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EFFECTS OF BORON APPLICATION ON THE GERMINATION, GROWTH AND NUTRIENT UPTAKE BY *AMARANTHUSUS GANGETICUS* AND *AMARANTHUSUS LIVIDUS*

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ABSTRACT

Boron (B) is required for a variety of physiological and biochemical activities that contribute to crop quality improvement. As a result, a pot experiment was carried out to see how B affected the germination, growth, and nutritional intake of two common vegetables, red Amaranthus (*Amaranthusus gangeticus*) and stem Amaranthus (*Amaranthusus lividus*). The trial included four levels of B (0, 1, 1.5, and 2 kg ha^{-1}) and three replications in a completely randomized design. The results showed that the application of B had no effect on germination, shoot and root length of red Amaranthus seedlings but it did reduce stem Amaranthus germination to 40% at the maximum dosage of B (2 kg ha^{-1}). With increasing B concentration, stem Amaranthus seedlings' shoot and root lengths decreased significantly ($p \leq 0.05$). After applying B at a rate of 1.5 kg ha^{-1}, yield, dry weight, fresh weight, leaf number, height, and protein content of both vegetables increased significantly, although higher B concentrations (2 kg B ha^{-1}) tended to decrease the same parameters. The addition of B enhanced the concentration and uptake of nutrients (N, P, K, Ca, Mg, and B) in both vegetables as compared to control. Phosphorus had the highest nutrient utilization efficiency, whereas calcium had an increased efficiency as B concentration increased. Application of 1.5 kg B ha^{-1} had the highest B use efficiency for both vegetables. According to the findings, using B at a rate of 1.5 kg B ha^{-1} could help increase red Amaranthus and stem Amaranthus production.

Keywords: Boron, Germination, Growth, Nutrient, Vegetables

INTRODUCTION

Amaranthusus leaves and stems are rich sources of antioxidants, protein, carotenoids, vitamin C, dietary fiber, and minerals such as calcium, iron, zinc, and magnesium (Sarker and Oba, 2018). Flashy succulent stems and leaves of Amaranthusus are very

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popular in Bangladesh including Asia and Africa, and are becoming increasingly popular in the rest of the continent due to its attractive leaf and stem color, taste and nutritional value. Amaranthusus is one of the cheapest vegetables because of its low production cost, high yield and promising economic value (Rastogi and Shukla, 2013). Vegetable crops require substantial amounts of plant nutrients and respond very well to the added nutrients. In Bangladesh, the fertilizer application rate has increased but the application of micronutrients has largely been neglected. Therefore, rational and optimum use of micronutrients coupled with recommended fertilizers would be beneficial for increasing vegetable yield per unit area. Boron is an essential micronutrient as it involves in the growth of cells in newly emerging shoots and roots of plants. It plays important roles in cell wall synthesis, lignification (Loomis and Durst, 1992) and cell wall structure (Fleischer et al., 1998).

Boron is normally less available to plants with high soil pH. Due to the high calcareousness of soils, B may precipitate with $CaCO_3$ (Keren and Ben-Hur, 2003) which makes B unavailable for plant uptake (Shorrocks, 1997). High calcium availability enhances the requirement of B for plant growth (Brady and Weil, 2013). Boron deficiency reduces the yield of many crops including vegetables. A study conducted by FAO on micronutrients in soils revealed that B deficiency was the most common problem, affecting at least 8 million hectares worldwide (Tariq and Mott, 2007). Deficiency of B restricts stomata opening and transpiratory water loss and also leads to enhanced leakage of solutes across the plasma membrane. The deficiency of B resulted in considerable yield reduction in various crops, like cereals (rice, corn, wheat), legume, oilseed and fruit trees (Niaz et al., 2007; Rashid and Rafique, 2017; Jhonson et al., 2005). The southwest region of Bangladesh has potential vegetable production areas where the application of B may increase crop yield as well as improve the quality of the crops (Quddus et al., 2018; Rashid et al., 2005).

Previous studies found that the growth and yield of wheat (Akter et al., 2019) and mustard (Masum et al., 2019) grown in various parts of Bangladesh were accelerated with B addition. Although information concerning the effects of B on major crops is available, the vegetables' response to B in the soils of the southwest region of Bangladesh is scarce. So, the existing knowledge of vegetable production coupled with B application seems to be necessary for vegetable growth in this region. Therefore, this study aims at investigating the effect of B levels on germination, growth, yield and uptake of nutrients by red Amaranthus and stem Amaranthus. And this will augment the current literature with information regarding B application in vegetable production.

MATERIALS AND METHODS

A pot experiment was conducted on silty clay soil at Khulna University in Batighata from March 2019 to April 2019. Each pot contained three kg of sieved (2mm mesh) soil. The general properties of soil are described in table 1.

Table 1. General properties of soil used in the study

Soil property	Value
Soil Moisture Content (%)	25
Sand (%)	11.02
Silt (%)	53.32
Clay (%)	35.66
Soil Textural Class	Silty clay
Particle Density (g cm^{-3})	2.50
Bulk Density (g cm^{-3})	1.15
pH	7.80
EC (dS m^{-1})	0.13
Organic Carbon (%)	0.36
Total Nitrogen (%)	0.03
Total Phosphorus (%)	0.07
Total Potassium (%)	0.11
Total Calcium (%)	0.95
Total Magnesium (%)	0.78
Boron (mg kg^{-1})	0.33

B was applied to the soil at the rate of 0, 1.0, 1.5 and 2.0 kg ha^{-1} (designated as T_0, T_1, T_2 and T_3 respectively) as H_3BO_3. In each pot, three plants each of red Amaranthus (*Amaranthusus gangeticus*) and stem Amaranthus (*Amaranthusus lividus*) were used as test crops. All the pots were arranged in a completely randomized design (CRD) with three replications. A basal fertilizer application of 60 kg N, 60 kg P_2O_5 and 100 kg K_2O ha^{-1} was applied as suggested in FRG (2018).

The crops were harvested after 45 days of seed sowing and yields were recorded. For the germination study, ten seeds were placed between Whatman no 1 filter papers in petridishes and moistened with 5 ml of different concentrations of B solution. Distilled water served as the control treatment. The experiment was conducted in a CRD design maintaining three replicates for each treatment. Petri dishes were kept in laboratory condition at 25^0C. After 7 days, shoot and root length were measured by a ruler and germination percentage was determined as described in (Gupta and Solanki, 2012):

% Germination = (Number of germinated seeds)/(Total number of seeds kept for germination) x 100

Plant samples were harvested and processed for chemical analysis taking special care. The samples were digested in HNO_3:$HClO_4$ (2:1) mixture and B concentration was determined by Azomethine - H method (Bingham, 1982; Mohammaed et al., 2014; Wolf, 1974). Nitrogen and phosphorus were analyzed by micro Kjeldahl (Bremmer and Mulvaney, 1982) and vanadomolybdophosphoric yellow color (Jackson, 1972) methods, respectively.

Potassium, calcium and magnesium contents were measured by ammonium acetate method (Pratt, 1965). Nutrient uptake for N, P, K, Ca, Mg and B (mg plant^{-1}) was calculated on the basis of DW of each plant and the corresponding values of concentrations were calculated: Nutrient uptake = dry weight (DW) x nutrient concentration (Zhang et al., 2007). The calculation of Nutrient Use Efficiency (NUE) values of the various nutrients was determined from the total DW of each plant and the uptake of each nutrient element on the basis of the equation NUE = Total DW/ Total nutrient absorption (Zhang et al., 2007).

The protein content was computed from the nitrogen content multiplied by a factor of 6.25. The analysis of variance followed by DMRT (Duncan's Multiple Range Test) was used to analyze the data and to separate the means. The data analysis procedures were followed as described by Gomez and Gomez (1984) using Minitab and MS Excel.

RESULTS AND DISCUSSION

Germination study

The treatments T_1 and T_3 led to the highest germination in red Amaranthus but these changes were not found to be significant as compared to control. In stem Amaranthus, however, T_1 caused the highest germination and T_3 significantly inhibited germination ability of the seeds (Table 2). Boron concentration of boric acid might cause an improvement in the germination ability of red Amaranthus and B toxicity at higher B concentration was attributed to the poor germination performance of stem Amaranthus. The shoot and root growth of red Amaranthus were found unaffected against different doses of B concentrations (Table 2). However, the effects of B application over the shoot and root growth of stem Amaranthus were different as compared to red Amaranthus. Control treatment showed the highest shoot and root growth in stem Amaranthus.

The shoot growth of stem Amaranthus decreased with T_1 which did not vary significantly with the increased shoot growth at T_2 and T_3. Root growth of the stem Amaranthus decreased with increasing B concentrations and this decrement may be due to the B toxicity which inhibited cell elongation and cell division in the root. The result was in accordance with the findings of Culpan et al. (2019) and Ashgare et al. (2014) who observed reduced seed germination and seedling growth of various safflower genotypes and wheat plants respectively with high B concentrations.

Table 2. Effect of different levels of B application in some germination and seedling growth parameters in red and stem Amaranthus

Treatment	Red Amaranthus			Stem Amaranthus		
	Germination (%)	Shoot length (cm)	Root length (cm)	Germination (%)	Shoot length (cm)	Root length (cm)
T_0	80.00a±1.00	0.90a ± 0.10	0.40a ± 0.00	53.33a±1.15	0.90a ± 0.1	0.53a ± 0.00
T_1	86.67a±1.15	0.73 a± 0.06	0.33a ± 0.06	60.00a±1.73	0.47 b± 0.06	0.30b ± 0.06
T_2	80.00a±1.00	0.73a ± 0.25	0.37a ± 0.06	56.67a±1.15	0.57 b± 0.25	0.27b ± 0.06
T_3	86.67a±1.15	0.70a ± 0.10	0.37a ± 0.06	40.00b±1.00	0.57b± 0.10	0.27b ± 0.06
Mean	83.34	0.77	0.37	52.50	0.63	0.34

Means with the same letter in the same column are not significantly different at $P \leq 0.05$ (Duncan's multiple range test) (T0=control, T1=1.0kgBha^{-1}, T_2=1.5kgBha^{-1} and T_3=2.0kgBha^{-1})

Agronomic study

For both vegetables, the application of B to the soil had a considerable impact on growth and yield (Table 3). T_2 showed the highest values for all of the growth measures.

The application of B caused substantial variation in the height of red and stem Amaranthus, with the maximum plant height being recorded with T_2 (21.33 cm) in red Amaranthus, which differed considerably from T_3 and control but not from T_1. T_2 had the maximum height (25.33 cm) in stem Amaranthus, which differed substantially from T_0 and control but not from T_1. The B treatment with T_2 produced the most leaves (12) in red Amaranthus, resulting in significant differences from other treatments in which T_1 and T_3 differed nonsignificantly but did from the control treatment. T_2 generated the most leaves (18) in stem Amaranthus, which differed insignificantly from T_1 but significantly from T_3 and control.

The fresh and dry weights of red Amaranthus shoots altered in a similar pattern, with T_2 having the highest fresh and dry weights of 5.00 g and 0.56 g, respectively. While in stem Amaranthus, T_2 treatment had the largest fresh and dry weight of shoot (5.54g and 0.64g respectively), which changed much more than the other treatments used, where T_1 and T_3 exhibited small variances but not control. B played a big impact in raising the yield of red Amaranthus, which had the highest yield (10 tha^{-1}) obtained with T_2 with a considerable yield decline at the highest B levels (T_3). T_2 produced the highest yield (11.09 tha^{-1}) in stem Amaranthus, which dropped as B content increased.

Table 3. Growth and yield attributes of red and stem Amaranthus as affected by different levels of B application

Treatment	Red Amaranthus					Stem Amaranthus				
	Height (cm)	Leaf No.	Shoot FW (g)	Shoot DW (g/plant)	Yield (tha^{-1})	Height (cm)	Leaf No.	Shoot FW (g)	Shoot DW (g/plant)	Yield (tha^{-1})
T0	15.17c	5.0c	2.44c	0.36c	4.87c	18.67c	9c	3.41c	0.48c	6.83c
T_1	18.97ab	10b	3.50b	0.48b	7.0b	22.45a	16a	4.54b	0.58b	9.08b
T_2	21.33a	12a	5.00a	0.56a	10.0a	25.33a	18a	5.54a	0.64a	11.09a
T_3	18.37b	8.0b	3.43b	0.54b	6.85b	22.33b	11b	4.47b	0.56b	8.95b
Mean	18.46	8.75	3.59	0.46	7.17	22.20	13.5	4.49	0.58	8.99
CV (%)	3.23	8.46	2.52	2.16	2.49	2.13	5.73	4.38	7.65	5.41

Means with the same letter in the same column are not significantly different at $P \leq 0.05$ (Duncan's multiple range test) (T0=control, T_1=1.0 kg B ha^{-1}, T_2=1.5 kg Bha^{-1} and T_3=2.0 kg B ha^{-1})

However, control (T0) had the lowest values of all agronomic and yield qualities for the tested vegetables, which could be due to B insufficiency. The application of 1.5 t ha^{-1} B (T_2) had a favorable effect on the growth and yield of both vegetables, according to the study. Higher shoot dry matter production in these two vegetables could be related to an increase in photosynthetic activity following boron application, which enhanced carbohydrate production and accumulation in the plant's vegetative component. However, the maximum application rate of B resulted in a considerable reduction in growth and yield. This could indicate that B application rates of more than 1.5 kg ha^{-1} are unsuitable for the growth of red and stem Amaranthus, possibly due to B toxicity created in the soil. Several researchers (Solanki et al., 2018; Moklikar et al., 2018; Alam and Jahan, 2007; Talukder et al., 2000) observed similar outcomes with the administration of B to various vegetable crops.

Nutrient uptake

The use of B enhanced nutritional absorption significantly in both of the vegetables studied (Table 4). In both plants, there was minimal uptake of these nutrients when the control was used. T_2 had the maximum uptake of N, P, and K (17.78, 2.19, and 9.67 mg/plant, respectively) in red Amaranthus, which then reduced as B concentration increased. However, T_3 treatment resulted in the highest Ca, Mg, and B uptake (8.34, 2.16 mg/plant, and 0.094 µg/plant, respectively), which did not differ significantly from T_2 but differed from T_1 and control. However, when the amount of B application increased, the uptake of N, P, K, Ca, and Mg increased dramatically in stem Amaranthus. T_2 treatment yielded the highest (20.05, 2.48, 11.25, 6.40, and 5.51 mg/plant), followed by a reduction in T_3 treatment. Boron uptake rose as the amount of B application increased, with T_3 having the maximum uptake at 0.161 µg/plant. Enhanced B availability may influence the production of nitrogen-containing metabolites (e.g. protein and DNA) in these vegetables, resulting in increased N uptake in both vegetables (Debnath and Ghosh, 2011). Reduced nitrogen reductase activity could be causing the decline in N uptake at high B concentrations (Mahboobi et al., 2002). B excess lowered net nitrate absorption in sensitive tomatoes, reducing PM H-ATPase activity (Princi et al., 2013). Boron application to soil promotes ideal circumstances for photosynthesis, respiration, and enzyme activity, which could explain why vegetables are absorbing more P (Ganie et al., 2013).

The rise in K intake with increasing B concentration could be related to greater vegetable growth, which would boost K absorption from the soil, resulting in higher uptake. This may indicate the presence of available boron in soil solution as a result of boron application to the soil. B treatment to the soil altered Ca and Mg uptake, with T_2 yielding the best results for both vegetables.

The improvement in Ca content in the tested vegetables was due to the synergistic actions of B against Ca. A negative response was observed for Mg, resulting in lower Mg absorption in the vegetables at high B concentrations. López-Lefebre et al (2002) found comparable results in tobacco plants, confirming the findings. Atilla et al (2010), on the other hand, reported antagonistic effects of B with Ca in cucumber plants as B concentrations increased. T_3 showed the maximum uptake of B in red and stem Amaranthus, with 0.094 and 0.161 µg/plant, respectively.

Table 4. Effect of B application on nutrient uptake by red Amaranthus and stem Amaranthus

Treatment	Red Amaranthus						Stem Amaranthus					
	N	P	K	Ca	Mg	B	N	P	K	Ca	Mg	B
	mg/plant					µg/ plant	mg/plant					µg/ plant
T0	8.67c	1.24c	5.03c	6.62c	1.17c	0.062c	11.87c	1.77c	6.77c	5.80b	3.53c	0.096d
T_1	12.98b	1.77b	6.96b	7.52b	1.90b	0.080b	16.50b	2.19b	8.41b	6.84a	4.69b	0.119c
T_2	17.78a	2.19a	9.67a	8.29a	2.10a	0.092a	20.05a	2.48a	11.25a	6.40a	5.51a	0.139b
T_3	12.00b	1.69b	6.43b	8.34a	2.16a	0.094a	15.92b	2.14b	8.12b	5.91b	4.54b	0.161a
Mean	14.36	1.82	7.77	7.69	1.83	0.082	16.09	2.15	8.64	6.24	4.57	0.121
CV (%)	4.02	2.88	2.45	9.70	6.39	15.85	3.46	8.14	5.89	3.63	3.69	20.04

Means with the same letter in the same column are not significantly different at $P \leq 0.05$ (Duncan's multiple range test) (T0=control, T_1=1.0kgBha^{-1}, T_2=1.5kgBha^{-1} and T_3=2.0kgBha^{-1})

The increasing concentration of B in soil could explain the increase in B content with rising B levels. The majority of nutrient uptake was lowered in both vegetables with

T_3 treatment, and the reduction in nutrient uptake with higher B application could be due to B toxicity. Due to abscisic acid synthesis in the cell membrane, B poisoning caused the stomata in these investigated vegetables to close. Finally, due to B toxicity, the closed stomata lowered transpiration, which impeded nutrition delivery from the roots to the tops of the plants. The findings are consistent with those of Ayvaz, et al. (2012) who found that B toxicity inhibited nutrient absorption in pepper plants.

Nutrient Use Efficiency (NUE)

In red and stem Amaranthus grown at four B concentrations, NUE as measured by mg of nutrient element per gram dry weight revealed substantial differences among nutrients in terms of NUE (Table 5). P had the highest NUE in both plants, ranging from 0.766 to 0.860 in red Amaranthus and 0.770 to 0.815 in stem Amaranthus, depending on B levels.

The NUE ranged from 0.095-0.124 for N, 0.174-0.210 for K, 0.053-0.068 for Ca, 0.204-0.308 for Mg, and 0.0057-0.0061 for B in red Amaranthus, and 0.093-0.123, 0.170-0.214, 0.083-0.100, 0.116-0.136 and 0.0035-0.0051 for N, K, Ca, Mg, and B in stem Amaranthus, respectively.

Table 5. Effect of B application on nutrient use efficiency (NUE) in red and stem Amaranthus

Treatment	Red Amaranthus						Stem Amaranthus					
	N	P	K	Ca	Mg	B	N	P	K	Ca	Mg	B
T0	0.124a	0.860a	0.210a	0.054b	0.308a	0.0058b	0.123a	0.815a	0.214a	0.083b	0.136a	0.0051a
T_1	0.112b	0.819a	0.208a	0.064a	0.253b	0.0060a	0.106b	0.794b	0.207a	0.085b	0.124b	0.0049a
T_2	0.095c	0.766b	0.174b	0.068a	0.267b	0.0061a	0.093c	0.770b	0.170b	0.100a	0.116b	0.0046a
T_3	0.111b	0.787b	0.207a	0.053b	0.204c	0.0057b	0.106b	0.789b	0.210a	0.095a	0.123b	0.0035b
Mean	0.111	0.808	0.200	0.060	0.258	0.0059	0.107	0.792	0.200	0.091	0.125	0.0045
CV (%)	6.57	2.99	1.85	2.18	10.61	4.54	12.62	2.30	9.13	11.26	13.40	3.83

Means with the same letter in the same column are not significantly different at $P \leq 0.05$ (Duncan's multiple range test) (T0=control, T_1=1.0kgBha^{-1}, T_2=1.5kgBha^{-1} and T_3=2.0kgBha^{-1})

The results showed that following the application of B, both vegetables were unable to utilize N effectively. When no B was applied to red Amaranthus, P was effective, but when B was applied to stem Amaranthus, it was ineffective. The maximum K usage efficiency was found with the highest levels of B application in both the vegetables and the highest K use efficiency was found with the highest levels of B application. T_2 showed the highest Ca use efficiency in red Amaranthus, which did not differ from T_1, and Ca use efficiency declined dramatically in this vegetable at high B concentrations. In stem Amaranthus, T_3 had the highest Ca usage efficiency, which did not change much from T_2. The application of B, on the other hand, had no effect on the efficiency of Mg utilization in the investigated vegetable. The efficiency of B use was raised with B application up to a certain point, but it was lowered in both vegetables when high B was applied. B negatively affected different compounds of nitrogen could be a result of low nitrogen use efficiency. Because the accessible forms of P and B are anions, a putative rivalry between them could explain the decrease in P use efficiency. Ayvaz, et al. (2012) discovered a similar result while studying the forms of P and B in soil. Mg use efficiency decreased at high B concentration followed a different mechanism. On the other hand, B application significantly increased the use efficiency of K in both vegetables indicated the importance of B application. The toxicity imposed by B at high rates, which may cause toxicity in the cell membrane in red Amaranthus, could explain the reduced Ca utilization efficiency in this plant. Working with barley varieties, Atilla, et al. (2010) found a similar outcome. When higher rates were used, Boron use efficiency (BUE) in both vegetables reduced dramatically. This indicated that neither vegetable was able to successfully utilize B for growth. This could be explained by the fact that when B is applied in the form of boric acid, which has a high water solubility and mobility, it does not react well with the soil, making it more susceptible to leaching. Solanki, et al. (2018) reported a similar pattern with increasing B concentration in soil in an experiment with cauliflower.

Protein content

With increasing B concentrations, the protein content (%) in red and stem Amaranthus varied considerably ($p<0.05$) (Fig 1). T_2 treatment resulted in the highest protein level in both plants, 19.83 percent and 20.13 percent for red and stem Amaranthus, respectively. This could be owing to the presence of B, which is crucial for plant protein synthesis. The increase in protein yield with B application has been reported by Solanki, et al. (2018). The lowest protein content for both the vegetables was found in control which was identical with T_1 and T_3.

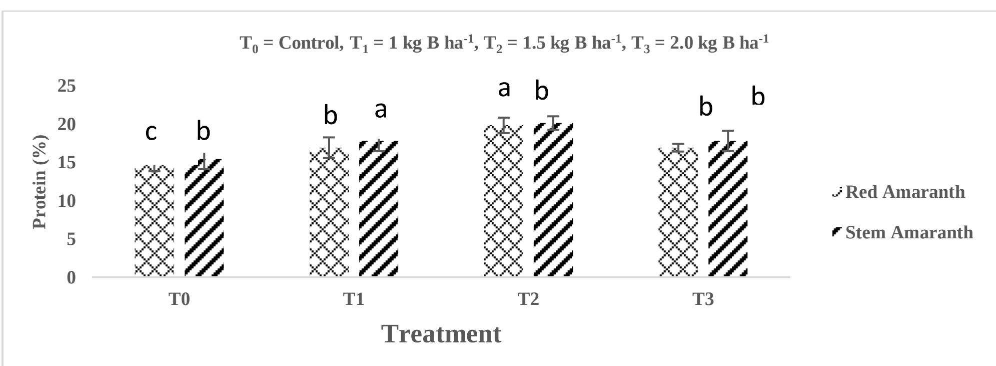

Figure 1. Effect of B application on protein content in red and stem Amaranthus

CONCLUSION

To explore the impact of B in germination, growth, yield, protein content, nutrient uptake, and nutrient usage efficiency of red Amaranthus and stem Amaranthus, researchers grew them at various B concentrations. Boron treatment had a lower success rate in the germination of red Amaranthus. Boron application rates improved the growth, yield, protein content, and nutrient status of Amaranthus plants under study. As compared to the control, red Amaranthus and stem Amaranthus yields were increased to 5.13 t ha^{-1} and 4.26 t ha^{-1}, respectively, after T_2 treatment (1.5 kg B ha^{-1}). Higher B concentrations resulted in increased nutrient absorption. Nutrient use efficiencies varied depending on B levels, however, in both plants, the maximum B use efficiency was reported in the T_2 treatment. Finally, the results show that T_2 (1.5 kg B ha^{-1}) produced the best outcomes across all boron levels in terms of the parameters investigated. As a result, utilizing B at a rate of 1.5 kg ha^{-1} will be more effective for growing Amaranthuss.

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