Variation among Rice Cultivars in Root Acidification and Its Relation to Cadmium Uptake

LIU Jian-guo 1, 2, XU Hai 1, CAI Guo-liang 1, QIAN Min 1, WANG De-ke 1, ZHU Qing-sen 2
(1 Department of Environmental and Safety Engineering, Jiangsu Polytechnic University, Changzhou 213016, China; 2 Agricultural College, Yangzhou University, Yangzhou 225009, China)

Abstract: To understand the mechanisms of Cd uptake and accumulation in rice, soil acidification by root activities was investigated in six rice cultivars differing in Cd accumulation. The results showed a significant difference among the cultivars in pH of pot water and root exudate. Soil acidification abilities varied with rice cultivars. Both pH of pot water and root exudate were lower in indica cultivars than in japonica ones. The difference in root acidification was larger in Cd treated cultivars than the control. Under Cd stress, the pH of pot water and root exudate correlated negatively and significantly with Cd concentrations in rice plants. It was suggested that the soil acidification by root exudates, especially in Cd contaminated soils, may be one of the mechanisms responsible for Cd uptake in rice cultivars.

Key words: cadmium; rice (Oryza sativa); root acidification; uptake

Cadmium (Cd) is one of the most toxic pollutants, which can easily enter into food chain through cereal. Excessive intake of Cd by human body may damage kidney and has several other chronic effects [1]. Though plants do not require Cd for growth and development, but the bioaccumulation index of Cd in plants is high and may exceed many essential elements [2]. Moreover, Cd may pose a risk to human and animal health at plant tissue concentrations that are not generally phytotoxic [3]. Therefore, the Cd uptake by crops in contaminated soil is gaining the public concern.

The availability of metals in soil is one of the major factors that influences metal uptake in plants. The phyto-availability of metals can be controlled by the chemical characteristics of the metal, rhizosphere soil properties, and the specific characteristics of plant species or cultivars. Among all factors, plants play a decisive role in dominating metal bio-availability by root secretion, affecting metal mobilization [4]. The root exudates released are able to increase the metals solubility in the rhizosphere [5]. It has been previously reported that the mobilization of Cd in the rhizosphere was related to soil acidification in wheat [6-7], but soil acidification due to rice root secretion and its relation metal uptake was rarely reported. It has been observed that rice cultivars differed significantly in Cd uptake and accumulation [8-11]. However, limited work has been done on the mechanisms involved in variation among rice cultivars.

Based on our previous studies [8-9], rice cultivars with higher and lower Cd accumulating abilities were used in the present experiment. The major objective of the present work was to investigate the relationship between Cd uptake among different rice cultivars and soil acidification by root activities, and to understand the mechanisms involved in variation of Cd uptake and accumulation among rice cultivars.

MATERIALS AND METHODS

Soil preparation

The experiment was conducted in pots with 25 cm diameter and 30 cm height. Each pot contained ten kilogram of soil. Cadmium was added as CdCl$_2$ to obtain a Cd level of 100 mg / kg (dry weight). It created a highly Cd-contaminated soil without severe inhibition to rice growth [8]. The soils without Cd served as controls. The properties of the soil are given in Table 1.
Rice plant materials and experimental design

Based on our previous studies [8-9], six rice cultivars differing in Cd accumulation were used in this experiment, i.e. Liangyoupeijiu (indica hybrid, with high Cd accumulating), CV6 (new plant type, with medium Cd accumulating), Shanyou 63 (indica hybrid, with high Cd accumulating), Yangdao 6 (indica, with high Cd accumulating), Wuyunjing 7 (japonica, with low Cd accumulating) and Yu 44 (japonica, with low Cd accumulating). The pot remained submerging (with 2-3 cm of water above soil surface) during the whole growth period.

The experiments were carried out in open-air during rice growing season (early June to late September). The pots were arranged in a randomized complete block design with five replicates.

Sample preparation and analytical methods

To determine the Cd concentration, the plants (with soil) in sampling pots were uprooted at the tillering (40 d after transplanting), and heading stages (70 d after transplanting), and washed carefully with tap water and then with deionized water. The plants were divided into roots, culms and leaves, and oven-dried at 70°C. The oven-dried samples were ground with a stainless steel grinder (FW-100, China) to pass through a 100-mesh sieve. The Cd concentrations of the samples were determined by an Atomic Absorption Spectrophotometer (Solaar S4 + Graphite Furnace System 97, Thermo Elemental, USA) with HNO3-HClO4 (4 : 1) digestion [12].

The pH of pot water was measured 40 d (tillering stage) and 70 d (heading stage) after transplanting with a pH meter, once a day for three consecutive days.

For measuring the pH of root exudates, the whole plants were sampled on the 40th day (tillering stage) after transplanting, and washed thoroughly with tap water and then deionized water. Moreover, the roots were submerged into 200 mL of deionized water (pH 6.81) for three hours, while the pH of the water containing rice root exudates were measured with a pH meter.

Data were analyzed with the statistical package SPSS10.0 and EXCEL 2000 for Windows.

RESULTS

Variations among rice cultivars in the pH of pot water and root exudate

The pHs of pot water and root exudates of the six rice cultivars were significantly different both in Cd treatment as well as in the control (Fig. 1 and Fig. 2). The lowest pH was noted in Shanyou 63, while the highest pH was in the two japonica cultivars (Wuyunjing 7 and Yu 44).

The differences among the rice cultivars in the pH of pot water and root exudates were larger in Cd treatment than in the control. Thus, for the control, the differences between the lowest and the highest pH were 0.48 at the tillering stage and 0.80 at the heading stage for pot water, and 0.33 for root exudates. However, in Cd treated plants, the difference was 0.60 at the tillering stage and 1.22 at the heading stage for pot water, and 0.44 for root exudates.
Compared to the control, in the Cd treated plants, a significant decrease has been noted in the pH of pot water and root exudates for Liangyoupeijiu, CV6 and Shanyou 63, but few changes were observed in Wuyunjing 7 and Yu 44. Therefore, the larger difference of rice cultivars in the pH of pot water and root exudate in Cd treatment than in the control may resulted from different reaction of the cultivars to soil Cd stress in acidification by root exudates.

Differences in Cd uptake and accumulation among rice cultivars

There were large variations among the six rice cultivars in both Cd concentration and accumulations in rice plants at the tillering and heading stages (Table 2). Shanyou 63 and Liangyoupeijiu showed higher Cd uptake and accumulation, while Wuyunjing 7 and Yu 44 were relatively lower. Generally, the concentration and accumulation of Cd was significantly higher in indica cultivars than in japonica. The present results are consistent with our previous results [8-9].

Relationship between the pH of pot water, root exudate and plant Cd uptake

The statistical analysis on correlation of coefficients indicated that the pH of pot water and root exudates was negatively correlated with Cd concentration in rice plants (Fig. 3 and Fig. 4).

The correlations between the pH of pot water with plant Cd concentration were all significant in Cd treatment ($P<0.01$) both at the tillering and heading stages, but in the control the correlation between the pH of pot water with Cd concentrations in rice plants was only significant at the tillering stage (Fig. 3).

The correlations between the pH of root exudate

<table>
<thead>
<tr>
<th>Cultivar</th>
<th>Cd concentration (µg/g DW)</th>
<th>Cd accumulation (mg/pot)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Tillering stage</td>
<td>Heading stage</td>
</tr>
<tr>
<td>Liangyoupeijiu</td>
<td>174.22 c</td>
<td>89.07 a</td>
</tr>
<tr>
<td>CV6</td>
<td>189.54 b</td>
<td>83.12 b</td>
</tr>
<tr>
<td>Shanyou 63</td>
<td>233.56 a</td>
<td>85.10 ab</td>
</tr>
<tr>
<td>Yangdao 6</td>
<td>162.97 c</td>
<td>86.41 ab</td>
</tr>
<tr>
<td>Wuyunjing 7</td>
<td>134.11 c</td>
<td>56.96 c</td>
</tr>
<tr>
<td>Yu 44</td>
<td>128.43 d</td>
<td>5.37</td>
</tr>
</tbody>
</table>

Different letters within a column indicate significant differences between the cultivars at the 0.05 level.
soil properties. Among them, soil pH is known to be one of the most important parameters as the solubility of Cd will decrease with the increase in soil pH [2].

Wu et al. [13] reported that pH of soil solution decreased nearly 2 U at 30 d after planting in Indian mustard, and suggested that rhizosphere soil acidification might be one of the important mechanisms for plant to mobilize soil nutrients and heavy metals. It has been indicated that Al hyper-accumulators had low pH values in plant tissues and reduced rhizosphere pH which could increase Al availability for uptake, but Al excluders had higher pH values in plant tissues and raised pH in rhizosphere which could decrease Al uptake by root [14]. When exposed to high Al concentration stress, the organic acid content in root apices and root exudation both increased in Zea mays [15].

The present results showed that rice cultivars varied greatly in soil acidification in both Cd-stressed and control plants. For the control, pH of soil solutions decreased significantly due to the rice plant growth (such as Shanyou 63 and Yangdao 6), but some other cultivars (Wuyunjing 7 and Yu 44) showed few changes. Compared to the control, the reactions of different rice cultivars in root acidification to Cd stress even varied more substantially, e.g., the pH of soil solution and root exudate decreased significantly in Liangyoupeijiu, CV6 and Shanyou 63, but not in Wuyunjing 7 and Yu 44. As a result, the differences among the rice cultivars in soil acidification were even larger under soil Cd stress than the control.

For the control, Cd accumulation of the rice cultivars was significantly correlated with the pH of soil solution at the tillering stage, but not at the heading stage. However, under Cd stress, Cd accumulation in different cultivars was significantly correlated with soil solution pH both at the tillering and heading stages. This indicated a distinct difference in root acidification among rice cultivars even in the absence of Cd stress, while the difference was considerably large when the plants were exposed to Cd stress. Under Cd stress, the rice cultivars with higher Cd-accumulation abilities may excrete more acidic exudates than the cultivars with lower Cd-accumulation abilities, thus move more Cd for plant
uptake. However, the relations between the organic acids secretion and other root exudates and soil acidification need further studies.

ACKNOWLEDGEMENTS

Thanks must go to the Science and Technology Project of Changzhou (CS2005003) for financial support.

REFERENCES