JFST No. 174, Vol. 23, August 2026

Journal of Food Science and Technology (Iran)

Homepage: www.fsct.modares.ir

Scientific Research

Effects of Foliar Application of Boron and Sorbitol on Growth, Yield, and the Accumulation of Sugars and β-Carotene in Carrot (*Daucus carota* L.)

Salwa Abbas Miteb and Khalid Abed Mutar

Horticulture and Landscape Department, College of Agriculture, University of Kerbala, Kerbala, Iraq.

ARTICLE INFO

Article History:

Received: 2026/01/31
Review: 2026/04/06
Accepted: 2026/05/11

Keywords:

Carrot,

foliar nutrition,

boron,

sorbitol.

DOI: **10.48311/fsct.2026.119059.83040**

*Corresponding Author E-Mail:
salwa.abbas@s.uokerbala.edu.iq

ABSTRACT

This study was carried out in a field at Ibn Al-Baytar Vocational Preparatory School in Kerbala/Al-Husayniyah District during the 2024-2025 growing season. The research was focused on the impact of foliar spraying with boron and sorbitol on enhancing some growth, yield, and quality indicators of carrot plants (Daucus carota L.) cv. Nantes. The experiment was set up based on a randomized complete block design (RCBD) with a factorial arrangement and three replications. The first factor included three levels of boron spraying (0, 50, and 100 mg L^{-1}). The second factor was four levels of sorbitol spraying (0, 20, 30, and 40 g L^{-1}). There were significant differences between the concentrations of boron sprays. The above-mentioned parameters were used to assess the treatments. However, B_2 (100 mg L^{-1}) performed better in all the parameters mentioned above. On the other hand, there was a significant difference between the treatments in terms of root diameter, where treatment B_1 (50 mg L^{-1}) was better (30.64 mm). For sorbitol spray concentrations, similar results were observed, with treatment S_3 (40 g L^{-1}) outperforming the rest in all parameters: plant height (39.36 cm), leaf area (23.80 dm^2), chlorophyll concentration (3.43 mg g^{-1} FW), root length (18.17 cm), root diameter (33.22 mm), total yield (31.30 t ha^{-1}), beta-carotene content (2.76 mg g^{-1} FW), and root sugar content (2.07 mg g^{-1} FW). In regard to the interaction between factors, treatment B_2S_3 was the best, which proved the efficacy of the boron-sorbitol interaction in enhancing carrot growth and yield. The lowest values for all the studied traits, including the lowest chlorophyll content of 2.20 mg g^{-1} FW, were recorded in the control treatment (B_0S_0)

1-Introduction

The carrot (*Daucus carota* L.) is a member of the family Apiaceae, which includes major crops. This family comprises herbaceous plants with inflorescences that are umbels of the compound type [1]. The carrot ranks among the top ten vegetable crops and is considered one of the most economically important horticultural crops internationally. Its global production is about 42.8 million tons, according to the Food and Agriculture Organization of the United Nations [2].

The area cultivated with carrots in 2018 was 1,004 dunums with a total production of 2,441 tons. Limited production available compared to local demand and a clear need to boost both productivity and quality of carrot crops [3,4].

First grown as a medicine, then a food, carrots are mainly produced for their fleshy taproots, which are consumed fresh or cooked alone or with other vegetables, fruits, and pickles [5,6]. They provide vital vitamins, carbohydrates, proteins, and dietary fiber, and are known to be one of the vegetables with considerable nutritional and health benefits in the world [7].

Plant nutrition stands as one of the major factors that directly affect physiological growth and productivity. Mostly, minerals are taken up by roots from the soil; however, some can be absorbed through the leaves after being sprayed onto them. This has been a topic of concern among vegetable specialists in several studies [5,8]. Not only is this concern related to macronutrients, in which large amounts are required by plants like nitrogen, phosphorus, and potassium, but also to the micronutrients needed in small quantities. Among the micronutrient elements, boron is one of the most important essential elements because it is needed by plants for the completion of many vital physiological processes; it has a major role in tissue growth and development [9].

Boron is also very important in the defense of plasma membranes and the governance of physiological and biochemical processes within cells, so it is indispensable for normal development and the continuance of metabolic activity in plants. Boron deficiency is more common as a nutritional deficiency that can limit the growth and development of many horticultural crops. This has sparked many research studies attempting to clarify its role in the processes that determine cell wall formation, symmetry, and structural integrity [10].

Sugars and alcohols such as sorbitol are synthetic compounds of carbohydrates; they have high mobility due to hydroxyl groups (OH) in their structure, thus easily moving in different tissues of plants. These compounds are stabilized and made more mobile within the internal transport systems by the reduction of the aldehyde group (CHO) to a hydroxyl group (CH_2OH). In plants, sorbitol and mannitol are the two major sugar alcohols. They perform essential roles by allowing stable complexation for the transport of boron and some other essential micronutrients; for example, di-sorbitol borate ester complex formed in the phloem. This will, in turn, enhance boron transport in plant tissues [12]. Therefore, the present study was conducted to investigate the effects of different combinations of foliar application of boron and sorbitol and their optimum concentrations on the growth and quality attributes of the carrot plant.

2-Materials and Methods

2.1. Experimental Site and Design

The experiment was conducted in an open field at Ibn Al-Baytar Vocational Preparatory School, located in the Kerbala/Al-Husayniyah District, during the 2024-2025 growing season to study the effect of foliar application of boron and sorbitol on some quality characteristics of carrot plants (*Daucus carota* L.) cv. Nantes. The treatments were replicated three times and were laid out in a factorial arrangement within a randomized complete block design. The first treatment factor involved three levels of boron (0, 50, and 100 mg L^{-1}) denoted as B_0, B_1, and B_2, respectively. The second factor was comprised of four levels of sorbitol (0, 20, 30, and 40 g L^{-1}) denoted as S_0, S_1, S_2, and S_3, respectively.

2.2. Field Preparation and Planting

Field soil was plowed using a moldboard plow, then after plowing, the soil was leveled and marked into three replicates. Each replicate contained 12 experimental units, making a total of 36 experimental units. Each unit measured 5 × 2.1 m, comprising four rows. Row spacing was set at 25 cm while plant spacing within the rows was 10 cm, resulting in a plant density of 266,666 plants ha^{-1}. Buffer spaces were included between plots to ease spraying without interference. Soil samples were collected before planting from different locations at a depth of 0-30 cm for the determination of soil physical and chemical properties as indicated in Table 1.

2.3. Foliar Spraying Application

Sorbitol was sprayed three times during the season, while boron was sprayed twice. The first spraying was performed 40 days after seedling emergence, the second spraying 21 days after the first, and the third spraying (sorbitol only) 15 days after the second. To prevent interference between the two compounds, sorbitol and boron were applied 24 hours apart. All sprays were applied at sunset until runoff using a 5-liter manual sprayer. Plants were irrigated before spraying to increase the absorption efficiency of the sprayed materials. Routine agronomic practices were carried out whenever necessary during the growing season.

2.4. Measured Traits

2.4.1. Plant Height (cm)

The height of the plants was measured from the soil surface to the top of emerging leaves using a meter rule. Eight plants were randomly selected from each experimental unit for the measurement.

2.4.2. Leaf Area (cm²)

Eight plants were chosen randomly in each experimental unit, and their leaf areas were determined. The area of each leaf was calculated with ImageJ software, and the general average leaf area was determined following Ferreira and Rasband (2011) [13]. Total leaf area per plant was then found by multiplying the average leaf area by the total number of leaves.

2.4.3. Root Length (cm)

Diameter of the root (mm). The thickness of the root was measured at the midpoint of the root, using a slide caliper. Length was also taken with a metal rule to ensure accuracy.

2.4.4. Root Diameter (mm)

Diameter of the root (mm). The thickness of the root was measured at the middle part of the root, using a slide caliper. To ensure accuracy, the length of the root was taken with a metal rule.

In each experimental unit, eight roots were taken, and their diameters were measured with a Vernier caliper. Thereafter, the averages of the readings were calculated.

2.4.5. Total Yield (tons ha^{-1})

Total yield was calculated using the following equation:

Total yield (tons ha^{-1}) = Average root weight per plant (kg) × Number of plants per hectare

The number of plants per hectare was calculated based on the planting density (266,666 plants ha^{-1}).

2.4.6. Beta-Carotene Content (mg g^{-1} fresh weight)

Beta-carotene was estimated following the same method as total leaf chlorophyll, with the light absorption reading taken at a wavelength of 444 nm according to Rodriguez-Amaya (2001) [14]. The concentration was calculated using the following equation:

$$\beta\text{-Carotene (mg g}^{-1}\text{ FW)} = (D_{444} \times V \times 1000) / (W \times 620)$$

where:

- D_{444} = absorbance at 444 nm

- V = volume of extract (mL)
- W = sample weight (g)
- 620 = extinction coefficient (L g^{-1} cm^{-1}) for beta-carotene in the solvent system used [14]

2.4.7. Root Sugar Concentration (mg g^{-1} fresh weight)

Root sugar concentration was determined using the phenol-sulfuric acid method according to Masuko et al. (2005) [15]. Briefly, the absorbance of the reaction mixture was measured at 490 nm using a microplate reader.

2.5. Statistical Analysis

The data were statistically analyzed using analysis of variance (ANOVA) appropriate for a randomized complete block design (RCBD). The least significant difference (LSD) test at a probability level of 0.05 was used to compare and separate the means [16]. All analyses were performed using GenStat 12th edition statistical software (VSN International, UK).

Table 1. Some physical and chemical properties of the soil used in the experiment.

Property	Value	Unit
pH	6.5	---
Electrical Conductivity (EC)	2.3	dS m^{-1}
Organic Matter (OM)	1.24	%
Nitrogen (N)	0.137	mg kg^{-1}
Phosphorus (P)	13.825	mg kg^{-1}
Potassium (K)	37.042	mg kg^{-1}
Soil Particle Size Distribution		
Sand	7.01	g kg^{-1}
Silt	57.10	g kg^{-1}
Clay	35.89	g kg^{-1}
Soil Texture	Loam	---

3-Results

Growth Indicators

Plant Height (cm)

The results (Table 2) showed a significant effect of boron spray concentrations on average plant height. Treatment B_2 (100 mg L^{-1}) resulted in the highest average height of 38.40 cm, compared to the control treatment (B_0), which resulted in the lowest average height of 34.36 cm. The same table also showed that sorbitol spraying had a significant effect on this trait, with treatment S_3 (40 g L^{-1}) recording the highest average height of 39.36 cm, while the control treatment (S_0) recorded the lowest average height of 34.13 cm. The results also demonstrated a significant interaction between the factors, with treatment B_2S_3 showing the highest interaction at 41.75 cm, while the control treatment (B_0S_0) showed the lowest interaction at 32.09 cm.

Table 2. Effect of boron and sorbitol spraying and their interaction on plant height (cm) of carrot cv. Nantes.

Boron (mg L^{-1})	S_0 (0 g L^{-1})	S_1 (20 g L^{-1})	S_2 (30 g L^{-1})	S_3 (40 g L^{-1})	Mean
B_0 (0)	32.09	33.88	34.79	36.69	34.36
B_1 (50)	34.55	35.92	37.21	39.63	36.83
B_2 (100)	35.75	37.13	38.79	41.75	38.40
Mean	34.13	35.70	36.93	39.36	
LSD (0.05)	B = 0.29	S = 0.33	B × S = 0.58		

Leaf Area (dm^2)

The results (Table 3) showed a significant effect of boron spray concentrations on average leaf area. Treatment B_2 recorded the highest average at 26.51 dm^2, compared to the control treatment (B_0), which yielded the lowest average at 17.03 dm^2. The same table also showed that sorbitol spraying had a significant effect on leaf area, with treatment S_3 recording the highest average at 23.80 dm^2, not significantly different from treatment S_2, which recorded an average of 22.87 dm^2. The control treatment (S_0) recorded the lowest average at 19.24 dm^2. Furthermore, the interaction between the factors showed significant differences, with treatment B_2S_3 recording the highest average at 29.06 dm^2, while the control treatment (B_0S_0) recorded the lowest at 15.66 dm^2.

Table 3. Effect of boron and sorbitol spraying and their interaction on leaf area (dm^2) of carrot cv. Nantes.

Boron (mg L^{-1})	S_0 (0 g L^{-1})	S_1 (20 g L^{-1})	S_2 (30 g L^{-1})	S_3 (40 g L^{-1})	Mean
B_0 (0)	15.66	16.84	17.55	18.08	17.03

Boron (mg L^{-1})	S_0 (0 g L^{-1})	S_1 (20 g L^{-1})	S_2 (30 g L^{-1})	S_3 (40 g L^{-1})	Mean
B_1 (50)	19.82	21.66	22.33	24.26	22.01
B_2 (100)	22.26	25.98	28.75	29.06	26.51
Mean	19.24	21.49	22.87	23.80	
LSD (0.05)	B = 1.12	S = 1.80	B × S = 3.10		

Total Chlorophyll in Leaves (mg g^{-1} FW)

The results (Table 4) showed a significant effect of boron spray concentrations on total leaf chlorophyll content. Treatment B_2 (100 mg L^{-1}) showed the highest average content of 3.36 mg g^{-1} FW, compared to the control treatment (B_0), which showed the lowest average content of 2.48 mg g^{-1} FW. The same table also showed that sorbitol spraying had a significant effect on this trait. Treatment S_3 recorded the highest average content of 3.43 mg g^{-1} FW, while the control treatment (S_0) recorded the lowest average content of 2.48 mg g^{-1} FW. Furthermore, the interaction between the factors showed significant differences. Treatment B_2S_3 recorded the highest average content of 4.03 mg g^{-1} FW, while the control treatment (B_0S_0) recorded the lowest interaction content of 2.20 mg g^{-1} FW.

Table 4. Effect of boron and sorbitol spraying and their interaction on total chlorophyll content (mg g^{-1} FW) of carrot cv. Nantes.

Boron (mg L^{-1})	S_0 (0 g L^{-1})	S_1 (20 g L^{-1})	S_2 (30 g L^{-1})	S_3 (40 g L^{-1})	Mean
B_0 (0)	2.20	2.38	2.44	2.91	2.48
B_1 (50)	2.54	2.79	3.05	3.36	2.93
B_2 (100)	2.70	3.06	3.67	4.03	3.36
Mean	2.48	2.74	3.05	3.34	
LSD (0.05)	B = 0.12	S = 0.14	B × S = 0.24		

Yield Indicators

Root Length (cm)

The results (Table 5) showed a significant effect of boron spray concentrations on average root length. Treatment B_2 resulted in the highest average length of 18.09 cm, compared to the control treatment (B_0), which resulted in the lowest average length of 15.33 cm. The same table also showed that sorbitol spraying had a significant effect on this trait, with treatment S_3 recording the highest average length of 18.17 cm, while the control treatment (S_0) recorded the lowest average length of 15.75 cm. Furthermore, the interaction between the factors showed significant differences. Treatment B_2S_3 recorded the highest interaction length of 19.67 cm, while the control treatment (B_0S_0) recorded the lowest of 14.26 cm.

Table 5. Effect of boron and sorbitol spraying and their interaction on root length (cm) of carrot cv. Nantes.

Boron (mg L^{-1})	S_0 (0 g L^{-1})	S_1 (20 g L^{-1})	S_2 (30 g L^{-1})	S_3 (40 g L^{-1})	Mean
B_0 (0)	14.26	14.77	15.45	16.83	15.33
B_1 (50)	16.03	16.40	17.98	18.02	17.11
B_2 (100)	16.96	17.48	18.27	19.67	18.09
Mean	15.75	16.22	17.23	18.17	
LSD (0.05)	B = 0.14	S = 0.16	B × S = 0.29		

Root Diameter (mm)

The results (Table 6) showed a significant effect of boron spray concentrations on average root diameter. Treatment B_1 (50 mg L^{-1}) yielded the highest average of 30.64 mm, compared to the control treatment (B_0), which yielded the lowest average of 26.02 mm. The same table also showed that sorbitol spraying had a significant effect on this trait, with treatment S_3 recording the highest average of 33.22 mm, while the control treatment (S_0) recorded the lowest average of 23.45 mm. Furthermore, the interaction between the factors showed significant differences, with treatment B_1S_3 recording the highest interaction of 35.61 mm, while the control treatment (B_0S_0) recorded the lowest of 20.26 mm.

Table 6. Effect of boron and sorbitol spraying and their interaction on root diameter (mm) of carrot cv. Nantes.

Boron (mg L^{-1})	S_0 (0 g L^{-1})	S_1 (20 g L^{-1})	S_2 (30 g L^{-1})	S_3 (40 g L^{-1})	Mean
B_0 (0)	20.26	25.54	27.28	30.99	26.02
B_1 (50)	26.32	28.84	31.81	35.61	30.64

Boron (mg L^{-1})	S_0 (0 g L^{-1})	S_1 (20 g L^{-1})	S_2 (30 g L^{-1})	S_3 (40 g L^{-1})	Mean
B_2 (100)	23.76	26.18	29.79	33.05	28.20
Mean	23.45	26.85	29.63	33.22	
LSD (0.05)	B = 0.43	S = 0.50	B × S = 0.87		

Carrot Yield (ton ha⁻¹)

The results (Table 7) showed a significant effect of boron spray concentrations on average carrot yield. Treatment B_2 was superior, giving the highest average of 30.56 tons ha^{-1}, compared to the control treatment (B_0), which gave the lowest average of 22.38 tons ha^{-1}. The same table also showed that spraying with sorbitol had a significant effect on yield, as treatment S_3 recorded the highest average of 31.61 tons ha^{-1}, while the control treatment (S_0) recorded the lowest average of 23.09 tons ha^{-1}. The interaction between the factors also showed significant differences, as treatment B_2S_3 recorded the highest interaction of 36.99 tons ha^{-1}, while the control treatment (B_0S_0) recorded the lowest of 21.30 tons ha^{-1}.

Table 7. Effect of boron and sorbitol spraying and their interaction on carrot yield (ton ha^{-1}) of carrot cv. Nantes.

Boron (mg L^{-1})	S_0 (0 g L^{-1})	S_1 (20 g L^{-1})	S_2 (30 g L^{-1})	S_3 (40 g L^{-1})	Mean
B_0 (0)	21.30	22.31	22.82	23.11	22.38
B_1 (50)	23.81	26.34	31.65	34.73	29.13
B_2 (100)	24.18	28.95	32.15	36.99	30.56
Mean	23.09	28.86	28.87	31.61	
LSD (0.05)	B = 0.54	S = 0.62	B × S = 1.08		

Qualitative Indicators

Beta-Carotene Content (mg g⁻¹ FW)

The results (Table 8) showed that boron spray concentrations significantly affected the beta-carotene content of the roots. Treatment B_2 (100 mg L^{-1}) recorded the highest average at 2.67 mg g^{-1} FW, while the control treatment (B_0) recorded the lowest average at 1.53 mg g^{-1} FW. The results also showed that sorbitol spraying significantly affected this trait, with treatment S_3 achieving the highest average of 2.76 mg g^{-1} FW, while the control treatment (S_0) recorded the lowest average of 1.35 mg g^{-1} FW. Furthermore, the interaction between the factors significantly increased beta-carotene content. Treatment B_2S_3 recorded the highest average of 3.29 mg g^{-1} FW, while the control treatment (B_0S_0) recorded the lowest average of 0.82 mg g^{-1} FW.

Table 8. Effect of boron and sorbitol spraying and their interaction on beta-carotene content (mg g^{-1} FW) of carrot cv. Nantes.

Boron (mg L^{-1})	S_0 (0 g L^{-1})	S_1 (20 g L^{-1})	S_2 (30 g L^{-1})	S_3 (40 g L^{-1})	Mean
B_0 (0)	0.82	1.34	1.86	2.10	1.53
B_1 (50)	1.41	2.07	2.25	2.90	2.15
B_2 (100)	1.84	2.55	3.02	3.29	2.67
Mean	1.35	1.98	2.37	2.76	
LSD (0.05)	B = 0.04	S = 0.05	B × S = 0.08		

Total Sugars (mg g^{-1} FW)

The results (Table 9) showed a significant effect of boron spray concentrations on the total sugar content in the roots. Treatment B_2 (100 mg L^{-1}) showed the highest average content of 1.93 mg g^{-1} FW, compared to the control treatment (B_0), which showed the lowest average content of 1.54 mg g^{-1} FW. The same table also showed that sorbitol spray concentrations significantly affected this trait. Treatment S_3 recorded the highest average content of 2.07 mg g^{-1} FW, while the control treatment (S_0) recorded the lowest average content of 1.22 mg g^{-1} FW. The interaction between the factors also showed significant differences in total sugar content of the roots, with treatment B_2S_3 recording the highest interaction of 2.18 mg g^{-1} FW, while the control treatment (B_0S_0) recorded the lowest interaction of 0.98 mg g^{-1} FW.

Table 9. Effect of boron and sorbitol spraying and their interaction on total sugars content (mg g^{-1} FW) of carrot cv. Nantes.

Boron (mg L^{-1})	S_0 (0 g L^{-1})	S_1 (20 g L^{-1})	S_2 (30 g L^{-1})	S_3 (40 g L^{-1})	Mean
B_0 (0)	0.98	1.43	1.80	1.96	1.54
B_1 (50)	1.12	1.89	1.97	2.02	1.76
B_2 (100)	1.57	1.98	2.01	2.18	1.93

Boron (mg L^{-1})	S_0 (0 g L^{-1})	S_1 (20 g L^{-1})	S_2 (30 g L^{-1})	S_3 (40 g L^{-1})	Mean
Mean	1.22	1.76	1.92	2.07	
LSD (0.05)	B = 0.05	S = 0.06	B × S = 0.11		

4-Discussion

Tables 2–9 of this research indicated that boron foliar application had a significant effect on the physiological and productive responses of carrot plants. This increase was noticed in both plant height and leaf area because boron plays a key role in the regulation of cell division and elongation by stabilizing components in the cell wall to increase tissue responsiveness to hormonal regulators [16]. Vascular tissue was made better by boron so that it is more effective in the translocation of water and nutrients to the leaves; this also resulted in better photosynthesis and enhanced photosynthetic efficiency and chlorophyll content by maintaining the structural integrity of the thylakoid membranes and reducing degradation of photosynthetic pigments [17-19]. Boron also assisted in the translocation of photoassimilates to the storage roots via the phloem; it enhanced the length and diameter of the root by promoting the cambial meristematic activity and elasticity of the cell wall, and it supported metabolic processes of the development of storage tissue [20,21].

Boron spraying enhanced soluble sugar and beta-carotene contents in the roots by improving carbon allocation and flux efficiency and by regulating enzyme activities that take part in carbohydrate metabolism and carotenoid biosynthesis pathways. It also reduced oxidative stress from reactive oxygen species, thus helping to keep plastid function. These results are in line with the improvement of both quantitative and qualitative traits related to carrot yield.

Another parameter that may be responsible for the improvement in growth and yield components of carrot plants after foliar application of sorbitol (Tables 2–9) is its status as a translocatable carbohydrate and physiological regulator of metabolic activities in a plant. It increases translocation of carbohydrates and nutrients in the phloem toward developing tissues and storage organs (mainly roots), thereby increasing photosynthate translocation and raising sink strength of roots for nutrient uptake. The physiological activity of sorbitol in the plant may be important to maintain cellular osmotic balance since it allows effective cell elongation and division under conditions of growth and development in shoot and root tissues [24]; this is where most of the cellular structures and organelles are active. This combined function leads to improved vegetative growth, which includes increased height of the plant, expanded area of the leaf, and higher chlorophyll content in the leaves due to enhanced photosynthesizing capacity and increased nutrient uptake [25]. In other words, the improved efficiency of the roots delivered and stored more photoassimilates in roots, and that led to their growth [26].

Also, increased flow of photoassimilates to the roots, which sorbitol promotes, would mean more significant carbon and energy supplies as well as metabolic substrates for the carotenoid biosynthetic pathway, including beta-carotene synthesized in chromoplasts. The additional transportable sugars enhance isoprenoid metabolism via the mevalonate pathway and allow a higher rate of carbon precursor production for carotenoid biosynthesis. Sorbitol also takes part in the process of translocation of sugars and their subsequent accumulation in storage tissues, which raises total carbohydrate content in the roots and improves quality attributes in carrots. This eventually improves the overall yield of carrots in quality and total productivity per area. Results are in agreement with the works of Ruan (2014) and Al-Taie and Al-Shammari (2022). [27,28].

5-Conclusions

Foliar application of boron and sorbitol significantly enhanced the growth, yield, and quality characteristics of Nantes carrot plants (*Daucus carota* L.). The most effective treatment was that of 100 mg L^{-1} boron (as B_2), which resulted in the best performance for most parameters studied: plant height, leaf area, chlorophyll content, length of the taproot, total yield, beta-carotene, and total sugars. The level for root diameter was optimum at 50 mg L^{-1} (B_1). All other levels of study had their best results with the highest level of 40 g L^{-1} sorbitol (as S_3). The interaction B_2S_3 resulted in the best performance for most parameters studied, indicating that micronutrients and sugar alcohols are complementary in improving photosynthetic efficiency and translocation of nutrients and assimilates to storage roots. This proves the synergistic effect of boron and sorbitol, that is, they are most effective when used together than when each is used alone. Based on these results, the foliar application of 100 mg L^{-1} of boron and 40 g L^{-1} of sorbitol is recommended for optimum growth and quality of carrots by farmers and horticulturists under similar agro-climatic conditions. A subsequent study could be on the long-term effects of this treatment on soil health and its performance in different environmental stresses, for example, drought or salinity. Another area of research is on the molecular mechanisms that underlie the interaction of boron with sorbitol in boosting carotenoid biosynthesis.

Conflict of interest

The authors have no conflicts of interest to disclose that are compatible with the subject matter of this article.

Consent to participate

All authors have expressed their authorization to engage in this publication.

Funding

This research did not receive any specific funding.

Ethical Statement

Except for sensory evaluation, we have not conducted any human or animal investigations during this study. Regarding the sensory case.

6- References

[1] Siqueira, M.V.B.M., da Silveira, M.E., Cavagnaro, P.F., de Brito, G.R., de Morais, L.K., Arbizu, C.I., & de Campos Júnior, E.O. (2025). Genetic studies in carrot (Daucus carota L.): Advancements and trends in research. Preprints.org, 2-19.

[2] FAO. (2021). *FAOSTAT Agricultural statistics database*. Food and Agriculture Organization of the United Nations, Rome, p. 350.

[3] CSO. (2018). *Annual statistical collection*. Ministry of Planning - Directorate of Agricultural Statistics, Department of Publishing and Public Relations, Baghdad, Iraq, p. 48.

[4] Sharma, S., Abrol, G., Sharma, R., & Sharma, K.D. (2025). Carrot and carrot products: A superb functional food. In K.D. Sharma, S. Kumar, R. Sharma, & R.K. Keservani (Eds.), *Functional Compounds and Foods of Plant Origin* (pp. 269–290). Apple Academic Press.

[5] AL-Mashhadany, A.H., & AL-Mharib, M.Z.K. (2023). Effect of fertilizers starter solutions on growth and production of broccoli (*Brassica oleracea* var. *italica*). *Research on Crops*, 24(1), 119-122.

[6] Farhan, S.S., & Mutar, K.A. (2025). Effect of *Azotobacter* and nitrogen fertilizer on the growth, yield, and accumulation of capsaicin content in chili peppers. *SABRAO Journal of Breeding and Genetics*, 57(3), 1318-1325.

[7] Mutar, K.A., Farhan, S.S., & Salman, F.A. (2024). Effect of foliar application of NPK and amino acid on the growth and yield-related traits of broccoli (*Brassica oleracea* var. *Italica*). *SABRAO Journal of Breeding and Genetics*, 56(3), 1-10.

[8] Mutar, K.A., Salman, F.A., & Jaafar, H.S. (2020). Role of organic foliar fertilizer spraying in vegetative growth, yield and quality of two hybrids of cauliflower. *International Journal of Agricultural and Statistical Sciences*, 16(Supplement 1), 1205-1208.

[9] Batyal, D., Ali, A., Mukhtar, S., Devi, M., Mansoor, T., Khajuria, A., & Kaur, J. (2024). Foliar fertilization of micronutrients in orchards: A comprehensive

review. *International Journal of Plant & Soil Science*, 36(11), 426-440.

[10] Tiwari, V.K., Kathayat, K., Singh, N., Rawat, M., Pandey, A.K., & Dwivedi, S.K. (2024). Effect of zinc and boron on improved physiological traits, productivity and phytoconstituents of carrot grown at Trans-Himalayan region. *Plant Science Today*, 11(3), 775-784.

[11] Edmond, V. de V., Hong, Z., & Nelson, A.S. (2025). Sugar alcohols in plants: Implications for enhancing tree seedlings' drought tolerance and production strategies. *BMC Plant Biology*, 25, 891.

[12] Hasanović, M., Durmić-Pašić, A., & Karalija, E. (2025). Seed priming beyond stress adaptation: Broadening the agronomic horizon. *Agronomy*, 15(8), 1829.

[13] Ferreira, T., & Rasband, W. (2011). *ImageJ user guide*. National Institutes of Health, USA, p. 199.

[14] Joslyn, M.A. (1970). *Methods on food analysis: Physical, chemical and industrial methods of analysis* (2nd ed.). Academic Press, New York and London, p. 278.

[15] Al-Mohammadi, S.M., & Al-Mohammadi, F.M. (2012). *Statistics and experimental design*. Dar Osama for Publishing and Distribution, Amman, Jordan, p. 355.

[16] Alam, M.S., Mehedi, M.N.H., Islam, M.R., & Islam, M.R. (2021). Effects of cow dung, boron and zinc on growth and yield of carrot. *Journal of Agriculture and Veterinary Science*, 14(10), 26-32.

[17] Mia, S., Bulbul, M.T.A., Hasan, T., Sheikh, M.H., & Haque, M.T. (2024). Maximizing carrot productivity: The role of potassium and boron in crop performance. *Tropical Agroecosystems (TAEC)*, 5(1), 47-50.

[18] Monib, A.W., Niazi, P., & Sediqi, S. (2023). Investigating approaches for optimizing agricultural yield: A comprehensive review of the crucial role of micronutrients in enhancing plant growth and maximizing production. *Journal for Research in Applied Sciences and Biotechnology*, 2(5), 168-180.

[19] Sultana, S., Muhmood, A., Shah, S., Saleem, I., Niaz, A., Ahmed, Z., & Wakeel, A. (2015). Boron uptake, yield and quality of carrot (*Daucus carota* L.) in response to boron application. *International Journal of Plant & Soil Science*, 8(5), 1-5.

[20] Elsagan, M.A.M., & Shokry, A.M. (2020). Effect of calcium and boron spray on growth, yield and dried grated quality of some carrot cultivars. *Plant Archives*, 20(2), 8239-8252.

[21] Singh, D.P., Beloy, J., McInerney, J.K., & Day, L. (2012). Impact of boron, calcium and genetic factors on vitamin C, carotenoids, phenolic acids, anthocyanins and antioxidant capacity of carrots (*Daucus carota*). *Food Chemistry*, 132(3), 1161-1170.

[22] Rodriguez-Amaya, D.B., Nascimento, P.N.B. do, & Meléndez-Martínez, A.J. (2023). Comprehensive update on carotenoid colorants from plants and microalgae: Challenges and advances from research laboratories to industry. *Foods*, 12(22), 4080.

[23] Subba, S.K., Yambem, P., Asha, R.K., Das, A., Chattopadhyay, S.B., & Choudhuri, P. (2016). Effects of potassium and boron on quality parameters of carrot (*Daucus carota* L.). *An International Quarterly Journal of Environmental Sciences*, 487-490.

[24] Pleyerová, I., Hamet, J., Konrádová, H., & Lipavská, H. (2022). Versatile roles of sorbitol in higher plants: Luxury resource, effective defender or something else? *Planta*, 256(1), 13.

[25] Muslim, M.F., & Rasool, A.J. (2018). Effect of spraying boron, sorbitol, and mannitol on growth, fruit quality, and seed yield of pepper (California Wonder). *International Journal of Agricultural and Statistical Sciences*, 14(2), 1-8.

[26] Kocaman, B. (2024). Effect of sorbitol spraying on chlorophyll, total phenolic and flavonoid in *Fragaria ananassa* Duch. cv. Albion leaves. *Turkish Journal of Agriculture - Food Science and Technology*, 12(8), 1352-1358.

[27] Ruan, Y.L. (2014). Sucrose metabolism: Gateway to diverse carbon use and sugar signaling. *Annual Review of Plant Biology*, 65(1), 33-67.

[28] Al-Taie, R.W.M., & Al-Shammari, M.F.M. (2022). Effect of foliar spraying with organic fertilizer and sorbitol sugar on growth and yield of cabbage. *Journal of Aquatic Sciences*, 13(1), 362-367.