EnvironmentAsia
The international journal published by the Thai Society of Higher Education Institutes on Environment

Available online at www.tshe.org/EA
EnvironmentAsia 3(2) (2010) 34-37

Uptake of Arsenic in Rice Plant Varieties Cultivated with Arsenic Rich Groundwater

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Abstract

Groundwater of many areas of West Bengal, India is severely contaminated with arsenic. The paddy soil gets contaminated from the groundwater and thus there is a probability of bioaccumulation of arsenic in rice plants cultivated with arsenic contaminated groundwater and soil. This study aims at assessing the level of arsenic in irrigation water and soil and to investigate the seasonal bioaccumulation of arsenic in the various parts (straw, husk and grain) of the rice plant of different varieties in the arsenic affected two blocks (Chakdaha and Ranaghat-I) of Nadia district, West Bengal. It was found that the arsenic uptake in rice during the pre-monsoon season is more than that of the post-monsoon season. The accumulation of arsenic found to vary with different rice varieties; the maximum accumulation was in White minikit (0.31±0.005 mg/kg) and IR 50 (0.29±0.001 mg/kg) rice varieties and minimum was found to be in the Jaya rice variety (0.14±0.002 mg/kg). In rice plant maximum arsenic accumulation occurred in the straw part (0.89±0.019-1.65±0.021 mg/kg) compared to the accumulation in husk (0.31±0.011-0.85±0.016 mg/kg) and grain (0.14±0.002-0.31±0.005 mg/kg) parts. For any rice sample concentration of arsenic in the grain did not exceed the WHO recommended permissible limit in rice (1.0 mg/kg).

Keywords: Arsenic; bioaccumulation; rice (*Oryza sativa* L.); irrigation water; West Bengal

1. Introduction

Arsenic is a highly toxic and carcinogenic environmental pollutant and thus its presence in groundwater and agricultural field soil is of great concern all around the world (Rahman *et al*., 2007). Arsenic has been linked to an increased risk of cancer as well as to cardiovascular diseases (Pizarro *et al*., 2004). Arsenic-contaminated rice is viewed as a newly recognized disaster for South-East Asia, where rice is a staple food (Meharg, 2004). Groundwater arsenic contamination in the Bengal Delta plain has been termed as the largest mass poisoning in history (Smith *et al*., 2000). Nine out of total nineteen districts of West Bengal has groundwater arsenic contamination (Chakraborty *et al*., 2002; Roychowdhury *et al*., 2002; Bhattacharya *et al*., 2010). In West Bengal (India) groundwater arsenic contamination is in alarming condition for long and in the rural area the arsenic contaminated groundwater is not only used for drinking purpose, but also used for irrigation of various crops and especially for rice. Abedin *et al*. (2002) and Meharg and Rahman (2003) have reported about the rice samples with arsenic accumulation much above the WHO recommended permissible level (1.0 mg/kg). Delowar *et al*., (2005) reported the accumulation of arsenic in rice grain in the range 0.0-0.14 mg/kg which was cultivated with 0.0-20.0 mg/L of arsenic-contaminated water. Arsenic accumulation in rice straw at very high levels indicates that the cattle populations are in direct threat for their health and also, indirectly, human population, via consuming contaminated bovine meat and milk (Abedin *et al*., 2002).

A few works have been done to analyze the effect of arsenic on different varieties of rice plants and the said reports established that the rate of accumulation of arsenic in rice plants varied with different varieties of rice samples (Alam *et al*., 2003; Delowar *et al*., 2005; Williams *et al*., 2006; Rahman *et al*., 2007). The objective of the present study was to determine the accumulation of arsenic in different fractions of the rice plant of various varieties on seasonal basis, cultivated with arsenic-contaminated irrigation water in the two blocks of Nadia district, West Bengal.

2. Materials and Methods

2.1. Study area

The study area (Nadia district, West Bengal, India) is highly contaminated with arsenic. Two blocks of Nadia district (Chakdaha and Ranaghat-I) have been chosen for the present study. In all these areas the level of arsenic in groundwater is frequently exceeding WHO recommended permissible limit for drinking water (0.01 mg/L) (WHO 1992) and Food and Agricultural Organization (FAO) recommeded permissible limit for irrigation water (0.10 mg/L) (FAO 1985).

2.2. Sample collection

The irrigation water samples were collected in polyethylene bottles and preserved with concentrated HNO_3. Soil and rice samples were collected by composite sampling and transferred to airtight polyethylene bags. Soil samples were collected from 10-15 cm depth in a 2 m^2 area. Similarly, rice plant samples were collected from a selected plot (2 m^2 areas) during harvesting time.

2.3. Sample treatment

The water samples were filtered using 0.45 µ Millipore filter paper and were kept in polyethylene bottles at 4°C prior to analysis. The soil samples were dried in the hot air oven at 60°C for 72 h. The samples were then grinded and passed through 2.0 mm pore sized sieve to make homogenized representative powder sample. The rice samples were washed and finally rinsed with de-ionized water. The samples were then dried in the hot air oven at 60°C for 72 h. Finally the soil and rice samples were stored in polyethylene bags at room temperature. The samples were digested following the heating block digestion procedure (Rahman *et al*., 2007). Proper care was taken at each step to minimize any kind of contamination. All glassware were previously acid washed with 2% HNO_3 followed by rinsing with de-ionized water and drying.

2.4. Sample analysis

Total arsenic of the samples was analyzed by flow injection hydride generation atomic absorption spectrophotometer, FI-HG-AAS (Perkin Elmer AAnalyst 400). Standard Reference Materials (SRM) (from NIST, USA) was analyzed in the same procedure at the start, during and at the end of the measurements to ensure continued accuracy. The observed arsenic concentrations (mg/kg dry weight) of the SRMs were as follows: San Joaquin soil (SRM 2709A) 16.3±0.8 (certified value 17.7±0.8), Rice Flour (SRM 1568A) 0.28±0.04 (certified value 0.29±0.03). Thus the certified and the observed values were in good agreement.

3. Results and Discussion

In the study area, during the pre-monsoon period (January-April) the irrigation is done mainly with the groundwater, as there is very little or no rainfall and during the post-monsoon season (July-October) cultivation is mainly rain-fed. In the present study, samples of irrigation water, agricultural field soil and rice plant were collected from the arsenic affected two blocks of Nadia district (West Bengal) and analyzed for total arsenic. The concentrations of arsenic in irrigation water, soil and tissues of rice plant of various varieties are presented in Table 1.

3.1. Arsenic content in irrigation water and soil

Usually shallow tube well pumps are used for irrigation in the study area (running approximately 8 h/day, 8 months/year). Results showed that the irrigation water has an average arsenic concentration of 0.36±0.004-0.47±0.001 mg/L. The paddy soil gets contaminated from the groundwater and the average concentration has been found to be between 4.26±0.213 and 5.85±0.175 mg/kg dry weight of arsenic. The source of this elevated level of arsenic is mainly of geological origin. Along with it, sediment deposition, addition of fertilizers, pesticides, herbicides that have relevant presence of arsenic, play a significant role, as predicted by Meharg and Rahman (2003). For all the studied soil samples the arsenic concentration was below the reported global average of 10.0 mg/kg (Das *et al*., 2004) and was much below the maximum acceptable limit for agricultural soil of 20.0 mg/kg, as recommended by

Table 1. Seasonal concentrations of arsenic in irrigation water, soil and in the tissues of rice plant of different varieties

Season	Rice varieties	Arsenic concentrations (mean ± SD)				
		(mg/L) Irrigation water	(mg/kg)			
			Soil	Rice straw	Rice husk	Rice grain
Pre-monsoon	IR 50	0.47±0.001	5.85±0.175	1.65±0.021	0.77±0.005	0.29±0.001
	Ratna			1.18±0.008	0.41±0.001	0.20±0.005
	Red minikit			1.22±0.013	0.79±0.009	0.24±0.009
	White minikit			1.63±0.015	0.85±0.016	0.31±0.005
Post-monsoon	Ganga-kaveri	0.36±0.004	4.26±0.213	1.37±0.015	0.48±0.004	0.19±0.003
	Jaya			0.89±0.019	0.31±0.011	0.14±0.002
	Lal Sanna			1.28±0.013	0.39±0.007	0.20±0.001
	Nayanmani			1.14±0.035	0.56±0.007	0.16±0.002

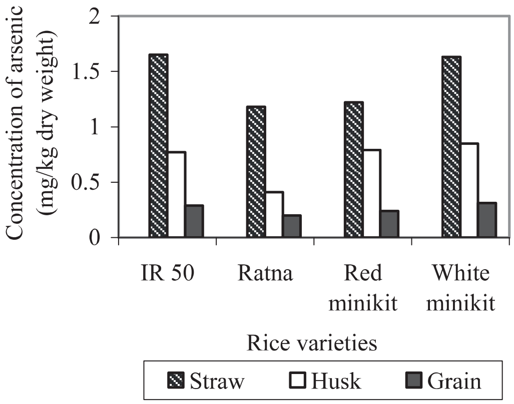

Figure 1. Graphical representation of the concentrations of arsenic in the different parts of the rice plant (*Oryza sativa* L.) of four different varieties during pre-monsoon season

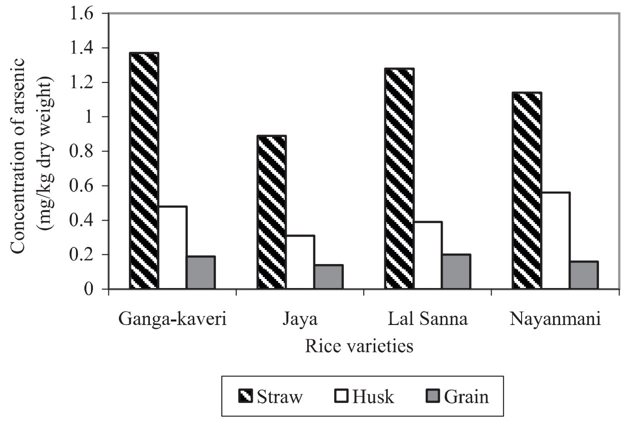

Figure 2. Graphical representation of the concentrations of arsenic in the different parts of the rice plant (*Oryza sativa* L.) of four different varieties during post-monsoon season

the European Community (Rahman *et al*., 2007). But the arsenic concentrations in groundwater was much higher than the WHO recommended limit for drinking water (0.01 mg/L) (Smith 1998; Rahman *et al*., 2007) and FAO recommended permissible limit for irrigation water (0.10 mg/L) (FAO 1985). Thus there is a high possibility of increase of arsenic concentration in the soil in near future, if the trend of using large amount of arsenic contaminated ground water for irrigation continues.

3.2. Arsenic content in various parts of rice plant of different varieties

Rice is widely cultivated in West Bengal to ensure food security which requires huge groundwater for irrigation. But groundwater of West Bengal is highly contaminated with arsenic. Williams *et al*. (2006) reported that daily consumption of rice with a total arsenic level of 0.08 mg/kg would be equivalent to drinking contaminated water with arsenic level of 0.01 mg/L. Graphical representations of the concentrations of arsenic in different parts of the rice plant in the arsenic affected two blocks of Nadia district during pre-monsoon and post-monsoon seasons are shown in Figs. 1 and 2, respectively. The uptake of arsenic (mg/kg dry weight basis) in the various parts of the rice plant of different varieties during pre-monsoon season has been found to have following ranges- straw: 1.18-1.65; husk: 0.41-0.85 and grain: 0.20-0.31, respectively and that for the post-monsoon season- straw: 0.89-1.37; husk: 0.31-0.56; grain: 0.14-0.20, respectively. From the data the accumulation of arsenic was found to be more during the pre-monsoon season than that of the post-monsoon season. This may be due to the fact that in the pre-monsoon season farmers are mostly dependent on the groundwater for irrigation, which is contaminated by arsenic.

An important finding from the results is that the accumulation of arsenic varies with different rice varieties, which is concurrent with the previous observations by Alam *et al*. (2003), Delowar *et al*. (2005) and Williams *et al*. (2006). It was noticed that some of the rice varieties (IR 50, White Minikit, Red Minikit) are high accumulator of arsenic (0.24±0.009-0.31±0.005 mg/kg) with respect to varieties (Nayanmani, Jaya, Ratna, Ganga-kaveri, Lal Sanna) with low accumulation (0.14±0.002-0.20±0.005 mg/kg). Among them Ganga-kaveri is a hybrid variety of rice, and Nayanmani and Lal Sanna are the two local rice varieties. All other rice samples (IR 50, White Minikit, Red Minikit, Jaya, Ratna) are high yielding varieties (HYV). The maximum accumulation of arsenic was found in the White minikit (0.31±0.005 mg/kg) and in the IR 50 (0.29±0.001 mg/kg) rice varieties while the minimum accumulation was found in the Jaya rice variety (0.14±0.002 mg/kg). The Government should take proper initiative for a detailed study on this and subsequently encourage the farmers to cultivate the rice varieties which are less susceptible to arsenic accumulation. The results clearly showed that irrespective of variety, location and season maximum accumulation was occurred in the straw (0.89±0.019-1.65±0.021 mg/kg) of the rice plant, followed by husk (0.31±0.011-0.85±0.016 mg/kg) and grain (0.14±0.002-0.31±0.005 mg/kg) parts. This finding is in good agreement with the findings previously reported by Liu *et al*. (2006), Rahman *et al*. (2007) and Bhattacharya *et al*. (2010). For any studied rice samples the concentration of arsenic in the grain part (0.14±0.002-0.31±0.005 mg/kg) did not exceed the WHO recommended permissible limit in rice (1.0 mg/kg) (Das *et al*., 2004; Rahman *et al*., 2007). In Bangladesh rice grain has been reported to accumulate arsenic upto 2.0 mg/kg by Meharg and Rahman (2003) and Islam et al. (2004). In comparison to that it can be concluded that the risk of chronic arsenic poisoning by the arsenic ingestion from rice is low in the study area.

3.3. Health hazard to cattle population

The rice plants grown in the arsenic contaminated study area have a good accumulation of arsenic in the straw (0.89±0.019-1.65±0.021 mg/kg). Thus severe health hazard to the large cattle population of the study area consuming the straw part of the rice plant has become a concern. The Muslim populations of the area are used to eat beef as a readily available and cheap source of meat. The cow milk has served the protein requirement of people of all the religions. Thus there is further risk of entering of arsenic to human bodies. From a study in Bangladesh the same concern was predicted by Abedin *et al*. (2002).

Acknowledgement

The authors are thankful to the Department of Environment, Government of West Bengal, India for providing fund to carry out the investigation.

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Received 23 May 2010
Accepted 11 June 2010

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