

Effect of spraying with boron and sorbitol on the growth, yield and quality of carrots (*Daucus carota* L.)

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Abstract

This experiment was carried out during the growing season of 2024-2025 in Ibn Al-Bitar Vocational Preparatory School. This school is located in Al-Husseiniya District, Kerbala Governorate and was conducted to study how both Boron and Sorbitol can be used together or independently to increase certain indicators of growth and yield of Carrot cv. Nantes. The experiment was laid out according to a Randomized Complete Block Design (RCBD) in a factorial arrangement with three replications. The first factor was Boron treatment at three different concentrations (0, 50 and 100 mg L⁻¹) hereafter referred to as B0, B1 and B2. The second factor consisted of four different concentrations of Sorbitol (0, 20, 30 and 40 g L⁻¹) hereafter referred to as S0, S1, S2 and S3. The results showed significant differences between the boron spray concentrations, treatment B2 (100 mg L⁻¹) significantly outperformed the other treatments in leaf nitrogen, phosphorus, potassium, boron, and total chlorophyll, as well as in the number of leaves, shoot dry weight, carrot yield, juice volume, and fiber percentage in the roots, with averages of 2.32%, 0.413%, 1.44%, 62.51 mg kg⁻¹, 3.36 mg g⁻¹ FW, 14.11 leaf plant⁻¹, 11.95 g plant⁻¹, 30.31 tons ha⁻¹, 77.83 mm carrot⁻¹ and 2.79%, respectively. The results also showed significant differences between sorbitol spray concentrations. Treatment S3 (40 g L⁻¹) was superior in leaf concentrations of nitrogen, phosphorus, potassium, boron, and total chlorophyll, as well as in the number of leaves, shoot dry weight, carrot yield, juice volume, and root fiber percentage, with averages of 2.28%, 0.411%, 1.40%, 62.07 mg kg⁻¹, 3.43 mg g⁻¹ FW, 13.65 leaf plant⁻¹, 11.27 g plant⁻¹, 31.27 tons ha⁻¹, 81.91 mm carrot⁻¹ and 2.98%, respectively. The interaction of these factors showed that the B2S3 treatment was superior in most of the studied traits.

Keywords: Carrot, Foliar nutrition, Boron, Sorbitol

Introduction

Carrots (*Daucus carota* L.) are one of the most widely consumed vegetables across the world because of their high nutritional value, economic value, and taxonomic classification within the Apiaceae family [1] that has a characteristic of having a compound umbel as its flower cluster. Due to the increased focus on carrots worldwide, it is estimated that approximately 41.4 million tons of carrots were produced [2] which reflects the global geographic distribution for carrot production as well as the numerous ways that carrots can be used as food and in industry. Although carrots

are a globally significant crop, they are relatively limited in Iraq. The estimates from the Central Statistical Organization show that the area of land cultivated with carrots in Iraq is 1638 donums with an average yield of 1967 kg per donum for a total carrot production of 3222 tons [3] which does not meet the growing demand in the local market. Thus, there is an urgent need to enhance the agricultural and management practices associated with growing carrots, particularly in relation to improving the efficiency of plant nutrition and quality and yield.

Carrot was historically known for its medicinal use, but its production has expanded over the years into a staple crop. Carrots are consumed fresh and cooked due in part to their incorporation into various food processing industries, including salads, jams, and pickles. Carrots have a high nutritional value due to their high vitamin, carbohydrate, protein, and fiber content, ranking as one of the major vegetable crops found in many dietary systems around the globe [4].

The efficiency of Plant nutrition plays a significant role in how well agricultural crops grow Physiologically, as well as how productive the crops are economically. Plants rely on Minerals to execute vital metabolic functions. Therefore, mineral Nutrients must be accessible to Plants either through Roots from the Soil or through Foliar nutrients. The importance of nutrition has been studied extensively in recent years regarding vegetable production [5]. The emphasis placed on nutrition by researchers has focused on macronutrients such as nitrogen, phosphorus, and potassium, however micronutrients, although required in much smaller quantities, also have vital physiological functions. An example of a macro- and micronutrient, among these, boron is considered one of the most prominent elements is essential for the growth and development of plant tissue and maintenance of the plasma membrane's integrity. Additionally, it supports many of the critical functions within the plant cell's cell wall, thereby contributing to plant development and allowing for a continuous metabolic unit [6]. In the context of research exploring the benefits of micronutrients for root crops' growth and productivity [7] research on carrot revealed that foliar application of boric acid at three different concentrations (0, 1, and 2 g L⁻¹) caused significant variation among the treatments. The treatment of 2 g L⁻¹ reached a

Materials and Methods

A study was conducted in a field owned by Ibn Al-Baytar Vocational Preparatory School that

remarkable level in terms of plant height, the number of leaves, fresh weight of leaves and roots, and dry matter percentages of both leaves and roots. Moreover, this treatment contributed to the improvements in root length and diameter, which in turn led to an increase in carrot yield per hectare.

On the other hand, the focus of current research has shifted toward an evaluation of the use of organic substances applied on the vegetative parts of the plant as a means of increasing the physiological responsiveness of the vegetable crop's various functions, such as through enhanced plant metabolism through physiological effects. Sugar alcohols are one of these substances; sugar alcohols are carbohydrates whose molecular structure has hydroxyl groups and therefore possesses chemical and physical properties that will allow for greater stability and mobility within plant tissues than many other carbohydrates. Sugar alcohols are produced by the reduction of 1-a-carbon to 1-b-carbon, which will allow for increased transport through the plant through the use of both the xylem and phloem conducting systems [8]. Sugar alcohols include the two most common sugar alcohols, namely sorbitol and mannitol, both of which regulate the osmotic balance of plants and aid in carbohydrate and mineral nutrient translocation. Moreover, they are involved in the translocation of boron and other micronutrients. For example, the formation of stable chemical complexes between boron and sugar alcohols (e.g., di-sorbitol borate esters) increases the efficiency of boron transport and distribution in plants [9]. Therefore, this study aims to determine the effect of spraying boron and sorbitol, as well as to evaluate their combined effect on the growth, yield, and quality of carrots.

is located in Kerbala/Al-Husayniya District during the growing season (2024-2025). The Investigation used the Randomized Complete Block Design (RCBD) with a Factorial

treatment arrangement and three replications for each treatment. The first treatment was three levels of boron (0, 50, 100 mg L⁻¹), designated as B0, B1, and B2. The second treatment was four levels of sorbitol spray (0, 20, 30, 40 g L⁻¹) designated as S0, S1, S2, S3, respectively. The Research was conducted by plowing, leveling, and dividing the field into three replications of 12 experimental units each to allow for a total of 36 experimental units, each measuring 5 x 2.1 m, with four planting lines per experimental unit. The line spacing within each unit was 25 cm; the plant spacing in each row was 10 cm, producing a planting density of 266666 plants ha⁻¹. Space was maintained between the plots to ensure that the spraying process did not interfere with the effects of other factors. Soil samples were analyzed before planting by taking samples from different locations at a depth of 0-30 cm to determine the physical and chemical properties of the soil (Table 1). The sorbitol spraying process was carried out with three sprays and boron with two sprays during the season. The first spraying was 40 days after the emergence of the seedlings, the second spraying was 21 days after the first spraying, and the third spraying was 15 days after the second spraying. Note that the spraying period between sorbitol and boron is 24 hours, as the spraying was carried out at sunset to the point of complete wetness with a manual sprayer with a capacity of (5 liters). The plants were also watered before spraying to increase the efficiency of absorption of the sprayed material, in addition to carrying out service operations whenever necessary during the growing season.

Data recorded

The traits were recorded during the growing season, while the yield and quality traits were recorded at the end of the growing season on 10/2/2024.

Nitrogen concentration in leaves (%): The nitrogen concentration in leaves was determined by the digestion of plant material with concentrated sulfuric acid, followed by the

isolation and distillation of the ammonia produced, where the nitrogen level of the ammonia is titrated by means of the Micro-Kjeldahl process as demonstrated in [10].

Phosphorus concentration in leaves (%): The phosphorus concentration in leaves using the ammonium molybdate and ascorbic acid method determined the phosphorus concentration using the spectrophotometer reading at 882 nm as indicated in [11].

Potassium concentration in leaves (%): Potassium concentration in leaves was measured using flame emission spectroscopy as described in [12].

Boron concentration in leaves (mg kg⁻¹): The boron concentration was measured using a PGI-2000 Flame Photometer, and the final concentration was calculated by multiplying the reading by the dilution factor and dividing it by the weight of the dry sample, according to the method adopted by [13].

Total chlorophyll concentration (mg g⁻¹ fresh weight): The total chlorophyll content of the leaves was determined experimentally by taking five random samples from each experimental unit and washing them thoroughly with water to remove dust. Then, 1 g of each sample was taken, 10 ml of 85% acetone was added after cutting the sample, and it was thoroughly crushed in a ceramic mortar. The filtrate was then separated from the precipitate using filter paper, and the process was repeated to extract any remaining pigment. The volume of the filtrate was then increased to 100 ml with acetone [14]. The total chlorophyll content was then measured using a spectrophotometer at wavelengths of 645 and 663 nm, and the total chlorophyll content was calculated using the following equation:

$$\text{Total Chlorophyll} = \frac{20.2 \times D(645) + 8.02 \times D(663) \times V}{W \times 1000}$$

Number of leaves (leaves plant⁻¹): The number of leaves was counted for eight randomly selected plants from each

experimental unit, and the average was calculated for each treatment.

Dry weight of the shoot system (g plant⁻¹): The dry weight of vegetative parts was measured for eight randomly selected plants from each experimental unit after drying the samples in an electric oven at 65–70°C until a constant weight was reached. The samples were then weighed using a sensitive balance, and the average was calculated for each treatment.

Total yield (ton ha⁻¹): The total yield of carrots was calculated using the equation:

Total yield = plant yield x No. of plants per hectare

Juice volume (mL root⁻¹): A representative sample of roots was taken for each treatment and then squeezed using an electric juicer. The volume of juice produced was measured using

a graduated glass cylinder, and the readings were then recorded.

Fiber percentage (%): The fiber percentage in root was estimated by taking approximately 2 g of the plant sample, first digesting it with sulfuric acid (12.5% H₂SO₄) and heating it for 10 minutes from the onset of boiling, then filtering it using a vacuum filtration funnel (Buchner funnel). The precipitate was returned to the beaker and digested again with sodium hydroxide (12.5% NaOH) and heating it for a similar duration. This was followed by filtering the remaining precipitate and transferring it to a clean, dry crucible. The sample was dried in an oven at 135°C for 2 hours and then weighed. It was then burned in a combustion furnace at 600°C for 2 hours, and the weight was re-weighed. The fiber content was calculated based on the weight difference before and after burning [15], using the following equation:

$$\text{Fiber (\%)} = \frac{\text{weight after drying at } 100^\circ\text{C} - \text{weight after drying at } 600^\circ\text{C}}{\text{Dry sample weight} \times 100}$$

Statistical analysis

Results were analyzed statistically based on ANOVA and on randomized complete block design (RCBD). Means were compared and

separated by Least Significant Difference test L.S.D_{0.05} [16]. All analyses were conducted with GenStat 12 statistical software.

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

Unit	Value	Property
-----	6.5	pH
dS m ⁻¹	2.3	Electrical Conductivity (EC)
%	1.24	Organic Matter (O.M)
mg kg ⁻¹	0.137	Nitrogen (N)
mg kg ⁻¹	13.825	Phosphorus (P)
mg kg ⁻¹	37.042	Potassium (K)
Soil Particle Size Distribution		
%	7.01	Sand
%	57.1	Silt
%	35.89	Clay
Loam soil		Soil Texture

Results

Chemical Indicators

Nitrogen Concentration (%)

The results (Table 2) indicated a significant effect between boron spray concentrations on nitrogen concentration in leaves, as treatment B2 outperformed the other treatments and gave an average of 2.32%, compared to the control Treatment (B0), which gave the lowest average

of 1.71%. The results also showed that sorbitol spraying significantly affected nitrogen concentration in leaves, as treatment S3 recorded the highest average of 2.28%. In contrast, the control treatment (S0) recorded the lowest average of 1.84%. The interaction between the factors showed significant differences, as the interaction treatment B2S3 recorded the highest average of 2.63%, while the control treatment recorded the lowest interaction, with a mean of 1.61%.

Table 2: Effect of boron and sorbitol spraying and their interaction on the mean nitrogen concentration in leaves (%)

Means	Sorbitol concentrations (g L^{-1})				Boron concentrations (mg L^{-1})
	S3	S2	S1	S0	
1.71	1.84	1.72	1.68	1.61	B0
2.12	2.37	2.16	2.01	1.95	B1
2.32	2.63	2.48	2.20	1.97	B2
	2.28	2.12	1.96	1.84	Means
$B \times S = 0.195$		$S = 0.112$		$B = 0.097$	
L.S.D _{0.05}					
B0: 0 mg L^{-1} , B1: 50 mg L^{-1} , B2: 100 mg L^{-1} / S0: 0 g L^{-1} , S1: 20 g L^{-1} , S2: 30 g L^{-1} , S3: 40					

Phosphorus Concentration(%)

The results (Table 3) showed that boron spray concentrations significantly affected phosphorus concentration in the leaves, treatment B2 recorded the highest average of 0.413%, surpassing all other treatments, in contrast the control treatment (B0) recorded the lowest average of 0.339%. The results also showed that sorbitol spraying significantly

affected phosphorus concentration in the leaves, with treatment S3 achieving the highest average of 0.411%, while the control treatment (S0) recorded the lowest average of 0.342%. Furthermore, the interaction between the factors showed significant differences, with the interaction treatment B2S3 recording the highest average of 0.452%, while the control treatment recorded the lowest interaction, with an average of 0.277%.

Table 3: Effect of boron and sorbitol spraying and their interaction on the mean phosphorus concentration in leaves (%)

Means	Sorbitol concentrations (g L^{-1})				Boron concentrations (mg L^{-1})
	S3	S2	S1	S0	
0.339	0.386	0.376	0.320	0.277	B0
0.378	0.396	0.383	0.377	0.358	B1
0.413	0.452	0.417	0.394	0.392	B2
	0.411	0.392	0.363	0.342	Means
$B \times S = 0.0095$		$S = 0.005$		$B = 0.004$	L.S.D _{0.05}

B0: 0 mg L^{-1} , B1: 50 mg L^{-1} , B2: 100 mg L^{-1} / S0: 0 g L^{-1} , S1: 20 g L^{-1} , S2: 30 g L^{-1} , S3: 40 g L^{-1}

Potassium Concentration(%)

The results (Table 4) indicate a significant effect of boron spray concentrations on leaf potassium concentration, treatment B2 achieved the highest average of 1.44%, compared to the control treatment (B0), which showed the lowest average of 1.08%. Similarly, foliar application of sorbitol had a significant

effect on leaf potassium concentration, as treatment S3 achieved the highest average of 1.40%, while the control treatment (S0) recorded the lowest average of 1.10%. In contrast, the results showed no significant interaction between the factors in leaf potassium concentration

Table 4: Effect of boron and sorbitol spraying and their interaction on the mean potassium concentration in leaves (%)

Means	Sorbitol concentrations (g L^{-1})				Boron concentrations (mg L^{-1})
	S3	S2	S1	S0	
1.08	1.12	1.10	1.06	1.05	B0
1.27	1.38	1.37	1.22	1.12	B1
1.44	1.72	1.48	1.43	1.14	B2
	1.40	1.31	1.23	1.10	Means
$B \times S = \text{N.S}$		$S = 0.169$		$B = 0.146$	L.S.D _{0.05}

B0: 0 mg L^{-1} , B1: 50 mg L^{-1} , B2: 100 mg L^{-1} / S0: 0 g L^{-1} , S1: 20 g L^{-1} , S2: 30 g L^{-1} , S3: 40 g L^{-1}

Boron Concentration (mg kg^{-1})

The results in Table (5) indicate a significant effect of boron spray concentrations on leaf boron concentration. Treatment B2 recorded the highest average concentration of 62.51 mg kg^{-1} , compared to the control treatment (B0), which recorded the lowest average concentration of 41.24 mg kg^{-1} . Conversely, significant differences were also observed between sorbitol spray concentrations on leaf boron concentration. Treatment S3 recorded the

highest average concentration of 62.07 mg kg^{-1} , while the control treatment (S0) recorded the lowest average concentration of 41.56 mg kg^{-1} . The results also indicated a significant interaction between the factors in leaf boron content. Treatment B2S3 recorded the highest interaction with an average concentration of 74.51 mg kg^{-1} , while the control treatment (B0S0) recorded the lowest interaction with an average concentration of 34.26 mg kg^{-1} .

Table 5: Effect of boron and sorbitol spraying and their interaction on the mean boron concentration in leaves (mg kg^{-1})

Means	Sorbitol concentrations (g L^{-1})				Boron concentrations (mg L^{-1})
	S3	S2	S1	S0	
41.24	49.00	44.14	37.57	34.26	B0
51.42	62.70	56.47	47.31	39.19	B1
62.51	74.51	66.39	57.89	51.23	B2
	62.07	55.67	47.59	41.56	Means
$B \times S = 3.911$		$S = 2.258$		$B = 1.955$	
$L.S.D_{0.05}$					
B0: 0 mg L^{-1} , B1: 50 mg L^{-1} , B2: 100 mg L^{-1} / S0: 0 g L^{-1} , S1: 20 g L^{-1} , S2: 30 g L^{-1} , S3: 40					

Total chlorophyll in leaves (mg g^{-1} fresh weight)

The results (Table 6) showed a significant effect between boron spray concentrations on total chlorophyll content in leaves, treatment B2 was superior, giving the highest average of 3.36 mg g^{-1} fresh weight, compared to the control treatment (B0), which gave the lowest average of 2.48 mg g^{-1} fresh weight. Similarly, showed that sorbitol spraying had a significant effect on total chlorophyll content in leaves,

treatment S3 recorded the highest average of 3.43 mg g^{-1} fresh weight, in contrast, the control treatment (S0) recorded the lowest average of 2.48 mg g^{-1} fresh weight. The interaction between the factors also showed significant differences in the total chlorophyll content of the leaves, as the interaction treatment B2S3 recorded the highest average of 4.03 mg g^{-1} fresh weight, while the control treatment (B0S0) recorded the lowest interaction of 2.20 mg g^{-1} fresh weight.

Table 6: Effect of boron and sorbitol spraying and their interaction on total chlorophyll content in leaves (mg g^{-1} fresh weight)

Means	Sorbitol concentrations (g L^{-1})				Boron concentrations (mg L^{-1})
	S3	S2	S1	S0	
2.48	2.91	2.44	2.38	2.20	B0
2.93	3.36	3.05	2.79	2.54	B1
3.36	4.03	3.67	3.06	2.70	B2
	3.43	3.05	2.74	2.48	Means
$B \times S = 0.244$		$S = 0.141$		$B = 0.122$	
$L.S.D_{0.05}$					
B0: 0 mg L^{-1} , B1: 50 mg L^{-1} , B2: 100 mg L^{-1} / S0: 0 g L^{-1} , S1: 20 g L^{-1} , S2: 30 g L^{-1} , S3: 40					

Number of leaves (leaves⁻¹ plant)

The results (Table 7) showed a significant effect of boron spray concentrations on the average number of leaves per plant, treatment B2 resulted in the highest average of 14.11 leaves plant⁻¹, in contrast, the control treatment (B0) recorded an average of 10.33 leaves plant⁻¹. The same table also showed that sorbitol

spraying had a significant effect on the number of leaves, with treatment S3 recording the highest average of 13.65 leaves plant⁻¹, while the control treatment (S0) recorded the lowest average of 9.10 leaves plant⁻¹. The interaction between the factors also showed significant differences in the average number of leaves, with treatment B2S3 recording the highest interaction, with a mean of 15.20 leaves plant⁻¹, while the control treatment recorded the lowest interaction, with a mean of 9.10 leaves plant⁻¹.

Table 7: Effect of boron and sorbitol spraying and their interaction on number of leaves per plant (leaves plant⁻¹)

Means	Sorbitol concentrations (g L ⁻¹)				Boron concentrations (mg L ⁻¹)
	S3	S2	S1	S0	
10.33	11.64	10.84	9.75	9.10	B0
12.83	14.13	13.34	12.00	11.88	B1
14.11	15.20	14.96	12.93	13.38	B2
	13.65	13.04	11.56	11.45	Means
B × S = 0.195		S = 0.112		B = 0.097	L.S.D _{0.05}
B0: 0 mg L ⁻¹ , B1: 50 mg L ⁻¹ , B2: 100 mg L ⁻¹ / S0: 0 g L ⁻¹ , S1: 20 g L ⁻¹ , S2: 30 g L ⁻¹ , S3: 40					

Shoot dry weight (g plant⁻¹)

The results (Table 8) showed a significant effect of boron spray concentrations on the average dry weight of shoots, treatment B2 was superior, giving the highest average of 11.95 g plant⁻¹, compared to the control treatment (B0), which gave the lowest average of 6.20 g plant⁻¹. The same table also showed that sorbitol spraying had a significant effect on the dry weight of shoots, with treatment S3 recording

the highest average of 11.27 g plant⁻¹, in contrast, the control treatment (S0) recorded the lowest average of 6.86 g plant⁻¹. The interaction between the factors also showed significant differences in the dry weight of shoots, with the interaction treatment B1S3 recording the highest average of 14.50 g plant⁻¹, while the control treatment recorded the lowest interaction of 5.00 g plant⁻¹.

Table 8: Effect of boron and sorbitol spraying and their interaction on the mean shoot dry weight (g plant⁻¹)

Means	Sorbitol concentrations (g L ⁻¹)				Boron concentrations (mg L ⁻¹)
	S3	S2	S1	S0	
6.20	7.14	7.02	5.66	5.00	B0
9.03	12.17	9.34	8.00	6.62	B1
11.95	14.50	13.70	10.66	8.96	B2
	11.27	10.02	8.10	6.86	Means
B × S = 0.5866		S = 0.3387		B = 0.2933	L.S.D _{0.05}
B0: 0 mg L ⁻¹ , B1: 50 mg L ⁻¹ , B2: 100 mg L ⁻¹ / S0: 0 g L ⁻¹ , S1: 20 g L ⁻¹ , S2: 30 g L ⁻¹ , S3: 40					

Total yield (tons ha⁻¹)

The results (Table 9) showed a significant effect between the concentrations of boron spraying on the total yield of carrots, as treatment B2 was superior, giving the highest average of 30.31 tons ha⁻¹, compared to the control treatment (B0), 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 the total yield, as treatment

S3 recorded the highest average of 31.27 tons ha⁻¹, while the control treatment (S0) recorded the lowest average of 23.09 tons ha⁻¹. The interaction between the factors also showed significant differences, as treatment B2S3 recorded the highest interaction of 36.99 tons ha⁻¹, while the control treatment (B0S0) recorded the lowest interaction of 21.30 tons ha⁻¹.

Table 9: Effect of boron and sorbitol spraying and their interaction on the total yield of carrots (tons ha⁻¹)

Means	Sorbitol concentrations (g L ⁻¹)				Boron concentrations (mg L ⁻¹)
	S3	S2	S1	S0	
22.38	23.11	22.82	22.31	21.30	B0
29.13	34.73	31.65	26.34	23.81	B1
30.31	35.99	32.15	28.95	24.18	B2
	31.27	28.87	25.86	23.09	Means
B × S = 1.369		S = 0.790		B = 0.684	L.S.D _{0.05}

B0: 0 mg L⁻¹, B1: 50 mg L⁻¹, B2: 100 mg L⁻¹ / S0: 0 g L⁻¹, S1: 20 g L⁻¹, S2: 30 g L⁻¹, S3: 40 g L⁻¹

Quality indicators**Juice volume (mm)**

The results (Table 10) showed that boron spray concentrations had a significant effect on root juice volume in carrot, as treatment B2 recorded the highest average of 77.83 mm root⁻¹. In contrast, the control treatment (B0) recorded the lowest average of 56.04 mm root⁻¹. In addition, spraying of sorbitol significantly affected juice volume, with treatment S3 achieving the highest average of

81.91 mm root⁻¹, while the control treatment (S0) recorded the lowest average of 51.26 mm root⁻¹. Furthermore, the results demonstrated that the interaction between the factors significantly increased root sap content. The interaction treatment (B2S3) recorded the highest average of 94.10 mm root⁻¹, while the control treatment recorded the lowest average of 45.27 mm root⁻¹.

Table 10: Effect of boron and sorbitol spraying and their interaction on juice volume (mm root^{-1})

Means	Sorbitol concentrations (g L^{-1})				Boron concentrations (mg L^{-1})
	S3	S2	S1	S0	
56.04	68.11	59.67	51.11	45.27	B0
70.66	83.15	78.49	69.30	51.32	B1
77.83	94.10	85.90	74.10	57.20	B2
	81.91	74.69	64.84	51.26	Means
$B \times S = 5.377$		$S = 3.104$		$B = 2.688$	$L.S.D_{0.05}$

B0: 0 mg L^{-1} , B1: 50 mg L^{-1} , B2: 100 mg L^{-1} / S0: 0 g L^{-1} , S1: 20 g L^{-1} , S2: 30 g L^{-1} , S3: 40 g L^{-1}

Fiber percentage (%)

The results (Table 11) showed that boron spray concentrations had a significant effect on fiber percentage in carrot roots, as treatment B2 resulted in the lowest fiber percentage of 2.79% compared with the control treatment (B0), which recorded an average of 4.19%. Sorbitol spraying also significantly affected fiber percentage, with treatment S3 achieving the

lowest average of 2.98%, whereas the control treatment (S0) recorded the highest average of 4.12%. Likewise, the interaction between the two factors caused significant differences in root fiber content, as the combined treatment B2S3 recorded the lowest interaction, with an average of 2.11%, compared to the control treatment, which had an interaction of 4.55%.

Table 11: Effect of boron and sorbitol spraying and their interaction on fiber content in roots (%)

Means	Sorbitol concentrations (g L^{-1})				Boron concentrations (mg L^{-1})
	S3	S2	S1	S0	
4.19	3.79	4.10	4.32	4.55	B0
3.54	3.06	3.27	3.75	4.08	B1
2.79	2.11	2.43	2.91	3.73	B2
	2.98	3.26	3.66	4.12	Means
$B \times S = 0.1623$		$S = 0.0937$		$B = 0.0811$	$L.S.D_{0.05}$

B0: 0 mg L^{-1} , B1: 50 mg L^{-1} , B2: 100 mg L^{-1} / S0: 0 g L^{-1} , S1: 20 g L^{-1} , S2: 30 g L^{-1} , S3: 40 g L^{-1}

Discussion

From the obtained results, as shown in Table (2-11), it was found that the foliar treatment of a boron solution with a concentration of 100 mg L^{-1} resulted in a significant improvement in the traits of carrot plant growth, production, and quality, indicating the central role played by this element in improving the efficiency of metabolism and the combined function of fundamental physiological activities. Boron affects the stability of cellular membranes and the chloroplast, especially the thylakoid membranes, thus reducing chlorophyll loss and improving photosynthesis absorption efficiency [17]. This process increases photosynthesis productivity and the conversion of carbohydrates in the storage organs.

The higher nitrogen could be related to increased fluxes of sugar and amino acids, and activation of enzymes related to nitrogen assimilation and its subsequent inclusion in proteins to attain functional integration of photosynthesis and nutrient transport [18]. This functional integration also includes phosphorus nutrition due to increased demand for energy molecules ATP and activation of energy-producing enzymes in mitochondria, which agrees with results obtained by [19]. Additionally, enhanced potassium uptake also goes hand in hand with the role of boron in osmotic regulation, stomatal control, and enzyme activation, all of which improve water, use efficiency and nutrient utilization [20]. The increased boron concentration in leaves is a natural consequence of direct foliar absorption. The element enters the mesophyll through the cuticle and remains relatively concentrated in the mesophyll cells due to its limited mobility in the phloem during vegetative growth. A study by [21] demonstrated that boron is a relatively immobile element within plants, leading to higher accumulation in leaves when applied foliarly. The rise in leaf number is explained by the structural role of boron in cell division regulation in meristematic tissues through its interaction with rhamnolacturonan, II (RG, II) units and the formation of borate diester cross, links that not

only reinforce but also stabilize the cell wall [22], as supported by further research [23,24]. Similarly, the heavier dry weight of the shoot system could be basically linked to the improved efficiency of PSII, the increased net photosynthetic rate, the greater accumulation of carbohydrates, and the regulation of gene expression associated with the biosynthesis of proteins and complex carbohydrates [25]. The enhanced yield of carrots represents the better source-sink relation generated by the higher translocation of photosynthates into the storage root. This was linked with the increased volume of cellular juice, which is a measure of the degree of vacuole saturation due to the accumulation of sugars and higher osmotic pressures [26]. On the other hand, the relative reduction in the percentage of fibers may be considered as the effect of the proportional enhancement of the water and sugar content in the parenchymatous tissue rather than the lignified tissue due to the overall promotion of root mass with lesser absolute contents of fibers [27].

The data emerging in Table (2-11) also showed that the effect of sorbitol treatment, especially in a concentration of 40 g L^{-1} , led to a significant enhancement in the growth, productivity, and quality attributes of carrot plants. Such an effect may be caused by the key function of sorbitol in controlling the osmoregulation and promotion of sugar and mineral substance translocation in the plant. Sorbitol plays an important part in increasing the osmotic pressure in leaf and root cells, hence resisting water evaporation and protecting chloroplasts, hence an increase in chlorophyll content in leaves [28]. The rise in nitrogen can be attributed to the capacity of the sorbitol osmolyte to promote root uptake based on the improvement in osmotic potential, hence the entry of nitrate, as well as the entry of amino acids, into the plant cells [29]. On the other hand, the rise in phosphorus can be attributed to the improvement in the movement of water, solubility of phosphorus, as well as the transport of phosphorus in the rhizosphere towards the roots, specifically towards the

leaves [30]. The rise in potassium concentration can also be attributed to the improvement in the osmotic balance of the cells of the roots, hence the entry of the potassium ion inside the cells [31]. The increased boron concentration in leaves after sorbitol spraying can be explained by the ability of sugar alcohols to form soluble complexes with boron, such as boron-polyol complexes. This increases boron's mobility within the plant compared to its free form. The formation of these complexes enhances boron transport through vegetative tissues and its accumulation in leaves, thus explaining the observed increase in its concentration under the influence of sorbitol [32].

The increase in the number of leaves is related to the role of sugar alcohols in maintaining turgescence pressure in meristematic tissues. This is in line with the view of [33], which cited that the effect of boron resulted in greater meristematic activity as well as the formation of leaves. The increase in dry weights can be attributed to real growth due to the increase in photosynthetic efficiencies as well as the amount of carbohydrates. Sugar alcohols enhance the increase in dry weights due to increased accumulation of organic matters [34].

Conclusion

The current study's findings reveal that foliar application of boron and sorbitol, both, significantly helped to improve vegetative growth, yield, and quality of carrot plants (cv. Nantes). In most of the evaluated traits, the boron treatment at 100 mg L⁻¹ and the sorbitol treatment at 40 g L⁻¹ showed better results than other treatments. This can be attributed to their

The increased yield of carrot is due to the role of sorbitol as a transported carbohydrate and physiological regulator, which promotes the transport of photosynthetic substances in the phloem towards the actively growing regions. The increased yield is also due to the role of sorbitol in the support of osmotic regulation, elongation, and cell division in the shoot and root systems [35,36].

The increased volume of cellular juice reflects the indicator of increased vacuolar filling due to the deposition of sugars, together with the reduction in the osmotic potential of the cells, which facilitates the entry of water [37]. On the other hand, a relative decrease in the percentage of fibers was also noted, and this can be ascribed to the increment in the mass of the parenchymatous tissue, which contains higher amounts of water and sugars, at the expense of the lignified tissue. This decrease in fibers is of a relative nature, as it was brought about by the escalation in the total mass of the root, as opposed to an actual decrease in the absolute amounts of the fibers. Moreover, the mentioned alteration has been linked to the enhancement in root attributes of quality, texture, and marketability [38,39].

roles in enhancing photosynthetic efficiency, regulating osmotic balance, and metallochaperone translocation nutrient within the plant. Moreover, the interaction between these two factors showed the highest performance of the B2S3 treatment, thus, confirming that an optimum level of boron and sorbitol is an efficient way to promote physiological performance and increase the yield of carrot plants in the field.

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