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Aluminium/silicon interactions in cereal seedlings

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ABSTRACT The objective of this study was to examine the effects of Al and Si treatments on the growth and potassium uptake of roots and transport toward the shoots of common wheat (*Triticum aestivum* L.), durum wheat (*T. durum* Desf.), triticale (x*Triticosecale* Wittmack) and rye (*Secale cereale* L.). Seedlings were grown hydroponically at pH 4.1 with different levels of Al and Si. Increased levels of Al in the solution reduced root growth in the order of Al-tolerance (rye>triticale>common wheat>durum wheat). Shoot growth was only moderately influenced at higher Al concentrations. Si in the growth solution enabled plants to overcome Al toxicity symptoms, however, different species respond differently to Si applications. In short-term (6h) uptake experiments, Si reduced the stimulatory effect of Al on K^+(^{86}Rb) uptake of roots, which indicates a definite Al-Si interaction at the plant level.
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KEY WORDS

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Crop yield is reduced by soil acidity on ca. 30%. Much of the damage to plant production is due to excess aluminium (Al), the most common metal in soil. Al in soils with pH>5 mostly forms insoluble oxides and complex alumino-silicates. At lower pH values there is a release of bioactive forms of Al, particularly monomeric Al (Kinraide 1997), which is toxic to plants. Recently a number of workers have shown that silicon (Si) can decrease the toxic effects of Al in hydroponic culture in several species (Cocker et al.1998, Ma et al. 1997; Zsoldos et al. 2002). However, the exact explanation for the mechanism of Al detoxification by Si is unclear. Our aim in the present work was to investigate the effect of Si and Al, separately and in combination, on the growth and potassium uptake of four cereal species at low pH.

Materials and Methods

Common wheat (*Triticum aestivum* L. cv. Jubilejnaja 50), durum wheat (*T. durum* Desf. cv. GK Betadur), triticale (x*Triticosecale* Wittmack cv. GK Marco) and rye (*Secale cereale* L. cv. GK Wibro) provided the experimental material in this study. Seedlings were grown hydroponically in 0.5 mM $CaSO_4$ solution at pH 4.1 with different levels of Al and Si in a Conviron growth chamber under controlled conditions.

^{86}Rb was used to monitor the K^+ transport in plants. The K^+(^{86}Rb) uptake experiments lasted for 6 hours. Roots and shoots were then separated and the radioactivity of ^{86}Rb in the plant material was measured by a liquid scintillation counter (Canberra Packard Prias PL, Tri-Carb).

The dry weights of the roots and shoots of all plants were determined upon harvesting. Shoots and roots were harvested separately and subsequently dried at 70°C to constant weight.

Results

In Figure 1 growth data are presented, showing that 50 µM Al concentration causes a significant decrease in root dry matter yield in the order of Al-tolerance (rye (17%)>triticale (21%)>common wheat (56%)>durum wheat (63%)), shoot growth was only moderately influenced in 7d experiments.

Figure 2 shows the effects of 10 µM Al and 1 mM Si on the growth (DW) of different cereal species. As it was expected the Al toxicity was the most pronounced in GK

Treatment	-Si		+Si	
	Average (cm)	STDEVP	Average (cm)	STDEVP
-Al	9.00	1.42	8.33	1.34
10 µM Al	6.00	1.53	11.06	1.58
50 µM Al	1.49	0.15	4.89	1.91
100 µM Al	1.06	0.23	2.37	1.17

Table 1. Effects of Al and Si treatments on the root elongation of Jubilejnaja 50 seedlings, grown for 7 days on varied Al concentrations in 0.5 mM $CaSO_4$ solution in the absence (-Si) and in presence (+Si) of 1500 µM Na_2SiO_3 as indicated, pH was 4.1.

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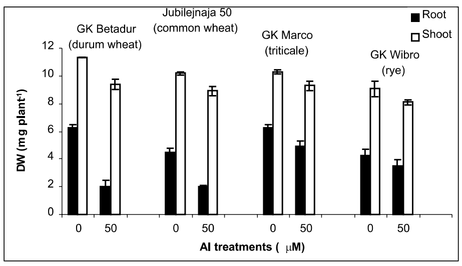

Figure 1. Effects of Al treatments on the growth of different cereal seedlings. Plants were grown for 7 days on Al in 0.5 mM $CaSO_4$ + 50 µM $AlCl_3$ solution as indicated on the graph, pH was 4.1. All data show the means ±SD (n=8).

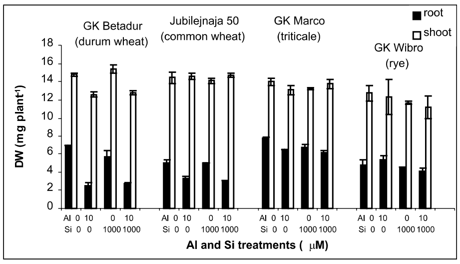

Figure 2. Effects of Al and Si treatments on Al-toxicity (DW) of different cereal seedlings. Plants were grown in 0.5 mM $CaSO_4$ solution + Al and Si at pH 4.1 for 7 days as indicated on the graph. All data show the means ±SD (n=8).

Betadur, while GK Wibro does not show any toxic effect of Al-treatments under this experimental condition. The presence of Si in the growth solution led to reduction of Al toxicity, particularly by Al-tolerant Jubilejnaja 50 (Table 1). In other cultivars, however, the ameliorative effect of Si was not so unambiguous, in comparison with the untreated control plants and Jubilejnaja 50, respectively.

Figure 3 shows the effect of short-term (6h) Al and Si exposure on $K^+(^{86}Rb)$ uptake of the roots and the transport toward the shoots in different cereal seedlings at pH 4.1. The addition of Si to the uptake solution weakened the stimulatory effect of Al on $K^+(^{86}Rb)$ uptake of roots (except in GK Wibro). The $K^+(^{86}Rb)$ transport toward the shoots in case of GK Marco was more pronounced than in other cultivars.

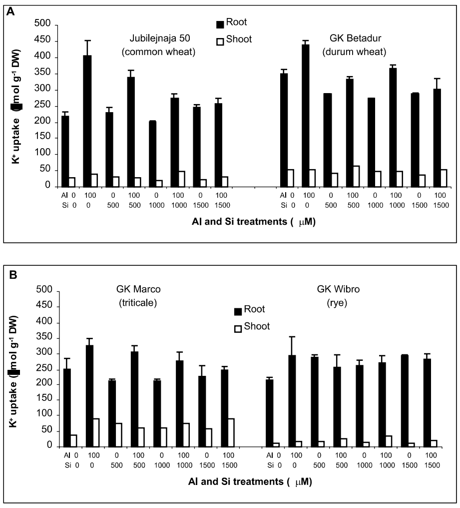

Figure 3. Effects of Al and Si treatments on the $K^+(^{86}Rb)$ uptake of the roots and the translocation toward the shoots of different cereal seedlings. Plants were grown for 7 days in 0.5 mM $CaSO_4$ solution at pH 6.5. After the 7th day the seedlings were treated for 6h with 1 mM $K(^{86}Rb)Cl$ + 0.5 mM $CaCl_2$ + $AlCl_3$ and Si solution as indicated on the graph, pH value was 4.1. All data show the means ±SD (n=8).

Discussion

Both an ameliorative effect, and no or little effect of Si on Al toxicity have been reported. Such inconsistency may result from differences in growth solution, duration of treatments, initial Si state of plants used, different plant age and development, different plant species and cultivars (Cocker et al. 1998).

Comparing of the growth of different cereal cultivars in an identical growth medium we found a highly significant positive Al-Si interaction in root elongation of Jubilejnaja 50 (Table 1), while no significant effect was demonstrated in DW production of different cereal seedlings (Fig. 2).

The fact that different cereal cultivars respond to different extents on Al-Si treatments is strongly indicative that this involves in planta effects, though complexation of Al and Si in solution ex planta may also occur.

It was reported by Zsoldos et al. (2000), that in short-term (6-24 h) experiments the uptake of $K^+(^{86}Rb)$ and its transport toward the shoot was positively correlated with Al concentration of the outer medium. Present data clearly show Si treatments abolish this formerly experienced stimulatory effect of Al on $K^+(^{86}Rb)$ uptake of roots (Fig. 3), most probably through the co-deposition of Al and Si in root cell walls (Cocker et al. 1998).

In summary, our data indicate the beneficial effect of Si is not only due to its influence on Al speciation in the solution, but also due to Al-Si interactions at plant level. The results confirmed, that different cereals respond differently to Si applications. It seems from the $K^+(^{86}Rb)$ uptake data that Si can exert effect on the membrane transport processes, probably through formation of Al-Si complexes in root cell walls (apoplast).

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