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Variation of As concentration between soil types and rice genotypes and the selection of cultivars for reducing As in the diet

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ABSTRACT

Human exposure to toxic heavy metals via the food chain is of increasing concern. In the present study, the effects of soil type and genotype on variation in arsenic (As) concentrations of different organs were investigated by using nine rice cultivars grown in two soils, with two levels of As contamination. There were significant genotypic differences ($P < 0.05$) in As concentrations of all organs, and As concentrations of polished grain were significantly affected by genotype and soil type. The As concentration in polished grain was higher in red paddy soil under As treatment, with range from 0.24 to 1.03 mg kg^{-1}, and the As concentration of three cultivars exceeded the concentration of Chinese Food Hygiene Standard (0.7 mg kg^{-1}). The As concentrations in stems, leaves and polished grain were all significantly and positively correlated. The As concentrations in polished grain were positively and significantly ($P < 0.01$) correlated with As root–grain translocation factor. The results indicated that As concentration in grain was partially governed by As uptake and the transfer of As from root to grain. The grain As concentration of the nine cultivars was significantly correlated between the two soil types at different levels of As contamination. Some genotypes, such as japonica rice (e.g. Ning jing 1 and Nan jing 32) had consistently low grain As concentrations. The results suggest the possibility of breeding the As rice cultivars to produce grain for safe consumption from soils with slight and moderate levels of As.

1. Introduction

Arsenic (As) is a metalloid that is toxic to plants and animals. Anthropogenic activities, such as contaminated irrigation water, mining and smelting industries, have released large amounts of As into paddy soils (Galbraith et al., 1995; Kham et al., 2010). This is especially true in China, where rapid industrial development and population expansion has substantial increased As contamination of agricultural soils (Zhu et al., 2008).

Rice more efficiently absorbs As than other cereals (Williams et al., 2007; Su et al., 2010) owing to the anaerobic conditions in paddy soils. When rice is grown on As-contaminated paddy soils, it can accumulate high levels of As and increase the transfer of As from soils to rice, posing a health risk to consumers (Xie and Huang, 1998; Abedin et al., 2002). Ohno et al. (2007) reported that the average proportions of total As intake were 13% from drinking water and 56% from cooked rice. Therefore, rice may be a main pathway of As intake by humans, and it is imperative to reduce toxic As accumulation in rice, especially in regions where it is a staple food.

The variation in As uptake and accumulation in rice plants may depend on cultivars and soil types (Norton et al., 2009a,b; Ahmed et al., 2011). Large variations in grain As concentration have been well reported from rice fields and market-basket surveys (Duxbury et al., 2003; Zavala and Duxbury, 2008). A study indicated that rice grain can accumulate relatively large amounts of As even from soils not contaminated by As (Daum et al., 2001). The bioavailability of As to the rice plant in different soil types is also an important factor. The bioavailability of As in paddy soil is very important for understanding the variation of As accumulation in rice, which may also be related to the geographic location, soil properties, redox conditions and cropping season (Meharg and Rahman, 2003). The key soil factors reported to govern As bioavailability to plants include pH and organic matter (Bhattacharya et al., 2010), redox status (Marin et al., 1993), clay content (Sheppard, 1992), and the presence of poorly crystalline iron (Fe) oxide (Takahashi et al., 2004; Bogdan and Schenk, 2009). However, the bioavailability of As in different soil types and the translocation of As within different rice cultivars, especially into grain, is poorly understood.

In China, >60% of the population relies on rice as a staple food, and the amount of rice consumed represents 55% of all cereals annually (Dong et al., 2011). Moreover, the types of paddy soil were various kinds (Gong et al., 1999), and the As polluted status

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in rice was serious. Therefore, the behavior of As in paddy soils and its accumulation by rice plants is important for assessing As accumulation in paddy fields and the potential impact on rice quality and safety, and finally to develop reduction strategies for As pollution. The present study was designed to investigate the As accumulation in nine rice cultivars (of three types) on two main types of soils in the middle and lower reaches of the Yangtse River. The overall aim of this study was to investigate the effect of rice genotype and soil type on the absorption of As in rice and the possibility of reducing pollution risk by selecting rice cultivars with low As concentrations. The following issues were addressed:

(1) Variations among rice cultivars in As concentration of different organs (roots, stems, leaves and polished grain) in two soil types.
(2) The roles of genotype, soil type and interaction between these two factors on As concentration in grain at different As levels.
(3) The relationship between As concentration of different organs in nine rice cultivars and As translocation from root to grain. In addition, possible cultivars for producing rice with low health risk in terms of low As accumulation are discussed.

2. Materials and methods

2.1. Soil

Two typical paddy soils, red paddy soil (RP) and yellow clayey paddy soil (YP) were sampled from the surface layer (0–15 cm depth) of uncontaminated paddy fields for pot experiments. Red paddy soil (Typical Fe-accumuli-stagnic Anthrosols) derived from Quaternary red clay, was collected from Yingtan City, Jiangxi Province, China (28°12′N, 116°57′E). Yellow clayey paddy soil (Typical Fe-accumuli-stagnic Anthrosols) derived from alluvial deposit, was collected from Changshu City, Jiangsu Province, China (31°36′N, 120°35′E). The soil physico-chemical properties are listed in Table 1.

Soil (7 kg) was placed in each pot (35 cm in diameter and 30 cm in height). There were two treatments: As addition level of 45 mg kg^{-1} and a control (no As addition). $Na_3AsO_4 \cdot 12H_2O$ was dissolved in deionized water and poured into the soil slowly, while mixing the soil at the same time. The thoroughly mixed soil was stored in pots and incubated at 80% water holding capacity for 3 months.

2.2. Rice cultivars

Nine rice cultivars of three types were used in this experiment. These were hybrid rice (cvs. De nong 2000, Tian xie 6 and Gang you 118), japonica rice (cvs. Wanjing 9707, Ning jing 1 and Nan jing 32), indica rice (cvs. Zhong yu 1, Te san ai 2 and Zhe 1500). These cultivars are common in the middle and lower reaches of the Yangtse River and southern coastal region in China. Rice seeds were submerged in a water bath for about 48 h at room temperature (20–25 °C) and germinated under moist conditions (seeds were covered with two layers of moist gauze) at 32 °C for another 30 h. The germinated seeds were grown in an uncontaminated paddy field. After 15 d, the seedlings were transplanted into the pots. The pot soil was maintained under flooded conditions (with 2–3 cm of water above the soil surface) during the whole growth period.

2.3. Experimental design

The pot trial was carried out at Zhongshan Botanical Gardens in Nanjing City during the rice-growing season (mid-May to early October) in a glasshouse. The pots were arranged in a randomized complete block design with three replicates. Nitrogen, phosphorus and potassium fertilizers were applied to each pot with 1 g of urea (N content 460 g kg^{-1}), 0.28 g of $Ca(H_2PO_4)_2$ and 0.7 g of K_2SO_4, respectively.

2.4. Analysis methods

Soil pH was measured using a glass electrode and a soil:water ratio of 1:2.5; organic carbon content was determined by wet digestion following the method of Nelson and Sommers (2001) and cation exchange capacity (CEC) by NH_4OAC leaching described by Lu (2000). Soil texture was analyzed using the method of Bowman and Hutka (2002). Total soil As was determined by atomic fluorescence spectrometry (AFS-230E, China) with a mixture of hydrochloric and nitric acids (3:1) (Bogdan and Schenk, 2009). A certified sediment reference material (GBW07456 from the National Research Center for Standard Materials in China) with As concentration of 13.3 mg kg^{-1} was used with soil digestions. The available-As content was determined by the $NaHCO_3$-extraction method (Olsen and Sommers, 1982). The Fe oxide content was extracted with acidified ammonium oxalate (Scheinost and Schwertmann, 1999).

At maturity, whole rice plants were harvested and washed thoroughly with tap water and then with deionized water. The plants were divided into roots, leaves, stems and grains. The roots, stems and leaves were oven-dried at 70 °C to constant weight. The oven-dried samples were ground with a stainless steel grinder (FW-80, China). The grains were air-dried to constant weight, and polished with a rice polishing machine (LTJM-12, China). The samples of polished rice were oven-dried at 60 °C to constant weight. The oven-dried samples were ground with a stainless steel grinder (FW-80, China). The As concentrations of the samples were determined by atomic fluorescence spectrometry (AFS-230E, China) following HNO_3–H_2O_2 digestion procedures (Tang and Miller, 1991). A certified rice reference material (GBW 10010 from the National Research Center for Standard Materials in China) with As concentration of 0.1 mg kg^{-1} was used with all rice sample digestions.

2.5. Data analysis

Soil and root to grain transfer factors (TF) were calculated as follows:

$$TF = \frac{C_a}{C_b},$$

where C_a is As concentration of polished grain, and C_b is As concentration of soil or root.

Table 1
Physico-chemical properties of the studied soils.

Soil	pH	OC (g kg^{-1})	CEC (cmol kg^{-1})	Fe oxide (mg kg^{-1})	Clay (%)	As concentration (mg kg^{-1})	
						Total	$NaHCO_3$
RP	5.07	12.03	9.39	1.99	18.8	4.29	0.22
YP	6.15	26.72	17.98	4.11	26.1	9.04	0.31