Effects of foliar application of silicon on uptake and translocation of arsenite and DMA in rice (*Oryza sativa*)

W.-J. Liu, Y. Sun & Q.-L. Zhao

College of Resources and Environmental Science, Hebei Agricultural University, Baoding, P.R. China

ABSTRACT: A hydroponic experiment was conducted to explore the effects of foliar application of silicon on the uptake and translocation of As(III) and DMA in rice. The result showed that the ratio of foliar application of Si concentration and the As concentration in the solution at 100:1 decreased significantly arsenic concentrations in the phloem sap and the rice shoots. However, when DMA supplied, Si/As ratio at 200:1 increased significantly arsenic and silicon concentrations in rice phloem ($P < 0.05$). In addition, there was a positive correlation between arsenic concentrations and silicon concentration in rice phloem ($R = 0.856$, $P < 0.01$, $n = 12$). Regardless of whether As(III) or DMA was supplied to rice, foliar application of low concentration of silicon (Si/As at 100:1) could decrease arsenic concentration and translocation in rice seedlings.

1 INTRODUCTION

Arsenite (As(III)) is the predominant species of As in soil solution from flooded paddy fields. As(III) as H_3AsO_3^0 is an analogue of silicic acid (H_4SiO_4^0) ($\text{pH} < 8$) and can be taken up by rice roots through the silicic acid transport system (Ma *et al.*, 2008). The similar situation had happened to Di-methylated arsenic (DMA) into rice roots (Li *et al.*, 2009). However, application Si in the submerged soil would increase As(III) and DMA mobility (Lee *et al.*, 2014; Liu *et al.*, 2014). Therefore, we want to know that the impact of foliar application Si with the different concentrations on the uptake and translocation of As(III) and DMA in rice.

2 METHODS/EXPERIMENTAL

2.1 Plant growth

Rice (*Oryza sativa* L. cv. Italica Carolina, the Japonica type, an early flowering cultivar) seeds were sterilized in 30% H_2O_2 solution for 15 min followed by thorough washing with de-ionized water. The seeds were germinated in moist quartz sand. After 3 weeks, rice seedlings were transplanted to 500 mL PVC pots (7.5 cm diameter and height 14 cm, one plant per pot) containing half-strength Kimura B solution. The composition of the nutrient solution was 0.091 mM KNO_3 , 0.183 mM $\text{Ca}(\text{NO}_3)_2$, 0.274 mM MgSO_4 , 0.091 mM KH_2PO_4 , 0.183 mM $(\text{NH}_4)_2\text{SO}_4$, 0.5 μM MnCl_2 , 3 μM H_3BO_3 , 0.1 μM $(\text{NH}_4)_6\text{Mo}_7\text{O}_{24}$, 0.4 μM ZnSO_4 , 0.2 μM CuSO_4 , 20 μM NaFe(III)-EDTA (pH adjusted to 5.5 with KOH). Nutrient solutions were renewed once every 3 d. The growth conditions were 14 h photoperiod with a light intensity of $280 \mu\text{mol m}^{-2} \text{s}^{-1}$ and day/night temperatures were maintained at 28/25°C.

2.2 Experiment treatments

Rice plants at heading stage were exposed to the half-strength Kimura B nutrient solution containing 10 μM As(III) or 10 μM DMA. Different levels of 0 (CK), 1000 (D_{Si}), 2000 (G_{Si}) μM Si as silicic acid were sprayed on the rice shoots at 10:10 am every day and the exposure of As and Si would last for 72 h. Thus, the ratios of Si to As (Si/As) would be 100:1 and 200:1. Silicic acid was prepared by passing potassium silicate through a cation-exchange resin (Amberlite IR-120B, H^+ form).

After 72 h of As and Si exposure, phloem sap, rice shoot and rice root were collected for total arsenic detection.

2.3 Total As analysis

Shoots (0.2 g FW) and roots (approx. 0.1 g FW) samples were digested in 5 mL HNO_3 (Liu *et al.*, 2004b). Reagent blank and certified reference material (GBW07603 from the National Research Center for Standard Materials in China) were included to verify the accuracy and precision of the digestion procedure and subsequent analysis. Total As concentrations in the samples (phloem sap, rice shoot and root) were determined atomic by fluorescence spectrometry (AFS9600, Beijing Haiguang Instrument Co., Beijing, China).

2.4 Statistical analysis

The significance of treatment effects was determined by analysis of variance (ANOVA) using statistical package SPSS 17.0 for windows. Tukey's multiple comparison tests were carried out according to the LSD (least significance difference) values.

3 RESULTS AND DISCUSSION

3.1 Arsenic in phloem sap influenced by foliar application of Si

For As(III) treatment, the foliar application of Si concentration at 1000 μM (Si/As ratio at 100:1) decreased significantly As levels in phloem sap ($P < 0.05$) (Fig. 1). However, when DMA applied in nutrient solution, the foliar application of Si increased As concentrations in phloem sap significantly. There was a positive correlation between As concentrations and silicon levels in rice phloem only for rice exposed to medium with DMA ($R = 0.856$, $P < 0.01$, $n = 12$).

3.2 Arsenic concentrations in rice root and shoot influenced by Si foliar application

When As(III) supplied in nutrient solution, Si foliar application did not influence As accumulation in root while 1 mM Si addition decreased As levels in root significantly (Table 1). For DMA treatment, both 1 mM and 2 mM silicic acid foliar application reduced arsenic accumulation in rice roots and shoots. It indicated that foliar application Si could mediate As transported into rice grain under DMA in the growth medium and foliar Si application would be better to control As accumulation in rice plants for DMA treatment than that of As(III) supply.

3.3 Arsenic translocation affected by Si foliar application

As translocation factor ranged from ~ 0.03 – 0.05 for As(III) treatment while from ~ 0.17 – 0.19 for DMA treatment (Fig. 2), which meant DMA had higher efficiency to transport from root to shoot than that of

Figure 2. The translocation factor of arsenic in rice root to shoot under different Si treatments.

As(III). When 1 mM Si was sprayed on the rice shoots, the ratios of arsenic concentrations from roots to shoots were lowest regardless of whether As(III) or DMA in the growth medium.

4 CONCLUSIONS

The ratio of foliar application of Si concentration to As concentration in the solution at 100:1 decreased significantly As levels in phloem sap and rice shoots for arsenite treatment. When DMA supplied, Si/As ratio at 200:1 increased significantly arsenic and silicon concentrations in rice phloem ($P < 0.05$). In addition, there was a positive correlation between As concentrations and silicon levels in rice phloem ($R = 0.856$, $P < 0.01$, $n = 12$). Whether As(III) or DMA was supplied to rice, foliar application of low concentration of silicon (Si/As at 100:1) decrease arsenic concentration and translocation in rice.

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Figure 1. As concentration in rice phloem sap under the different Si concentration.

Table 1. As concentration in rice roots and shoots under the different treatments.

	CK	Dsi	Gsi
Root-As (mg/kg)			
As(III)	216.3 ± 2.03b	304.2 ± 8.53a	202.0 ± 9.08b
DMA	24.4 ± 0.41a	19.5 ± 1.25b	16.0 ± 1.21c
Shoot-As (mg/kg)			
As(III)	10.5 ± 0.07a	9.01 ± 0.19b	10.6 ± 0.07a
DMA	4.96 ± 0.34a	3.23 ± 0.39b	2.99 ± 0.25b