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Effect of Silicon Application on Wheat Under Boron Stress

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Abstract: In this study, effects of different silicon (Si) concentrations (0.75, 5, 10 mM) on wheat under boron(B) stress, investigated by means of some stress indicators such as tissue length, malondialdehyde (MDA), ion leakage, relative water content (RWC) and total chlorophyll content. Stress mitigating effects of silicon were observed mainly as reductions on membrane damage with reduced MDA concentrations and decreased ion leakage levels. Although necrosis was present on shoot tissues due to the boron stress, no significant change observed on shoot and root length with the application of Si. On the contrary, relative water content (RWC) has changed positively with the implementation of Si under boron stress. Furthermore Si has enhanced RWC level in Si+B co-applicated sets to the level of control plants. Total chlorophyll content increased with the existance of 0.75 and 5 mM Si, while 10 mM Si had no effect on the chorophyll content under boron stress. Overall, silicon was found to have a potential to alleviate boron stress in wheat production.

Silisyum Uygulamasının Bor Stresi Altındaki Buğday Üzerindeki Etkisi

Anahtar Kelimeler
Bor toksisitesi,
Silisyum uygulaması,
Buğday bor stresi,
Membran hasarı,
Bağıl su içeriği,
Klorofil içeriği

Özet: Bu araştırmada, bor (B) stresi altındaki buğday bitkisinde farklı silisyum (Si) konsantrasyonlarının (0.75, 5, 10 mM) etkisi, doku uzunluğu, malondialdehit (MDA), iyon sızıntısı, bağıl su içeriği (RWC) ve toplam klorofil içeriği gibi bazı stres göstergeleri aracılığıyla incelenmiştir. Silisyumun stres azaltıcı etkisi membran hasarının iyileştirilmesi ile MDA ve iyon sızıntısı seviyelerinin pozitif düzenlenmesi üzerinde gözlenmiştir. Bor (B) stresi nedeniyle gövde dokularında nekroz meydana gelmesine rağmen silisyum uygulamasının sürgün ve kök uzunlukları üzerinde önemli bir değişiklik gerçekleştirmediği gözlemlenmiştir. Ancak tam aksine bağıl su içeriği (RWC), bor stresi altında silisyum uygulanması ile pozitif olarak değişmiştir. Ayrıca silisyum ve bor stresinin (Si+B) birlikte uygulandığı setlerde silisyum, bağıl su içeriğini kontrol bitkilerindeki seviyelere kadar artırmaktadır. Toplam klorofil içeriği 0.75 ve 5 mM silisyum varlığı ile artarken 10 mM silisyumun bor stresi altında klorofil içeriğine herhangi bir etkisi olmamıştır. Genel olarak, silisyumun buğday üretiminde bor stresini azaltıcı bir potansiyele sahip olduğu bulunmuştur.

1. Introduction

Boron (B) is a necessary microelement for plant growth. B has numerous functions over plant metabolism and physiology [1]. Important example for B in plants emerged as structural and functional substance of cell walls. Boron (B) provides structural component of cell walls with rhamnogalacturonan II complex [2,3]. Boron toxicity is changeable among plants but difference between toxicity and deficiency becomes more sensitive when considering internal boron concentration. Furthermore as reported information by Inal et al, B concentration decreased due to probable creation of B-Si (boron-silicate) complexes both in soil and within plant when presence of Si [4]. Including Turkey there is a lot of country has boron toxicity problem such as America, China, South Africa especially in arid and waterless region [5,6,7]. wheat is classified as low boron requirements plant. In soil just a few mg/kg boron may cause considerable yield losses [8]. Therefore the result of present investigation is substantial.

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Earth's crust is contain silicon (Si) as a second ample element. Plants could absorb silicon from soil when pH under 9 as monomeric molecule [$Si(OH)_4$] silicic acid [9,10]. Before 2 decades ago believed that silicon has no effect for direct growth but now a days when plant deal with abiotic and biotic stress factor silicon helps for exceed unfavorable conditions [11,12,13,14]. Si plays a role over apoplastic bypass flow to decrease and partial blockage. Thus provides reduction of heavy metal transport from root to leaves [15,16]. Most of plants undergo various stress in their life span, therefore, Si has the potential to be used in agriculture. Si has still remain a lot of unknown features in plant growth [17,18].

The point of this study to understand the role of silicon under boron stress. Effects of co-application under different doses of silicon and boron in wheat were investigated. Our recent study [19] showed that Si has a potential to change boron transporter and some aquaporin gene expressions. The present study showed that under different silicon and boron applications, RWC, ion leakage, MDA and chlorophyll contents of wheat plants varied significantly. This study will be a guide for further studies to comprehend roles of Si over B stress.

2. Material and Method

2.1. Plant materials, growth conditions and stress treatments

Plant meterials as a seeds of wheat (Triticum aestivum.) cv. Ayyıldız were indulgently supplied by East Anatolian Agricultural Research Institute of Turkey. Firstly for prevent contamination the seeds were superficially strerilized with with 10 % sodium hypochloride solution afterwards three to four times washed out with autoclaved distilled water. Seedlings were grown plastic pots (Figure 1) loaded with perlite in a stable growth chamber at 23 ± 1°C with 8 hours dark and 16 hours light (400 $\mu mol\ m^{-2}\ s^{-1}$) photo-cycle. Experiment was initiated mainly as seed germination with ½ Hoagland's solution [20]. Germinated seeds were become larger on 12 th day of growth, subsequently boron stress were started by implementations ½ hoagland's solution including determined boron (7.5 mM) concentration for 3 days. Control sets also were performed with seedlings which were irrigated ½ Hoagland's solution regularly. Silicon (0.75,5,10 mM) was added as sodium silicate ($Na_2Si_3O_7$) solution from the initiate of seedling germination. Furthermore in overall, five individual treatments were given as Control, 0 Si+ 7.5 mM B, 0.75 mM Si+7.5 mM B, 5 mM Si+7.5 mM B, 10 mM Si+7.5 mM B. Si and B represent silicon and boron respectively. Plants were reaped 15th day of growth which means that three days exposure of boron stress. Experiment was carried out for per sets of analysis at least 3 times.

2.2. Growth parameters

Shoot and root pieces of wheat were taken out from perlite after 15 days of developed seedlings and tissue lengths were measured (Figure 1).

Figure 1. Wheat plants under boron stress
*Pots from left to right belong 7.5 mM B, 0.75 mM Si+7.5 mM B, 5 mM Si+7.5 mM B, 10 mM Si + 7.5 mM B respectively (Figure 1).

2.3. Relative water content

Leaf tissues were used for obtain relative water content (RWC) values. Firstly wet mass weight were measured before incubation of immersion in water for 24 hours at 23 ^{0}C. After turgid mass were determinated by weighed to hydrated tissues. Shoot tissues were afterwards dried in incubator at 60 ^{0}C for 48 hours later weighed to assess the dry masses. Smart and Bingham [21] method were used to calculate relative water content via RWC (%) = {WM-DM}/{TM-DM}X100 formula.

2.4. Determination of membrane damage

Membran damage was evaluated by quantification of electrolyte leaked from both shoot and root tissues pursuant to method of Nanjo et al [22]. Thermo Scientific Orion 013016MD conductivity meter was used for evaluate electrical conductance to tissues in 0.4 M mannitol.

2.5. Determination of malondialdehyde (MDA) content

Lipid peroxidation was evaluated by prediction of the malondialdehyde (MDA) content through of Ohkawa et al. method [23]. Tissues belongs to crisp root and shoot were blended in 5 % trichloroacetic acid (TCA). The blended tissues were centrifuged at 12000 rpm for 15 minutes. Thiobarbituric acid added in trichloroacetic acid (1/4 w/w) then supernatant in same amount were incubated 25 minutes at 96 ^{0}C on dry heat block. The purpose of obtain supernatant in samples, 10000 rpm for 5 minutes centrifuged then absorbance of supernatant was assessed at 532 nm afterwards for determine and substract to non-specific turbidity absorbance was readed at 600 nm. Malondialdehyde contents were calculated by using an extinction coefficient of 155 $mM^{-1}\ cm^{-1}$.

2.6. Total cholorophyll content

Total chlorophyll content was determined by using methanol based method [24]. Prepared tissues homogenized with methanol were centrifuged at 4000 rpm for 5 minutes at 23 ^{0}C. Acquired supernatant were mixed with methanol then absorbance readed at 653 and 666 nm. After calculate of chlorophyll a and chlorophyll b. Total chlorophyll content has been determined.

2.7. Data analysis

Experiments were conducted with 3 replicates per analysis. The importance of the implementation effect was determined at 5 % prospect level by utilize Tukey test of one-way ANAVO by the assistance of SPSS 15.

3. Results

The goal of the research was to comprehend the role of Si under boron stress. Therefore, tissue length, malonedialdehyde (MDA), ion leakage, relative water content and total cholorophyll content analysis were (Table 1) performed in wheat (*Triticum aestivum*) cv. Ayyıldız tissues.

Present study showed that effect of Si, on both MDA and ion leakage in shoot tissues mitigated stress impact under boron toxicity. Although in root tissues, change in MDA level was not statistically important, ion leakage levels clearly showed positive effects of Si under boron stress.

Although shoot and root tissue length data were not found statistically important, leaf tip necrosis was observed in boron and co-applicated Si+B plants. Even though there were necrosis over all boron treated plant leaves even at the presence of Si, total chlorophyll content has changed significantly.

All doses of Si application improved relative water content (RWC) under boron stress when compared to control plants, while under 7.5 mM B treatment without silicon existance, change was found statistically significant. Presence of Si increased water retaining capacity as much as control plants, under boron stress.

Shoot tissue MDA contents indicated a substantial reduction under the Si + B co-presence when compared to only B treated plant. However, in root tissues there were no substantial change which is statistically significant.

All analysis were performed under three different (0.75 mM, 5 mM, 10 mM) Si concentrations and under 7.5 mM boron stress. According to our findings Si helps to alleviate B toxicity. In general increasing Si concentration has some effect over MDA content of shoot tissues. 0.75 mM Si and 5 mM Si applications had more positive impact when compared to 10 mM Si application. Moreover, there were significant changes in relative water contents. All concentration of Si helped the plants to deal with boron stress and provided better water retaining capacity as much as to the level of control plants.

Si also had a positive impact on ion leakage levels in shoot tissues. Although the levels were not reduced to the level of control plants, all Si concentrations significantly decreased leakage under B toxicity.

Furthermore, interestingly in root tissues both 0,75 mM and 10 mM Si applications had more positive impacts when compared to 5 mM Si application under boron stress. Also all Si treatments decreased ion leakage levels when compared to only B application.

Although total chlorophyll content negatively affected from boron stress, presence of 0.75 mM and 5 mM Si increased chlorophyll contents under boron toxicity, while 10 mM Si didn't have any impact on chlorophyll contents.

Table 1. Conducted analysis on shoot and root tissues

Shoot tissues	Tissue length(cm)	MDA(nmol/g)	Ion leakage %	RWC %	Total Chlorophyll
C	28,81±0,21	8,02±0,41$_{b}$	12,06±2,69$_{b}$	88,81±0,94$_{a}$	13,69±0,45$_{a}$
0 Si+7.5 B	27,50±0,24	9,86±0,13$_{a}$	26,28±1,16$_{a}$	78,86±0,86$_{b}$	10,78±0,40$_{b}$
0.75 Si+7.5 B	27,91±0,29	8,03±0,34$_{b}$	18,17±1,22$_{ab}$	85,63±1,12$_{a}$	11,69±0,34$_{ab}$
5 Si+7.5 B	26,91±0,64	8,24±0,14$_{b}$	20,04±1,30$_{ab}$	86,65±0,85$_{a}$	12,71±0,72$_{ab}$
10 Si+7.5 B	28,40±0,69	8,94±0,42$_{ab}$	19,90±2,43$_{ab}$	84,14±1,27$_{a}$	10,72±0,47$_{b}$
Root tissues	Root length (cm)	MDA(nmol/g)	Ion leakage %		
C	14,10±0,95	4,97±0,31	24,17±0,98$_{c}$	-	-
0 Si+7.5 B	12,95±0,55	6,04±0,69	30,87±0,31$_{a}$	-	-
0.75 Si+7.5 B	13,80±1,09	5,43±0,48	27,97±0,36$_{b}$	-	-
5 Si+7.5 B	13,76±0,98	5,35±0,26	28,98±0,56$_{ab}$	-	-
10 Si+7.5 B	13,44±0,73	5,32±0,21	27,52±0,28$_{b}$	-	-

* Treatments C, B, Si+B indicates; normal growth (control), 7.5 mM B application, simultaneous application of 0.75 mM Si and 7.5 mM B, 5 mM Si and 7.5 mM B, 10 mM Si and 7,5 mM B respectively.

*MDA and RWC stands for malonedialdehyde and relative water content respectively.

* The values appointed by distinct characters are meaningfully different on 5 % significance level.

4. Discussion and Conclusion

Boron toxicity is notably limiting wheat production. The toxicity symptoms of B were seen as general firstly chlorosis and later necrosis at the leaf tips in wheat [3,25,8]. Although necrosis was observed due to the application of boron stress, no significant difference on shoot and root lengths was detected in another study performed on barley, which were quite similar to our findings [19]. Therefore probably three days of stress treatment didn't show any difference in tissue length. Furthermore other studies also supporting that B toxicity importantly diminish shoot growth [4,26,27]. Stress mitigating effect of si was monitored on MDA level in shoot tissues which was parallel to other studies [28,29,30]. However, no substantial change found statistically important in root tissues MDA level.

Based on the present work both MDA and ion leakage analysis were consistent meaning of understand membrane damage with boron stress. Which affect ameliorated by Si treatment of both two analysis. It was supported by previous studies [4,26,30]. Plants water retain capacity has decreased due to boron stress. Si has positive effect over RWC even increased water retain capacity as much as control plant under boron stress with the three different application dose. Stress alleviating effects of silicon can be associated with the competitive role of silicon for the transport via boron transporters under toxic boron levels [19].

Boron stress were dwindle total chlorophyll content when compared with control and 7.5 mM B treated plants, chlorophyll content affects negatively. Which were also expressed by reid [31]. Presence of 0,75 mM and 5 mM Si increased chlorophyll content under boron stress while 10 mM Si didn't make any difference. Similar results were supported by Eraslan [32].

Previous investigations emphasis that silicon were beneficial against environmental stress by amelioration of oxidative damage with the inducing efficient plant antioxidative defense system [28,32,33,34]. The consistency of present study analysis were approved that Si has a positive role of boron toxicity. Another study on barley which was quite similar to present study, determined that Si were change gene expressions profile under boron stress. Moreover more specifically silicon were changed aquaporin and boron transporter gene expression under boron toxicity [19]. This kind of change provides lower B concentration within plant tissues. Therefore silicon probably provide stress alleviation under B stress in present study. Overall, silicon was found to have a potential to alleviate boron stress in wheat production.

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References

[1] Herrera-Rodríguez, M. B., González-Fontes, A., Rexach, J., Camacho-Cristóbal, J. J., Maldonado, J. M., Navarro-Gochicoa, M. T. 2010. Role of boron in vascular plants and response mechanisms to boron stresses. Plant Stress, 4(2), 115-122.

[2] Kobayashi, M., Matoh, T., Azuma, J. 1996. Two Chains of Rhamnogalacturonan II are Cross-Linked by Borate-diol Ester Bonds in Higher Plant Cell Walls. Plant Physiology, 110, 1017-120.

[3] Schnurbusch, T., Hayes, J., Sutton, T. 2010. Boron Toxicity Tolerance in Wheat and Barley: Australian Perspectives. Breeding Science, 60, 297–304.

[4] Inal, A., Pilbeam, D. J., Gunes, A. 2009. Silicon Increases Tolerance to Boron Toxicity and Reduces Oxidative Damage in Barley. Journal of Plant Nutrition, 32(1), 112-128.

[5] Türe, C., Bell, R.W. 2004. Plant Distribution and its Relationship to Extractable Boron in Naturally Occurring High Boron Soils in Turkey. Israel Journal of Plant Science, 52, 125–132.

[6] Onthong, J., Yoajui, N., Kaewsichan, L. 2011. Alleviation of Plant Boron Toxicity by Using Water to Leach Boron from Soil Contaminated by Wastewater from Rubber Wood Factories. Science Asia, 37, 314–319.

[7] Cervilla, L. M., Blasco, J. J., Rios, M. A., Rosales, E., Sánchez-Rodríguez, M. M., Rubio-Wilhelmi, L., Romero, L., Ruiz, J. M. 2012. Parameters Symptomatic for Boron Toxicity in Leaves of Tomato Plants. Journal of Botany, 1–17.

[8] Brdar-Jokanović, M., Maksimović, I., Kraljević-Balalić, M., Zeremski-Škorić, T., Kondić-Špika, A., Kobiljski, B. 2013. Boron Concentration vs. Content as Criterion for Estimating Boron Tolerance in Wheat. Journal of Plant Nutrition, 36(3), 470-480.

[9] Epstein, E. 1999. Silicon. Annual Review of Plant Physiology and Plant Molecular Biology, 50, 641–664.

[10] Miwa, K., Kamiya, T., Fujiwara, T. 2009. Homeostasis of the Structurally Important Micronutrients, B and Si. Current Opinion in Plant Biology, 12(3), 307-311.

[11] Ma, C.C., Li, Q.F., Gao, Y.B., Xin, T.R. 2004. Effects of Silicon Application on Drought Resistance of Cucumber Plants. Soil Science Plant Nutrition, 50, 623-632.

[12] Güneş, A., Inal, A., Esra, G., Çoban, S. 2006. Silicon-Mediated Changes on Some Physiological and Enzymatic Parameters Symptomatic of Oxidative Stress in Barley Grown in Sodic-Boron Toxic Soil. Journal of Plant Physiology, 164(6) 807–811.

[13] Ahmed, M., Hassen, F., Khurshid, Y. 2011. Does Silicon and Irrigation Have Impact on Drought Tolerance Mechanism of Sorghum. Agricultural Water Management, 98, 1808-1812.

[14] Balakhnina, T.I., Matichenkov, V.V., Wodarczyk, T., Borkowska, A., Nosalewicz, M., Fomina, I.R. 2012. Effects of Silicon on Growth Processes and Adaptive Potential of Barley Plants Under Optimal Soil Watering and Flooding. Plant Growth Regulation, 1(67), 35-43.

[15] Jia-Wen, W. U., Yu, S. H. I., Yong-Xing, Z. H. U., Yi-Chao, W. A. N. G., Hai-Jun, G. O. N. G. (2013). Mechanisms of enhanced heavy metal tolerance in plants by silicon: a review. Pedosphere, 23(6), 815-825.

[16] Ma, J.F., Yamaji, N., 2005. Silicon Uptake and Accumulation in Higher Plants. Plant Science11, 5

[17] Epstein, E. 2009. Silicon: its manifold roles in plants. Annals of Applied Biology, 155(2), 155-160.

[18] Etesami, H., Jeong, B. R. 2018. Silicon (Si): Review and Future Prospects on the Action Mechanisms in Alleviating Biotic and Abiotic Stresses in Plants. Ecotoxicology and Environmental Safety, 147, 881-896.

[19] Akcay, U. C., Erkan, I. E. 2016. Silicon induced Antioxidative Responses and Expression of BOR2 and Two PIP Family Aquaporin Genes in Barley Grown Under Boron Toxicity. Plant Molecular Biology Reporter, 34(1), 318-326.

[20] Hoagland, D.R., Arnon, D.I. 1950. The Water-Culture Method for Growing Plants Without Soil. California Agricultural Experiment Station, 347, 1-32.

[21] Smart, R.E., Bingham, G.E. 1974. Rapid Estimates of Relative Water Content. Plant Physiology, 53(2), 258–260.

[22] Nanjo, T., Kobayashi, M., Yoshiba, Y., Kakubari, Y., Yamaguchi-Shinozaki, K., Shinozaki, K. 1999. Antisense Suppression of Proline Degradation Improves Tolerance to Freezing and Salinity in Arabidopsis thaliana. FEBS Letters, 461(3), 205–210.

[23] Ohkawa, H., Ohishi, N., Yagi, K. 1979. Assay for lipid peroxides in animal tissues by thiobarbituric acid reaction. Analytical Biochemistry, 95(2), 351–358.

[24] Lichtenthaler, H. K., Wellburn, A. R. 1983. Determinations of Total Carotenoids and Chlorophylls a and b of Leaf Extracts in Different Solvents. Biochemical Society Transactions, 11(5), 591-592.

[25] Masood, S., Saleh, L., Witzel, K., Plieth, C., Mühling Karl, H. 2012. Determination of Oxidative Stress in wheat Leaves as Influenced by Boron Toxicity and NaCl Stress. Plant Physiology and Biochemistry, 56, 56-61.

[26] Karabal, E., Yucel, M., Oktem, H.A. 2003. Antioxidant Responses of Tolerant and Sensitive Barley Cultivars to Boron Toxicity. Plant Science, 164(6), 925–933

[27] Alpaslan, M., Gunes, A. 2001. Interactive Effects of Boron and Salinity Stress on the Growth, Membrane Permeability and Mineral Composition of Tomato and Cucumber Plants. Plant and Soil, 236(1), 123–128.

[28] Gunes, A., Inal, A., Bagci, E. G., Coban, S., Sahin, O. 2007. Silicon Increases Boron Tolerance and Reduces Oxidative Damage of Wheat Grown in Soil With Excess Boron. Biologia Plantarum, 51(3), 571-574.

[29] Gunes, A., Inal, A., Bagci, E. G., Coban, S. 2007. Silicon-mediated Changes on Some Physiological and Enzymatic Parameters Symptomatic of Oxidative Stress in Barley Grown in Sodic-B Toxic Soil. Journal of Plant Physiology, 164(6), 807-811.

[30] Soylemezoglu, G., Demir, K., Inal, A., Gunes, A. 2009. Effect of Silicon on Antioxidant and Stomatal Response of Two Grapevine (Vitis vinifera L.) Rootstocks Grown in Boron Toxic, Saline and Boron Toxic-Saline Soil. Scientia horticulturae, 123(2), 240-246.

[31] Reid, R. 2007. Update on Boron Toxicity and Tolerance in Plants. Proceedings of the 3rd International Symposium on all of Plant and Animal Boron Nutrition, 10-13 September, Wuhan, 83-90.

[32] Eraslan, F., Inal, A., Pilbeam, D. J., 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 Regulation, 55(3), 207.

[33] Bakhat, H. F., Bibi, N., Zia, Z., Abbas, S., Hammad, H. M., Fahad, S., Ashraf, M. R., Shah, G. M., Rabbani, F., Saeed, S. 2018. Silicon Mitigates Biotic Stresses in Crop Plants: a review. Crop Protection, 104, 21-34.

[34] Etesami, H., Jeong, B. R. 2018. Silicon (Si): Review and Future Prospects on the Action Mechanisms in Alleviating Biotic and Abiotic Stresses in Plants. Ecotoxicology and environmental safety, 147, 881-896.