Ecosystem Aspects of Arsenic Poisoning: Human Exposure to Arsenic from Food Chain

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Abstract

Although the main source of arsenic to human body is ground water, the use of arsenic contaminated ground water for irrigation raise the question whether arsenic uptake in crop plants could also be another potential pathway of human exposure to arsenic. Arsenic content in straw, grain and husk of rice is especially important as rice is the staple food for man and straw and husk have been used as cattle feed. It was estimated that the daily intake of arsenic in human body from rice (containing 0.40 mg As/kg, the highest concentration of arsenic found in the present experiment in treatment containing 40 mg As/kg soil) is 0.20 to 0.32 mg/day (as the average consumption of rice by the people above five years old is between 400 and 650 gm/day) whereas it is 0.20 mg/day from drinking water (as the recommended safe level arsenic in drinking water is 0.05 mg As/L for Bangladesh and the average intake of water by an adult is about 4 liters). This finding suggests that arsenic intake in human body through rice could be a potential pathway in addition to drinking water. Therefore, a hypothesis have been put forward that the human have not been suffering from arsenicosis only from drinking water but also from "Plant-Animal-Man" and some other food chain pathways.

Introduction

Arsenic contamination in ground water has become one of the most severe problems in many countries including Bangladesh, India (West Bengal), China, Taiwan, Vietnam, United State of America, Argentina, Chile, Mexico etc. In Bangladesh, arsenic concentration in ground water accede the danger level (0.05 mg/L) in 59 districts out of 64 districts and 80 million people have been facing the arsenic poisoning. The natural contamination of shallow hand tube wells in Bangladesh with arsenic has led to widespread human exposure to arsenic through drinking water (Karim, 2000*;* Paul *et al.*, 2000). What are the other significant pathways of human exposure to arsenic? Use of shallow tube well water (which is also arsenic contaminated) for irrigation of crops raises the question. Arsenic uptake by food crops can also be a significant route of human exposure to arsenic. At the same time, other consumers of natural ecosystem (such as primary, secondary or tertiary consumers) also take arsenic contaminated water, which also raises the question whether there are some other routes of human exposure to arsenic, as human are the top consumer of the food chain of natural ecosystem. The impact of arsenic contaminated irrigation water on the arsenic content in rice is especially important as rice is the major staple food and it is grown in flooded (reduced) condition where arsenic availability is high (Duxbury *et al.*, 2003).

The question is that, what is the extent and severity of arsenic poisoning in human body ingested from these crop plants directly or indirectly. Our investigation was to find the answer of this question. We tried to asses the potentiality of human exposure to arsenic through food chain pathways of natural ecosystem. In this paper, we discussed mainly the extent and severity of arsenic poisoning in human body from “Plant-Animal-Man” food chain pathway.

Materials and Methods

Field experiment

Pot experiments were conducted in a glasshouse situated at Bangladesh Rice Research Institute (BRRI). Soils for the experiments were collected from BRRI farm and dried, crushed, sieved with 2 mm sieve. Arsenic (as $Na_2HAsO_4.7H_2O$) was mixed thoroughly at the rates of 0 (control), 10, 20, 30, 40, 50, 60, 70, 80 and 90 mg As/kg soil. Five kilogram soils were potted in six liter plastic pots.

The pots were placed on a cement table. The overall temperature in the glasshouse ranged from 22.4 to 33.9 ºC, relative humidity from 59.9 to 83.7%, sunshine from 3.4 to 7.8 h/day. BRRI dhan26 was used as test crop. Four seedlings of 35 days old were transplanted in each pot separately with equal spacing. After transplantation, the plants were grown under flooded condition. Normal tap water (used for irrigation) was applied regularly throughout the post-transplantation period until harvesting. Urea, TSP and MP fertilizers were applied to the initial soil at the rate of 30, 40 and 20 kg/hector for N, P and K. One-third amount of urea and full amount of other two fertilizers were applied as basal into the individual pots before transplantation. The fertilizers were incorporated into the soil by hand. The second and third splits of urea were applied after 30 days (maximum tillering stage) and 60 days (panicle initiation stage) after transplanting. The experiment was laid out in completely randomized design (CRD) with three replications for each treatment.

Chemical analysis for arsenic

The plant samples (straw, grain and husk) were digested with concentrated HNO_3 and $HClO_4$. About 0.5 g of the sample was taken into a dry clean digestion tube and 5 ml of concentrate nitric acid was added. The mixture was allowed to stand over night under fume shade. In the following day, the digestion tubes were placed on a heating block and the temperature was raised to 60 ºC. After heating, the tubes were allowed to cool and 2 ml of concentrated perchloric acid was added. Again, the tubes were heated at 160 ºC for about 4 to 5 hours. Heating was stopped when the dense white fumes of perchloric acid occurred. The digests were cooled, diluted in 25 ml distilled deionized water and filtered through filter paper (Whatman, No.-1) into plastic bottles. Total arsenic was determined by hydride generation atomic absorption spectrophotometer (HG-AAS) using matrix-malched standards (Welsch *et al.*, 1990). All glassware and plastic bottles were previously washed by distilled deionized water and dried.

Statistics analysis

The test of significance was computed by Duncan’s Multiple Range Test (DMRT) at 5% level of significance using SPSS (version 10.0 for Windows).

Results and Discussion

A. Physico-chemical properties of initial soil

Initial soil means the field soil that was used in the experiment. The toxicity limit and mobility of arsenic are closely associated with the physico-chemical properties of soil such as particle size, texture, soil reaction, mineral nutrient content etc. Therefore, it is relevant to know the soil properties to evaluate the influence of soil arsenic concentrations on rice plant as well as on soil. The result of the physico-chemical properties of initial soil have been presented in Table–1 and 2.

B. Arsenic concentration in rice plant

Arsenic concentration was measured in different tissues of rice plant which have been used as food stuff for some consumers of the natural ecosystem. From the experiment, it was observed that arsenic concentration in rice straw and husk increased steadily up to the treatment receiving 60 mg As/kg soil while grain arsenic content was almost constant (Figs.1 and 2). Regardless of soil arsenic concentrations, rice tissue arsenic concentration followed the trend: straw > husk > grain.

In rice straw, arsenic content was determined at two growth stages, at panicle initiation (PI) stage and at maturity stage. Soil arsenic concentrations influenced the contents in straw at both growth stages. At PI stage, the highest arsenic content in straw was 20.6 mg/kg dry weight in 60 mg As/kg soil, while the lowest was 0.6 mg/kgdry weight in control treatment. In 70 and 80 mg As/kg soil treatments, arsenic contents were found much less than that of in 60 mg As/kg soil treatment but higher than those of other treatments (Table-3).

At mature stage, the straw arsenic content increased with the soil arsenic concentrations up to 60 mg As/kg soil treatment (Fig.1). The highest straw arsenic content was 23.7 mg/kg dry weight in 60 mg As/kg soil treatment and the lowest was 0.9 mg/kg dry weight in control treatment. In 70, 80 and 90 mg As/kg soil treatments, the straw arsenic contents were found less than that of 60 mg As/kg soil treatment but higher than that of other treatments. Abedin *et al.* (2002) also reported the significant increase of arsenic concentrations in rice root, straw and husk with the increase of arsenate concentration in irrigation water. He found straw arsenic concentration as 3.9 mg/kg at the lowest arsenate treatment, which increased progressively with increasing arsenate application and reached to 91.8 mg/kg in the highest arsenate treatment (8.0 mg As/L).

The arsenic contents in rice grain were not significantly influenced by the soil arsenic concentrations. The highest grain arsenic content was 0.5 mg/kg dry weight in 40 mg As/kg soil treatment and the lowest was 0.2 mg/kg dry weight in control and 90 mg As/kg soil treatment (Table-3). Abedin *et al.* (2002) also reported that arsenic concentration in grain remained statistically similar with increasing arsenate concentration in irrigation water. He found the lowest grain arsenic concentration 0.15 mg/kg dry weight in control treatment and the highest was 0.24 mg/kg dry weight in treatment receiving 4.0 mg As/L.

The husk arsenic contents steadily up to the treatment receiving 50 mg As/kg soil and then decreased (Fig. 2). The highest arsenic content was 1.6 mg/kg in 60 mg As/kg soil treatment and the lowest was 0.2 mg/kg in control treatment (Table-3).

C. Human exposure to arsenic from "Plant-Animal-Man" food chain pathway

Arsenic have been found to be deposited in tissues of crop plants especially those which are grown in arsenic rich soil and irrigated with arsenic contaminated water. Arsenic accumulation has been reported in maize (Sadiq, 1986), barley and ryegrass (Jiang *et al.*, 1994) and rice (Duxbury *et al.*, 2003; Abedin *et al.*, 2002; Rahman et al., 2004). The accumulation of arsenic by plants occurs primarily through the root system which is then translocated to the aerial parts of the plants and the highest arsenic concentrations are reported in plant roots and tubers (Anastasia *et al.*, 1973). Plants seldom accumulate arsenic at concentrations hazardous to human and animal health because phytotoxicity usually occurs before such concentrations are reached (Walsh and Keeney, 1975).

Although human may be exposed to arsenic from a variety of environmental sources, food constitutes the largest source of arsenic intake with smaller contribution from air and drinking water (Chen *et al.*, 1994). Daily water consumption by an adult of tropical countries like Bangladesh ranged between 4 and 6 litters (Alam *et al.*, 2000). An adult is expected to intake 0.20 to 0.30 mg As/day only from drinking water when the arsenic concentration in drinking water is 0.05 mg/L. On the other hand, the average daily consumption of rice by an adult of this area is between 400 and 650 g raw rice grain/day (Duxbury *et al.*, 2003). The highest concentration of arsenic in rice grain was found to be 0.50 mg/kg in treatment receiving 40 mg As/kg soil in this experiment. On the basis of this data, the daily intake of arsenic from rice grain is 0.20 to 0.32 mg. These data indicate that intake of arsenic through rice and its potentiality to human exposure should be ignored.

The highest straw arsenic concentration was found to be 23.7 mg/kg dry weight in treatment receiving 60 mg As/kg soil while 12.3 mg As/kg dry straw was found in 40 mg As/kg soil treatment. Tsutsumi *et al.* (1980) reported 149 mg As/kg in rice straw when soil arsenic concentration was 313 mg/kg. Abedin *et al.* (2002) found 25 mg of As/kg in straw in treatment treated with 2 mg of As/L (equivalent dose reported to be the highest contamination of Bangladesh groundwater), which is 25-fold higher than the legal limit for foodstuffs (NFA, 1993). Straw given in the U.K. to cattle contained less than 0.20 mg As/kg (Nicholson et al., 1999). As the rice straw is found to be containing very high level of arsenic and is used as fodder for cattle, the people of Bangladesh are at risk of being affected by arsenic through their food. Cattle are the primary consumer of food chain of the ecosystem in nature. They eat rice straw and husk and thus may become exposed to arsenic poisoning. Human is the secondary consumer as they eat beef and mutton. Although there have not been found adequate report on the presence of arsenic in milk and meat of the cattle of Bangladesh and those imported from west Bengal, India, there is an ample scope of arsenic to be deposited in cattle body especially from high arsenic-containing straw and husk eaten by cattle. Thereby, the human have not been suffering from arsenicosis only from drinking water but also from "Plant-Animal-Man" and some other food chain pathways.

D. Bioaccumulation of Arsenic in Terrestrial food chain

Bioaccumulation Factor (BAF) or Bioconcentration Factor (BCF) is very important to asses the health risk of arsenic to different organisms. Mason *et al.* (2000) reported that the levels of arsenic decreased with increasing trophic level. He also suggested that the subsequent transfer of arsenic to higher trophic levels is related to both the ability of the organisms to depurate and the mode of accumulation, either directly from water or from food. Total arsenic concentrations in organisms after accumulation from foods decreased one order of magnitude per elevation of the trophic level.

Klose and Braun (1997) studied the arsenic content of soil and uptake by crops as included fodder plants, spring barley, potatoes, maize, winter rape, pasture grass and clover. In maize, rape, barley and potatoes, arsenic content ranged from 0.04 to 1.31 mg/kg dry matter when grown on soil containing 60-362 mg As/kg soil. In experiment with pasture grasses soil arsenic content ranged from 90 to 1050 mg/kg soil and plant arsenic content ranged from 0.18 to 6.7 mg/kg dry matter. Limited reports are available on bioaccumulation of arsenic in consumers such as animals, insects, birds and also the men. Because arsenic concentrations in terrestrial plants generally low, the uptake of arsenic by animals from this source is also low. Direct ingestion of arsenic from soil can be a major source of dietary arsenic for grazing livestock (Thornton and Webb, 1979). It is estimated that about 1% of the arsenic in the soil was actually ingested by the cattle, with the remaining being excreted directly.

This study showed that not only "Soil-Water-Man" but also "Plant-Man" and "Plant-Animal-Man" are the pathways through which arsenic has been causing poisoning in human body. It is predicted that in some cases the “Plant-Animal-Man” food chain pathway could be more potentially threatened to arsenic poisoning in human body than the direct “Soil-Water-Man” pathway. Adequate importance should be given on this matter.

Acknowledgements

Authors are grateful to the BRRI authority for facilitating their Arsenic Laboratory, Soil Science Division, for conduction experiments. The second author is also thankful to the “Ministry of Science, Information and Communication Technology”, Government of the People’s Republic of Bangladesh, for awarding the NSICT fellowship during this research work.

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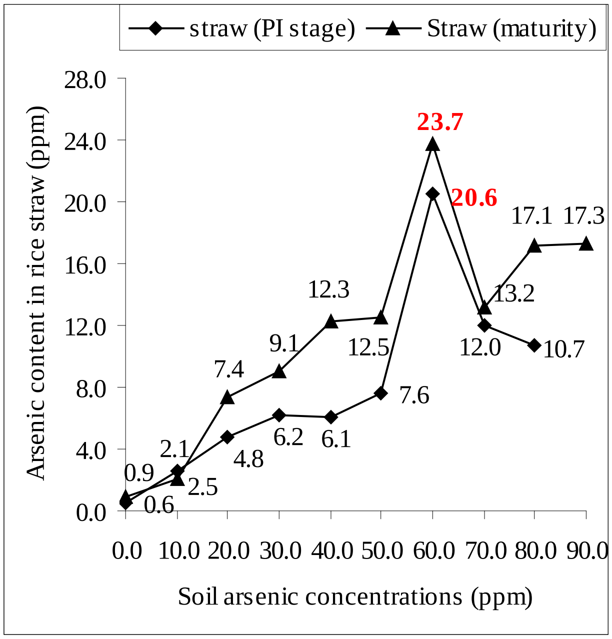

Figure 1: Effect of soil arsenic concentrations on arsenic uptake in rice straw. Arsenic in straw was measured at two growth stages of rice plant. At the panicle initiation (PI) stage, about 30 days after transplantation and at maturity stage (after harvest).

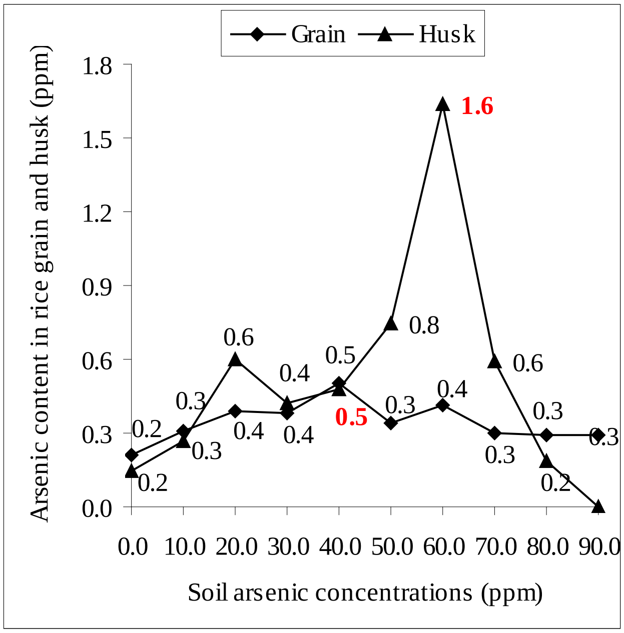

Figure 2: Effect of soil arsenic concentrations on arsenic uptake in rice grain and husk. Raw rice was sun dried and the husk was removed from rice grain to determine arsenic separately.

Table 1: Physical properties of initial soil

Physical properties of initial soil	Values
% Sand (2 – 0.05 mm)	12.30
% Silt (0.05 – 0.002 mm)	53.00
% Clay (< 0.002 mm)	34.70
Texural Class	Silty-clay-loam
Moisture (%)	16.04

Table 2: Chemical properties of initial soil

Chemical properties of initial soil	Values
pH (Soil : Water = 1 : 2.50)	5.27
Organic Carbon (%)	0.77
Organic Matter (%)	1.32
Total Nitrogen (%)	0.25
Total Phosphorus (%)	0.02
Total Potassium (%)	0.12
Total Iron (%)	2.01
Total Arsenic (mg kg^{-1})	3.25
Available Phosphorus (mg kg^{-1})	6.15
Available Iron (mg kg^{-1})	48.02

Table 3: Arsenic accumulation in rice plant tissues affected by soil arsenic concentrations

Added soil arsenic concentration (ppm)	Arsenic content (mg kg^{-1} dry weight)			
	straw (PI stage)	Straw (maturity stage)	Husk	Grain
0.0	0.6±0.01a	0.9±0.01a	0.2±0.01a	0.2±0.01a
10.0	2.5±0.02ab	2.1±0.01b	0.3±0.01b	0.3±0.01bc
20.0	4.8±0.10bc	7.4±0.02c	0.6±0.03c	0.4±0.04bc
30.0	6.2±0.04cd	9.1±0.04c	0.4±0.02bd	0.4±0.04bce
40.0	6.1±0.03cd	12.3±0.03d	0.5±0.04d	0.5±0.02d
50.0	7.6±0.22e	12.5±0.02d	0.8±0.02e	0.3±0.11bc
60.0	20.6±0.52f	23.7±0.44e	1.6±0.15c	0.4±0.01bce
70.0	12.0±0.03g	13.2±0.05d	0.6±0.01c	0.3±0.03bc
80.0	10.7±0.01g	17.1±0.32f	0.2±0.01a	0.3±0.02bc
90.0	ND[a]	17.3±0.21f	ND[a]	ND[a]

The results are expressed as mean± standard deviation of three replicates. In a column, value having same letter does not differ significantly ($p < 0.05$) from each other.

[a] no data was found.