

DOCTORAL THESIS

Effects of radial oxygen loss (ROL) on arsenic tolerance, uptake and distribution by rice (*Oryza sativa* L.)

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**Effects of Radial Oxygen Loss (ROL) on Arsenic
Tolerance, Uptake and Distribution by Rice
(*Oryza sativa* L.)**

WU Chuan

**A thesis submitted in partial fulfillment of the requirements
for the degree of
Doctor of Philosophy**

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Abstract

Arsenic (As) contamination is currently an environmental problem that has been receiving increasing concern. Substantial arsenic contamination of paddy soil has now been found in many areas around the world, and has adversely affected the health of millions of people that relies on rice as a staple food source. Therefore, there is an urgency to understand the mechanism of As tolerance and uptake by rice. The results of present study may be very valuable in revealing and explaining the physiological mechanisms of As uptake by rice, and can potentially provide valuable information in screening and breeding rice with low concentrations of As in their grains.

Root aeration, arsenic accumulation and speciation in rice of 20 different genotypes treated with 0.4 mg l^{-1} of As were investigated. Different genotypes had different root anatomy demonstrated by entire root porosity (ranging from 12.43 to 33.21%), which was significantly correlated with radial oxygen loss (ROL) ($R = 0.64$, $P < 0.01$). As accumulation differed among genotypes, but there were no significant differences between Indica and Japonica subspecies, as well as paddy and upland rice. Generally, total ROL from entire roots was correlated with metal tolerance and negatively correlated with total As ($R = -0.67$, $P < 0.01$) and inorganic As ($R = -0.47$, $P < 0.05$) in rice grains. There were also significant genotypic effects in percentage of inorganic As ($F = 15.8$, $P < 0.001$) and percentage of DMA ($F = 22.1$, $P < 0.001$) respectively. Root aeration of different genotypes and variation of genotypes on As accumulation and speciation would be useful for selecting genotypes to grow in areas contaminated by As.

Another greenhouse experiment was conducted to examine As dynamics, iron

plaque formation and radial oxygen loss and their relationships with As uptake and speciation in rice. Three genotypes were grown in low As soil amended with different concentrations of As. As concentrations in soil solution were built up during the flooded period, with Arsenic (III) the predominant form. There was a slight increase of iron plaque formation, a decrease in the rates of ROL, and induced a shift in the spatial ROL pattern from the “tight” to the “partial” barrier type. Arsenic speciation results showed that the percentage of DMA increased from 19-28% to 53-58 %, while the percentage of inorganic As decreased from 53-58% to 36-42% with the increasing soil As concentrations; the percentage of organic As was greatly elevated in rice grains (53-70%) compared with small percentages in rice roots (1-2%) and straws (2-6%).

The experiment was conducted to further study whether rice paddy soils would indicate enhanced mobility and bioavailability of this metalloid in soils with impeded drainage. The fate of As was investigated in two types of soils originated from the United Kingdom that were, derived from different sources of industrial waste. Arsenic mobility of soil was measured by soil pore-water sampling under flooded and drained watering regimes. Results showed that the flooding of one test soil greatly enhanced iron (Fe) and manganese (Mn) content of pore-water, followed by increases in As content and poor growth of rice. It is argued that testing As-contaminated soils by flooding combined with chemical analyses and plant assays, provides a realistic indication of future risk associated with waterlogged conditions.

In addition, to elucidate the mechanisms for genotypic differences of rice in As

uptake and tolerance, and that cause rice genotypes with higher ROL to have lower As accumulation, hydroponic experiments were conducted to investigate the effect of internal and external aeration on iron plaque formation, As accumulation and speciation in rice. The present study shows that there were significant correlations between ROL and Fe concentrations in iron plaque ($R = 0.61$, $P < 0.001$) of different genotypes of rice. Iron plaque sequestered more arsenate than arsenite, leading to decreased As accumulation in rice roots. In addition, there were significant correlations between Fe concentrations and As accumulation in iron plaque in both arsenite ($R = 0.87$, $P < 0.001$) and arsenate ($R = 0.81$, $P < 0.001$) treatments. There were significant differences in the amounts of iron plaque formed in different genotypes ($P < 0.01$), in different positions of rice roots ($P < 0.001$) and under different aerated conditions (aerated, normal and stagnant treatments) ($P < 0.001$). Compared with aerated treatment, rice tended to have a higher ROL in stagnant solution, with the highest in the root tip ($P < 0.001$), in accordance with the trend of spatial ROL. The majority As species detected in rice roots and shoots was arsenite ranging from 34-78% of total As in different treatments and genotypes.

Moreover, the effects of root oxidization and P fertilization were conducted to investigate As mobility in soils, As uptake, translocation and speciation in rice. Results showed that root oxidization could significantly influence As mobility in rhizosphere. Genotype TD71 with higher ROL could induce more Fe plaque formation and sequester more As and P in iron plaque and rhizosphere soil,

finally reduce As accumulation in rice plants. Additionally, P mobilized As in soil solution, and increased As accumulation in rice plants. Arsenic speciation results showed that the majority of As species in husks detected was inorganic As, accounting for 82-93% of the total As, while in rice husks and rice grains the majority of As was inorganic As and DMA, accounting for 33-64% of the total As. It was also noted that the percentage of inorganic As decreased, while percentage of DMA increased along the concentration gradient of As and P. The study elucidated the mechanisms involved in ROL on As tolerance and accumulation in rice.

The present study provides valuable information regarding As uptake, accumulation and speciation in rice related with ROL, iron plaque formation and soil chemistry. It provides potential strategies to mitigate the health risk posed by As contamination in rice. However, the mechanism for As tolerance and accumulation, as well as field application for mitigating As accumulation in rice grains need further investigation.

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