneficial impacts of boron application on yield enhancement, as well as on the improvement of fruit setting and quality in pepper crops.In a study conducted by García and Fernández (2021), boron application significantly improved fruit size and weight, contributing to overall crop quality enhancement. Moreover, the researchers noted that boron enhances pollination and fruit setting within flowers by promoting interactive responses between pollinated cells and flowers, thereby increasing fruit number and significantly boosting productivity.

In another study by Al-Mana (2022), foliar boron application on pepper plants resulted in a substantial increase in the number of set fruits, aligning with findings from previous research. This study also showed that boron spraying improved cellular tissue cohesion in fruits, leading to enhanced fruit characteristics such as size and firmness, as well as increased nutrient content, including essential vitamins and minerals.

Additionally, a study by Cakmak et al. (2008) highlighted that boron improves the plant's ability to convert nutrients into fruits, thereby enhancing overall productivity. It was observed that boron enhances the interaction between boron and calcium, improving cell wall health and resulting in fruits with stronger skin and higher quality. The researchers also noted that improved fruit setting due to boron application can increase the number of fruits per unit area, ultimately raising the plant's overall yield.

Similarly, Shorrocks (1997) demonstrated that boron plays a critical role in regulating the internal distribution of nutrients within plants, thereby improving productivity and fruit quality. Boron enhances nutrient uptake and increases the efficiency of physiological processes that contribute to plant growth and overall crop quality.

Based on the above, understanding the effect of boron foliar application on peppers can contribute to increased productivity and improved fruit quality. This study will examine the impact of boron foliar spraying on pepper plants by investigating its effects on growth and productivity factors. Consequently, the results of this research could contribute to improving pepper cultivation techniques and providing solutions to agricultural challenges related to micronutrient deficiencies in the soil.

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II. MATERIALS AND METHODS

2.1 Experimental Site

The research was conducted in 2024 at the Agricultural Engineering Faculty Farm, University of Idlib, located in north western Syria, 300 km away from Damascus and 35 km south of the Syrian-Turkish border. The farm is situated at an altitude of approximately 450 meters above sea level and receives an average annual rainfall of around 495 mm.

2.2 Plant Material

The study utilized pepper plants (*Capsicum annuum* L.) of the hybrid cultivar "Extra," an F1 generation of Turkish origin.

The seeds of the studied cultivar were sown in early February in the greenhouse at the Agricultural Engineering Faculty, University of Idlib, using plastic trays filled with peat moss. Seedlings emerged approximately 15 days after sowing. The seedlings reached the appropriate size for transplanting after one and a half months (mid-March). The seedlings were then transplanted into 5-liter pots filled with a mixture of red soil and well-decomposed organic manure in a 1:1 ratio, with one plant per pot. The plants were grown under greenhouse conditions at the Agricultural Engineering Faculty.

Flowering began in early May, fruit setting occurred by mid-May, immature green fruits were harvested in early June, and fully ripened red fruits were obtained in early July. The plants were irrigated every three days, and fertilizers were applied via fertigation every 15 days, using a balanced fertilizer formulation (N-P-K: 20-20-20 with traces of micronutrients). An integrated pest and disease management program was implemented as needed for the experimental plants.

2.3 Experimental Treatments

The experimental plants were divided into two groups:

- **Boron-treated group (Bo):** Plants were subjected to foliar spraying with a 200-ppm boron solution.
- **Control group (Ctrl):** Plants were sprayed with water only (no boron treatment).

Foliar spraying began at the onset of flowering (early May) and continued throughout the experiment (4 months), with applications every 15 days. Each spray covered the plants to the point of full wetting, with approximately 100 mL applied per plant.

Each treatment was replicated three times, with each replicate consisting of five pepper plants in separate pots, resulting in a total of 30 plants.

2.4 Studied Parameters

2.4.1 Development of the Number of Fruits Formed per Plant

The number of fruits produced was recorded throughout the experimental period (from day 0, marking the onset of flowering, to day 120, the end of the experiment). The daily count of newly formed fruits was documented.

2.4.2 Vegetative Growth Parameters

- Plant Height (cm): This measurement is taken from the base of the plant to the apex of the stem.
- Height of the First Branching Point (cm): The distance from the base of the plant to the initial branching point was recorded.
- Number of Main Branches: The count of main branches for each plant was conducted during the flowering phase.
- Leaf Area: The overall leaf area was quantified utilizing ImageJ software, and the mean area of 10 leaves was documented.

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2.4.3 Yield-Related Traits

- Number of Fruits: The total count of fruits produced by each plant across all replicates (15 plants) was recorded.
- Fruit Weight (g): Individual fruit weights were assessed using a precision balance.
- Fruit Volume (cm^3): The volume of the fruits was ascertained through a water displacement technique.
- Fruit Length (cm): The length of the fruits was gauged with a vernier caliper.
- Fruit Diameter (cm): The diameter of the fruits was similarly measured using a precise graduated instrument.
- Total Yield: The total yield (g/plant) was computed based on the aggregate weight of all fruits produced by each plant.

2.5 Experimental Design and Statistical Analysis

The treatments were arranged in a completely randomized design (CRD). Data analysis was performed using GenStat 12 statistical software, and treatment means were compared using the Least Significant Difference (LSD) test at the 5% level of significance.

III. RESULTS AND DISCUSSION

3.1 Effect of Boron Foliar Application on Fruit Set Number Over Time

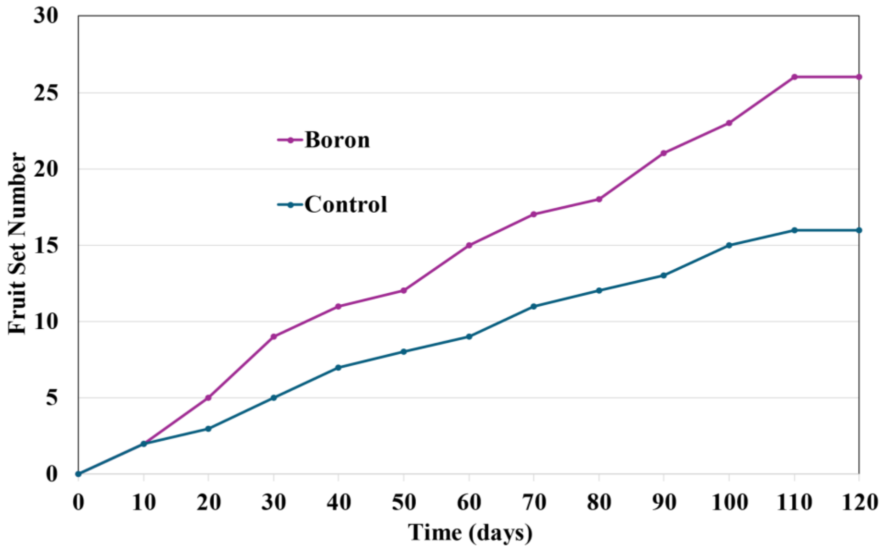

Figure 1: Effect of Boron Foliar Application on the Number of Fruit Set Over Time

From Figure (1), it can be observed that the number of fruits in plants treated with boron (Bo) increases significantly more than the control (Ctrl) as days progress. On day 10, the number of fruits in both Bo and Ctrl was equal (2 fruits). As the days progressed, the number of fruits in Bo started to increase faster compared to the control. On day 120, the number of fruits in the Bo group stabilized at 26, while it was only 16 fruits in the control.

The findings indicate that the application of boron on pepper plants results in a notable increase in the quantity of fruits produced when compared to the untreated control group, which is consistent with earlier research (Hernández et al., 2017). This phenomenon may be linked to the function of boron in facilitating pollination and the processes involved in fruit set, as boron is recognized as a crucial element for promoting these essential biological functions in plants, including peppers. The increased fruit count observed in the boron-treated group suggests that boron may enhance the plant's responsiveness and encourage improved fruit development. Research has shown that boron significantly contributes to cellular growth stimulation and enhances the plant's capacity to yield fruits by improving pollination and fruit set (Blevins &Lukaszewski, 1998; Kumar et al., 2008).

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3.2 Effect of Foliar Boron Application on Vegetative Growth Parameters

Table 1: Effect of Foliar Boron Application on Pepper Vegetative Growth Traits

Trait	Control	Boron	$LSD_{(5\%)}$
Height of Branching Point (cm)	33.50	35.17	2.14
Plant Height (cm)	62.00	65.83	3.11
Number of Primary Branches	4	4	0.05
Leaf Area (cm²)	15.63	21.64	2.87

It is clear from Table (1) that there are no substantial differences in the height of the branching point between the Bo treatment and the control treatment, with measurements of 35.17 cm and 33.50 cm, respectively, indicating a slight difference of 1.67 cm. Zhou et al. (2020) established that the impact of stimulants such as boron on branches may differ based on the type of plant and the environmental conditions in which the plants are cultivated. Therefore, the small difference observed between the two treatments in this study may be attributed to these factors.

Regarding plant height, Table (1) shows the significant superiority of the boron treatment over the control treatment, with a difference of 3.83 cm and values of 65.83 cm and 62 cm, respectively. According to Shah et al. (2017), a significant increase in plant height was observed when plants were sprayed with boron. Another study by Kumar et al. (2018) confirmed that boron enhances the vertical growth of plants, aligning with the results of our study, where plants treated with boron showed increased height compared to the control.

For the number of primary branches per plant, there were no significant differences between the foliar boron spray treatment and the control treatment, as both treatments recorded 4 branches (Table 1).

Regarding leaf area, Table (1) shows the significant superiority of the foliar boron spray treatment over the control treatment, with a difference of 6.01 cm² and leaf areas of 21.64 cm² and 15.63 cm² for the treatments, respectively. Wang et al. (2019) indicate that chemical stimulants like boron can lead to an increase in leaf area due to enhanced physiological activity and increased photosynthetic rates in plants. This agrees with the results obtained in our study, where leaf area increased with boron treatment. Additionally, Zhang et al. (2017) confirmed that increased leaf area could result from the stimulation of overall plant growth. The larger leaf size may contribute to improved photosynthetic efficiency, which is consistent with the findings of the current study.

3.3 Effect of Foliar Boron Application on Productivity Parameters

Table 2: Effect of Foliar Boron Application on the Pepper Productivity Traits

Trait	Control	Boron	$LSD_{(5\%)}$
Fruit Weight (g)	4.17	4.57	0.15
Fruit Volume (cm³)	5.85	7.00	0.30
Fruit Diameter (cm)	1.08	1.25	0.05
Fruit Length (cm)	13.30	14.16	0.30
Fruit Peduncle Length (cm)	2.63	3.10	0.10
Number of Fruits	16	26	2.50
Yield (g/plant)	66.72	118.73	6.00

The results in Table (2) show a significant superiority of the boron foliar spray treatment compared to the control in all studied traits. For fruit weight, the boron treatment achieved a significant increase compared to the control, with values of 4.57 g and 4.17 g, respectively. Regarding fruit volume, the boron spray treatment significantly outperformed the control, with values of 7 cm³ and 5.85 cm³, respectively. For fruit diameter, the values were 1.25 cm and 1.08 cm for the boron treatment and control, respectively.

For fruit length, the boron spray treatment resulted in a significant increase compared to the control, with values of 14.16 cm and 13.30 cm, respectively. Similarly, for the length of the fruit peduncle, the boron foliar spray significantly increased the length

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compared to the control, with values of 3.10 cm and 2.63 cm, respectively.

In terms of the number of fruits, the difference was clear, with the boron spray treatment significantly increasing the number of fruits to 26 compared to 16 in the control. As for the total productivity of pepper plants, the boron foliar spray treatment significantly outperformed the control, with yields of 118.73 g and 66.72 g, respectively.

The results of the study demonstrate a positive effect of boron foliar spraying on various productivity traits of pepper plants compared to the control, reflecting the importance of this element in enhancing growth and productivity. The increase in fruit weight (0.4 g) with boron spraying is a clear indication of its role in improving fruit characteristics. Several studies have shown that boron enhances cell formation and stimulates organic growth, resulting in increased fruit weight. Ibrahim et al. (2017) reported that the application of boron on pepper plants improved fruit weight due to enhanced nutrient absorption and increased enzyme activity.

The increase in fruit volume (1.15 cm^3) observed with boron spraying indicates its role in promoting cell expansion and increasing fruit size. Abdullah et al. (2015) found that boron spraying on pepper plants contributed significantly to increased fruit volume by stimulating nutrient uptake and enhancing cell growth.

The increase in fruit diameter (0.17 cm) represents an improvement in the external appearance of the fruit, which can be attributed to boron’s role in stimulating cell growth and strengthening cell walls. Zhang et al. (2019) confirmed that boron enhances the thickness of plant cell walls, contributing to a significant increase in fruit diameter.

The increase in fruit length (0.86 cm) with boron spraying is a result of improved cell division and elongation. This finding is consistent with the study by Al-Tai et al. (2020), which showed that boron promotes tissue growth and contributes to an increase in fruit length.

The increase in fruit neck length (0.47 cm) also highlights the effect of boron on improving plant growth, particularly in the parts connecting the fruit to the stem. Previous studies (Khoshgoftarmanesh& Schenk, 2014) demonstrated that boron regulates tissue growth and stimulates cell elongation, thereby enhancing the length of plant structures.

Finally, the substantial increase in the number of fruits (10 fruits) and productivity (177.95%) with boron spraying indicates its role in enhancing pollination and improving fruit quality. Noor et al. (2018) confirmed that boron increases overall plant productivity by improving pollination rates and increasing the number of fruits produced.

IV. CONCLUSIONS

The results of the study demonstrated that foliar application of boron positively influenced all evaluated traits compared with the control. Boron spraying significantly increased the number of set fruits, indicating improved pollination efficiency and fruit set. In addition, boron application promoted greater plant height and increased leaf area, reflecting enhanced physiological activity and improved photosynthetic efficiency. The use of boron also positively influenced fruit characteristics, including weight, size, length, and diameter, underscoring its importance in facilitating cell formation and fruit development. In addition, plants treated with boron demonstrated a marked increase in productivity compared to the control, highlighting its effectiveness in boosting agricultural yields. Finally, the study affirms that boron is essential for supporting critical plant processes such as cell division, longitudinal growth, and cell expansion, thus enhancing the overall performance of plants.

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