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Potentially toxic elements concentration in milled rice differ among various planting patterns

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ABSTRACT

Soil contamination with potentially toxic elements (PTEs) due to rapid development of industry and agriculture has threatened the food security. Rice, the staple food of more than half of the world's population is thought as the prominent source for intake of PTEs by human beings. In present study, we compared different rice planting patterns, viz., dry direct-seeded aerobic rice (DSA), dry direct-seeded flooded rice (DSF) and transplanted-flooded rice (TFR) regarding PTEs (Mn, Co, Ni, Cu, Zn, Mo, Cd and As) concentration in milled rice and milled rice yield. Two inbred (Lvhan1, Huanghuazhan) and two hybrid (Hanyou3, Yangliangyou6) cultivars were used in present study. We found that Mn, Co, Ni, Cu, Zn and Cd concentrations in milled rice under DSF were lower than that in DSA, and were comparable with that under TFR. Furthermore, Mo and As in milled rice under DSF were lower than that under TFR and a little higher than DSA. Our results also depicted that on average, there were no significant differences in milled rice yield among various planting patterns across cultivars and years. None of the PTE exceeded the critical limits for milled rice except Cd in DSA and As in TFR. Along with the benefits of higher resource use efficiency and less labor requirement; comparable yield with TFR and moderate PTEs accumulation indicated that DSF is a more suitable planting pattern in the context of environmental sustainability. Cultivar variations were also apparent regarding PTEs concentration in milled rice and milled rice yield, which suggested that future studies should focus on breeding/selection of high yielding cultivars with low PTEs accumulation.

1. Introduction

Increasing soil contamination by the potentially toxic elements (PTEs) has emerged one of the gravest threats to environmental sustainability and global food security (Rodriguez et al., 2007). In China, nearly 19.4% of arable land has been contaminated by PTEs mainly including cadmium, lead, copper, nickel, arsenic, zinc, mercury, and chromium (Jin, 2014). Soil contamination by the PTEs is governed by several factors including solid-waste disposal and atmospheric deposition. Moreover, fertilizers and pesticide use, application of the wastewater irrigation and sewage sludge in the field are also considered as the major cause of PTEs accumulation (Cui et al., 2005; Wilson and Pyatt, 2007). As the PTEs in the plants are taken up from soil, therefore, soil contamination with toxic elements and their transfer from soil to plant have got increasing concern (Zhao et al., 2010).

Rice (*Oryza sativa* L.) is arguably one of the major staple foods feeding more than half of world's population. In China, it covers 24% of all farm lands accounting 40% of total crop yields (Hu et al., 2002). Moreover, it has been considered as a major source of PTEs intake by humans in Asian countries (Mondal and Polya, 2008; Solidum et al., 2012; Tsukahara et al., 2003). Therefore, the security of rice has attracted more and more attention, in recent years. The increasing rice demand in future has deployed tremendous concerns to minimize PTE contamination for sustainable and productive rice based systems.

Looming water crisis and labor shortage have threatened the traditional transplanted-flooded rice (TFR) system and boosted the direct-seeded rice as alternate establishment method (Liu et al., 2014). However, a series of researches had reported that direct-seeded rice may increase the PTEs concentration in milled rice (Kawasaki et al., 2012; Peng et al., 2012; Zhang et al., 2006). In fact, water management had a significant influence on soil properties, including redox potential, organic matter, pH, and pedogenic oxide (Alloway, 2009; Fu et al., 2008), thus affecting the PTEs uptake by plants (Gao et al., 2012; Spanu et al., 2012). Gao et al. (2012) showed

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Table 1
Chemical properties and element concentration of soil used in the field experiment prior to any field operation.

Index	Unit	Value (mean ± SE)
pH	–	5.02 ± 0.1
Organic C	g/kg	17.7 ± 1.6
Total N	%	0.17 ± 0.01
Available P	mg kg^{-1}	30.4 ± 1.9
Available K	mg kg^{-1}	80.7 ± 5.0
CEC	cmolc/kg	49.9 ± 0.18
Clay	%	10 ± 0.95
Silt	%	64 ± 0.88
Sand	%	26 ± 0.55
Mn	mg kg^{-1}	285.2 ± 48.7
Co	mg kg^{-1}	14.0 ± 1.3
Ni	mg kg^{-1}	27.6 ± 0.1
Cu	mg kg^{-1}	19.4 ± 0.1
Zn	mg kg^{-1}	47.6 ± 1.5
Mo	μg/kg	<0.0
Cd	μg/kg	124.0 ± 5.5
As	mg kg^{-1}	5.3 ± 1.0

that aerobic soil conditions in dry direct-seeded aerobic rice (DSA) system provided a favorable environment for the activity of mycorrhizal fungi and mycorrhizal inoculation, which could be beneficial for increasing the bioavailability of Zinc (Zn), thus increasing Zn content in rice plants. In consistent with Zn content in rice plant, Cd content in rice plant was also increased by aerobic soil conditions (Arao et al., 2009; Kawasaki et al., 2012). In contrast, arsenic (As), another PTE was found to be easily accumulated in flooded rice (Marin et al., 1993). While aerobic soil condition inhibited As translocation from soil to plant (Talukder et al., 2012).

Despite availability of volumetric information regarding response of Cd, As, Zn, etc. to different water regimes, little is known about effect of water management on Mn, Ni, Cu, Co and Mo accumulation in milled rice. It is imperative to initiate studies on such global issue in the scenario of reducing PTEs accumulation in food-chain. Therefore, present study was designed in Central China for comparative assessment of different planting patterns and cultivars regarding PTEs (Mn, Co, Ni, Cu, Zn, Cd, Mo, As) concentration in milled rice and milled rice yield under field conditions.

2. Materials and methods

2.1. Site description

Present study was conducted at Zhougan Village (29°51′ N, 115°33′ E), Dajin Town, Wuxue County, Hubei Province, China during 2012 and 2013 growing seasons. Prior to any field operation, soil samples were collected at the depth of 20 cm for analysis of soil physico-chemical properties and PETs concentration (Table 1). The soil of the experimental site was a silt loam with proportion of sand, silt and clay as 26, 64 and 10%, respectively.

2.2. Experimentation

The experiment was arranged in a randomized complete block design under split plot arrangements with four replications. Three different planting patterns, viz., dry direct-seeded aerobic rice (DSA), dry direct-seeded flooded rice (DSF) and transplanted-flooded rice (TFR) were assigned to main plot, and four indica cultivars (Lvhan1 (LH1), Hanyou3 (HY3), Huanghuazhan (HHZ), and Yangliangyou6 (YLY6)) were kept in subplots. LH1 (inbred) and HY3 (hybrid) are drought-resistance cultivars, while HHZ (inbred) and YLY6 (hybrid) are two of the most popular and commonly grown cultivars by rice farmers in Central China.

In dry direct-seeded plots (dry direct-seeded aerobic rice and dry direct-seeded flooded rice), the soil was dry ploughed and harrowed without puddling. Dry seeds were sown at 25 cm wide rows by drill using seed rate of 60 kg ha^{-1} for each cultivar. In transplanted-flooded rice plots, 25-day-old seedlings were transplanted at a hill spacing of 25 cm × 13.3 cm with three seedlings per hill. The water management in DSA was different from that in DSF. In DSA plots, no standing water was applied during the whole growing season, while in DSF plots, standing water with a depth of 5–10 cm was kept after five-leaf stage. The water management in TFR plots was opted as used by the farmers. Fresh canal water was used for the irrigation purpose. The concentrations of PTE in irrigation water were far below than their critical limits (data not shown). Fertilizers in all planting patterns were applied equally at the rate of 150:40:100:5 kg N:P_2O_5:K_2O:Zn ha^{-1} Whole of the P_2O_5 and Zn, 26% of the N and 50% of K_2O was applied as a starter basal dose, while residual N was equally splitted at middle tillering stage and panicle initiation stage. 50% of potassium was top dressed at panicle initiation. Weeds, diseases and insects were controlled during the whole growing season intensively in both years.

2.3. Data recorded

To calculate the milled rice yield, grain yield was determined from a 5 m^2 area in each plot and adjusted to the standard moisture content of 0.14 g H_2O g^{-1} fresh weight. Twenty-six grams of rough rice was de-husked using a husker (SY88-TH, BRIC, Korea) to get brown rice and then 10 g brown rice was milled by Miller (Pearlest, Kett, Japan) and then a separator (JFQS-13*20, China) was used for removing the broken rice to get milled rice for calculation of milled rice yield. Finally, after oven drying at 70 °C, the milled rice was ground to fine powder. Samples (0.5 g) were digested in 5:1 (v/v) HNO_3/H_2O_2 (5 mL) in a microwave oven (MLS 1200, Milestone, FKV, Italy) (Arao et al., 2008). A series of elements (Mn, Co, Ni, Cu, Zn, Mo, Cd and As) concentration in the digested samples, were determined by inductively coupled plasma (ICP)-optical emission spectroscopy (Vista-PRO, Varian, Inc., Palo Alto, CA) and ICP-mass spectrometry (ICP-MS) (ELAN DRC-e, Perkin-Elmer Sciex, DE). Accuracy was evaluated by the use of a certified reference material (rice flour, NMIJ CRM 7502-a No.7 Cd Level II).

2.4. Statistical analysis

Data were analyzed to confirm its variability following analysis of variance using Statistix 8.0. The differences between treatments were separated using Least Significance Difference (LSD) test at 0.05 probability level.

3. Results

3.1. PTEs concentration in the soil at the experimental field

Data regarding chemical properties and total PTEs concentration in the soil are presented in Table 1. The PTEs concentration in the soil showed a trend of Mn > Zn > Ni > Cu > Co > As > Cd > Mo. Among them, Mn had the highest concentration (285.5 mg kg^{-1}) followed by Zn (50 mg kg^{-1}). Cd and Mo were the two elements with the lowest concentration (<1 mg kg^{-1}) in the soil. Total Co, Ni and Cu were about 20 mg kg^{-1}, whereas, As concentration was 5.3 mg kg^{-1}. None of the PTEs in the experimental site exceeded the critical limit of soil environmental quality standard in China (GB156182 1995).

3.2. Comparison on milled rice yield among different planting patterns

On average, there were no significant differences in milled rice yield among various planting patterns across cultivars and years (Table 2). Milled rice yield under DSA (4.84 t ha^{-1}) was 5.8% and