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Effects of High Boron on the Nutrients Uptake of Aegilops Genotypes Differing in Their B Tolerance Level †

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Abstract: In this study, we have used 19 Aegilops genotypes differing in their boron (B) toxicity tolerance level along with a B toxicity tolerant cultivar, Bolal and estimated their root-shoot nutrient concentrations under B toxic growth condition. Further, the association between their root-shoot nutrient concentrations and level of B toxicity tolerance was evaluated. The experimental genotypes were grown under three different B growth conditions in hydroponic system including Control (3.1 μM B); toxic (1 mM B), and highly toxic (10 mM B) boron treatment. The macro and micronutrient concentrations in the roots and shoots of the genotypes showed large variations and were observed to be differentially affected by high B stress.

Keywords: abiotic stress; Aegilops; boron toxicity; nutrient content; stress tolerance; wild wheat

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1. Introduction

Wheat wild relatives are considered as an important source of tolerance to several abiotic stress conditions [1–3]. Their genetic diversity can be effectively utilized to develop breeding lines and modern wheat cultivars with greater stress tolerances. Despite their great potential, Aegilops species have not been completely explored for such tolerances and mechanisms involved in making them tolerant. Boron (B) toxicity is one of the crucial abiotic stress conditions that negatively affect the wheat productivity in arid and semi-arid regions of the world. Other than several symptoms, high B is known to impede the uptake and translocation of macro and micronutrients in plants [4]. Thus, the hypothesis is that the plants showing less effect of B toxic growth conditions on nutrients uptake and translocation can be more tolerant to B toxicity. To test this hypothesis, the elemental analysis of root and shoot samples of 19 Aegilops genotypes (Figure 1) grown under different B concentrations in hydroponic system was done. The aim of this study was to determine the effect of high B on the macro and micronutrient content in roots and shoots of experimental genotypes. The results may provide an answer to the question that whether the accumulation of different nutrients can be associated with the B toxicity tolerance of the Aegilops genotypes. Further, research can be conducted to see the effect of additional supply of those nutrients towards increasing the tolerance level of less tolerant genotypes.

Figure 1. Pictures of the 19 Aegilops accessions provided by the Turkish Seed Gene Bank (TSGB), Ankara, and AARI National Gene Bank, ˙Izmir, Turkey. (a) Ab1 (Aegilops biuncialis1: TGB 026218; 4x); (b) Ab2 (A. biuncialis2: TGB 026219; 4x); (c) Ab3 (A. biuncialis3: TGB 037313; 4x); (d) Ac1 (A. columnaris1: TGB 037373; 4x); (e) Ac2 (A. columnaris2: TGB 038488; 4x); (f) Ac3 (A. columnaris3: TGB 037489; 4x); (g) Ac4 (A. columnaris4: TGB 000107; 4x); (h) Ac5 (A. columnaris5: TR57295; 4x); (i) As1 (A. speltoides1: TGB 037791; 2x); (j) As2 (A. speltoides2: TR 62174; 2x); (k) Al1 (A. ligustica1: TGB 000803; 2x); (l) Al2 (A. ligustica2: TR 39488;2x); (m) At1 (A. triuncialis1: TGB 037311; 4x); (n) At2 (A. triuncialis2: TGB 037355; 4x); (o) At3 (A. triuncialis3: TGB 037376; 4x); (p) At4 (A. triuncialis4: TR 72224; 4x); (q) Au1 (A. umbellulata1: TGB 037353; 2x); (r) Au2 (A. umbellulata2: TGB 037356; 2x); (s) Au3 (A. umbellulata1: TR 72200; 2x) [3].

2. Materials and Methods

The study comprised of 19 Aegilops genotypes supplied by the Turkish Seed Gene Bank (TSGB), Ankara, and AARI National Gene Bank, Izmir, Turkey and a well-known B toxicity tolerant Turkish hexaploid cultivar Bolal 2973 [5]. The B tolerance level of these genotypes has already been identified in one of our previous studies [3].

The genotypes were grown in a hydroponic system with conditions adjusted to 22 ± 10 °C, 16/8 h light/dark photoperiod, 16,000 Lx/day light intensity and 45–55% humidity. Three replicates of all the genotypes with five plants each were grown in three different B concentrations including Control (1/5th Hoagland solution containing 3.1 μM B), toxic B (1 mM B), and highly toxic B (10 mM B)]. The plants were treated with different B concentrations for 7 days followed by the harvest of root and shoot samples. After washing with 0.1 N HCl solution and deionized water, the harvested samples were kept in oven at 70 °C for drying. This was followed by the crushing of the dried samples and dissolving 0.15–0.20 g of the powdered sample in 5 mL of 65% HNO_3 and 2 mL of 35% H_2O_2. The mixture was digested in a closed microwave accelerating reaction system (CemMarsxpress, Matthews, NC, USA) and further, ICP-AES (Varian, Vista, Palo Alto, CA, USA) was employed to identify the nutrient concentration in the stock solution [6]. The percentage changes in each of the measured macro and micronutrient under 1 mM and 10 mM B treatment as compared to Control were estimated using MS Excel 2010.

3. Results

The purpose of this experiment was to determine the variation in 19 Aegilops genotypes in terms of nutrient accumulation in roots and shoots under different B toxic growth environment. Moreover, it was aimed to identify that whether the accumulation of nutrients is associated with the tolerance level of experimental genotypes that was already identified by Khan et al. [3].

3.1. Calcium (Ca)

The percentage change in shoot Ca (SCa) accumulation under highly toxic B treatment as compared to Control ranged from -145% to 38%. While At3 and At4 showed 145% and 71% decrement in the SCa content under a highly toxic B condition as compared to Control respectively, Ac4 and Bolal revealed the highest increase (38%) in SCa content as compared to Control (Table 1).

In root Ca (RCa) accumulation, the percentage change in 10 mM B treatment ranged from -287% to 60%. A maximum reduction (287%) was observed in Ac2 followed by Ac1 (251%). However, the Aegilops accession, At1 (60%), and Al1 (56%), showed a maximum increase in RCa content under 10 mM B treatment as compared to Control.

3.2. Phosphorus (P)

The percentage change in shoot P (SP) accumulation under highly toxic B treatment as compared to Control ranged from −181% to 50%. While At3 and As2 showed 181% and 170% decrement in the SP content under a highly toxic B condition as compared to Control respectively, Ac4 and Au2 revealed the highest increase of 50% and 35% respectively in SP content as compared to Control (Table 1).

In root P (RP) accumulation, the percentage change in 10 mM B treatment ranged from −457% to 100%. A maximum reduction (457%) was observed in As2 followed by Ac2 (313%). However, the Aegilops accession, Ab2 (100%), and Ab3 (48%), showed a maximum increase in RP content under 10 mM B treatment as compared to Control.

3.3. Sodium (Na)

The percentage change in shoot Na (SNa) accumulation under highly toxic B treatment as compared to Control ranged from −47% to 76%. While As2 showed 47% decrement in the SNa content under a highly toxic B condition as compared to Control, Au2 and Au3 revealed the highest increase of 76% and 71% respectively in SNa content as compared to Control (Table 1).

In root Na (RNa) accumulation, the percentage change in 10 mM B treatment ranged from −236% to 78%. A maximum reduction (236%) was observed in As2 followed by Ac1 (212%). However, the Aegilops accession, Ab3 (78%), and Ac4 (58%), showed a maximum increase in RNa content under 10 mM B treatment as compared to Control.

3.4. Magnesium (Mg)

The percentage change in shoot Mg (SMg) accumulation under highly toxic B treatment as compared to Control ranged from −146% to 26%. While At3 and As2 showed 146% and 117% decrement in the SMg content under a highly toxic B condition as compared to Control respectively, Ac4 and Bolal 2973 revealed the highest increase of 26% and 24% respectively in SMg content as compared to Control (Table 1).

In root Mg (RMg) accumulation, the percentage change in 10 mM B treatment ranged from −404% to 42%. A maximum reduction (404%) was observed in Ac2 followed by Ac1 (395%). However, the Aegilops accession, At1 (42%), and Ab3 (32%), showed a maximum increase in SMg content under 10 mM B treatment as compared to Control.

3.5. Manganese (Mn)

The percentage change in shoot Mn (SMn) accumulation under highly toxic B treatment as compared to Control ranged from −350% to 40%. While At3 and As2 showed 350% and 213% decrement in the SMn content under a highly toxic B condition as com-pared to Control respectively, Ac4 and Bolal 2973 revealed the highest increase of 40% and 5% respectively in SMn content as compared to Control (Table 1).

In root Mn (RMn) accumulation, the percentage change in 10 mM B treatment ranged from −393% to 52%. A maximum reduction (393%) was observed in Ac2 followed by As1 (300%). However, the Aegilops accession, Au3 (52%), and At1 (41%), showed a maximum increase in RMn content under 10 mM B treatment as compared to Control.

3.6. Copper (Cu)

The percentage change in shoot Cu (SCu) accumulation under highly toxic B treatment as compared to Control ranged from −229% to 37%. While Ac3 and Ab3 showed 229% and 192% decrement in the SCu content under a highly toxic B condition as compared to Control respectively, Au2 and At2 revealed the highest increase of 37% and 31% respectively in SCu content as compared to Control (Table 1).

In root Cu (RCu) accumulation, the percentage change in 10 mM B treatment ranged from −492% to 44%. A maximum reduction (492%) was observed in Ac2 followed by Ac1 (173%). However, the Aegilops accession, Al1 (44%), and At1 (38%), showed a maximum increase in RCu content under 10 mM B treatment as compared to Control.

Table 1. The percentage changes in the macro- and micronutrient content of 19 Aegilops genotypes and the B-tolerant check cultivar, Bolal 2973 in highly toxic B (10 mM B) treatment as compared to Control.

Code	Taxon	Ploidy	SCa	RCa	SP	RP	SNa	RNa	SMg	RMg	SMn	RMn	SCu	RCu	SFe	RFe
Ab1	*Aegilops biuncialis*	4x	−20	20	−28	31	45	50	−20	−4	−5	−21	−167	2	−57	55
Ab2	*Aegilops biuncialis*	4x	−13	−37	4	100	58	58	−12	−95	−1	−104	−124	−123	−81	−152
Ab3	*Aegilops biuncialis*	4x	−39	26	−17	48	27	78	−32	32	−24	33	−192	36	−104	60
Ac1	*Aegilops columnaris*	4x	−42	−251	−78	−300	53	−212	−49	−395	−103	−65	−80	−173	−71	−211
Ac2	*Aegilops columnaris*	4x	−11	−287	−2	−313	4	−27	−7	−404	−55	−393	−78	−492	−115	−456
Ac3	*Aegilops columnaris*	4x	−29	−10	−62	−303	22	−204	−23	−76	−25	−156	−229	10	−79	−98
Ac4	*Aegilops columnaris*	4x	38	−17	50	−102	58	58	26	−100	40	−131	−68	−92	11	−97
Ac5	*Aegilops columnaris*	4x	−57	−74	−80	−195	30	−71	−49	−188	−75	7	−11	−37	−148	−210
As1	*Aegilops speltoides*	2x	5	−29	−30	−242	60	−158	0	−183	−48	−300	23	32	−26	−14
As2	*Aegilops speltoides*	2x	−69	−131	−170	−457	−47	−236	−117	−210	−213	−241	−52	−89	−211	−177
Al1	*Aegilops ligustica*	2x	−19	56	1	−17	41	13	−5	−25	−35	9	−19	44	19	27
Al2	*Aegilops ligustica*	2x	−45	−5	−120	−227	20	−130	−91	−156	−107	−152	−21	−116	−72	−156
At1	*Aegilops triuncialis*	4x	6	60	−55	16	50	48	−33	42	−37	41	30	38	−135	7
At2	*Aegilops triuncialis*	4x	26	37	24	1	61	53	8	17	−9	29	31	−18	−83	−31
At3	*Aegilops triuncialis*	4x	−145	−11	−181	−115	37	−19	−146	−54	−350	−165	−108	−44	−193	−9760
At4	*Aegilops triuncialis*	4x	−71	−72	−94	−137	26	−19	−50	−44	−81	−11	−62	−31	−83	−218
Au1	*Aegilops umbellula-ta*	2x	−30	−27	−3	−27	48	31	−10	−54	−17	−9	−40	9	−51	−75
Au2	*Aegilops umbellula-ta*	2x	24	−87	35	−71	76	8	20	−109	−12	−10	37	−131	33	−186
Au3	*Aegilops umbellula-ta*	2x	18	19	−5	−100	71	37	11	−45	−4	52	29	23	−44	−35
Bolal	*Triticum aestivum*	6x	38	−36	−1	−76	51	−9	24	−91	5	25	16	−39	−6	21

4. Discussion

A large variability was observed in the root-shoot nutrient content of the studied Aegilops genotypes under B toxic stress condition. The two Aegilops genotypes, Ab2 and Ac4 that were found to be tolerant in our previous study [3] did not show maximum decrement in the uptake and translocation of any of the studied nutrients. In fact, among the two genotypes, Ac4 showed maximum concentration of several nutrients in shoots including Ca, P, Mg and Mn. However, no clear association has been found between the tolerance level of the genotypes and uptake or accumulation of any specific nutrient. The large folds of increment and decrement in the nutrient uptake of different genotypes showed the greater influence of high B stress on the ion equilibrium of plants. The results were in accordance with the results of several previous studies where abiotic stress is known to be affecting nutrient content in roots and shoots [7,8].

Author Contributions: M.K.K. and A.P. conceived, wrote, and edited the manuscript. M.K.K., A.P., M.H., M.O., and M.R.O. conducted the experiment and analysis. M.K.K. arranged Figure 1, which comprises the original spike pictures of all the studied Aegilops accessions. F.G., A.T., and S.G. made an intellectual contribution to the manuscript. All authors have read and agreed to the content.

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