Arsenic accumulation in rice (Oryza sativa L.): Human exposure through food chain

Arsenic Accumulation in Rice (*Oryza sativa* L.); Human Exposure through Food Chain

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Abstract

Although human exposure to arsenic is sought to be caused mainly through arsenic contaminated underground drinking water, the use of this water for irrigation enhances the possibility of arsenic uptake into crop plants. Rice is the staple food grain all over Bangladesh. As such arsenic content in straw, grain and husk of rice is especially important since paddy fields are extensively irrigated with underground water having high level of arsenic concentration. On the contrary, straw and husk are widely used as cattle feed. Arsenic concentration in rice grain was 0.5±0.02 mg kg^{-1} with the highest concentrations being in grains grown on soil treated with 40 mg As kg^{-1} soil. With the average rice consumption between 400 and 650 g/day by typical adults of the arsenic affected areas of Bangladesh, the intake of arsenic through rice stood at 0.20 to 0.35 mg/day when with a daily consumption of 4 L, arsenic intake through drinking water was 0.2 mg/day. Moreover, when the rice plant was grown in 60 mg of As kg^{-1} soil, arsenic concentrations in rice straw were 20.6±0.52 at panicle initiation stage and 23.7±0.44 at maturity stage while it was 1.6±0.20 mg kg^{-1} in husk. Cattle drink a large amount of water. So alike human beings, arsenic gets deposited into cattle body through rice straw and husk as well as from drinking water which in turn finds route into human body. Arsenic intake in human body from rice and cattle could be potential in addition to that from drinking water. Therefore, a hypothesis has been put forward elucidating the possible food chain pathways through which arsenic may enter into human body.

Key words: Arsenic, Rice, Toxicity, Food chain, Human exposure

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Introduction

Arsenic contamination in ground water has turned into the gravest natural disaster with spatial extent encompassing Bangladesh, India (West Bengal), China, Taiwan, Vietnam, United States of America, Argentina, Chile, Mexico etc. In Bangladesh, arsenic concentration in ground water has exceeded the safe level (0.05 mg As L^{-1} of water is the Bangladesh standard) in 59 districts out of 64 districts and about 80 million people are exposed to arsenic poisoning. The natural contamination of shallow hand tube wells in Bangladesh with arsenic has caused widespread human exposure to this toxic element through drinking water (Karim, 2000; Paul et al., 2000*)*. Use of arsenic-contaminated shallow tube-well water for irrigation of crops has put forward the question - is arsenic contaminated drinking water the only pathway of human exposure to arsenic? If not, what are the other pathways through which such exposure is taking place? With this question in mind, we conducted glasshouse and field level experiments to investigate the concentrations of arsenic in rice, the main food stuff of Bangladeshis, and straw and husk of rice, the main fodder for cattle in the country.

The impact of arsenic contaminated irrigation water on the arsenic content in rice is especially important as rice is the staple food for the population of arsenic epidemic areas and it is grown in flooded (reduced) condition where arsenic availability is high (Duxbury et al., 2003). Different consumers of natural ecosystem, such as primary, secondary or tertiary,

are taking arsenic contaminated food and water and as manifested by reports - arsenic is getting deposited into their bodies (Bruce et al., 2003; Shariatpanahi and Anderson, 1984; Thornton and Webb, 1979).

Another important aspect of the present study is the extent and severity of arsenic poisoning in human body through these crop plants, directly or indirectly. We tried to trace food chain pathways of natural ecosystem through which arsenic may enter into human body so that we can asses the potentiality of these pathways in exposing human to arsenic. It is quite difficult to investigate all the arsenic transferring food chain pathways of natural ecosystem even in small scale. So in this paper, we focused mainly on the extent and severity of arsenic poisoning in human body through "Plant (rice)-Animal (cattle)-Man" food chain pathway.

Materials and Methods

Soil Preparation

Pot experiments were conducted in a glasshouse at Bangladesh Rice Research Institute (BRRI). Soil, collected from BRRI farm at a depth of 0-15cm, were sun dried for 7 days and then the massive aggregates were broken down by gentle crushing with hammer. The unwanted materials viz. dry roots, grasses, stones were removed from the bulk soil. Then the soil was mixed thoroughly, crushed and sieved with 2 mm sieve. Sample from this initial soil was collected into a plastic bottle for physico-chemical analysis.

Pot Preparation

Five kilogram soil was taken in six liter plastic pots which were used to avoid leaching and to protect absorption of water soluble arsenic from the soil. Before taking the soils into them, all plastic pots were washed by tap water and sun dried. There were altogether 30 pots

103 comprising ten arsenic treatments with three replications for each. The pots were arranged
104 following the factorial Randomized Complete Block Design (RCBD).
105
106 **Arsenic Treatment**
107 The arsenic concentration in agricultural soil of arsenic affected areas of Bangladesh is
108 between 20 and 90 mg kg^{-1} (Ullah, 1998). Therefore, arsenic was mixed thoroughly with the
109 soil at the rate of 0 (control), 10, 20, 30, 40, 50, 60, 70, 80 and 90 mg As kg^{-1} soil. After
110 application of arsenic as aqueous solution of sodium arsenate, the spiked soils were left for
111 two days without irrigation. Before transplantation each pot was irrigated by 4.5 L of water
112 having an arsenic concentration of 0.01 mg l^{-1}.
113
114 **Intercultural Operation and Fertilizer Application**
115 The pots were placed on a plane cemented table. The overall temperature in the glasshouse
116 ranged from 22.4 to 33.9ºC, relative humidity from 59.9 to 83.7%, average evaporation
117 from 3.8 to 6.0 mm, sunshine from 3.4 to 7.8 h/day. BRRI dhan26 (Rice) was used as test
118 crop. Four 35-days old seedlings were transplanted in each pot at equal spacing. After
119 transplantation, the rice plants were grown under flooded condition. Pots were irrigated
120 regularly, maintaining a water depth of 3 cm, throughout the post-transplantation period
121 until harvesting. Urea, Triple Super Phosphate (TSP) and Muriate of Potash (MP) were
122 applied at the rate of 30, 40 and 20 kg per hectare for nitrogen, phosphorous and potassium,
123 respectively in the spiked soil. One-third of the amount of urea and full amount of other two
124 fertilizers were applied as basal in the individual pot before transplantation. The fertilizers
125 were incorporated with the soil by hand. The second and third splits of urea were applied
126 after 30 (maximum tillering stage) and 60 days (panicle initiation stage) of transplantation.
127
128 **Physico-chemical Properties of Initial Soil**

The physico-chemical properties of initial soil were measured to determine its fertility and behavior since the toxicity limit and mobility of arsenic are function of the physico-chemical properties of soil such as particle size, texture, soil reaction, mineral nutrient content etc. In sandy soil, arsenic is more mobile and bio-available than that of clayey soil. The availability of the arsenic in soils is affected by changes in pH. In general there is an increase in arsenic toxicity effects on plants, as the soil become acidic, particularly at pH below 5. However, the uptake of arsenic by plants may be increased on higher pH soil (Campbell et al., 1985). Phosphate has been reported to displace arsenic from soil (Peryea, 1991). Heavy additions of P to arsenic polluted soils have been reported to displace approximately 77% of total arsenic in the soil. Therefore, it is relevant to know about these soil properties to evaluate the influence of arsenic on its accumulation in rice as well as on soil properties. The results of the physico-chemical properties of initial soil have been presented in Table 1 and 2.

Physical Properties: Physical properties of soil such as distribution of particle size, textural classes, moisture content were determined and are presented in Table 1. The soil was Silty-clay-loam (Sand 12.30%, Silt 53.00% and Clay 34.70%) and blackish in color. The moisture content of the soil was 16.04%.

Chemical Properties: Chemical properties of soil such as pH, organic carbon, organic matter, total nitrogen, total phosphorus, total potassium, total iron, total arsenic, available phosphorus and available iron were determined and the results are presented in Table 2. The initial soil was acidic (pH 5.27) in nature. The background arsenic of the experimental soil was 3.25 mg kg^{-1}. The soil was rich in iron with available iron of 48.02 mg kg^{-1}. Organic carbon and organic matter was about 0.77 and 1.32%, respectively. Total nutrients such as nitrogen, phosphorus and potassium in soils were not sufficient (0.25, 0.02 and 0.12%,

155 respectively). Fertilizers of these nutrients elements were applied to reduce their deficiency.
156 Available phosphorus was about 6.15% in the soil.
157
158 **Collection of Field Samples**
159 Rice (*Oryza sativa* L.) samples (1 kg) of two varieties (BRRI dhan28 and BRRI hybrid
160 dhan1) were collected from a severely arsenic affected area of Bangladesh with three
161 replications. Soil samples (1 kg) were also collected from $2m^2$ areas and 10-15 cm depth of
162 the selected plots using soil auger. Samples were collected during harvest and sun dried
163 immediately after collection, tagged properly, air tied in polyethylene bags and kept in room
164 temperature for farther laboratory analysis.
165
166 **Chemical Analysis for Arsenic**
167 The plant samples (straw, grain and husk) were digested with concentrated nitric acid and
168 perchloric acid. 0.5 g of the sample was taken into a dry clean digestion tube and 5 ml of
169 65% nitric acid was added. The mixture was allowed to stand over night under fume shade.
170 In the following day, the digestion tubes were placed on a heating block and the temperature
171 was raised to 60ºC. After heating for about 1 h, the tubes were allowed to cool and 2 ml of
172 concentrated perchloric acid was added. Again, the tubes were heated at 160ºC. Heating
173 was stopped when the dense white fumes of perchloric acid occurred. The digests were
174 cooled, diluted in 25 ml distilled deionized water and filtered into plastic bottles through
175 filter paper (Whatman, No.1). Total arsenic was determined by hydride generation atomic
176 absorption spectrophotometer (HG-AAS) using matrix-malched standards (Welsch et al.,
177 1990). All glassware and plastic bottles were previously washed by distilled deionized
178 water and dried.
179 All instruments were calibrated using matrix-malched standards. In each analytical batch at
180 least two reagent blanks, one spike and three duplicate samples were included in the acid

digests to asses the accuracy of the chemical analysis. Accuracy of the method, according to the spike, was 92.3±1.5%.

Chemicals

Nitric acid (HNO_3), Sulfuric acid (H_2SO_4), Perchloric acid ($HClO_4$) and Sodium arsenate ($Na_2HAsO_4.7H_2O$) were purchased from Mark. Other chemicals were from AnalaR. All the reagents were of analytical grade.

Statistical Analysis

Duncan's Multiple Range Test (DMRT) was computed at 5% level to see the significant differences among the treatments and Pearson correlation was estimated by SPSS 10.0 for windows.

Results and Discussion

To investigate the potential of "plant-human" food chain pathway in arsenic poisoning of human body, we determined the arsenic concentration in tissues of rice. A hypothesis may also demonstrated from it reflecting the possibility of arsenic poisoning of human body through different food chain pathways, especially the "Plant-Animal-Man", on the basis of data of "plant-human" food chain pathway. In the first phase of this experiment, rice was cultivated in artificially spiked soil with deferent levels of arsenic in a glasshouse and the results were compared with that of field data.

Arsenic Concentration in Rice Tissues

Glasshouse study

Rice plants were grown in arsenic-spiked soils to determine the arsenic concentration in tissues of these plants. Pearson correlation analysis revealed that arsenic concentrations in

rice straw increased significantly (r = 0.781 and 0.852; p = 0.013 and 0.002 for straw of PI stage and maturity stage, respectively) with the increase of soil arsenic concentrations (Figure 2). In 60 mg of As kg^{-1} soil treatment, arsenic contents in straw were 34.33- and 26.33- fold higher than that of control. However, correlation analysis also showed that arsenic contents in husk and grain for different soil arsenic treatments did not differ significantly (r = 0.358 and 0.014; p = 0.344 and 0.970 for husk and grain, respectively) from each other (Figure 3). In 60 mg of As kg^{-1} soil treatment, husk arsenic content was 8-fold higher than that of control and it was 2.5-fold higher for grain in 40 mg of As kg^{-1} soil treatment. In 70, 80 and 90 mg of As kg^{-1} soil treatments, arsenic contents in husk and grain were less (but not significant) than those of other arsenic treatments. The results indicate that at higher levels of soil arsenic concentrations, the toxic element causes severe toxicity to rice plant resulting reduced growth rate and lowered translocation of arsenic as well as other nutrients from soil solution into the rice grain. Regardless of soil arsenic concentrations, arsenic concentration in rice tissues followed the trend: straw > husk > grain. Both the fresh and dried rice straw has been used widely as fodder for cattle in arsenic affected areas like Bangladesh and west Bengal, India. Therefore, arsenic concentrations were measured in rice straw at both panicle initiation (PI) stage and maturity stage (after harvest). Results imply that soil arsenic concentrations influenced its contents in straw of both stages. In straw of PI stage, the highest arsenic content was 20.6±0.52 mg kg^{-1} dry weight at 60 mg of As kg^{-1} soil treatment. In 70 and 80 mg of As kg^{-1} soil treatments, arsenic contents were less than that of in 60 mg of As kg^{-1} soil treatment, possibly, because of reduced translocation of arsenic as well as other nutrients resulted from severe toxicity of this metal to rice plant (Table 3).

In straw of mature stage (after harvest), arsenic content followed the same order of magnitude as in straw of PI stage (Figure 2). However, the highest straw arsenic content was 23.7±0.44 mg kg^{-1} dry weight in 60 mg of As kg^{-1} soil treatment. Abedin et al. (2002a)

233 also reported significant increase of arsenic concentration in rice root, straw and husk with
234 the increase of arsenate concentration in irrigation water. He found 3.9 mg kg^{-1} arsenic in
235 straw at the lowest arsenate treatment (0.2 mg l^{-1}), which increased progressively with
236 increasing arsenate application and reached to 91.8 mg kg^{-1} in the highest arsenate treatment
237 (8.0 mg l^{-1}). Arsenic uptake by plants is a function of plant species (Liebig, 1966), arsenic
238 concentration in soil (NRC, 2001), pH and clay content (Johnson and Hiltbold, 1969), other
239 ions (Woolson et al., 1973, Khattak et al., 1991) and the chemical form of arsenic (Marin et
240 al., 2003).
241 Arsenic contents in rice grain were not significantly ($p > 0.05$) influenced by the soil arsenic
242 concentrations. The highest grain arsenic content was 0.5±0.02 mg kg^{-1} dry weight in 40 mg
243 of As kg^{-1} soil treatment and the lowest was 0.2±0.01 mg kg^{-1} dry weight in control and 90
244 mg As kg^{-1} soil treatment (Figure 3). Abedin et al. (2002a) also reported that arsenic
245 concentration in grain remained statistically indifferent with increasing arsenate
246 concentration in irrigation water. He found 0.15 mg As kg^{-1} dry weight in grain at control
247 treatment and 0.24 mg As kg^{-1} dry weight at 4.0 mg of As L^{-1} water treatment. Williams et
248 al. (2005) also reported mean arsenic concentration of 0.26 µg g^{-1} in US long grain rice and
249 0.40 µg g^{-1} as the highest grain arsenic concentration. They also found mean arsenic
250 concentration of 0.13 µg g^{-1} in Bangladesh rice grain.
251
252 **Field Study**
253 To get real scenario of arsenic concentrations in rice tissues, we also did a field level
254 investigation. Rice samples were collected directly form the field and measured the
255 concentrations of arsenic in rice tissues. The results of field investigation are presented in
256 figure 4. Arsenic concentration in field soil was 14.51±0.21 mg kg^{-1} and 0.07±0.02 mg L^{-1}
257 in water. Arsenic concentrations in straw, husk and grain of two rice strains (BRRI dhan28
258 and BRRI hybrid dhan1) did not differ significantly from each other (p>0.05). Arsenic

concentration in husk of BRRI hybrid dhan1 contains 3.8-fold higher than that of rice grain while it was 3.33-fold for BRRI dhan28.

In glasshouse experiment, arsenic concentrations in rice straw, husk grain were 2.09±0.09, 0.27±0.05 and 0.25±0.06 mg kg^{-1} dry weight, respectively when the soil arsenic concentration was 13.25 mg kg^{-1} (10 mg kg^{-1} was spiked arsenic and 3.25 mg kg^{-1} was background arsenic concentrations in the soil). In contrary, when the arsenic concentration in the field soil was 14.51±0.21 mg kg^{-1}, its concentrations in rice straw, husk and grain were 1.78±0.11, 1.36±0.01 and 0.41±0.01 mg kg^{-1} dry weight. The results revealed that arsenic concentrations in husk and grain of field samples were higher than that of glasshouse samples at the almost same soil arsenic concentration. This may be because the phosphate concentration in glasshouse soil was higher than that of field soil (Table 2) and the phosphate suppresses arsenic uptake in rice plant (Abedin et al., 2002b).

Human Exposure to Arsenic through "Plant-Animal-Man" Food Chain Pathway

It is clear from the present experiment and some other previous reports that arsenic deposits in tissues of crop plants grown in arsenic rich soil, irrigated with arsenic contaminated water. Arsenic accumulation has been reported in maize (Sadiq, 1986), barley and ryegrass (Jiang and Singh, 1994), rice (Duxbury et al., 2003; Abedin et al., 2002a; Marin et al., 1992; Bae et al., 2002; Onken and Hosner, 1995; Rahman et al., 2004; D'llio et al., 2002), *Spertina alterniflora* (Carbonell et al., 1998) too. The accumulation of arsenic in plants occurs primarily through the root system and the highest arsenic concentrations have been reported in plant roots and tubers (Anastasia and Kender, 1973; Marin et al., 2003). Therefore, tuber crops are expected to have higher arsenic contents than that of other crops when those are grown in arsenic contaminated soil. The concentration of arsenic in edible parts of most plants is generally low (Vaughan, 1993; O'Neil, 1995). Plants seldom accumulate arsenic at

284 concentrations hazardous to human and animal health because, phytotoxicity usually occurs
285 before such concentrations are reached (Walsh and Keeney, 1975).
286 Although human may be exposed to arsenic from a variety of environmental sources, food
287 constitutes the largest source of arsenic intake with smaller contribution from air and
288 drinking water (Chen and Lin, 1994). In a tropical country like Bangladesh, water
289 consumption is normally very high. Most of the arsenic affected areas are villages where
290 people are involved in agrarian manual labor. Daily water consumption by an adult ranged
291 between 4 and 6 litters (Farmer and Johnson, 1990) and when the arsenic concentration in
292 drinking water is 0.05 mg L^{-1}, the acceptable limit for drinking water in Bangladesh (though
293 in many areas, arsenic concentrations in drinking water has been found to be more than this),
294 an adult is expected to intake 0.2 to 0.3 mg of As/day from drinking water. In contrary, the
295 average daily rice consumption by an adult of this area is between 400 and 650 g raw rice
296 grain (Duxbury et al., 2003). In the preset study, arsenic concentrations in rice grain were
297 0.5±0.02 and 0.41±0.01 mg kg^{-1} dry weight for glasshouse and field sample, respectively
298 when the soil arsenic concentrations were 40 and 14.51±0.21 mg kg^{-1} soil, respectively. In
299 Bangladesh, the soil arsenic concentration has been found to be between 20 and 90 mg kg^{-1}
300 (Ullah, 1998).
301 The daily intake of arsenic from rice grain containing 0.5±0.02 mg kg^{-1} dry weight would
302 be between 0.20 and 0.35 mg (according to the glasshouse data) and between 0.164 and
303 0.266 mg (according to the field data). Bae et al. (2003) reported that the concentration of
304 arsenic in cooked rice was higher than that of raw rice. Rahman et al. (2006) reported
305 elevated concentrations of arsenic in cooked rice when the rice was cooked with arsenic
306 contaminated water and the gruel was not discarded after cooking. This was because the
307 arsenic in water was absorbed by cooked rice. Ackerman et al. (2005) found 89 - 105%
308 absorption of arsenic by rice from total volume of water [1:1 to 4:1 (water: rice)] used in
309 cooking for two different contaminated drinking water. Moreover, most of the arsenic in

310 drinking water is dissolved as toxic inorganic forms, while the species of arsenic in raw and
311 cooked rice are poorly characterized (Duxbury et al., 2003). Schoof et al. (1999) reported
312 that between 30 and 85% of arsenic in rice is inorganic. These reports suggest that intake of
313 arsenic from rice and its potential to human exposure should not be ignored.
314 The highest arsenic concentration in straw is 23.7±0.44 mg kg^{-1} dry weight at 60 mg of As
315 kg^{-1} soil treatment while it was 12.3±0.03 mg kg^{-1} at 40 mg of As kg^{-1} soil treatment.
316 Tsutsumi et al. (1980) reported 149 mg of As kg^{-1} dry weight in rice straw when soil arsenic
317 concentration was 313 mg kg^{-1}. Abedin et al. (2002a) found 25 mg of As kg^{-1} dry weight in
318 rice straw when the plant was irrigated by 2 mg of As l^{-1} water. Cattle are one of the
319 primary consumers of terrestrial ecosystem. They feed on rice straw and husk and drink
320 water as well. Though there is no direct report of arsenic accumulation in cattle body from
321 rice straw or husk, the consequence of exposure to this toxic element in organs such as the
322 liver and kidneys of this animal is well reported (WHO, 2001). Bruce et al., (2003) reported
323 arsenic accumulation in liver and other tissues of tailing paddock animals though the
324 accumulation was insignificant to cause chronic toxicity or any immediate perceivable
325 contamination. Because Bruce et al., (2003) conducted their experiment for a short time
326 (240 days); they expected more accumulation of arsenic in cattle if the experiment were for
327 longer time. However, the objective of the present experiment was not to calculate the acute
328 toxicity or sub chronic dose rates for cattle rather to justify the accumulation and transfer of
329 arsenic from cattle to human through food chain.
330 Straw given to cattle in U.K. contained less than 0.20 mg As kg^{-1} (Nicholson et al., 1999),
331 though arsenic metabolized by the cattle is dependent on the arsenic species in the straw and
332 on the metabolism of cattle (Abedin et al., 2002b). In another experiment, Shariatpanahi et
333 al. (1984) reported that, sheep those were feed on methylarsonate showed a significant
334 increase of arsenic accumulation in their tissues and milk. Although there have not been
335 found adequate data on the presence of arsenic in milk and meat of the cattle of Bangladesh

and those imported from west Bengal, India (another arsenic epidemic area, where arsenic contamination in ground water is alarming), there is an ample scope of arsenic deposition in cattle body, especially from high arsenic-containing rice straw and husk. Thus, a hypothesis has been put forward elucidating the possible deposition of arsenic in human body not only be from drinking water but also from beef and mutton through "Plant-Animal-Man" and some other food chain pathways (Figure 1). All studies suggest that the possible health risk of human being from arsenic toxicity through "Plant-Animal-Man" food chain pathway should not be ignored. Moreover, when the arsenic contaminated straw is burned as fuel, arsenic may pollute the air as arsenic oxides and inhaled by man.

Arsenic Transfer through Food Chain

The pattern of arsenic accumulation and its transfer from one trophic level to another is important. In the present article, we discussed this aspect by some previous data and the results were incorporated with our proposed hypothesis. Mason et al. (2000) reported a decrease of arsenic levels with the increase of higher 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 foodstuffs. Total arsenic concentrations in organisms after accumulation from foodstuffs decreased one order of magnitude per elevation of the trophic level.

Klose and Braun (1997) studied the arsenic content in soil and uptake by crops including 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^{-1} dry matter when grown on 60 – 362 mg of As kg^{-1}soil. In experiment with pasture grasses, plant arsenic content ranged from 0.18 to 6.7 mg kg^{-1} dry matter when the soil arsenic content ranged from 90 to 1050 mg kg^{-1} soil. Limited reports are available on bioaccumulation of arsenic in different consumers of trophic levels such as animals, insects, birds and also the men.

Because of low concentrations in terrestrial plants, arsenic accumulation in animals from this source is also low. Direct ingestion of arsenic from soil could be a major source of dietary arsenic for grazing livestock (Thornton et al., 1979). Bruce et al., (2003) also reported direct ingestion of arsenic from soil. It is estimated that about 1% of the arsenic in the soil was actually absorbed by the cattle, while the remaining being excreted directly. There have been different possible food chain pathways of natural ecosystem through which, human being (when considered as the topmost consumer of terrestrial ecosystem) may be exposed to arsenic toxicity (Figure 1).

Conclusion

Many previous reports demonstrated that foodstuffs collected from arsenic epidemic areas contain significant concentrations of arsenic. Roychowdhury et al. (2002) reported the arsenic concentrations in individual composites of cooked items, collected from an arsenic epidemic area of West Bengal, India, as rice (between 374.17 and 666.57 µg kg^{-1}), freshwater fish (between 830 and 900 µg kg^{-1}), potato curry (186 µg kg^{-1}), potato skin fried in oil (617 µg kg^{-1}), leaf of vegetables (578 µg kg^{-1}), mixed vegetable (277.33 µg kg^{-1}), pulses (143 µg kg^{-1}). Das et al. (2004) reported arsenic concentrations exceeding the food safety limits in *Calocasia antiquorum* (between 0.09 and 3.99 mg kg^{-1}), potato (between 0.07 and 1.36 mg kg^{-1}), *Ipomoea reptoms* (between 0.1 and 1.53 mg kg^{-1}) collected from an arsenic epidemic area of Bangladesh. Arsenic deposition in cattle body (Bruce et al., 2003; Thornton et al., 1979) and tissues and milk of sheep (Shariatpanahi et al., 1984) has also been reported. Liao and Ling (2003) conducted an experiment on arsenic bioaccumulation in tilapia fish (*Oreochromis mossambicus*) and found that the highest ninety-fifth percentile of potential health risk for inorganic arsenic ranged from 7.36×10^{-4} to 1.12×10^{-3} for the subsistence fishers of Blackfoot disease area of Taiwan. Thus, it is evident that not only "soil-water-human" but also "plant-human" and "plant-animal-human" may be other

potential food chain pathways of arsenic accumulation in human body, though arsenic contaminated drinking water is the major and direct source. Adequate emphasis should be given on this matter. To figure out the fact regarding arsenic poisoning in human body through these food chain pathways, intensive investigation on a complete food chain is needed, which is our future interest.

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538 Table 1: Physical properties of initial soil

Physical properties	Soil of glasshouse experiment	Field soil

% Sand (2 – 0.05 mm)	12.30	8.25
% Silt (0.05 – 0.002 mm)	53.00	27.5
% Clay (< 0.002 mm)	34.70	64.5
Textural Class	Silty-clay-loam	Clay-loam
Moisture (%)	16.04	-

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541 Table 2: Chemical properties of initial soil

Chemical properties	Soil of glasshouse experiment	Field soil
pH (Soil : Water = 1 : 2.50)	5.27	7.07
Organic Carbon (%)	0.77	-
Organic Matter (%)	1.32	-
Total Nitrogen (%)	0.25	-
Total Phosphorus (%)	0.02	-
Total Potassium (%)	0.12	-
Total Iron (%)	2.01	0.21
Total Arsenic (mg kg^{-1})	3.25 (+10)*	14.51
Available Phosphorus (mg kg^{-1})	6.15 (+3.12)**	6.03
Total Manganese (mg kg^{-1})	-	247.14

542 * 10 mg of As kg^{-1} soil was spiked to the initial soil of glasshouse experiment.

543 ** After the rice harvest, available phosphate in the soil was 9.27 mg kg^{-1}.

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546 Table 3: Arsenic accumulation in rice plant tissues affected by soil arsenic concentrations[a]

Spiked arsenic to the	Arsenic content (mg kg^{-1} dry weight)

initial soil (mg kg^{-1})	straw (PI stage)	Straw (maturity stage)	Husk	Grain
Control	0.6±0.01f	0.9±0.01f	0.2±0.01e	0.2±0.01e
10	2.5±0.02e	2.1±0.01e	0.3±0.01e	0.3±0.01bce
20	4.8±0.10d	7.4±0.02d	0.6±0.03bc	0.4±0.04bc
30	6.2±0.04c	9.1±0.04d	0.4±0.02de	0.4±0.04bc
40	6.1±0.03c	12.3±0.03c	0.5±0.04cd	0.5±0.02a
50	7.6±0.22c	12.5±0.02c	0.8±0.02b	0.3±0.11bc
60	20.6±0.52a	23.7±0.44a	1.6±0.15a	0.4±0.01bc
70	12.0±0.03b	13.2±0.05c	0.6±0.01bc	0.3±0.03bce
80	10.7±0.01b	17.1±0.32b	0.2±0.01e	0.3±0.02bce
90	-	17.3±0.21b	-	-

[a] The values are mean ± S.D. of three replicates. The data were statistically analyzed by Duncan Multiple Range Test (DMRT) at 5% level. In a column, values having different letters (a - f) indicate significant differences ($p < 0.05$) among them.

Figure 1:

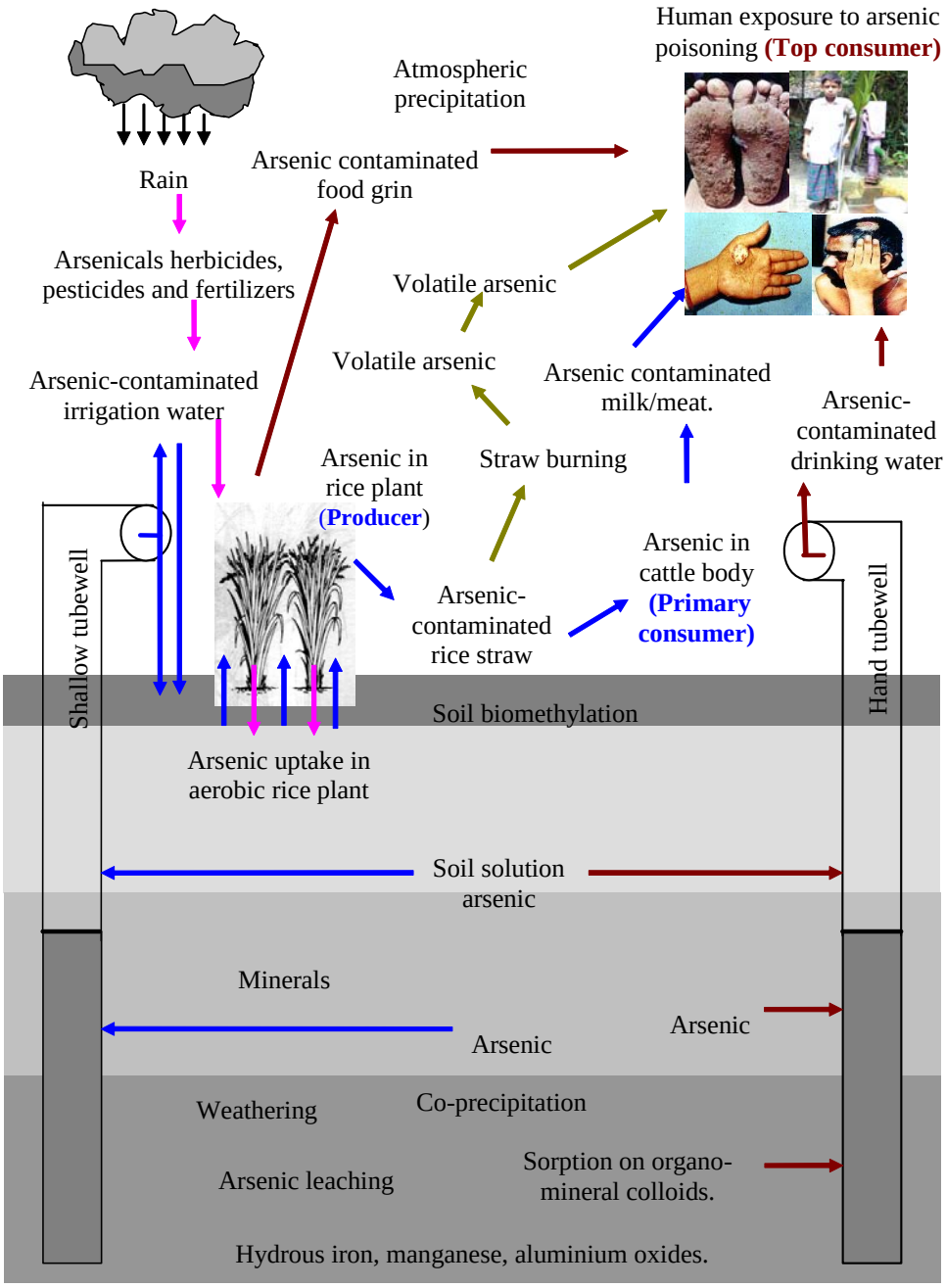


Figure 1: Populations of Bangladesh, one of the severely arsenic affected areas of the world, have been exposing arsenic poisoning from drinking water directly. There are some other possible food chain pathways of terrestrial ecosystem through which human may be exposed to arsenic poisoning from many sources as they are one of the topmost consumer of the ecosystem. In the above diagram, those possible food chain pathways have been shown and the "Plant-Man" food chain has been explained in this paper to understand the arsenic toxicity to human through this pathway. Some other pathways like "Plant-Animal-Man" could be potential for human exposure to arsenic and needs to be investigated.

Figure 2:

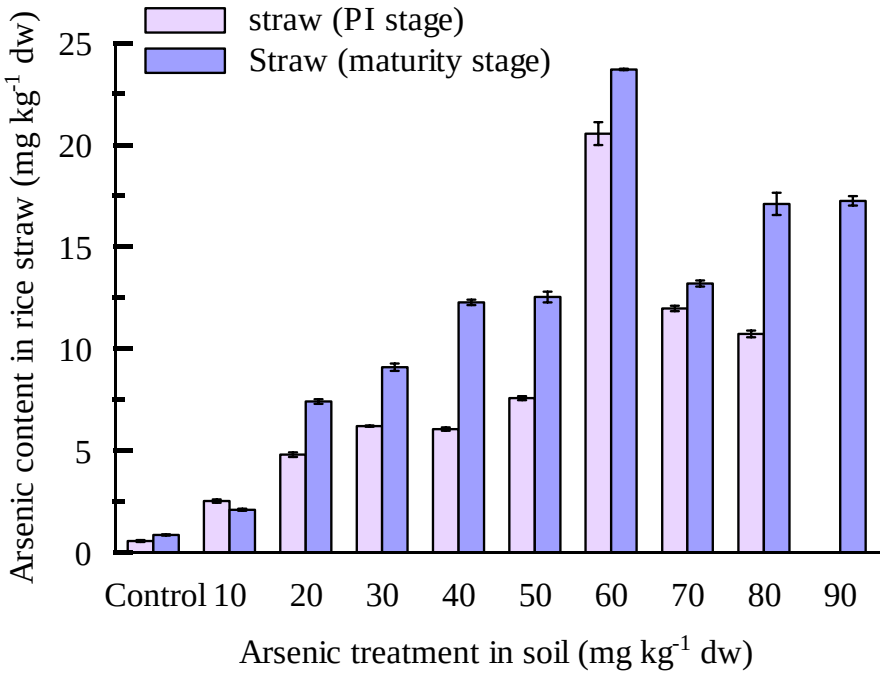


Figure 2: Effect of soil arsenic concentrations on arsenic uptake in rice straw. Error bars represent mean ± SEM of three replicates. Arsenic in straw was measured at two growth stages of rice plant. At the panicle initiation (PI) stage, about 30 days after transplantation and at maturity stage (after harvest).

Figure 3:

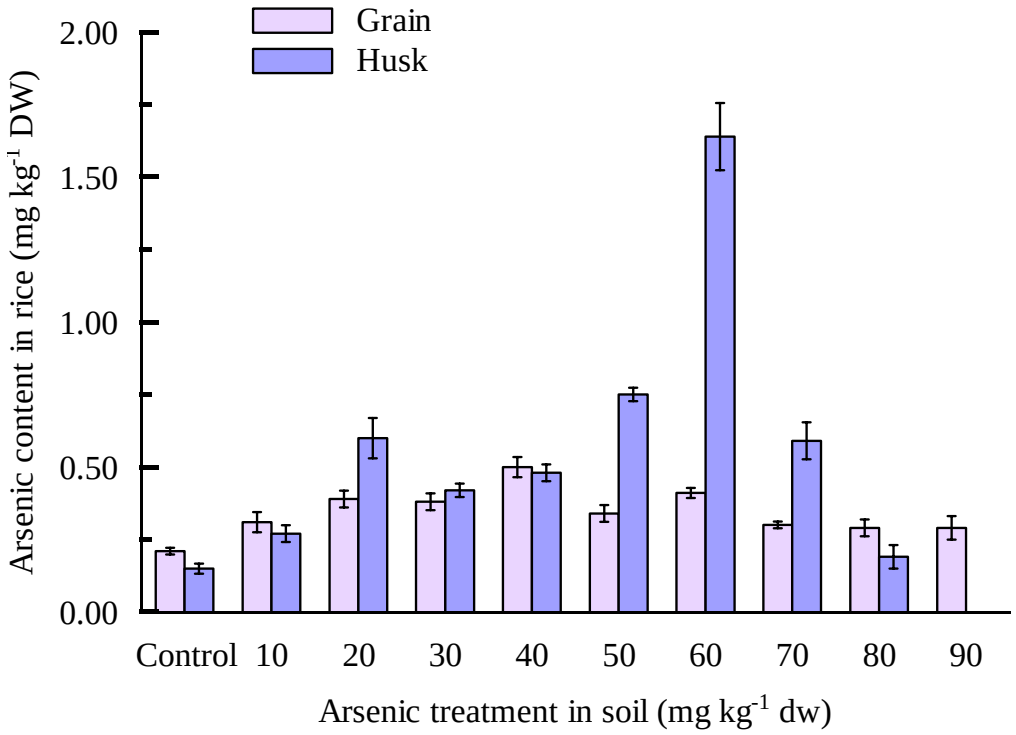
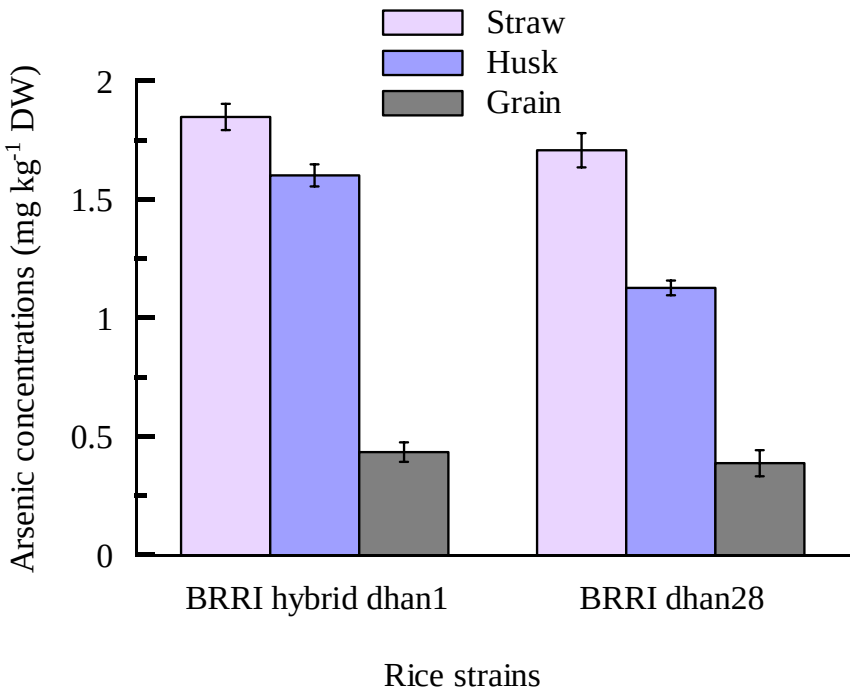


Figure 3: Effect of soil arsenic concentrations on arsenic uptake in rice grain and husk. Error bars represent mean ± SEM of three replicates. Raw rice was sun dried and the husk was removed from rice grain to determine arsenic.

Figure 4:



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608 Figure 4: Arsenic accumulation in rice tissues. Error bars represent mean ± SEM of three
609 replicates. Arsenic concentrations in field soil and irrigation water were
610 14.51±0.21 and 0.07±0.02 mg kg^{-1}.

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