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Effect of elevated boron concentrations on the growth and yield of barley (*Hordeum vulgare* L.) and alleviation of its toxicity using different plant growth modulators

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Abstract

This study was carried out to assess the role of elevated concentrations of boron in barley (*Hordeum vulgare* L. cv. Giza 123) growth and yield as well as to test the involvement of some plant growth modulators in counteracting the boron-mediated retardations to improve its tolerance. Barley grains were treated with B concentrations of 0, 0.5, 1.5, 3.0 and 6.0 mg L^{-1} (as boric acid). The alleviation of the growth inhibition in the presence of 3.0 mg L^{-1} B was investigated by adding the following growth modulators: glutamic acid (1 or 3 mM), glycine (1 or 3 mM), ascorbic acid (2 or 5 mM), salicylic acid (1 or 5 mM) and calcium chloride (1 or 5 mM). Barley grains were cultivated and samples were collected at vegetative (22-day-old), flowering (45-day-old) and harvesting stages (92-day-old). At vegetative stage, the application of 0.5 mg L^{-1} boron significantly increased ($P \leq 0.05$) shoot fresh weight by 1%. The addition of 0.5 and 1.5 mg L^{-1} boron significantly increased ($P \leq 0.05$ and 0.01) growth parameters (shoot and root fresh and dry weights) by 5%, leaf area by 4.5% and 7%, Chl a and Chl b contents by 3% and 7% at vegetative and flowering stages, respectively, and yield by 5.5%, compared to non-boron treated barley. The inhibitory effects of boron on barley growth started at concentrations above 3.0 mg L^{-1}, causing decrease in all the measured parameters. The five tested growth modulators alleviated boron toxicity at 3.0 mg L^{-1} at the following sequence: salicylic acid (1 mM), calcium chloride 5 mM ≥, ascorbic acid (2 mM) ≥, glycine (1 mM) and glutamic acid (3 mM). The boron-alleviating efficiency of either 1 mM salicylic acid or 5 mM calcium chloride recommended their application when cultivating barley in boron contaminated soils.

Keywords: Ascorbic acid; calcium chloride; growth criteria; salicylic acid.
Abbreviations: AA- ascorbic acid; GA- glutamic acid; Gly- glycine; NB-non-boron; SA- salicylic acid.

Introduction

Boron (B) is an essential nutrient for normal growth of higher plants and its availability in soil and irrigation water is an important determinant of agricultural production (Saleem et al., 2011). Boron deficiency causes different effects on very diverse processes in vascular plants such as root elongation, indoleacetic acid oxidase activity, sugar translocation, carbohydrate metabolism, nucleic acid synthesis, and pollen tube growth (Blevins and Lukaszewski, 1998; Goldbach and Wimmer, 2007; Saleem et al., 2011).

Besides, B can be involved in many processes as membrane potential, plasmalemma-bound enzymes and ion fluxes across membranes (Blaser-Grill et al., 1989; Goldbach et al., 2001), cytoskeletal proteins (Yu et al., 2003), accumulation of phenolics and polyamines and nitrogen metabolism (Camacho-Cristobal et al., 2004; 2005; Camacho-Cristobal and Gonzalez-Fontes, 2007). For many plant species there is only a narrow range in critical tissue concentrations between boron deficiency and boron toxicity (Blamey et al., 1997). Boron toxicity exerts different effects on vascular plants, such as reduced root cell division, lower photosynthetic rates, and decreased lignin and suberin levels (Nable et al., 1997; Reid, 2007). Accordingly, a reduced growth of shoots and roots is typical of plants exposed to high B levels (Nable et al., 1990). Different plant species respond differently to different levels of boron. B-deficiency reduced photosynthetic efficiency of sunflower leaves (El-Shintinawy, 1999). Boron application increased the rate of fruiting of grain crops and decreased the incidence of bare ears in maize and decreased empty pods of soybean and empty grains in rice (Li and Liang, 1997). Effects of foliar applications of B to soybean included increased yield and larger seed size (Gascho and McPherson, 1997). Although the emergence of pea was affected by excess boron, the plant height and the number of nodes were reduced (Bagheri et al., 1992).

Besides, yield reduction by 10 to 20% was estimated in rice tolerant varieties irrigated with the excess boron during rainless dry seasons (Koohkan et al., 2008). Ayfer et al. (2006) reported that the total amount of boron in wheat shoots showed a highly significant negative correlation with decreases in shoot dry weight under boron supply. In tomato plants, excess boron depressed fresh and dry weights and reduced the yield (Eraslan et al., 2007a; Kaya et al., 2009). Fresh and dry plant matter of melon plants decreased significantly with increasing B concentrations, while B concentration of plant leaves, stems, and fruits increased significantly with increasing B (Goldberg et al., 2003). Tariq and Mott (2006) observed that toxic effects accompanied by considerable yield decreases at higher levels of B supply in radish. In barley, the symptoms of boron toxicity developed

on mature foliage, usually starting as chlorotic leaf tips or chlorotic patches at leaf margins near the leaf base and eventually turned necrotic and leaves sometimes dropped (Kluge and Podleska, 1985; Poole et al., 1991). Addition of boron to the soil increased the symptoms of boron toxicity in barley. These symptoms include decreased shoot growth and substantial reduction in grain and straw yield (Riley 1987, Moody et al., 1993; Nable et al., 1997).

The role of growth modulators in alleviation of boron and other abiotic stresses is clearly evident in many plants. Wassif et al. (1999) reported that the yield of sugar beet plants significantly increased by increasing sulfur level at any levels of excessive boron. In addition, Gunes et al. (2000) indicated that Zn treatments reduced the inhibitory effect of boron on growth of tomato plants. Gunes et al. (2007a) concluded that silicon alleviates the sodicity and B toxicity in spinach and tomato plants grown in boron toxic soil. Amer and Katta (1990) stated that the exogenous addition of certain amino acids such as proline, glutamic acid and arginine at seedling stage in barley minimized the loss of relative grain yield under salinity condition through increasing the plants salt tolerance capacity. The ability of salicylic acid (SA) to produce a protective effect on plants under external stress conditions has raised a considerable interest in researchers. Mishra and Choudhuri (1999) found that deterioration of heavy metal stresses was partially alleviated by exogenous application of salycilic acid in *Oryza sativa*. The exogenous application of 0.5 mM of soil incorporated salicylic acid significantly decreased the hazardous effect of boron toxicity in maize (Gunes et al., 2007b). Salicylic acid application positively affected the dry weight storage root of carrots grown under boron toxicity (Eraslan et al., 2007b). In plants, calcium ions are ubiquitous signaling second messengers. There are a number of external stimuli lead to changes in cytosolic calcium concentrations, which in turn, regulate a wide variety of responses and several physiological processes (Bush, 1995). Nable et al. (1997) showed that addition of Ca in irrigation water may result in reduction in B accumulation in plants. Sotiropoulos et al. (1999) reported that Ca partially protected kiwifruit plants against the harmful effects of B excess. The degree of tolerance was increased by increment of Ca concentration, where high Ca concentration reduced the boron absorption. Also, the high B and Ca levels in the nutrient solution decreased P, K, Mg, and Zn concentrations. Turan et al. (2009) concluded that dry shoot and root of wheat plants were strongly depressed and decreased by boron; however, Ca applications reduced the inhibitory effect of B on the plant growth.

Boron toxicity is a serious economic problem for agriculture in dry areas of West Asia and North Africa including Turkey, Syria, Iraq, Jordan, Egypt, Libya and Morocco (Yau and Ryan, 1994). High B concentration may occur naturally in soil and ground waters, or be added to the soil from mining, fertilizers, irrigation water, flying ash and industrial pollution (Nable et al., 1997; Alpaslan and Gunes, 2001).

Moreover, the poor drainage of saline soils may be responsible for excessive accumulation of boron in the soil solution (Grieve and Poss, 2000). Re-use of drainage water is a necessary alternative in the Northen part of Nile Delta region in Egypt due to the shortage of fresh water. Therefore, farmers use irrigation water from open drains, which has boron content derived from sewage and/or industrial effluents (Abo-Waly et al., 1997).

In our knowledge, little is known about the involvement of growth modulators such as salicylic acid, calcium chloride, ascorbic acid, and the amino acids glycine and glutamic acid in counteracting with the B-mediated retardations in barley. Therefore, this study was carried out to understand the role of B deficiency and toxicity in barley growth and yield as well as to test the involvement of some plant growth modulators.

Results

Growth parameters

Application of 0.5 and 1.5 mg L^{-1} boron increased shoot and root fresh weights of barley at vegetative and flowering stages, compared to control [non-boron (NB) treated plants] (Table 1). The maximum increase in shoot and root weights were obtained with application of 1.5 mg L^{-1} B. However, increment of B concentration up to 6.0 mg L^{-1} decreased both parameters at both growth stages.

The maximum decrease for shoot and root fresh weights was observed in application of 6.0 mg L^{-1} B. Two-way ANOVA revealed highly significant effect of different boron concentrations ($P \leq 0.05$ and 0.01) on shoot and root fresh weights of barley, compared to NB control plants at both vegetative and flowering stages. Application of 0.5 and 1.5 mg L^{-1} B increased shoot and root dry weights of barley during all measured growth stages (Table1). Gradual increase in B concentration up to 6.0 mg L^{-1} had a reverse effect on both parameters. Application of 1.5 mg L^{-1} B increased shoot height about 1% and 5% and leaf area by about 4.5% and 7% at vegetative and flowering stages, respectively, as compared to control. However, addition of 3 and 6 mg L^{-1} B significantly decreased shoot height about 18% and 28% at vegetative stage and about 31% and 49% at flowering stage, respectively. Leaf area was significantly decreased with application of 3 and 6 by 20% and 30% at vegetative and by 32% and 50% at flowering stage, respectively (Table1).

Chl a and Chl b content

At vegetative stage, increasing B concentration up to 1.5 mg L^{-1} B increased Chl a and Chl b, compared to control (Table 2). The Presence of both 3 and 6 mg L^{-1} B in the nutrient solution caused a highly significant decrease of both Chl a and Chl b. At flowering stage, increasing B concentration to 1.5 mg L^{-1} B increased Chl a and Chl b compared to those of control (Table 2). Presence of both 3.0 and 6.0 mg L^{-1} B in the nutrient solution caused a highly significant decrease of both Chl a and Chl b.

Yield parameters

Addition of 0.5 mg L^{-1} B significantly increased the weight of straw and grains by 5.5%, as compared control. Increasing B concentration to 1.5 mg L^{-1} caused a significant increase in straw and grain weight (Table 3).

On the other hand, straw and grains weights showed a highly significant decrease in response to application of 3 and 6 mg L^{-1} B, compared to control. Weight of 100-grains was increased by about 3% and 7% by the addition of 0.5 and 1.5 mg L^{-1} B, while application of 3 and 6 mg L^{-1} B decreased this parameter by about 24% and 31% compared to those of

Table 1. Shoot and root fresh and dry weights (g plant^{-1}) of barley treated with different boron concentrations at vegetative and flowering stages.

Stage	Boron concentration (mg L^{-1})	Shoot fresh weight (g plant^{-1})	Root fresh weight (g plant^{-1})	Shoot dry weight (g plant^{-1})	Root dry weight (g plant^{-1})	Shoot height (cm)
Vegetative	0.0	2.48 ± 0.25	0.22 ± 0.003	0.400 ± 0.00	0.040 ± 0.000	21.7 ± 2.0
	0.5	2.71 ± 0.33 *	0.23 ± 0.004 ns	0.405 ± 0.06 ns	0.040 ± 0.002 ns	22.0 ± 1.3 ns
	1.5	2.75 ± 0.13 *	0.24 ± 0.003 *	0.411 ± 0.02 *	0.041 ± 0.001ns	22.2 ± 1.3 ns
	3.0	2.24 ± 0.20 *	0.16 ± 0.003 **	0.335 ± 0.10**	0.030 ± 0.001 **	17.8 ±1.4**
	6.0	1.86 ± 0.67 **	0.13 ± 0.004 **	0.278 ± 0.02 **	0.020 ± 0.001 **	15.0 ± 1.2**
	L.S.D 0.05	0.21	0.02	0.01	0.01	2.30
	L.S.D 0.01	0.29	0.03	0.01	0.01	3.27
Flowering	0.0	4.14 ± 0.21	0.66 ± 0.02	0.57 ± 0.004	0.110 ± 0.000	73.8 ± 1.02
	0.5	4.29 ± 0.28 **	0.69 ± 0.03 *	0.58 ± 0.006 *	0.111 ± 0.001 *	76.5 ± 0.63 *
	1.5	4.33 ± 0.24 **	0.71 ± 0.03 **	0.59 ± 0.014 **	0.113 ± 0.001**	77.8 ± 1.97 **
	3.0	3.08 ± 0.22 **	0.48 ± 0.04 **	0.42 ± 0.003 **	0.080 ± 0.001 **	53.0 ± 1.70 **
	6.0	2.28 ± 0.28 **	0.39 ± 0.03 **	0.31 ± 0.014 **	0.060 ± 0.002 **	37.5 ± 1.10 **
	L.S.D 0.05	0.09	0.01	0.01	0.001	2.64
	L.S.D 0.01	0.13	0.02	0.01	0.002	3.84

* Results significantly different from control at (P< 0.05). ** Results significantly different from control at (P< 0.01). ns: non significant.

Table 2. Leaf area and Chlorophyll (a and b) contents (mg/cm^2) of barley treated with different boron concentrations at vegetative and flowering stages.

Stage	Boron concentration (mg L^{-1})	Leaf area (cm^2)	Chl a (mg/cm^2)	Chl b (mg/cm$^{2)}$
Vegetative	0.0	4.4 ± 0.02	46.8 ± 0.95	22.5 ± 0.38
	0.5	4.5 ± 0.03 ns	47.6 ± 1.0 ns	23.4 ± 0.46 ns
	1.5	4.6 ± 0.07 *	48.2 ± 2.0 ns	24.1 ± 0.67 *
	3.0	3.5 ± 0.03 **	40.0 ± 2.1 **	19.5 ± 0.57 **
	6.0	3.0 ± 0.12 **	33.2 ± 1.3 **	17.8 ± 0.83 **
	L.S.D 0.05	0.114	2.76	1.47
	L.S.D 0.01	0.210	3.92	2.51
Flowering	0.0	23.3 ± 0.5	92.6 ± 1.2	44.3 ± 1.0
	0.5	24.5 ± 0.3 *	93.6 ± 1.1 *	45.1 ± 1.6 *
	1.5	24.9 ± 0.5 **	94.5 ± 1.3 **	45.9 ± 1.4 **
	3.0	16.4 ± 1.0 **	80.0 ± 2.0 *	37.0 ± 2.0 **
	6.0	11.7 ± 0.7 **	70.9 ± 1.7 **	33.4 ± 2.2**
	L.S.D 0.05	1.1	0.96	0.63
	L.S.D 0.01	1.6	1.02	0.98

* Results significantly different from control at (P< 0.05). ** Results significantly different from control at (P< 0.01). ns: non significant.

Table 3. Weight of straw and grains (g/20 individuals), weight of 100-grains (g) and B content (mg/kg DW) of barley grains treated with different B concentrations.

Boron concentration (mg L^{-1})	Straw	Grains	Weight of 100-grains	B
0.0	18.0 ±1.0	10.8 ± 0.9	2.9 ± 0.25	0.32 ± 0.02
0.5	19.0 ±1.2*	11.4 ± 1.3*	3.0 ± 0.30 ns	0.38 ± 0.02*
1.5	19.7 ±1.4*	11.9 ± 1.0*	3.1 ± 0.21*	0.41 ± 0.02*
3.0	11.0 ± 2.0**	6.6 ± 1.1**	2.2 ± 0.32**	0.46 ± 0.03*
6.0	7.8 ± 2.3**	4.7 ± 1.8**	2.0 ± 0.34*	0.51 ± 0.03*
L.S.D 0.05	0.98	0.58	0.11	0.05
L.S.D 0.01	1.91	1.14	0.21	0.10

* Results significantly different from control at (P< 0.05). ** Results significantly different from control at (P< 0.01). ns: non significant.

control, respectively. Besides, the addition of 6.0 mg L^{-1} B increased boron content in grains by about 59%.

Alleviation of boron toxicity

The highest efficiency in alleviation of adverse effects of B was obtained in salicylic acid (SA) and $CaCl_2$ among the five applied modulators, which followed by AA, Gly and GA, respectively (Table 4). The maximum significant recovery of shoot fresh weight of barley, treated with 3.0 mg L^{-1} B was induced by 18% under 1 mM SA application at vegetative stage. However, at flowering stage the highest recovery (34%) was obtained by 5 mM $CaCl_2$ applications. On the other hand, the maximum recovery of root fresh weight of barley treated with 3 mg L^{-1} B was induced under 1 mM SA and 5 mM $CaCl_2$ application at vegetative (25%) and flowering (35%) stages, respectively. Based on these observations, mineral contents were determined at 3 mg L^{-1} B treated barley under addition of 5 mM $Cacl_2$ and 1 mM SA (Table 5).

The presence of 1 mM SA or 5 mM $CaCl_2$ in the nutrient solution induced a reduction in B content in tissues of B-treated plants during all growth stages (the maximum decrease of 36% for shoots and 32% for roots was observed). In addition, the presence of 1 mM SA or 5 mM $CaCl_2$ in the nutrient solution reduced the P content in B-treated barley

tissues during all growth stages (the maximum decrease was 41% for shoots and 43% for roots). Also, the presence of 1 mM SA or 5 mM $CaCl_2$ in the nutrient solution reduced K content in B-treated barley tissues during all growth stages (the maximum decrease was 41% for shoots and 40% for roots). Moreover, the presence of 1 mM SA acid or 5 mM $CaCl_2$ in the nutrient solution reduced N content in B-treated barley tissues during all growth stages (the maximum decrease of was observed for both shoots and roots).

Discussion

The present study showed that barley growth was affected differently at various B levels (Table 1). When B was applied as 0.5 and 1.5 mg L^{-1}, all of the measured growth parameters significantly increased, especially during the flowering stage as compared to those of control.

Greater leaf area coupled with higher Chl a and Chl b contents were also detected at the same B concentrations (Table 2), suggesting that sufficient B concentration can promote barley leaf development. Moreover, straw and grains weights, yield parameters and B accumulation in barley grains were significantly increased under both B concentrations. The results were in agreement with the findings of Hu and Brown (1997) and Takano et al. (2005). Yu and Bell (1998) indicated that addition of boron in the nutrient solution increased dry matter and plant height of rice. Shoot and root mass of tobacco plants treated with only low B concentration was decreased, compared to plants sufficiently supplied with B (Hu and Brown, 1994).

In intact plant tissue the boron exists in water-soluble forms. The majority of boron seems to be localized in the apoplastic region as boric acid and water insoluble forms under stress condition (Mahboobi et al., 2001). This might be the main cause of tolerance induced under sufficient (optimum) boron application. The vital roles of boron are related to its capacity to form diester bridges between *cis* hydroxyl-containing molecules such as those present in plant cell walls and membranes (Bolanos et al., 2004; Nuttall, 2000).

Rapid boron-induced changes in membrane function could be attributed to the formation of boron complexing membrane constituents. The results showed that the addition of 3 mg L^{-1} boron has its inhibitory effects on barley growth. Boron toxicity resulted in a decrease in all the measured growth parameters. Lesser leaf area coupled with decreased Chl a and Chl b contents were also detected at the same B concentration, which consequently declined leaf development. Moreover, yield parameters were also decreased while B concentration in grains was significantly increased. These inhibitions reflected the toxic effect of excessive B in the nutrient solution on barley growth and yield. These results are in agreement with those obtained by Gunes et al. (2000), Aydin and Sevinc (2006) and Hosseini et al. (2007). Yau (2010) stated that the physiology and mechanisms of boron toxicity are not well understood. However, B uptake is closely related to the B concentration of the soil solution and the rate of water transpiration.

When B concentration in soil solution is large, B is distributed throughout the plant in normal transpiration stream, causing the accumulation of B in leaf margins and leaf tips. Excessive amounts of B appear to inhibit the formation of starch from sugars or results in the formation of carbohydrate complexes, and failing in grain filling. The reason of boron toxicity is still unclear, but, the complex-forming ability of boron may be the cause of this toxicity (Nuttall, 2000, Brown et al. 2002; Bolanos et al. 2004; Camacho-Cristobal et al. 2008). The inhibition of barley growth caused by application of 3 mg L^{-1} B was improved at different levels by application of some plant growth modulators (Table 4). A higher leaf area coupled with higher contents of Chl a and Chl b as well as increased yield parameters were detected in the presence of different concentrations of the applied growth modulators in plants exposed to 3 mg L^{-1} B application (Table 5). This reveals the efficiency of these modulators to ameliorate the toxic effect of B on barley growth and yield. The ameliorative effect of glutamic acid and glycine on barley growth could be explained as these amino acids were shown to have a role in inducing tolerance under drought stress in cotton, rice and maize (Thakur and Rai, 1982; Yang et al., 2000). In epidermal cells of *Vicia faba* leaf, some amino acids including glutamic acid stimulated stomatal opening leading to promote the K^+ influx into the guard cells. Glycine-rich proteins have been found in the cell walls in many higher plants, which form a third group of structural protein components of the wall (Ringlia et al 2001). The alleviation of inhibitory effect of B treatment using ascorbic acid could be attributed to its role as an antioxidant against reactive oxygen species that are formed from photosynthetic and respiratory processes (Pastori et al., 2003).

Foliar application of ascorbic acid was found to have positive effects on growth parameters in lemon grass (Tarraf et al., 1999), enhance photosynthesis in soybean (Gloden-Goldhirsh et al., 1995), and increase macronutrient contents (N, P and K) in sweet pepper (Talaat, 2003). Application of 3 mg L^{-1} B only induced the accumulation of B, N, P and K in barley shoots and roots compared to those determined in presence of SA or $CaCl_2$ (Table 6). Higher accumulation of B in barley shoots than roots in the present study is in close agreement with the findings of many investigators who demonstrated that B is taken up by the roots in the form of boric acid and transported through the xylem to the shoots. Thus, B concentrations in roots remain relatively low compared to those in leaves (Nable et al., 1997).

In the present study, the high ion content of barley tissues in response to addition of B is in agreement with the results obtained by many researchers such as Eraslan et al. (2008, 2007b) and Koohkan et al. (2008). There are a number of reported interactions between B and the other nutrients. Shelp and Shattuck (1987a, b) reported decrease of re-translocation of Cu, N, and Zn to sink tissues. However, overall increase of P under increment of B concentration suggests a promoted remobilization of P in plant tissues.

In agreement with our results, Wimmer et al. (2003) indicated that the slight tendency toward higher intercellular soluble K concentrations might indicate some membrane damage resulting in higher K leakage into the apoplastic space. Moreover, B functions in the regulation of plant membranes and ATPase of corn is a possible component of transport processes leading to a reduced capacity for the absorption of phosphate (Tariq and Mott, 2007). Also, effects of boron and membrane permeability could lead to association between B and K. The stimulation of K accumulation by ATPase proton pumps which may account for positive correlation between K and B recommended by Shorrocks (1990). Therefore, injured plasma membranes of barley tissues under excess B (3 mg L^{-1}) stress in our experiments may lose their control mechanism on the diffusions of ions as evidenced by a high influx of K, N and P. However, our results clearly demonstrated that B treated barley tissues responded positively to the five tested alleviators at the following sequence: salicylic acid >calcium

Table 4. Effect of different concentrations of glutamic acid (GA), glycine (Gly), ascorbic acid (AA), salicylic acid (SA) and calcium chloride ($CaCl_2$) on shoot and root fresh weight (g plant-1) of 3.0 (mg L-1)B treated barley at vegetative and flowering stages.

Treatment	Shoot				Root			
	Fresh weight		Dry weight		Fresh weight		Dry weight	
	Vegetative	Flowering	Vegetative	Flowering	Vegetative	Flowering	Vegetative	Flowering
3.0 mg/L B	2.24 ± 0.20	3.08 ± 0.24	0.335 ± 0.0	0.42 ± 0.03	0.16 ± 0.002	0.48 ±0.02	0.030 ± 0.001	0.080 ± 0.00
+ 1.0 mM GA	2.25 ± 0.13 ns	3.08 ± 0.22 ns	0.336 ± 0.01 ns	0.42 ± 0.02 ns	0.16 ± 0.003 ns	0.48 ±0.03 ns	0.030 ± 0.001 ns	0.080 ± 0.00 ns
+ 3.0 mM GA	2.26 ± 0.2 ns	3.10 ± 0.15 ns	0.338 ± 0.0 ns	0.42 ± 0.01 ns	0.17 ± 0.003*	0.48 ±0.03 ns	0.030 ± 0.001 ns	0.080 ± 0.00 ns
+ 1.0 mM Gly	2.32 ± 0.33 *	3.20 ± 0.22 *	0.346 ± 0.02 **	0.44 ± 0.03 **	0.17 ± 0.006*	0.50 ±0.04**	0.030 ± 0.001 ns	0.082 ± 0.00**
+ 3.0 mM Gly	2.28 ± 0.13 ns	3.14 ± 0.25 ns	0.340 ± 0.0 ns	0.43 ± 0.02**	1.17 ± 0.004*	0.49 ±0.04 ns	0.030 ± 0.001 ns	0.080 ± 0.00 ns
+ 2.0 mM AA	2.34 ± 0.4 **	3.20 ±0.20 **	0.350 ± 0.01**	0.44 ± 0.02 **	0.17 ±0.003 *	0.53 ±0.03 **	0.030 ± 0.001 ns	0.082 ± 0.00**
+ 5.0 mM AA	2.40 ± 0.33**	3.25 ± 0.30 **	0.357 ± 0.01**	0.46 ± 0.01 **	0.17 ± 0.002 *	0.53 ±0.02 **	0.031 ± 0.002*	0.089 ±0.00**
+ 1.0 mM SA	2.64 ± 0.27**	4.10 ± 0.26 **	0.394 ± 0.01 **	0.56 ± 0.02 **	0.20 ± 0.001 **	0.64 ± 0.02 **	0.040 ± 0.001**	0.113 ± 0.00**
+ 5.0 mM SA	2.52 ± 0.54**	3.87 ± 0.26**	0.376 ± 0.01 **	0.53 ± 0.02 **	0.18 ± 0.004 **	0.59 ± 0.02 **	0.032 ± 0.002**	0.098 ± 0.00**
+ 1.0 mM $CaCl_2$	2.46 ±0.13**	3.78 ± 0.23 **	0.368 ± 0.02 **	0.52 ± 0.02 **	0.18 ±0.002 **	0.58 ± 0.04 **	0.033 ± 0.001**	0.096 ± 0.00**
+ 5.0 mM $CaCl_2$	2.61 ± 0.2**	4.14 ± 0.20 **	0.390 ± 0.0**	0.57 ± 0.01**	0.20 ± 0.001 **	0.65 ± 0.02 **	0.040 ± 0.001**	0.110 ± 0.00**
L.S.D 0.05	0.06	0.12	0.01	0.01	0.01	0.01	0.001	0.002
L.S.D 0.01	0.08	0.22	0.01	0.01	0.01	0.02	0.01	0.01

* Results significantly different from control at (P < 0.05). ** Results significantly different from control at (P < 0.01). ns: non significant

Table 5. Effect of different concentrations of glutamic acid (GA), glycine (Gly), ascorbic acid (AA), salicylic acid (SA) and calcium chloride ($CaCl_2$) on leaf area, Chl a and Chl b of 3.0 mg/L B treated barley at vegetative and flowering stages.

Treatment	Leaf area (cm^2)		Chl a (mg/cm^2)		Chl b ($mg/cm^{2)}$	
	Vegetative	Flowering	Vegetative	Flowering	Vegetative	Flowering
3.0 mg/L B	3.55 ± 0.03	16.44 ± 1.00	40.0 ± 2.1	86.1 ± 1.8	19.5 ± 0.57	38.2 ± 2.0
+ 1.0 mM GA	3.56 ± 0.03 ns	16.47 ± 0.51 ns	40.1 ± 1.3 ns	86.3 ± 1.2 ns	19.5 ± 0.89 ns	39.2 ±1.2 ns
+ 3.0 mM GA	3.58 ± 0.03 ns	16.52 ± 0.92 ns	40.2 ± 1.2 ns	86.4 ± 2.0 *	19.7 ± 0.89 ns	40.1 ± 2.3 *
+ 1.0 mM Gly	3.85 ± 0.05 **	18.60 ± 0.97 **	41.5 ± 1.0 ns	86.2 ± 2.2 ns	20.9 ± 0.94 *	40.5 ± 1.1 **
+ 3.0 mM Gly	3.61 ± 0.06 ns	17.29 ± 1.10 ns	40.9 ± 1.1 ns	86.1 ± 2.2 ns	19.9 ± 0.97 ns	41.1 ± 2.1 **
+ 2.0 mM AA	3.80 ± 0.04 **	19.19 ±1.00 **	42.6 ± 2.0 ns	88.0 ± 1.8 **	22.2 ± 1.10 *	42.2 ± 2.7 **
+ 5.0 mM AA	3.95 ± 0.07 **	19.11 ± 0.22 **	42.0 ± 1.6 ns	88.0 ± 1.7 **	22.2 ± 1.00 *	43.0 ± 2.3 **
+ 1.0 mM SA	4.45 ± 0.02 **	23.21 ± 0.87 **	46.2 ± 1.8 **	91.2 ± 2.1 **	25.2 ± 0.82 **	44.8 ± 1.7 **
+ 5.0 mM SA	3.87 ± 0.07 **	20.98 ± 0.93 **	44.2 ± 1.5 **	89.5 ± 1.7 **	22.9 ± 1.00 **	42.9 ± 2.1 **
+ 1.0 mM $CaCl_2$	3.96 ± 0.08 **	20.25 ± 1.50 **	43.3 ± 1.5 *	90.2 ± 2.1**	22.9 ± 0.98 **	42.8 ± 1.3 **
+ 5.0 mM $CaCl_2$	4.43 ± 0.04 **	23.35 ± 0.78 **	46.5 ± 1.4 **	92.1 ± 1.3**	24.9 ± 0.79 **	44.9 ± 1.2 **
L.S.D 0.05	0.08	1.54	2.61	0.28	2.5	0.96
L.S.D 0.01	0.11	2.09	3.54	0.49	3.1	1.87

* Results significantly different from control at (P< 0.05). * Results significantly different from control at (P< 0.01). ns: non significant

Table 6. Mineral content (%) of 3.0 mg/L B treated barley in presence of SA or $CaCl_2$ at various growth stages.

Stage	Treatment	Boron (%)		Nitrogen (%)		Phosphorus (%)		Potassium (%)	
		Shoot	Root	Shoot	Root	Shoot	Root	Shoot	Root
Vegetative	3.0 mg/L B	9.4 ± 0.81	3.0 ± 0.34	5.3 ± 0.33	4.4 ± 0.41	0.54 ± 0.02	0.68 ± 0.03	6.2 ± 0.31	0.75 ± 0.04
	+ 1.0 mM SA	7.1 ± 0.75 **	2.3 ± 0.30 **	3.6 ± 0.31 **	2.8 ± 0.32 **	0.37 ± 0.02 **	0.44 ± 0.02 **	4.3 ± 0.25 **	0.51 ± 0.01**
	+ 5.0 mM $CaCl_2$	7.1 ± 0.72 **	2.3 ± 0.18 **	3.6 ± 0.21 **	2.8 ± 0.30 **	0.36 ± 0.02 **	0.44 ± 0.01 **	4.3 ± 0.24 **	0.51 ± 0.01**
	L.S.D 0.05	1.43	0.29	0.52	0.62	0.03	0.036	0.49	0.04
	L.S.D 0.01	2.07	0.42	0.75	0.89	0.05	0.051	0.71	0.06
Flowering	3.0 mg/L B	13.9 ± 0.89	4.5 ± 0.36	5.5 ± 0.53	4.9 ± 0.51	0.56 ± 0.03	0.60 ± 0.02	6.6 ± 0.40	1.64 ± 0.12
	+ 1.0 mM SA	9.8 ± 0.92 **	3.2 ± 0.17 **	3.4 ± 0.30 **	2.8 ± 0.32 **	0.33 ± 0.02**	0.34 ± 0.01**	3.9 ± 0.25 **	1.0 ± 0.01**
	+ 5.0 mM $CaCl_2$	9.7 ± 0.46 **	3.2 ± 0.16 **	3.4 ± 0.21 **	2.8 ± 0.31 **	0.33 ± 0.02**	0.34 ± 0.01 **	3.9 ± 0.24 **	1.0 ± 0.01**
	L.S.D 0.05	1.46	0.43	0.70	0.7	0.04	0.03	0.55	0.12
	L.S.D 0.01	2.12	0.62	1.02	0.1	0.06	0.04	0.79	0.17
Harvesting	3.0 mg/L B	18.5 ± 1.03	6.8 ± 0.72	5.0 ± 0.46	5.13 ± 0.42	0.52 ± 0.02	0.91 ± 0.03	7.6 ± 0.39	0.57 ± 0.03
	+ 1.0 mM SA	12.0 ± 1.11 **	4.7 ± 0.63 **	3.0 ± 0.25 **	3.10 ± 0.36 **	0.31 ± 0.01 **	0.52 ± 0.02 **	4.5 ± 0.38 **	0.34 ± 0.02 **
	+ 5.0 mM $CaCl_2$	11.9 ± 0.99 **	4.6 ± 0.59**	3.0 ± 0.35 **	3.10 ± 0.34 **	0.31 ± 0.01 **	0.52 ± 0.02 **	4.5 ± 0.36 **	0.34 ± 0.02 **
	L.S.D 0.05	1.94	1.2	0.57	0.67	0.025	0.04	0.73	0.05
	L.S.D 0.01	2.82	1.7	0.83	0.98	0.04	0.06	1.06	0.07

* Results significantly different from control at (P< 0.05). ** Results significantly different from control at (P< 0.01). ns : non significant

chloride > ascorbic acid > glycine > glutamic acid. Interestingly, treatment with salicylic acid or calcium chloride induced almost the same ameliorative effect on growth of B treated barley. Increasing salicylic acid concentration from 1 mM to 5 mM inhibited its ameliorative effect while increasing calcium chloride concentration from 1 mM to 5 mM stimulated its ameliorative effect. The dose dependent biphasic action of SA was shown also by Sahu et al (2010) in wheat concerning phosphate uptake. Therefore, the ameliorative impact of both salicylic acid (1 mM) and calcium chloride (5 mM) on 3 mg L^{-1} B treated barley growth stimulate more extensive investigation in lab experiments.

Materials and methods

Plant material

Barley grains (*Hordeum vulgare* L. cv. Giza 123) were obtained from Sakha research Station Kafr El-Shaikh Governorate. The grains (30 grains) were surface sterilized and germinated in pots filled with sandy soil (pH 7.5 and B concentration 0.4 mg L^{-1}). All pots were irrigated with distilled water for two weeks, then Hoagland solution (2.5 mM $Ca(NO_3)_2$, 3.0 mM KNO_3 , 0.17 mM KH_2PO_4, 1.5 mM $MgSO_4$, 50 µM Fe as (Na Fe DTPA), µM $MnSO_4$, 0.4 µM $ZnSO_4$, 0.2 µM $CuSO_4$ and 0.1 µM H_2 MoO_4) was added twice a week.

Boron treatment

The effect of boron on barley growth was studied by using elevated B concentrations of 0, 0.5, 1.5, 3.0 and 6.0 mg L^{-1} (as boric acid added to Hoagland solution). The efficiency of some growth modulators in alleviating the growth inhibition was evaluated under B stress. The following substances were added to Hoagland solution in the presence of 3.0 mg L^{-1} B: glutamic acid (1 or 3 mM), glycine (1 or 3 mM), ascorbic acid (2 or 5 mM), salicylic acid (1 or 5 mM) and calcium chloride (1 or 5 mM).

Experimental design and data analysis

Barley grains were cultivated and left to grow till the end of the season. Samples were collected at vegetative (22-day-old), flowering (45-day-old) and harvesting stages (92-day-old). Three sets of treatments were prepared for the different measurements. In the set I, plants irrigated with Hoagland solution without B addition; set II, plants irrigated with Hoagland solution with the addition of different B concentrations and set III, plants irrigated with Hoagland solution with the addition of different concentrations of the above mentioned plant growth modulators in the presence of 3.0 mg L^{-1} B. Each experiment was set up as randomized complete block (RCBD) with 3 replicates each containing a row of all treatments. Samples from each treatment were collected and subjected to the different measurements. Data was statistically analyzed using Analysis of variance (ANOVA) for RCBD followed by the computation of least significant difference (LSD) at $p \leq 0.5$ and 0.01 levels according to Cochran and Cox (1960).

Growth parameters

Samples harvested at different growth stages (vegetative, flowering and harvesting) were weighed to determine theri fresh weights, then oven-dried at 70^0C for 2 days and reweighed to determine the dry weights. Both fresh and dry weights were estimated as gm individual^{-1}. Leaf area (cm^2) was calculated at vegetative (22-day-old) and flowering (45-day-old) stages using portable area meter model Li-3000A Li-COR. Weight of both straw and grains were estimated as g per 20 individuals.

Photosynthetic pigments

The photosynthetic pigments (Chl a and Chl b) were estimated in barley leaves at vegetative and flowering stages using the Arnon (1949) proposed approach.

Mineral nutrient contents

The powdered oven dry plant materials (shoots, roots and grains) were exposed to acid digestion as follows: 0.2 g of plant sample was digested in 5 ml of H_2O_2 and 1 ml $HClO_4$ as described by Chapman and Pratt (1961). The extract of digested plant materials was used for the determination of mineral nutrient contents as follow: Nitrogen (N) content by micro-Kjeldahl (Page, 1982), Total phosphorus (P) content by spectrophotometer (Snell and Snell, 1967), potassium (K) content using flame photometer (Jackson, 1967), and boron content according to John et al. (1975).

References

Abo-Waly ME, Abo El-Khir AM, El-Kammah AM, Elshahawy ME (1997) Contribution of drainage water to the pollution of Burullus Lake by heavy metals. Proceedings of the international symposium on sustainable management of salt affected soils in the arid ecosystem organized by university of Ain Shams international soil science society. 419-433.

Alpaslan A, Gunes A (2001). Interactive effects of boron and salinity stress on the growth, membrane permeability and mineral composition of tomato and cucumber plants. Plant Soil. 236: 123–128.

Amer AF, Katta MI (1990) Induction of salt tolerance in plants by foliar application of certain amino acids. Zagazig J Agr Res. 17:499-530

Arnon DI (1949) Copper enzymes in isolated chloroplasts. Polyphenol oxidase in *Beta Vulgaris*. Plant Physiol. 24: 1-15.

Aydin A, Sevinc A (2006). The effect of boron (B) application on the growth and nutrient contents of maize in zinc (Zn) deficient soils. Bulg J Agric Sci. 12: 387-392.

Ayfer AT, Yazici A, Erdem H, Cakmak I (2006) Genotypic variation in tolerance to boron toxicity in 70 drum wheat genotypes. Turk J Agric For. 30: 49-58.

Bagheri A, Paull JG, Rathjen AJ, Ali SM, Moody DB (1992) Genetic variation in the response of Pea *(Pisum Sativum L.)* to high soil concentrations of boron. Plant Soil. 146(1-2): 261- 269.

Blamey FPC, Zollinger RK, Schneiter AA (1997) Sunflower production and culture. In Schneiter AA (ed) Sunflower technology and production. American Society of Agronomy, Madison, Wis. p 595-670

Blaser-Grill J, Knoppik D, Amberger A, Goldbach H (1989) Influence of boron on the membrane potential in *Elodea densa* and *Helianthus annuus* roots and H+ extrusion of suspension cultured *Daucus carota* cells. Plant Physiol. 90: 280-284.

Blevins DG, Lukaszewski KM (1998) Boron in plant structure and function. Annu Rev Plant Phys 49: 481- 500.

Bolanos L, Lukaszewski K, Bonilla I, Blevins D (2004) Why boron. Plant Physiol Bioch 42(11): 907-912.

Brown PH, Bellaloui N, Wimmer MA, Bassil ES, Ruiz J, Hu H (2002) Boron in plant biology. Plant Biol. 4: 205-223.

Bush DS (1995) Calcium regulation in plant cells and its role in signaling. Annu Rev Plant Phys. 46:95-122.

Camacho-Cristobal JJ, Gonzalez-Fontes A (2007) Boron deficiency decreases plasmalemma H+ ATPase expression and nitrate uptake, and promotes ammonium assimilation into asparagine in tobacco roots. Planta. 226: 443- 451.

Camacho-Cristobal JJ, Maldonado JM, Gonzalez-Fontes A (2005) Boron deficiency increases putrescine levels in tobacco plants. Plant Physiol. 162: 921-928.

Camacho-Cristobal JJ, Lunar L, Lafont F, Baumert A, Gonzalez-Fontes A (2004) Boron deficiency causes accumulation of chlorogenic acid and caffeoyl polyamine conjugates in tobacco leaves. Plant Physiol. 161: 879-881.

Camacho-Cristobal JJ, Herrera-Rodriguez MB, Beato VM, Rexach J, Navarro-Gochicoa MT, Maldonado JM (2008) The expression of several cell wall-related genes in Arabidopsis roots is down-regulated under boron deficiency. Environ Exp Bot. 63: 351-358.

Chapman HD, Pratt PF (1961) Methods of Soil Analysis for Soils, Plant and Water. University of California, Agriculture Publications, Barkely, California, pp. 17.

Cochran WG, Cox GM 1960. Experimental Designs, 2nd ed. John Welly, New York, pp. 293-316.

El-Shintinawy F (1999) Structural and functional damage caused by boron deficiency in sunflower leaves. Photosynthetica. 36(4): 565-573.

Eraslan F, Inal A, Gunes A, Alpaslan M (2007a) Boron toxicity alters nitrate reductase activity, proline accumulation, membrane permeability and mineral constituents of tomato and pepper plants. Sci Hort. 30(60): 981-994.

Eraslan F, Inal A, Gunes A, Alpaslan M (2007b). Impact of exogenous salicylic acid on the growth, antioxidant activity and physiology of carrot plants subjected to combined salinity and boron toxicity. Sci Hort. 113: 120-128.

Eraslan F, Inal A, David JP, Gunes A (2008) Interactive effects of salicylic acid and silicon on oxidative damage and antioxidant activity in spinach (*Spinacia oleracea* L. cv. Matador) grown under boron toxicity and salinity. Plant Growth Regul. 55(3): 207- 219.

Gascho GJ, McPherson RM (1997) A foliar boron nutrition and insecticide program for soybeans. In: Bell RW, Rerkasem B (eds.) Boron in Soils and Plants. Kluwer Academic Publishers Netherland. pp. 11-15.

Goldbach HE, Wimmer M (2007) Boron in plants and animals: Is there a role beyond cell-wall structure? J Plant Nutr Soil Sc. 170: 39–48.

Goldbach HE, Yu Q, Wingender R, Schulz M, Wimmer M, Findeklee P, Baluska F (2001) Rapid response of roots to boron deprivation. J Plant Nutr Soil Sc. 164: 173-181.

Goldberg S, Shouse PJ, Lesch SM, Grieve CM, Poss JA, Forster HS, Suarez DL (2003) Effect of high boron application on boron content and growth of melons. Plant Soil. 265(2): 403-411.

Gloden-Goldhirsh A, Mozafar AA, Oertli JJ (1995) Effect of ascorbic acid on soybrean seedlings grown on medium containing a high concentration of copper. J Plant Nutr. 18:1735-1741.

Grieve CM, Poss JA (2000) Wheat response to interactive effects of boron and salinity. J Plant Nutr. 23:1217-1226.

Gunes A, Alpaslan M, Cikili Y, Ozcan H (2000) The effect of zinc on alleviation of boron toxicity in tomato plants. Turk J Agric For. 24: 505-509.

Gunes A, Inal A, Bagci EG, Pilbeam JD (2007a). Silicon-mediated changes of some physiological and enzymatic parameters symptomatic for oxidative stress in spinach and tomato grown in sodic-B toxic soil. Plant Soil. 290(1-2): 103-114.

Gunes A, Inal A, Alpaslan M, Eraslan F, Bagci EG, Cicek N (2007b). Salicylic acid induced changes on some physiological parameters symptomatic for oxidative stress and mineral nutrition in maize (*Zea mays* L.) grown under salinity. Plant Physiol. 164:728–736.

Hosseini SM, Maftoun M, Karimian N, Rounaghi A, Emam Y (2007) Effect of zinc and boron interaction on plant growth and tissue nutrient concentration of corn. J Plant Nutr. 30: 773-781.

Hu H, Brown PH (1994) Localization of boron in cell walls of squash and tobacco and its association with pectin: Evidence for a structural role of boron in cell walls. Plant Physiol. 105: 681-689.

Jackson ML (1967) Soil chemical analysis, 1966. Ed. Prentice Hall of India Private Limited, New Delhi, pp. 205.

John MK, Chauch HH, John HN (1975) Application of improved azomethine-H method to determination of boron in soil and plant. Anal Lett. 8: 559-568.

Kaya C, Tuna AL, Dikilitas M, Ashraf M, Koskeroglu S, Guneri M (2009) Supplementary phosphorus can alleviate boron toxicity in tomato. Sci Hort. 121:284–288.

Kluge R, Podlesak W (1985) Plant critical levels for the evaluation of boron toxicity in spring barley (*Hordeum Vulgare* L.). Plant Soil. 83(3) 381-388.

Koohkan H, Maftoun M, Emam Y (2008) Nitrogen and boron interactional effect on growth and shoot nitrogen and boron content in rice. J Crop Prod Proc. 12(44): 171-182.

Li Y, Liang H (1997) Soil boron content and the effects of boron application on yields of maize, soybean, rice, and sugarbeet in Heilongjiang Province, P.R. China. In: Bell RW, Rerkasem B (eds.) Boron in Soils and Plants. pp. 17-21.

Mahboobi H, Yucel M, Oktem HA (2001) Cell wall uronic acid concentrations of resistant and sensitive cultivars of wheat and barley under boron toxicity. J Plant Nutr. 24(12): 1965- 1973.

Mishra A, Choudhuri MA (1999) Effects of salicylic acid on heavy metal induced membrane deterioration mediated by lipoxygenase in rice. Biol Plantarum. 42: 409- 415.

Moody DB, Rathjen AJ, Cartwright B (1993) Yield evaluation of a gene for boron tolerance using backcross-dervied lines. In: Randall PJ, Delhaize E, Richards RA, Munns R (Eds), Genetic Aspects of plant mineral nutrition, Kluwer Academic Publishers, the Netherlands. pp. 363-366.

Nable RO, Banuelos GS, Paull JG (1997) Boron toxicity. Plant Soil. 193: 181-198.

Nable RO, Lance RCM, Cartwright B (1990) Uptake of boron and silicon by barley genotypes with differing susceptibilities to boron toxicity. Ann Bot. 66: 83-90.

Nuttall CY (2000) Boron tolerance and uptake in higher plants. Ph.D. Thesis, Department of Plant Science, University of Cambridge, UK

Page AL (1982) Methods of soil analysis, part 2: Chemical and Microbial Properties (2nd ed.) American Association of Agronomy, Madison, Wisconsin, USA. pp. 403–430.

Poole RT, Conover CA, Steinkamp K (1991) Symptoms of boron toxicity induced in foliage plants. Proc Fla State Hort Soc. 104: 301-303.

Riley MM (1987) Boron toxicity in barley. J. Plant Nutr. 10(9-16): 2109-2115.

Reid R (2007) Update on boron toxicity and tolerance in plants. In: Xu F, Goldbach HE, Brown PH, Bell RW, Fujiwara T, Hunt CD, Goldberg S, Shi L (eds) Advances in Plant and Animal Boron Nutrition. Springer, Dordrecht, The Netherlands. pp. 83–90.

Ringlia C, Keller B, Ryserb U (2001) Glycine-rich proteins as structural componentsof plant cell walls. Cell Mol Life Sci 58:1430–1441

Sahu GK, Kar M, Sabat SC (2010) Alteration in phosphate uptake potential of wheat plants co-cultivated with salicylic acid. Plant Physiol. 16(7): 326-328.

Saleem M, Khanif YM, Ishak F, Samsuri AW, Hafeez B (2011) Importance of Boron for Agriculture Productivity: A Review. Int Res J Agric Sci Soil Sci 1(8):293-300.

Shelp BJ, Shattuck VI (1987a) Boron nutrition and mobility and its relation to hollow stem and the elemental composition of greenhouse grown cauliflower. J Plant Nutr 10(2): 143-162.

Shelp BJ, Shattuck VI (1987b) Boron nutrition and mobility and its relation to the elemental composition of greenhouse grown root crops. I. Rutabaga. Commun Soil Sci Plan 18: 187-201.

Shorrocks VM (1990) Behavior, function and significance of boron in agriculture. Report on an International Workshop at St. John's College, Oxford, England. 23-25 July, 1990. Published by Borax Consolidated Limited, London. SW 1P 1H T.

Snell FD, Snell CT (1967) Colorimetric methods of analysis. D.Von Nastrand Company, Inc., pp. 551-552.

Sotiropoulos TE, Therios IN, Daimassi KN, Bosabalidis AM, Kofidis G (2002) Nutritional status, growth, CO_2 assimilation and leaf anatomical responses in two kiwi fruit species under boron toxicity. J Plant Nutr 25(6): 1249-1261.

Takano J, Miwa K, Yuan L, Wiren N, Fujiwara T (2005) Endocytosis and Degradation of BOR1, a Boron Transporter of *Arabidopsis thaliana* regulated by boron availability. P Natl Acad Sci USA 102: 12276-12281.

Talaat NB (2003) Physiological studies on the effect of salinity, ascorbic acid and putrescent of sweet pepper plant. Ph.D. Thesis, Faculty of Agricultural Cairo University.

Tariq M, Mott CJB (2007) Effect of Boron on the Behavior of Nutrients in Soil-Plant Systems: A Review. Asian J Plant Sci. 6 (1): 195-202.

Tariq M, Mott CJB (2006) Effect of boron supply on the uptake of micronutrients by radish (*Raphanus sativus L.*). J Agr Biol Sci 1(2): 1-8.

Tarraf SA, EL-Din KMG, Balbaa LK (1999) The response of vegetative growth, essential oil of lemon grass to foliar application of ascorbic acid, micotinamid and some micronutrients. Arab Univ J Agr Sci 7:247-259.

Thakur PS, Rai VK (1982) Dynamics of amino acid accumulation of two differentially drought resistant *Zea mays* cultivars in response to osmotic stress. Environ Exp Bot 22 (2): 221-226.

Turan MA, Taban N, Taban S (2009) Effect of calcium on the alleviation of boron toxicity and localization of boron and calcium in cell wall of wheat. Not Bot Horti Agrobo 37 (2): 99-103.

Wassif MM, El-Maghraby SE, Shabana MK, Ashour IA (1999) The use of elemental sulphur for controlling boron hazards of saline irrigation water. Proc Con On-Farm Irrigation and Agroclimatology. 1(2): 863-872.

Wimmer MA, Mukling KH, Lauchli A, Brown, PH, Goldebach HE (2003) The interaction between salinity and boron toxicity affects sub cellular distribution of ions and proteins in wheat leaves. Plant Cell Environ. 26: 1267-1274

Yang CW, Lin, CC, Kao Cll (2000) Proline, ornithin, arginine and glutamic acid contents in detached rice leaves. Biol Plantarum 43: 305-308.

Yau SK (2010) Boron Toxicity in Barley Genotypes: Effects of pattern and timing of boron application. Commun Soil Sci Plan 41(2): 144-154.

Yau SK, Ryan J (1994) Phenotypic variation in boron toxicity in barley, durum and bread wheat. Rachis. 13: 20-25.

Yu Q, Baluska F, Jasper F, Menzel D, Goldbach HE (2003) Short term boron deprivation enhances levels of cytoskeletal proteins in maize, but not zucchini, root apices. Physiol Plantarum 117: 270–278.

Yu X, Bell PF (1998) Nutrient deficiency symptoms and boron uptake mechanisms of rice. J Plant Nutr 21:2077-2088.