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Effects of fertilizers on arsenic accumulation in ratoon rice: implications for human health risks

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Introduction

Rice ratooning has received increased attention in recent years since it can reduce labor, seed, and energy inputs. However, ratoon rice often requires fertilizer supplementation due to its generally lower yield. Arsenic (As) in the soil becomes more mobile and bioavailable under long-term, flooded, anaerobic conditions. Consequently, large amounts of As can accumulate in rice grains, which is generally recognized as the main source of dietary As exposure in humans. Nevertheless, some recent research has indicated that rice ratooning can significantly reduce the concentration of grain As. Therefore, pot experiments were conducted in the present study to delineate the effects of different fertilizers on grain As accumulation in ratoon rice from three rice genotypes commonly cultivated in Taiwan. The interaction between iron (Fe) and As on the root Fe plaque was also determined, and the grain As concentration was further employed to assess the health risks associated with rice consumption.

Materials and methods

In this study, soil with a mean As concentration of 135.95 mg/kg was collected from central Taiwan and used for greenhouse pot experiments. Three local commonly cultivated rice genotypes, including two japonica cultivars TK9 and TK16 and one indica cultivar TCS17 were selected. Five treatments, including a control (denoted as CK), chemical fertilizer (Cf), organic fertilizer (Org), and rice husk amendments (0.5 and 1% [w/w], denoted as Husk0.5 and Husk1, respectively). After the main crop harvest, the remaining stubble was left at a height of 15–20 cm to cultivate the ratoon rice (Figure 1). At maturity, plant and soil samples were collected from the ratoon rice, and the root Fe plaque was extracted. The concentrations of total As and inorganic As (iAs) in the soil, plant tissues, and brown rice samples were precisely analyzed. Based on the results of the chemical analysis, the index of As sequestration by Fe oxides in root plaque (IAS) was calculated (Equation 1). Lastly, according to the grain iAs data, the hazard quotient (HQ) for non-carcinogenic risk and the target cancer risk (TR) for carcinogenic risk were calculated to evaluate the potential human health risks associated with the consumption of ratoon rice.

Index of As sequestration by Fe oxides in root plaque (IAS) :

$$IAS = \frac{IP_{AS}}{IP_{Fe}} \qquad (1)$$

IP_{As} : As concentration in root plaque (mg As/kg)
IP_{Fe} : Fe concentration in root plaque (g Fe/kg)

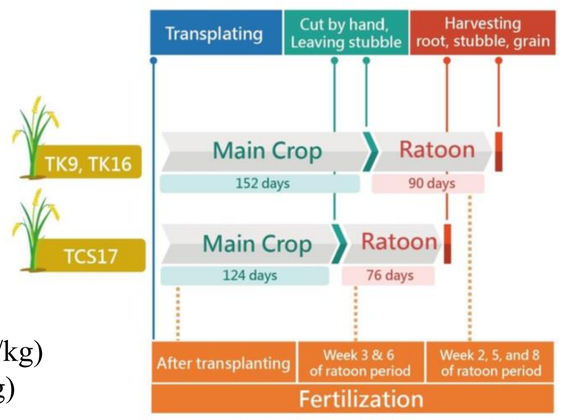

Figure 1. Schematic diagram of the pot experiment process in this study.

Results and Discussion

The As concentrations in ratoon rice are given in Table 1. The results showed that the As concentration in the husk was relatively lower than that of the shoot. The application of rice husk significantly reduced the As concentrations in both the shoot and husk of TK16. Furthermore, rice husk treatments showed different effects on the iAs concentrations in the brown rice of the three rice genotypes, indicating that the impact was highly genotype-specific. Specifically, this treatment significantly decreased the As accumulation in TCS17. These findings imply that different fertilizer application strategies should be adopted for different rice genotypes to effectively mitigate As accumulation in ratoon rice.

Table 1. Distributions of As in shoots, husks, and brown rice of the cultivars (i.e., TK9, TK16, and TCS17) during the ratoon period under different soil treatments.

Treatments	Shoot	Husk	Brown rice	
	As	As	iAs	As (tot) †
	------ mg/kg			
	TK9			
Control	38.8 a‡	3.2 a	0.43 b	0.56 b
Cf	38.8 a	2.9 a	0.52 b	0.58 b
Org	47.8 a	4.8 a	0.64 b	0.90 ab
Husk0.5	29.2 a	1.1 a	1.08 a	1.29 a
Husk1	32.1 a	1.7 a	0.52 b	0.64 b
	TK16			
Control	63.3 a	3.2 ab	0.44 b	0.57 b
Cf	38.4 ab	2.2 b	0.48 ab	0.59 b
Org	63.3 a	4.7 a	0.53 ab	0.81 a
Husk0.5	19.2 b	1.7 b	0.62 a	0.70 ab
Husk1	29.5 b	1.7 b	0.58 ab	0.68 ab
	TCS17			
Control	38.1 a	3.2 ab	0.21 a	0.33 ab
Cf	37.3 a	1.8 bc	0.22 a	0.36 a
Org	39.8 a	4.0 a	0.19 ab	0.37 a
Husk0.5	29.4 a	0.7 c	0.15 b	0.29 ab
Husk1	27.3 a	0.7 c	0.15 b	0.19 b

Fertilizer treatments had profound effects on As accumulation in root Fe plaque, with a remarkable difference in the IAS observed among the three cultivars, significant negative correlations were found between As in brown rice and the IAS value across all treatments (Figure 2). These results imply that greater As sequestration by root Fe plaque leads to lower As accumulation in brown rice. Therefore, managing IAS within the root Fe plaque environment represents a critical strategy for reducing grain As concentrations in rice ratooning systems.

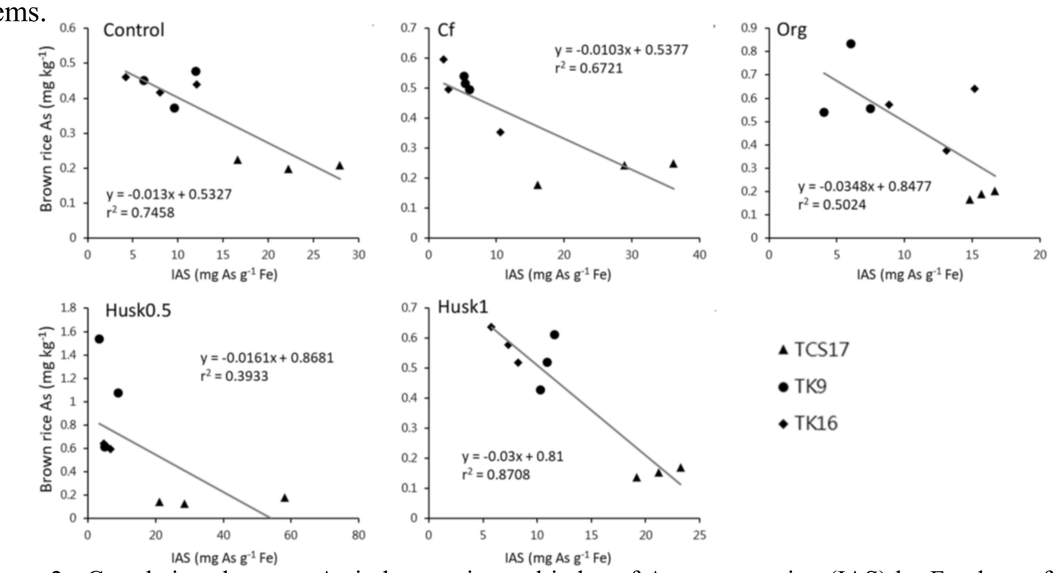

Figure 2. Correlations between As in brown rice and index of As sequestration (IAS) by Fe plaque for the three rice genotypes (TCS17, TK9, and TK16) grown in soils with the treatments (control, Cf, Org, Husk0.5, and Husk1).

According to the human health risk assessment results in Figure 3 and 4, a prominent gender effect was observed, both the HQ and TR values for adult male groups were higher than those for adult female groups across the same treatments. Additionally, the health risks associated with consuming the TCS17 was lower than for TK9 and TK16. Among the different fertilizer treatments, the addition of organic fertilizer and rice husk can effectively reduce the human health risks associated with consuming TCS17. In contrast, the consumption of TK9 and TK16 resulted in unacceptable health risks across all treatments because the calculated median non-cancer and cancer risk both exceeded the acceptable human health risk levels.

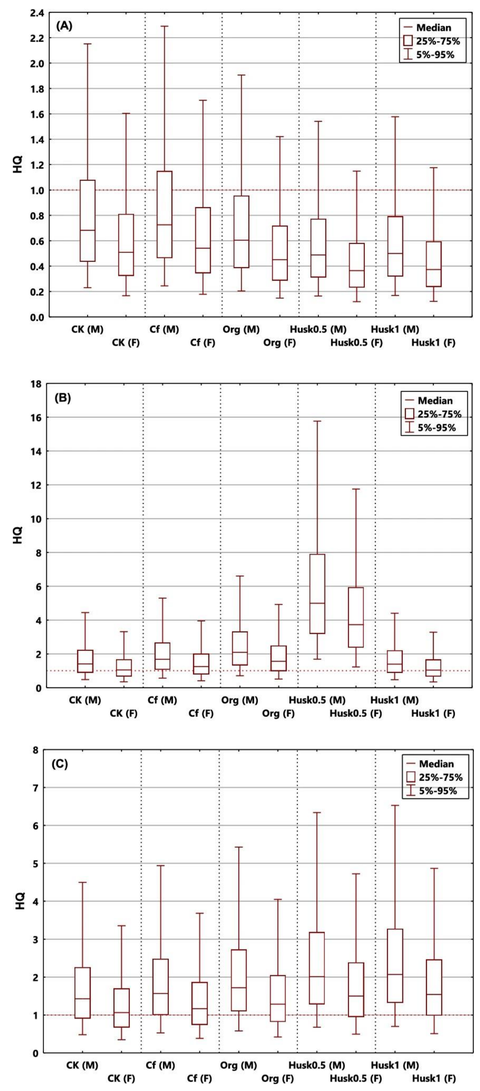

Figure 3. The hazard quotient (HQ) of iAs for both genders (M: male; F: female) associated with the consumption of ratoon rice with the rice genotypes (A) TCS17, (B) TK9, and (C) TK16 grown in soils with the treatments (control, Cf, Org, Husk0.5, and Husk1).

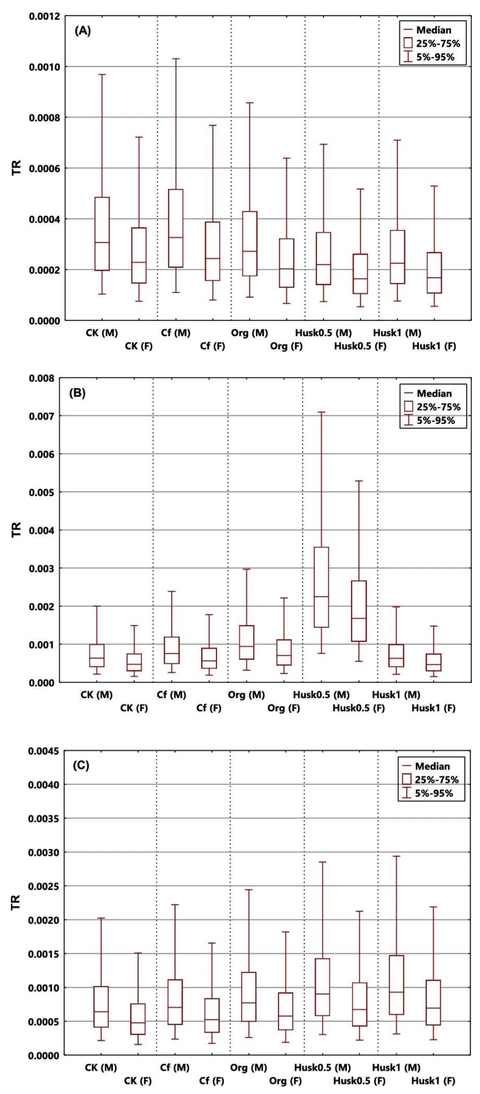

Figure 4. The target cancer risk (TR) of iAs for both genders (M: male; F: female) associated with the consumption of ratoon rice with the rice genotypes (A) TCS17, (B) TK9, and (C) TK16 grown in soils with the treatments (control, Cf, Org, Husk0.5, and Husk1).