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EFFECT OF SILICON ON SUNFLOWER GROWTH AND NUTRIENT ACCUMULATION UNDER LOW BORON SUPPLY

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SUMMARY

Study was focused on effect of silicon (Si) on growth and nutritional status of sunflower (*Helianthus annuus* L.) under low boron (B) external supply. Plants were grown under controlled environmental conditions in nutrient solutions with two low B treatments (0.2 μM B and 0.5 μM B) with or without addition of Si and control treatment containing sufficient B supply. Shoots growth was only slightly affected by Si supply while accumulation of B in fully developed leaves was significantly higher only at 0.5 μM B. In roots, nutrients contents were relatively constant, while accumulation of all nutrients in leaves was affected by addition of Si. Differences were significant only in K, Fe and Mo between treatments 0.5 μM B and 0.5 μM B with Si added and in Zn between both treatments. In comparison with other studies, results confirmed that plant species show different response to Si application. Interaction of B and Si should be involved in further research in B deficiency in sunflower.

Key words: boron deficiency, mineral elements, silicon, sunflower

INTRODUCTION

Boron (B) and silicon (Si) are elements similar in many chemical characteristics. Both are taken up by plant roots in the form of weak, undissociated acids (Marschner, 2012). Long time ago it has been shown that B is essential element for higher plants and its role in plant physiology is studied the least among all micronutrients (Mengel *et al.*, 2001). Under conditions of B deficiency plant growth is inhibited due its role in cell wall formation as well as limited mobility within most of the plants (Brown *et al.*, 1997). Cakmak *et al.* (1995) showed that B is very

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important for membrane stability, but its role in phenols and auxin metabolism, sinthesis of RNK still is not clear (Römheld *et al.*, 1991).

The essentiality of silicon (Si) for higher plants has been shown only in a few species, such as rice and sugarcane and this is why Si fertilizers are applied to these crops (Ma, 2004). Beneficial effects of Si on plant growth, development, yielding and disease resistance have been observed in both monocots and dicots (Ma, 2004; Epstein, 1999). Seems that Si is the only element that can enhance plant resistance to multiple stress. Proposed mechanisms for Si-enhanced resistance to diseases as well as effectiveness of Si in controlling plant diseases in different crops are well described by Ma (2004) and Ma *et al.* (2006).

Interaction of B and Si in higher plants has been studied, but results regarding role of Si in growth of B deficient plants are limited. Liang *et al.* (1994) showed direct competitive interaction of B and Si for oilseed rape. Under conditions of B deficiency Si enhanced B uptake and accumulation while lowered both under normal and toxic B external supply. Numerous studies showed that Si ameliorates B toxicity. Recently Kaya *et al.* (2011) obtained lower B accumulation as well as Si effect on reduction of antioxidant enzymes activity in tomato. Barley and wheat tolerance to high soil B in the presence of Si was shown by Gunes *et al.* (2007) and Inal *et al.* (2009), respectively.

Low B soils are spread in more than eighty countries around the world (Shorrocks, 1997) and agriculture production is often affected by B deficiency causing yield loss. Sunflower (*Helianthus annuus* L.) is sensitive to B deficiency, also more in the reproductive stage (Asad, 2002). Low B in soil often causes seed set reduction in sunflower. Recent study by Ozturk *et al.* (2011) showed a high positive correlation between B concentrations in leaves of sunflower grown on low B soil and applied B doses. Reddy *et al.* (2003) highlighted that sunflower harvest index can be improved by applying of B. Cases of B deficiency in sunflower based on response to B application were recorded in many countries including ex Yugoslavia (Shorrocks, 1997).

The aim of the study was to investigate the effect of Si on sunflower growth, nutrients uptake and accumulation under low B external supply.

MATERIALS AND METHODS

Plant material, growth conditions and treatments

Sunflower (cv. Duško) seeds were germinated in quartz send at 25^{o}C with addition of saturated $CaSO_4$ solution. Five days after germination seedlings were transferred to continuously aerated standard nutrient solution (4 plants per 2.5 l plastic pot) containing (mM): 0.7 K_2SO_4, 0.1 KCl, 2.0 $Ca(NO_3)_2$, 0.5 $MgSO_4$, 0.1 KH_2PO_4 and (μM) 0.5 $MnSO_4$, 0.5 $ZnSO_4$, 0.2 $CuSO_4$, 0.01 $(NH_4)_6Mo_7O_{24}$ and 20 Fe(III)-EDTA. B was supplied as H_3BO_3 at two deficient low supplies of 0.2 and 0.5 μM, including control treatment with 10 μM B. One half of the plants grown under two levels of low B concentration were supplied with 1.5 mM Si as $Si(OH)_4$. It was prepared by passing Na_2SiO_3 through a plastic column filled with cation-excange resin (Amberlite IR-120 H^+ form, Fluka, Deisenhofen, Germany).

Plants were grown under controlled environmental conditions with a light/dark regime of 16/8 h, air temperature of 25°C, photon flux density of around 300 μmol m^{-2} s^{-1} and a relative humidity of 70%. Nutrient solutions were renewed twice per week. Plants were harvested after two weeks and samples were taken for analysis.

Analytical methods

Roots and shoot were dried at 70°C and dry weight was determined. Afterwards plant material was microwave digested with 3 ml of HNO_3 and 2 ml of H_2O_2. B and other elements (P, K, Ca, Mg, S, Fe, Zn, Mn, Cu, Mo) in the roots and fully developed leaves were determined by ICP-OES.

Statistical analyses

Data were subjected to ANOVA and the means were compared by Dankan's multiple range test at $p \leq 0.05$, using COSTAT software package.

RESULTS AND DISCUSSION

Root and shoot dry weight of sunflower plants was differing between treatments, but not significantly. In all treatments, including control root weight was around 100 mg per plant (Figure 1). Seems that low B supply of 0.2 μM B and 0.5 μM B in nutrient solution didn't cause a strong reduction of root growth. Shoot growth was slightly decreased under B deficiency treatments 0.2 μM B and 0.5 μM B (around 650 mg per plant) compared to control (around 750 mg per plant), but addition of Si did not enhance significantly plants growth (Figure 1). Rogalla *et al.*, (2002) presented similar observations in cucumber plants grown under conditions of severe deficiency of 0.02 μM B. Cucumber plants were strongly affected by B deficiency and Si treated plants grew slightly better than plants not treated with Si, but this effect was not significant. Two low B concentrations applied in presented study were chosen with aim to avoid concentration effect which might appear due to inhibition of plant growth. Very low B concentrations such as 0.1 μM cause strong inhibition of plant growth, as showed for oilseed rape by Savić *et al.* (2012). On the other side, Liang *et al.*, (1994) showed positive effect of Si on oilseed rape grown in nutrient solutions with 0.025 μg B/ml (calculated by authors 0.4 μM B). In addition, increased levels of Si slightly decreased root length under 0.4 μM B treatment, while root dry weight was increased.

As it was expected, B concentration was the highest in both root and shoot in control treatment (Figure 2). In roots, B concentration was significantly higher in control in comparison to other treatments ($p \leq 0.05$), but diferences between both

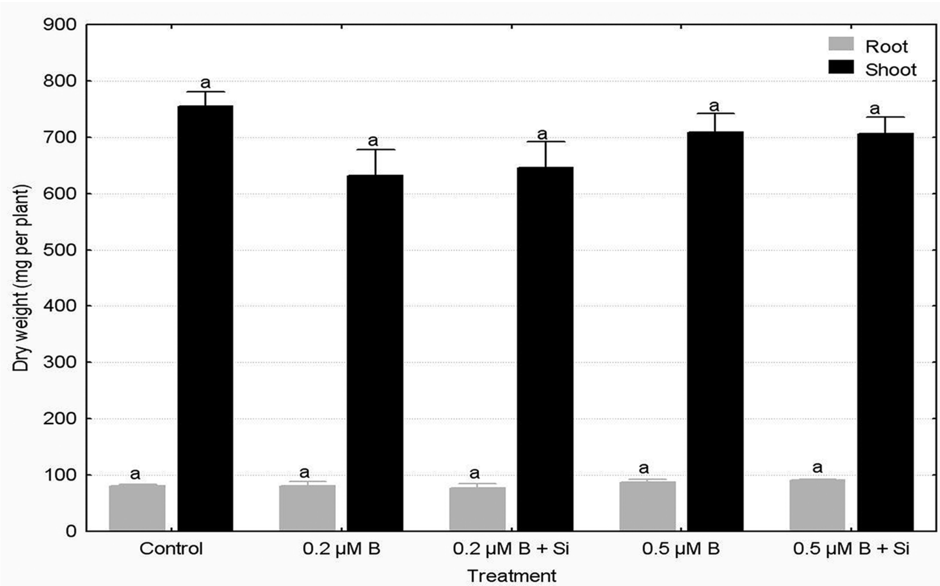

Figure 1: Effect of Si on root and shoot dry weight of sunflower plants subjected to low B external supply (0.2 μM B and 0.5 μM B). Si concentration in nutrient solution was 1.5 mM. Data are means (n=4)±SD. Significant differences at p≤0.05 are indicated by different letters.

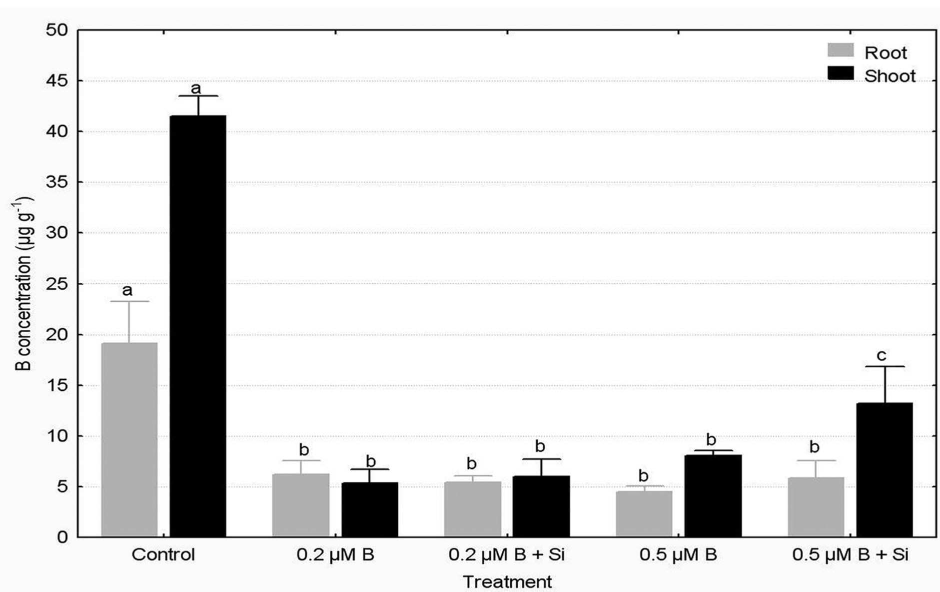

Figure 2: Effect of Si on B concentration in roots and shoots of sunflower plants subjected to low B external supply (0.2 μM B and 0.5 μM B). Si concentration in nutrient solution was 1.5 mM. Data are means (n=4)±SD. Significant differences at P≤0.05 are indicated by different letters.

0.2 μM B and 0.5 μM B treatments and those with Si added were very small. B concentration in shoots was also significantly higher in control compared to all other treatments. At 0.2 μM B and 0.2 μM B with Si added treatments B concentration in shoot was the same, while Si significantly increased B accumulation in plants grown in 0.5 μM B. Our results showed that plants were affected by low B external supply obtaining less than 10 $\mu g\ g^{-1}$ DW except at 0.5 μM B+Si treatment. According to Bergmann (1992) critical values for B deficiency in sunflower upper fully expanded leaves range between 10 and 13 $\mu g\ g^{-1}$ DW, while Blamey *et al.* (1979) proposed much higher values of around 30 $\mu g\ g^{-1}$ DW in top mature leaf at flowering stage in two sunflower cultivars. Increased B accumulation in plants grown under 0.5 μM B with Si added can be a result of B and Si interaction similar as in study by Liang and Shen (1994). They found that silicon enhance B uptake and accumulation by oilseed rape plants under B deficiency, but increased Si concentration in nutrient solution decrease it under sufficient B supply. In presented study, Si was not measured because we wanted to avoid digestion with HF and separate measurements of B and Si as well. This study was starting experiment for more detail study and we wanted to see the effect of Si on B uptake and accumulation and growth on sunflower plants under low B supply.

Table 1: Effects of Si supply on mineral element contents in roots of sunflower plants grown in nutrient solutions under conditions of B deficiency (0.2 μM B and 0.5 μM B) for two weeks

Treatment	P	K	Ca	Mg	S
	(mg g^{-1} DW)				
Control	8.0±1 ^{b}	32.6±5 ^{a}	7.47±2 ^{b}	3.99±0.2 ^{a}	9.4±1 ^{ab}
0.2 μM B	12.25±3 ^{a}	52.85±17 ^{b}	10.3±2 ^{ab}	2.08±0.3 ^{b}	8.0±1 ^{b}
0.2 μM B +Si	12.3±2 ^{a}	48.95±19 ^{ab}	12.15±1 ^{a}	2.38±0.3 ^{b}	11.2±1 ^{a}
0.5 μM B	8.0±1 ^{b}	31.9±10 ^{a}	9.4±1 ^{b}	1.95±0.2 ^{b}	10.2±0.5 ^{a}
0.5 μM B +Si	10.35±1^{ab}	38.15±7 ^{a}	7.53±1 ^{b}	1.90±0.1 ^{b}	8.1±0.5 ^{b}
Treatment	**Fe**	**Zn**	**Mn**	**Cu**	**Mo**
	(μg g^{-1} DW)				
Control	350±60 ^{a}	64.8±12 ^{a}	26±4 ^{ac}	47±8 ^{a}	8.3±1.1 ^{a}
0.2 μM B	322±25 ^{a}	33.3±7 ^{b}	35±8 ^{ab}	44±14 ^{a}	6.7±2 ^{a}
0.2 μM B +Si	254±28 ^{b}	37.7±11 ^{b}	39±2 ^{b}	45±5 ^{a}	6.8±1 ^{a}
0.5 μM B	295±15 ^{b}	19.4±4.4 ^{c}	20±0.5 ^{c}	42±4 ^{a}	7.5±0.1 ^{a}
0.5 μM B +Si	315±5 ^{ac}	24.6±5 ^{bc}	39±11 ^{b}	36±8 ^{a}	7.4±0.1 ^{a}

Data are means (n=4)±SD. Different lower case letters within a column denote significant differences at $P<0.05$

Widespread opinion that B uptake by plant roots is mainly passive process at sufficient supply as well as different mechanisms proposed for low supply, including active uptake by root cortex cells as shown for pea and tomato (Savić *et al.*, 2007) should be also taken under consideration. Sunflower was also often used in studies on B uptake, xylem loading and compartmentation. Under low B supply almost all root B is bounded to cell wall (Dannel *et al.*, 1998; Pfeffer *et al.*, 1999;

Dannel *et al.*, 2000) what could be of great importance for further study of B and Si interaction in sunflower.

Application of Si had no effect on P, K, Ca, Mg, Zn, Cu and Mo content in sunflower roots (Table 1). Mn content was significantly higher ($p \leq 0.05$) in treatment 0.5 μM B with Si added compared to that with no Si, while S and Fe were affected by Si on both ways increasing and decreasing their content at low B treatments. In leaves, Si enhanced accumulation of all nutrients P, K, Ca, Mg, S, Fe, Zn, Mg, Cu and Mo at both B levels 0.2 μM B and 0.5 μM B. (Table 2).

Table 2: Effects of Si supply on mineral element contents in fully developed leaves of sunflower plants grown in nutrient solutions under conditions of B deficiency (0.2 μM B and 0.5 μM B) for two weeks

Treatment	P	K	Ca	Mg	S
	(mg g^{-1} DW)				
Control	4.0±0.2 ^{a}	16.7±4 ^{a}	25.5±3 ^{ab}	4.1±0.6 ^{ab}	5.8±0.7 ^{ab}
0.2 μM B	4.1±0.5 ^{ab}	15.6±2 ^{a}	25.3±7 ^{ab}	3.6±0.2 ^{a}	5.4±0.2 ^{a}
0.2 μM B +Si	4.7±0.3 ^{b}	17.5±3 ^{ab}	26.1±6 ^{ab}	3.7±0.6 ^{ab}	6.1±0.5 ^{ab}
0.5 μM B	4.2±0.1 ^{ab}	16.0±2 ^{ac}	23.2±5 ^{b}	3.9±0.5 ^{ab}	5.5±0.6 ^{a}
0.5 μM B +Si	4.6±1.0 ^{ab}	17.8±1 ^{bd}	26.9±5 ^{a}	4.3±0.5 ^{b}	6.5±0.5 ^{b}
Treatment	Fe	Zn	Mn	Cu	Mo
	(μg g^{-1} DW)				
Control	80.5±4 ^{a}	31.7±0.7 ^{a}	33±0.8 ^{a}	10.1±0.4 ^{a}	2.1±0.4 ^{a}
0.2 μM B	58.0±6 ^{b}	29.7±1.2 ^{b}	44±6 ^{ab}	6.7±0.7 ^{b}	1.3±0.1 ^{b}
0.2 μM B +Si	63.7±12 ^{b}	34.3±2.4 ^{ac}	52±14 ^{b}	8.7±1 ^{ac}	1.5±0.2 ^{b}
0.5 μM B	63.0±5 ^{b}	27.2±3.6 ^{b}	37±8 ^{ab}	8.0±0.2 ^{c}	1.7±0.1 ^{b}
0.5 μM B +Si	76.5±5 ^{ac}	36.3±33 ^{c}	50±15 ^{b}	9.3±1 ^{ac}	2.0±0.1 ^{ac}

Data are means (n=4)±SD. Different lower case letters within a column denote significant differences at P>0.05

Although differences were significant only in K, Ca, Fe and Mo between treatments 0.5 μM B and 0.5 μM B with Si added and in Zn between both treatments. Similar results were reported by Liang *et al.*, (1994), who found that under low B supply addition of different Si levels had no effect on P, Ca and Mg accumulation in whole oilseed rape plants. Interestingly, in presented study contents of K, Zn and Mn were significantly higher in one of treatments with Si added than in control, indication that Si might also play a role in nutrient deficiency stresses.

CONCLUSIONS

The results presented here show that Si didn't affect sunflower growth under conditions of low B external supply. Enhancing of B accumulation by addition of Si was present in sunflower leaves at one low B supply. It appears that addition of Si also affected nutritional status of sunflower, by enhancing accumulation of both macronutrients and micronutrients. Interaction of B and Si should be included in further investigations with aim to find possible mechanisms involved in uptake and translocation of both elements.

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