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Effects of Silicon Application on Lead Accumulation in Rice Grain

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Abstract

By designing different silicon (Si) application levels (low, medium and high) and different Si application methods (one time and two times), the effects of Si application on grain yields and lead (Pb) concentrations of rice were conducted with two rice cultivars differed in grain Pb accumulations. The results showed that the grain yields of Yangdao 6 (high grain Pb accumulator) were raised by 2.22% - 7.79%, and that of Yu 44 (low grain Pb accumulator) were raised by 0.47% - 6.22% by the Si applications, compared to the control. The grain Pb concentrations of Yangdao 6 were reduced by 43.69% - 84.16%, and that of Yu 44 were cut by 36.07% - 79.37% by the Si applications. The grain yields increased, but grain Pb concentrations decreased sharply, with the rises of Si application levels and Si application times. The effects of Si applications on grain yields and Pb concentrations of rice were higher in Yangdao 6 than in Yu 44. The effects of Si applications on grain Pb concentrations were much higher than on grain yields. Grain yield can be raised by 6% or more, and grain Pb concentration can be reduced by 80% or more, by high level and two times Si application in rice plantation.

Keywords

Rice (*Oryza sativa* L.), Silicon (Si), Lead (Pb), Cultivar, Grain

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1. Introduction

Resulting from mining and smelting activities, fossil fuel utilization, road traffic, painting, papermaking, and disposal of municipal sewage sludge, lead (Pb) is well-known as a widespread metal pollutant [1, 2]. Pb is an unnecessary and toxic element to organisms. It can decrease sperm counts and increase prevalence of morphologically abnormal sperm in male, and increase risk of miscarriage in female. Prenatal and early postnatal exposure to Pb will result in damage to central nervous systems. The damage was characterized by diminished intelligence, shortened attention span, and slowed reaction time. The effects are irreversible, untreatable and lifelong [3]. Very high levels of Pb in some roadside, urban and agricultural soils have been found in China [4, 5]. It was reported that heavy metal contamination (Cd and Pb) in food crops grown around mine posed a great health risk to the local population through consumption of rice and vegetables [6]. Therefore, to develop the technology for preventing or diminishing Pb pollution in edible organs of crops has attracted wide concern.

Silicon (Si) is beneficial to the growth and development of plants, and it can improve plants' resistance to biotic and abiotic stresses, such as salinity, diseases, and toxicities of heavy metals [7-9]. Researches presented that Si can improve plant's resistances to Mn, Zn, Cd and Cr [10-13]. It was also reported that Si application can inhibit metal uptake and accumulation in crop plants [14]. Therefore, Si may be used as a candidate for the diminution of heavy metal contamination in crop products.

Paddy rice is one of the most important crops in the world, especially in China. However, little is known about effects of

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Si on Pb tolerance and accumulation in rice plants. With two rice cultivars of different Pb accumulation abilities [15], the objective of this study is to investigate the effects of Si application on grain yields and Pb concentrations of rice plants exposed to soil Pb pollution.

2. Materials and Methods

2.1. Soil and Plant Materials

The soil for the experiment was collected from a Pb-contaminated field (around mine). After air-dried and passed through a 2-mm sieve, the soil was measured for some properties. Some soil properties, available Si and total Pb concentrations of the soil are shown in Table 1. According to the relevant standard of China "Farmland Environmental Quality Evaluation Standards for Edible Agricultural Products" (HJ 332-2006), the maximum allowable concentration (MAC) of Pb in paddy soil is 80 mg/kg. The soil Pb concentration is more than four times higher than the MAC. Therefore, the soil used in this study is heavily polluted by Pb.

Table 1. Some Properties, Available Si and Total Pb Concentration of the Soil Used.

Soil Type	Particle Size (g/kg)			pH	OM [a] (g/kg)	CEC [b] (cmol/kg)	Available Si (mg/kg)	Total Pb (mg/kg)
	Sand	Silt	Clay					
Paddy Soil	512.6	273.3	214.1	6.6	24.7	15.1	97.7	427.5

a, organic matter; b, cation exchange capacity.

The Pb-polluted soil was placed in pots (18 cm in diameter, 20 cm in height, 4 kg soil for each pot). Based on our previous study [15], two rice cultivars varying largely in grain Pb accumulations were used in this experiment. The cultivars are Yangdao 6 (indica, high grain Pb accumulator) and Yu 44 (japonica, low grain Pb accumulator). Rice seeds were germinated under moist condition at 32°C for 30 h. The germinated seeds were grown in uncontaminated soil for 30 d. Then, uniform seedlings were selected and transplanted into the Pb-polluted soil (3 seedlings per pot).

2.2. Experimental Design

Three levels of Si treatments were designed, and they are 2.5 mM (low-Si), 5.0 mM (medium-Si) and 7.5 mM (high Si) Si solutions. The Si solutions were prepared by dissolving sodium silicate ($Na_2SiO_3 \cdot 9H_2O$) into distilled water. Distilled water was served as control. 1000 mL of the Si solutions or distilled water were applied to the pots with two methods. They are one time Si application (the 1000 mL solutions or distilled water were added into the pots at three days before rice seedling transplanting) and two times Si applications (the Si solutions or distilled water were added into the pots at three days before rice seedling transplanting and at 35 days after seedling transplanting, 500 mL for a pot each time). Under open-air condition, the pots were arranged in a randomized complete block design with three replicates.

2.3. Determination of Grain Yield and Pb Concentrations

Rice grains were harvested at maturity, and oven-dried at 70°C to a constant weight. The grain yield for each pot was weighed. Then, the dry grain samples were ground with a stainless steel grinder to pass through a 100-mesh sieve. Pb concentrations of the grain samples were determined with AAS.

2.4. Statistical Analysis

Data were analyzed with the statistical package SPSS 16.0. Means were compared through one-way ANOVA using Tukey's test at $P < 0.05$ and $P < 0.01$.

3. Results and Discussion

3.1. Effects of Si Application on Grain Yield of Rice

The results showed that the effects of Si application on grain yield of rice differed with rice cultivars, Si application levels and Si application methods. In general, grain yields of the rice cultivars increased with raise of Si application levels and Si application times.

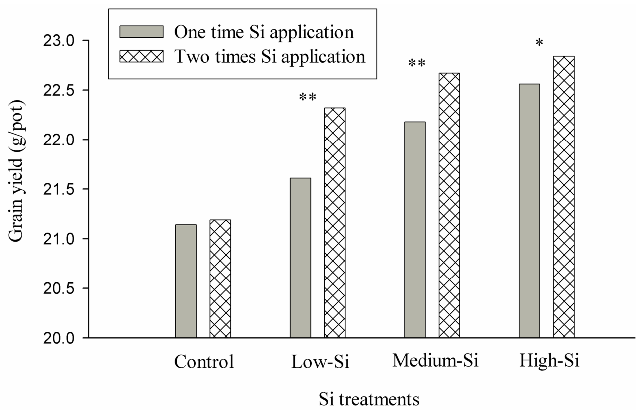

Figure 1. Effects of Si Applications on Grain Yields of Yangdao 6. **, * Significant difference between two Si application methods at $P < 0.01, 0.05$, respectively.

The effects of Si application on the grain yield of Yangdao 6 (indica, high grain Pb accumulator) are presented in Figure 1. Compared to the control, grain yields of Yangdao 6 were raised by 2.22%, 4.92% and 6.72% by low-, medium- and high- Si application level, respectively, for one-time Si application method. For two-times Si application method, the grain yields of Yangdao 6 were raised by 5.33%, 6.98% and 7.79%, respectively. The differences between two Si application methods in grain yields were little for the control, but highly significant for low-Si and medium-Si application ($P < 0.01$), and significant ($P < 0.05$) for high-Si application.

The effects of Si application on the grain yield of Yu 44 (japonica, low grain Pb accumulator) are shown in Figure 2. Compared to the control, grain yields of Yu 44 were raised by 0.47%, 2.84% and 4.78% by low-, medium- and high- Si application level, respectively, for one-time Si application method. For two-times Si application method, the grain yields of Yu 44 were raised by 2.71%, 4.70% and 6.22%, respectively. Therefore, the effects of Si application on the grain yields of Yangdao 6 were higher on those of Yu 44. With regard to Yu 44, the differences between two Si application methods in grain yields were little for the control, low and insignificant ($P > 0.05$) for high-Si application, but significant for low-Si and medium-Si application ($P < 0.05$).

Literatures presented that Si application alleviated Cd stress on plant by dilution effects [16]. Si could reduce ultra-structural disorders induced by Mn and Zn in maize and pea cells [17]. Co-depositing of metal and Si may be a cause for the detoxification in plants [18]. Si relieved Cd toxicity in *Solanum nigrum* by reducing Cd uptake and transport, and also by alleviating oxidative stress in plants [19]. Therefore, the mechanisms of Si-mediated tolerance to heavy metals in plants may include chelating with metal, reducing metal activities, inhibiting metal transport, stimulating the activities of antioxidants, regulating the expression of some genes, etc. [14].

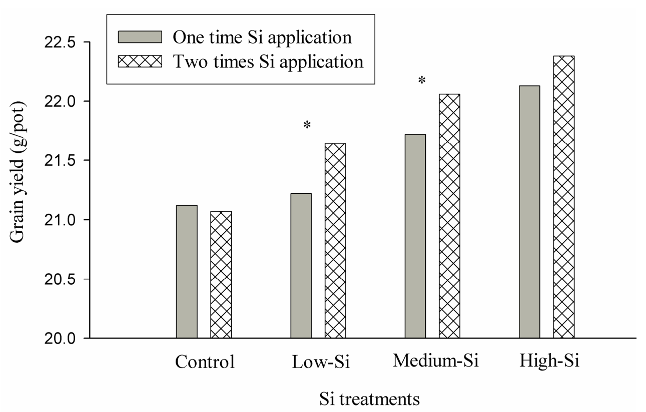

Figure 2. Effects of Si Applications on Grain Yields of Yu 44. * Significant difference between two Si application methods at $P < 0.05$.

3.2. Effects of Si Application on Grain Pb Concentrations of Rice

The effects of Si application on grain Pb concentrations of rice differed highly with rice cultivars, Si application levels and Si application methods. In general, grain Pb concentrations of the rice cultivars decreased fast with the raise of Si application levels and Si application times.

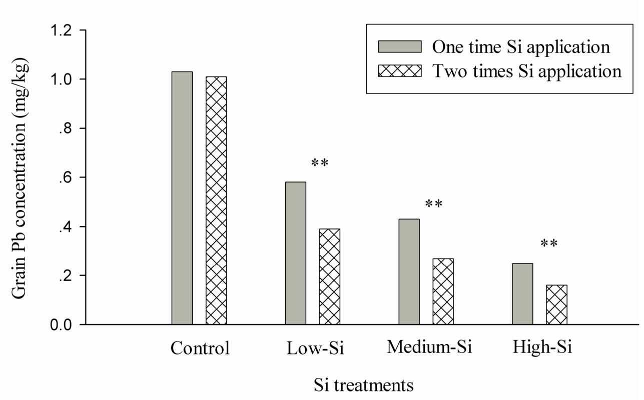

Figure 3. Effects of Si Application on Grain Pb Concentrations of Yangdao 6. ** Significant difference between two Si application methods at $P < 0.01$.

The effects of Si application on the grain Pb concentrations of Yangdao 6 are presented in Figure 3. Compared to the control, grain Pb concentrations of Yangdao 6 were reduced by 43.69%, 58.25% and 75.73% by low-, medium- and high- Si application level, respectively, for one-time Si application method. For two-time Si application method, the grain Pb concentrations of Yangdao 6 were reduced by 61.39%, 73.27% and 84.16%, respectively. The differences between two Si application methods in grain Pb concentrations were little for the control, but high and significant ($P < 0.01$) for three Si application levels (32.76% - 37.21%, the rate of two-times Si application lower than one-time Si application).

The effects of Si application on grain Pb concentrations of Yu 44 are shown in Figure 4. Compared to the control, grain Pb concentrations of Yu 44 were decreased by 36.07%, 49.18% and 70.49% by low-, medium- and high- Si application level, respectively, for one-time Si application method. For two-times Si application method, the grain Pb concentrations of Yu 44 were reduced by 57.14%, 66.67% and 79.37%, respectively. Therefore, the effects of Si application on the grain Pb concentrations of Yangdao 6 were also higher than on that of Yu 44. With regard to Yu 44, the difference between two Si application methods in grain Pb concentrations was little for the control, but high and significant ($P < 0.01$) for the three Si application levels (27.78% - 32.26%, the rate of two-times Si application lower than one-time Si application).

It was reported that the mechanisms on the effects of Si in reducing heavy metal transport in plants may be in two aspects: 1) Si can induce the deposition of lignin and the bounding with heavy metals in plant cell wall, so hinder the transport of heavy metals from root to aboveground parts in plant [20, 21]. (2) Co-precipitation of metal with Si by forming Si-metal complexes [22-24]. Former research found Less Mn in symplast and more Mn in the cell wall in Si-supplemented plants than in the control plants [25].

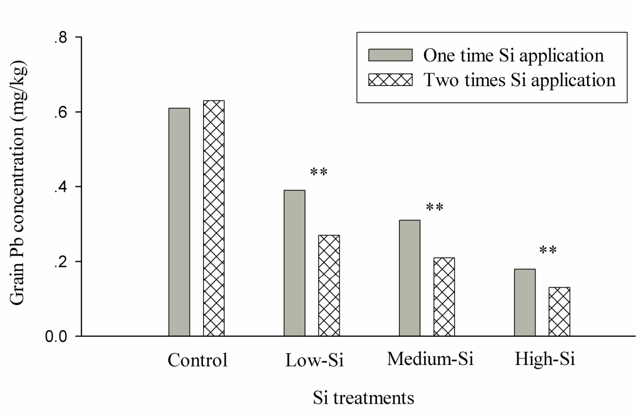

Figure 4. Effects of Si Application on Grain Pb Concentrations of Yu 44. ** Significant difference between two Si application methods at $P < 0.01$

4. Conclusion

Effects of Si application on grain yields and Pb concentrations of rice differed with rice cultivars, Si application levels and Si application methods. In general, grain yields of the rice cultivars increased with the raise of Si application levels and Si application times, but grain Pb concentrations of the rice cultivars decreased sharply with the increase of Si application levels and Si application times. The effects of Si application on grain yields and Pb concentrations were higher in the cultivar Yangdao 6 than in Yu 44. Compared to the control, the grain yields of Yangdao 6 were raised by 2.22% - 7.79% by the Si applications, and those of Yu 44 were raised by 0.47% - 6.22%. The grain Pb concentrations of Yangdao 6 were reduced by 43.69% - 84.16%, and those of Yu 44 were cut by 36.07% - 79.37%, by the Si applications. In conclusion, Si application in rice cultivation can increase grain yield significantly, and reduce grain Pb concentration greatly, specifically for the rice cultivar with high grain Pb accumulation ability. By high level and two times Si application in rice growth period, the grain yield can be raised by 6% or more, and the grain Pb concentration can be reduced by 80% or more.

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