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Tanay Bhatnagar
Department of Horticulture, Rajasthan College of Agriculture, MPUAT, Udaipur, Rajasthan, India

KD Ameta
Department of Horticulture, Rajasthan College of Agriculture, MPUAT, Udaipur, Rajasthan, India

Mohan Singh
Department of Horticulture, Rajasthan College of Agriculture, MPUAT, Udaipur, Rajasthan, India

Jitendra Kumar Tak
Department of Horticulture, Rajasthan College of Agriculture, MPUAT, Udaipur, Rajasthan, India

RA Kaushik
Department of Horticulture, Rajasthan College of Agriculture, MPUAT, Udaipur, Rajasthan, India

RB Dubey
Department of Genetics and Plant Breeding, RCA, MPUAT, Udaipur, Rajasthan, India

BG Chippa
Department of Horticulture, Rajasthan College of Agriculture, MPUAT, Udaipur, Rajasthan, India

Corresponding Author:
Tanay Bhatnagar
Department of Horticulture, Rajasthan College of Agriculture, MPUAT, Udaipur, Rajasthan, India

Influence of foliar application of boron on growth and yield of beetroot (*Beta vulgaris* L.)

Tanay Bhatnagar, KD Ameta, Mohan Singh, Jitendra Kumar Tak, RA Kaushik, RB Dubey and BG Chippa

Abstract
The present investigation entitled "Influence of foliar application of boron on growth and yield of beetroot (*Beta vulgaris* L.)." was carried out at Hi-Tech Unit, Department of Horticulture, Rajasthan College of Agriculture, MPUAT, Udaipur. The twelve treatments comprising of various combinations of 4 levels of boron, *viz*., B_0 - 0, B_1 - 100, B_2 - 150 and B_3 - 200 ppm and three spray application times, *viz*., D_1 - 30, D_2 - 45 and D_3 - 60 DAS. The treatments for beetroot crop were evaluated with three replications under factorial randomized block design. The experimental results show that different concentrations of boron, application times and their combinations significantly affected the growth, yield and quality of beetroot. The results showed that among different combinations of concentration of boron and time of boron spray, maximum plant height (41.48 cm), number of leaves (14.53), length of root (14.66 cm), diameter of root (10.31 cm), fresh weight of tops (140.42 g), fresh weight of roots (190.67 g), leaf area index (4.80), yield per plot (47.67 kg) and yield of root (476.68 q/ha) were recorded with treatment B_3D_1 (200 ppm boron spray at 30 DAS). Boron increases metabolic activity in plants, as well as growth and yield.

Keywords: Beetroot, boron, foliar application, time of spray, yield

Introduction
The Mediterranean region is the most likely origin of *Beta vulgaris* L. ssp. *maritima*, possibly through hybridization with *B. patula*, a closely related species from Portugal and the Canary Islands. The chromosome number of cultivated types is 2n=2x=18. The roots are fleshy and thick, storing a large amount of reserve food. The presence of red-violet pigment, beta-cyanins and yellow pigment, beta-xanthins, contributes to the root's colour (Natarajan and Veeraragavathatham, 2001) [19]. Betalains exist in two forms: betacyanin (red-violet pigment) and betaxanthin (yellow-orange pigment) and are commercially recognised as food dyes due to their non-hazardous, non-toxic, non-carcinogenic and non-poisonous nature. Betalains are more stable as food colourants across a wider pH range than anthocyanins, but their use is still limited because they are not always edible (Azeredo *et al*., 2009) [5]. Beetroot is also presumed to be a promising therapeutic treatment for a variety of clinical pathologies associated with oxidative stress and inflammation (Clifford *et al*., 2015) [7]. Boron is involved in cell wall and cell membrane's structural and functional integrity, ion fluxes (H^+, K^+, PO_4^{3-}, Rb^+ and Ca^{2+}) across membranes, cell division and elongation, nitrogen and carbohydrate metabolism, sugar transport, cytoskeletal proteins and plasmalemma-bound enzymes, nucleic acid, indole acetic acid, polyamines, ascorbic acid and phenol metabolism and transport (Shireen *et al*., 2018) [26]. it acts a vital role in many physio-biochemical operations such as plant respiration and buildup of meristematic tissue (Camacho-Cristobal *et al*., 2008), N fixation, is involved in the metabolism of protein and carbohydrate (Blevins and Lukaszewski, 1998) [6], sugar translocation (Armin and Asgharipour, 2012) [3] as well as the synergistic influence on N, phosphorus, and potassium uptake (Turan *et al*. 2010, Padbhushan and Kumar, 2015) [27, 23]. Boron deficiency also causes brown heart in beet roots, which is a physiological disorder in which the inner portion of the affected roots to appear grey or brown in colour. As a result, the roots are unfit for consumption. Several studies have shown that boron has a beneficial effect on sugar beets, including one by Kristek *et al.* (2006) [13]. Boron is required in the plant to facilitate sugar transport, it increases root weight and diameter, increases dry matter accumulation and enhances quality, these changes together result in an increase in sugar beet yield (Eweida *et al*., 1994) [11]. As all of these functions are essential to meristematic tissues, boron deficiency primarily causes harm to actively growing organs such as shoot and root tips,

causing the entire plant to be stunted or rosetting (Motagally, 2015) [18]. It has several advantages, including convenience, quick plant response and prevention of toxicity caused by excessive soil deposition of these nutrients over soil application (Obreza *et al*., 2010) [22]. Sugar beet uptake boron (B) in the form of $B(OH)_3$ or H_3BO_3 from the soil by roots (Marschner 1993) [16]. The higher quantities of free calcium carbonate, too higher quantities of phosphorus, and lower soil organic matter along with high soil pH decrease B uptake of plants and obtaining maximum benefit from B application (Niaz *et al*. 2016) [21]. Sugar beet continuously required relatively high levels of soil available B as compared to other crops (Dridi *et al*. 2018) [9].

Material and Methods

The present experiment on beetroot was conducted during winter season of the year 2020-21 at Hi-tech Unit, Department of Horticulture, Rajasthan College of Agriculture, Udaipur which is situated at 24°35'N and 74°42'E latitude at an 585.5 meters above mean sea level. The data recorded for evaluation of different treatments in beetroot was statistically analyzed using standard procedure as suggested by Panse and Sukhatme (1985) [24] for analysis of variance of Factorial RBD in order to test the significance of experimental findings. The experiment comprised of 12 treatment combinations of 4 levels of boron and 3 application times T_1 - B_0D_1- boron application @ 0 ppm on 30 DAS, T_2 - B_0D_2- boron application @ 0 ppm on 45 DAS, T_3 - B_0D_3- boron application @ 0 ppm on 60 DAS, T_4 - B_1D_1- boron application @ 100 ppm on 30 DAS, T_5- B_1D_2- boron application @ 100 ppm on 45 DAS, T_6 - B_1D_3- boron application @ 100 ppm on 60 DAS, T_7 - B_2D_1- boron application @ 150 ppm on 30 DAS, T_8 - B_2D_2- boron application @ 150 ppm on 45 DAS, T_9 - B_2D_3 -boron application @ 150 ppm on 60 DAS, T_{10} - B_3D_1- boron application @ 200 ppm on 30 DAS, T_{11} - B_3D_2- boron application @ 200 ppm on 45 DAS and T_{12} - B_3D_3- boron application @ 200 ppm on 60 DAS.

Results and Discussion

Findings of experiment showed that the varied boron levels had a significant influence on plant height of beetroot. Data presented in Table 1 cleared that various treatments with varying concentration of boron significantly influenced plant height, number of leaves, length of root (cm) and diameter of root. Results showed that the maximum plant height (37.94 cm) was noticed with the treatment B_3 (boron spray at 200 ppm) which was closely followed by treatment B_2 (boron spray at 150 ppm) having value of 35.94 cm, while minimum plant height having value of 29.67 cm was recorded with the treatment B_0 (boron spray at 0 ppm). This might be due to easier availability of boron to plant due to higher dose which might have better absorption and subsequent conversion into metabolic products whose accumulation culminates in more plant height than other treatment. These findings are also in agreement with the findings of Elsagan and Shokry (2020) [10] while working with carrot. Mekdad and Shaaban (2020) [17] also reported higher dose of boron resulted in maximum plant height in sugar beet. Different application times of boron had significant effect on plant height. Maximum plant height (36.52 cm) was recorded with treatment D_1 (boron spray at 30 DAS), while the minimum plant height (31.33 cm) was recorded for treatment D_3 (boron spray at 60 DAS). This is due to plants being able to absorb more boron, which might aid in various biological activities like cell division and cell elongation.

In different boron levels and time of application of boron spray, maximum number of leaves were found in treatment B_3 (boron spray at 200 ppm) and D_1 (boron spray at 30 DAS) with values of 13.67 and 13.32, respectively, while least number of leaves per plant in treatments B_0 (boron spray at 0 ppm) having values of 11.18. Higher number of leaves per plant in beetroot might be due to subdued apical dominance. Apical dominance seems to be regulated by the relative concentration of cytokinin and auxin. Plant boron status affects both auxin level in shoots and cytokinin level in roots. Since boron availability affects both the plant regulators that modulates apical dominance, perhaps boron-hormone interactions induced the release from apical dominance and subsequent increase in number of leaves due to foliar spray of boron. These findings are in line with the results found by Gondim *et al.* (2015) [12] and Attia *et al.* (2018) [4] who also recorded an increase in number of leaves in sugar beet due to foliar application of boron. Similar results in which increasing boron concentration, increased number of leaves; were recorded by Abdel-Nasser and Abdalla (2019) [2] and by Rampal *et al.* (2019) [25] when they applied boron to the soil while working on sugar beet and radish, respectively. Similar increase in number of leaves and plant height was also recorded by Manna and Maity (2015) [15] while working on onion. Different treatment combinations had no significant effect on number of leaves per plant. However, maximum number of leaves (14.53) were found with treatment B_3D_1 (200 ppm boron spray at 30 DAS), while minimum number of leaves (11.13) were recorded in three treatments B_0D_2 (0 ppm boron spray at 45 DAS), B_0D_3 (0 ppm boron spray at 60 DAS) and B_1D_3 (100 ppm boron spray at 60 DAS), which was at par the number of leaves (11.27) seen in treatments B_0D_1 (0 ppm boron spray at 30 DAS) and B_1D_2 (100 ppm boron spray at 45 DAS). Increased number of leaves may be due the higher nutrient uptake by plants which brought about maximum absorption and translocation of nutrients leading to increased cell multiplication and more number of leaves per plant was observed.

Results revealed that maximum root length (13.42 cm) and root diameter (9.37 cm) with treatment B_3 (boron spray at 200 ppm) which were at par (13.21 cm and 9.09 cm, respectively) treatment B_2 (boron spray at 150 ppm). While, minimum value (11.31 cm and 7.77 cm, respectively) for both parameters was found with treatment B_0 (boron spray at 0 ppm). This might be due to the application of boron which modulates the level of cytokinin in the plant, leading to an increase in cell division and meristem cell activity, this result in an increase in root length and root diameter. Results on the same line were obtained in sugar beet by Attia *et al.* (2018) [4] and Makhlouf *et al.* (2020) [14] when they applied increased concentrations of boron. Similar results in sugar beet were obtained by Mekdad *et al.* (2020) [17] when they supplied the soil with increased concentrations of boron. An increase in root diameter was also recorded by Nemeata *et al.* (2017) [20] when they applied foliar sprays of boron at similar concentrations on sugar beet. In interaction effect, maximum root diameter was reported in treatment B_3D_1 (200 ppm boron spray at 30 DAS) with values of 10.31 cm. While minimum root diameter (7.70 cm) was observed in B_1D_2 (0 ppm boron spray at 45 DAS). It may be due to availability of higher level of boron at an early stage of development leading to better assimilation of sugar which might have led to increased availability of energy for various important physiological and biological functions. This might have led to better overall development of root. This is in agreement with findings of Nemeata *et al.* (2019) when they applied foliar sprays of boron at an early stage of development, *viz.*, 6-8 leaf stage which corresponds with the vegetative development stage as seen at 30-35 DAS. Similar results were obtained by Elsagan *et al.* (2020) [10] while working on carrot. Analysed data showed that different combinations of levels of boron and application times of spray significantly influenced the root length of beetroot. Maximum root length (14.66 cm) was observed with the treatment B_3D_1 (200 ppm boron spray at 30 DAS) which was at par (14.34 cm) B_2D_1 (150 ppm boron spray at 30 DAS). Minimum root length (10.84 cm) was noticed in the treatment B_0D_3 (0 ppm boron spray at 60 DAS).

Data presented in Table 2 shows that various treatments with varying concentration of boron significantly influenced the fresh weight of tops, fresh weight of roots, leaf area index, yield per plot and total yield of root. Maximum fresh weight of tops (134.29 g) was recorded with treatment B_3 (boron spray at 200 ppm), while minimum fresh weight (105.98 g) was recorded with treatment B_0 (boron spray at 0 ppm). Treatment B_2 (boron spray at 150 ppm) was at par (131.30 g) treatment B_3 with respect to fresh weight of tops. This might be due to the essential role of boron for the activity of enzymes involved in photosynthesis and respiration. Also, it increased photosynthesis and higher assimilation of food lead to an increase in weight. These results are in agreement with findings of Nemeata *et al.* (2019) and Makhlouf *et al.* (2020) [14] when they applied increasing levels of boron through foliar application on sugar beet and recorded an increase in fresh weight of tops. Among different foliar application times, maximum fresh weight of tops (128.70 g) was observed with the treatment D_1 (boron spray at 30 DAS) while minimum fresh weight of tops (117.59 g) was reported in treatment D_3 (boron spray at 60 DAS. Various treatment combinations of concentration of boron and time of their application had no significant influence on fresh weight of tops. However, among various treatment combinations, highest fresh weight of tops (140.42 g) was recorded in B_3D_1 (200 ppm boron spray at 30 DAS) while the lowest fresh weight of tops (102.59 g) was recorded in treatment combination B_0D_2 (0 ppm boron spray at 45 DAS).

It is distinctly indicated from analysis of data that leaf area index was significantly affected by boron when applied as spray at various levels. Highest leaf area index (4.08) was recorded with application of 200 ppm spray of boron in B_3, whereas minimum leaf area index (3.38) was observed with treatment B_0 (boron spray at 0 ppm). This might be due to the application of higher dose of boron which might have induced a higher rate of cell division and elongation in leaves. Similar results were obtained by Makhlouf *et al.* (2020) [14] when they subjected sugar beet to increased amount of foliar dosage of boron. These results are also in consonance with findings of Rampal *et al.* (2019) [25] and Yatsenko *et al.* (2020) [28] while working with radish and garlic, respectively. Among different time of application of boron spray significant impact was found in the leaf area index. Maximum leaf area index (4.09) was found with treatment D_1 (boron spray at 30 DAS), while minimum value of leaf area index (3.48) was recorded in D_3 (boron spray at 60 DAS). This might be due to application of boron at an earlier stage of development which led to better absorption and uniform translocation of nutrients to various actively dividing cells of leaves. This might have led to an increase in both breadth and length of leaf. Statistically analyzed data shows that different combinations of concentrations of boron and spray time had a significant difference on leaf area index (LAI) of beetroot. Here, maximum leaf area index (4.80) was recorded with treatment B_3D_1 (200 ppm spray of boron at 30 DAS), whereas minimum leaf area index (3.32) was recorded with B_0D_2 which was at par (3.36) treatment B_0D_1 (0 ppm boron spray at 30 DAS) and leaf area index of 3.45 was recorded in treatment B_0D_3 (0 ppm boron spray at 60 DAS) and B_1D_2 (100 ppm boron spray at 45 DAS), respectively. Maximum fresh root weight, yield per plot and total yield (181.78 g, 45.44 kg and 454.45 q/ha, respectively) was recorded with treatment B_3 (boron spray at 200 ppm) and it was at par fresh weight, yield per plot and total yield (179.00 g, 44.75 kg and 447.50 q/ha, respectively) recorded with treatment B_2 (boron spray at 150 ppm). Minimum fresh weight of root (151.98 g) was recorded with treatment B_0 (boron spray at 0 ppm). These results may be due to the increased foliage fresh weight, root diameter and root length which can be attributed to the positive role of boron on translocation of photosynthates from leaves to roots. Nemeata (2017) [20] also concluded that increased concentration of boron applied as foliar spray led to an increase in root fresh weight, yield per plot and total yield. Similar findings were also reported by Makhlouf *et al.* (2020) [14] and Mekdad and Shaaban (2020) [17] while working on sugar beet. Among different application times of boron spray, significant impact was found on fresh weight of root. Best results were obtained with treatment D_1 (spray of boron at 30 DAS) closely followed by treatment D_2 (spray of boron at 45 DAS) with values 175.53 g and 170.42 g, respectively. While, various combinations of boron concentrations and spray time had no significant impact on fresh weight of root, yield per plot and total yield of root. Fresh weight of root, yield per plot and total yield had significant divergence for different combinations and maximum fresh root weight, yield per plot and total yield (190.67 g, 47.67 kg and 476.68 q/ha, respectively) was recorded for treatment B_3D_1 (200 ppm boron spray at 30 DAS), which was closely followed by fresh root weight (186.67 g & 183.34 g), yield per plot (46.67 kg & 45.83 kg) and total root yield (466.68 q/ha & 458.34 q/ha) in treatments B_2D_1 (boron spray at 150 ppm at 30 DAS) and B_3D_2 (200 ppm boron spray at 45 DAS), respectively. Similar results were found by Abbas *et al.* (2014) [1] and Dewdar *et al.* (2015) [8] while investigating similar interaction effect of boron and time of application on sugar beet. Boron at different levels had significant effect on fresh weight of roots.

Table 1: Main effects and interaction effects of concentration of boron, time of application and their combinations on plant height, number of leaves, root length and diameter of root of beetroot.

Treatment	Plant height (cm)	Number of leaves	Length of root (cm)	Diameter of root (cm)
Boron				
B_0	29.67	11.18	11.31	7.77
B_1	32.43	11.84	12.13	8.14
B_2	35.94	13.38	13.21	9.09
B_3	37.94	13.67	13.42	9.37

S.Em+	0.659	0.202	0.196	0.082
CD at 5%	1.934	.591	0.574	0.240
Time of application				
D_1	36.52	13.32	13.59	9.13
D_2	34.15	12.38	12.58	8.52
D_3	31.33	11.85	11.39	8.12
S.Em+	0.571	0.175	0.169	0.071
CD at 5%	1.675	0.512	0.497	0.208
B x D				
T_1 -B_0D_1	29.77	11.27	11.84	7.87
T_2 -B_0D_2	30.05	11.13	11.25	7.70
T_3 -B_0D_3	29.19	11.13	10.84	7.72
T_4 -B_1D_1	35.11	13.13	13.50	8.57
T_5 -B_1D_2	31.82	11.27	11.49	8.08
T_6 -B_1D_3	30.36	11.13	11.40	7.78
T_7 -B_2D_1	39.71	14.33	14.34	9.76
T_8 -B_2D_2	35.58	13.47	13.74	9.04
T_9 -B_2D_3	32.55	12.33	11.55	8.47
T_{10} -B_3D_1	41.48	14.53	14.66	10.31
T_{11} -B_3D_2	39.15	13.67	13.82	9.27
T_{12} -B_3D_3	33.21	12.80	11.78	8.52
S.Em+	1.142	0.349	0.339	0.142
CD at 5%	3.349	NS	0.994	0.416

Table 2: Main effects and interaction effects of concentration of boron, time of application and their combinations on fresh weight of tops, fresh weight of root, LAI, yield per plot and total yield of root of beetroot.

Treatment	Fresh weight of tops (g)	Fresh weight of roots (g)	Leaf Area Index	Yield per plot (kg)	Total yield of root (q/ha)
Boron					
B_0	105.98	151.98	3.38	37.99	379.96
B_1	121.17	167.55	3.54	41.89	418.89
B_2	131.30	179.00	3.94	44.75	447.50
B_3	134.29	181.78	4.08	45.44	454.45
S.Em+	2.164	3.230	0.028	0.807	8.074
CD at 5%	6.295	9.472	0.083	2.368	23.680
Time of application					
D_1	128.70	175.53	4.09	43.88	438.83
D_2	123.27	170.42	3.63	42.60	426.04
D_3	117.59	164.29	3.48	41.07	410.72
S.Em+	1.859	2.797	0.025	0.699	6.992
CD at 5%	5.452	8.203	0.072	2.051	20.507
B x D					
T_1 -B_0D_1	107.35	150.45	3.36	37.61	376.12
T_2 -B_0D_2	102.59	152.33	3.32	38.08	380.82
T_3 -B_0D_3	108.00	153.17	3.45	38.30	382.92
T_4 -B_1D_1	129.75	174.34	3.73	43.58	435.84
T_5 -B_1D_2	118.72	165.33	3.45	41.33	413.33
T_6 -B_1D_3	115.04	162.99	3.43	40.75	407.48
T_7 -B_2D_1	137.30	186.67	4.48	46.67	466.68
T_8 -B_2D_2	135.33	180.67	3.83	45.17	451.67
T_9 -B_2D_3	121.27	169.66	3.51	42.41	424.15
T_{10} -B_3D_1	140.42	190.67	4.80	47.67	476.68
T_{11} -B_3D_2	136.41	183.34	3.92	45.83	458.34
T_{12} -B_3D_3	126.05	171.33	3.53	42.83	428.33
S.Em+	3.718	5.594	0.049	1.398	13.98
CD at 5%	NS	NS	0.144	NS	NS

Conclusion
It may be concluded that among different combinations of concentrations of boron and time of application of boron spray had a significant effect on beetroot and treatment B_3D_1 (200 ppm boron spray at 30 DAS) was found to have superior performance in terms of growth and yield parameters of beetroot than the rest of treatments.

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