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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26 **Abstract**

27 Although human exposure to arsenic is sought to be caused mainly through arsenic

28 contaminated underground drinking water, the use of this water for irrigation enhances the

29 possibility of arsenic uptake into crop plants. Rice is the staple food grain all over

30 Bangladesh. As such arsenic content in straw, grain and husk of rice is especially important

31 since paddy fields are extensively irrigated with underground water having high level of

32 arsenic concentration. On the contrary, straw and husk are widely used as cattle feed.

33 Arsenic concentration in rice grain was 0.5 ± 0.02 mg kg^{-1} with the highest concentrations

34 being in grains grown on soil treated with 40 mg As kg^{-1} soil. With the average rice

35 consumption between 400 and 650 g/day by typical adults of the arsenic affected areas of

36 Bangladesh, the intake of arsenic through rice stood at 0.20 to 0.35 mg/day when with a

37 daily consumption of 4 L, arsenic intake through drinking water was 0.2 mg/day. Moreover,

38 when the rice plant was grown in 60 mg of As kg^{-1} soil, arsenic concentrations in rice straw

39 were 20.6 ± 0.52 at panicle initiation stage and 23.7 ± 0.44 at maturity stage while it was

40 1.6 ± 0.20 mg kg^{-1} in husk. Cattle drink a large amount of water. So alike human beings,

41 arsenic gets deposited into cattle body through rice straw and husk as well as from drinking

42 water which in turn finds route into human body. Arsenic intake in human body from rice

43 and cattle could be potential in addition to that from drinking water. Therefore, a hypothesis

44 has been put forward elucidating the possible food chain pathways through which arsenic

45 may enter into human body.

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Funding Sources:

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

181 digests to asses the accuracy of the chemical analysis. Accuracy of the method, according to

182 the spike, was 92.3±1.5%.

183

184 **Chemicals**

185 Nitric acid (HNO_3), Sulfuric acid (H_2SO_4), Perchloric acid ($HClO_4$) and Sodium arsenate

186 ($Na_2HAsO_4.7H_2O$) were purchased from Mark. Other chemicals were from AnalaR. All the

187 reagents were of analytical grade.

188

189 **Statistical Analysis**

190 Duncan's Multiple Range Test (DMRT) was computed at 5% level to see the significant

191 differences among the treatments and Pearson correlation was estimated by SPSS 10.0 for

192 windows.

193

194 ## Results and Discussion

195 To investigate the potential of "plant-human" food chain pathway in arsenic poisoning of

196 human body, we determined the arsenic concentration in tissues of rice. A hypothesis may

197 also demonstrated from it reflecting the possibility of arsenic poisoning of human body

198 through different food chain pathways, especially the "Plant-Animal-Man", on the basis of

199 data of "plant-human" food chain pathway. In the first phase of this experiment, rice was

200 cultivated in artificially spiked soil with deferent levels of arsenic in a glasshouse and the

201 results were compared with that of field data.

202

203 **Arsenic Concentration in Rice Tissues**

204 **Glasshouse study**

205 Rice plants were grown in arsenic-spiked soils to determine the arsenic concentration in

206 tissues of these plants. Pearson correlation analysis revealed that arsenic concentrations in

207 rice straw increased significantly (r = 0.781 and 0.852; p = 0.013 and 0.002 for straw of PI

208 stage and maturity stage, respectively) with the increase of soil arsenic concentrations

209 (Figure 2). In 60 mg of As kg^{-1} soil treatment, arsenic contents in straw were 34.33- and

210 26.33- fold higher than that of control. However, correlation analysis also showed that

211 arsenic contents in husk and grain for different soil arsenic treatments did not differ

212 significantly (r = 0.358 and 0.014; p = 0.344 and 0.970 for husk and grain, respectively)

213 from each other (Figure 3). In 60 mg of As kg^{-1} soil treatment, husk arsenic content was 8-

214 fold higher than that of control and it was 2.5-fold higher for grain in 40 mg of As kg^{-1} soil

215 treatment. In 70, 80 and 90 mg of As kg^{-1} soil treatments, arsenic contents in husk and grain

216 were less (but not significant) than those of other arsenic treatments. The results indicate

217 that at higher levels of soil arsenic concentrations, the toxic element causes severe toxicity

218 to rice plant resulting reduced growth rate and lowered translocation of arsenic as well as

219 other nutrients from soil solution into the rice grain. Regardless of soil arsenic

220 concentrations, arsenic concentration in rice tissues followed the trend: straw > husk > grain.

221 Both the fresh and dried rice straw has been used widely as fodder for cattle in arsenic

222 affected areas like Bangladesh and west Bengal, India. Therefore, arsenic concentrations

223 were measured in rice straw at both panicle initiation (PI) stage and maturity stage (after

224 harvest). Results imply that soil arsenic concentrations influenced its contents in straw of

225 both stages. In straw of PI stage, the highest arsenic content was 20.6±0.52 mg kg^{-1} dry

226 weight at 60 mg of As kg^{-1} soil treatment. In 70 and 80 mg of As kg^{-1} soil treatments,

227 arsenic contents were   less than that of in 60 mg of As kg^{-1} soil treatment, possibly, because

228 of reduced translocation of arsenic as well as other nutrients resulted from severe toxicity of

229 this metal to rice plant (Table 3).

230 In straw of mature stage (after harvest), arsenic content followed the same order of

231 magnitude as in straw of PI stage (Figure 2). However, the highest straw arsenic content

232 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

259 concentration in husk of BRRI hybrid dhan1 contains 3.8-fold higher than that of rice grain

260 while it was 3.33-fold for BRRI dhan28.

261 In glasshouse experiment, arsenic concentrations in rice straw, husk grain were 2.09±0.09,

262 0.27±0.05 and 0.25±0.06 mg kg^{-1} dry weight, respectively when the soil arsenic

263 concentration was 13.25 mg kg^{-1} (10 mg kg^{-1} was spiked arsenic and 3.25 mg kg^{-1} was

264 background arsenic concentrations in the soil). In contrary, when the arsenic concentration

265 in the field soil was 14.51±0.21 mg kg^{-1}, its concentrations in rice straw, husk and grain

266 were 1.78±0.11, 1.36±0.01 and 0.41±0.01 mg kg^{-1} dry weight. The results revealed that

267 arsenic concentrations in husk and grain of field samples were higher than that of

268 glasshouse samples at the almost same soil arsenic concentration. This may be because the

269 phosphate concentration in glasshouse soil was higher than that of field soil (Table 2) and

270 the phosphate suppresses arsenic uptake in rice plant (Abedin et al., 2002b).

271

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

273 It is clear from the present experiment and some other previous reports that arsenic deposits

274 in tissues of crop plants grown in arsenic rich soil, irrigated with arsenic contaminated water.

275 Arsenic accumulation has been reported in maize (Sadiq, 1986), barley and ryegrass (Jiang

276 and Singh, 1994), rice (Duxbury et al., 2003; Abedin et al., 2002a; Marin et al., 1992; Bae

277 et al., 2002; Onken and Hosner, 1995; Rahman et al., 2004; D'llio et al., 2002), *Spertina*

278 *alterniflora* (Carbonell et al., 1998) too. The accumulation of arsenic in plants occurs

279 primarily through the root system and the highest arsenic concentrations have been reported

280 in plant roots and tubers (Anastasia and Kender, 1973; Marin et al., 2003). Therefore, tuber

281 crops are expected to have higher arsenic contents than that of other crops when those are

282 grown in arsenic contaminated soil. The concentration of arsenic in edible parts of most

283 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

336   and those imported from west Bengal, India (another arsenic epidemic area, where arsenic

337   contamination in ground water is alarming), there is an ample scope of arsenic deposition in

338   cattle body, especially from high arsenic-containing rice straw and husk. Thus, a hypothesis

339   has been put forward elucidating the possible deposition of arsenic in human body not only

340   be from drinking water but also from beef and mutton through "Plant-Animal-Man" and

341   some other food chain pathways (Figure 1). All studies suggest that the possible health risk

342   of human being from arsenic toxicity through "Plant-Animal-Man" food chain pathway

343   should not be ignored. Moreover, when the arsenic contaminated straw is burned as fuel,

344   arsenic may pollute the air as arsenic oxides and inhaled by man.

345

346   **Arsenic Transfer through Food Chain**

347   The pattern of arsenic accumulation and its transfer from one trophic level to another is

348   important. In the present article, we discussed this aspect by some previous data and the

349   results were incorporated with our proposed hypothesis. Mason et al. (2000) reported a

350   decrease of arsenic levels with the increase of higher trophic level. He also suggested that

351   the subsequent transfer of arsenic to higher trophic levels is related to both the ability of the

352   organisms to depurate and the mode of accumulation, either directly from water or from

353   foodstuffs. Total arsenic concentrations in organisms after accumulation from foodstuffs

354   decreased one order of magnitude per elevation of the trophic level.

355   Klose and Braun (1997) studied the arsenic content in soil and uptake by crops including

356   fodder plants, spring barley, potatoes, maize, winter rape, pasture grass and clover. In maize,

357   rape, barley and potatoes, arsenic content ranged from 0.04 to 1.31 mg kg^{-1} dry matter when

358   grown on 60 – 362 mg of As kg^{-1}soil. In experiment with pasture grasses, plant arsenic

359   content ranged from 0.18 to 6.7 mg kg^{-1} dry matter when the soil arsenic content ranged

360   from 90 to 1050 mg kg^{-1} soil. Limited reports are available on bioaccumulation of arsenic in

361   different consumers of trophic levels such as animals, insects, birds and also the men.

362 Because of low concentrations in terrestrial plants, arsenic accumulation in animals from

363 this source is also low. Direct ingestion of arsenic from soil could be a major source of

364 dietary arsenic for grazing livestock (Thornton et al., 1979). Bruce et al., (2003) also

365 reported direct ingestion of arsenic from soil. It is estimated that about 1% of the arsenic in

366 the soil was actually absorbed by the cattle, while the remaining being excreted directly.

367 There have been different possible food chain pathways of natural ecosystem through which,

368 human being (when considered as the topmost consumer of terrestrial ecosystem) may be

369 exposed to arsenic toxicity (Figure 1).

370

371 **Conclusion**

372 Many previous reports demonstrated that foodstuffs collected from arsenic epidemic areas

373 contain significant concentrations of arsenic. Roychowdhury et al. (2002) reported the

374 arsenic concentrations in individual composites of cooked items, collected from an arsenic

375 epidemic area of West Bengal, India, as rice (between 374.17 and 666.57 $\mu g\ kg^{-1}$),

376 freshwater fish (between 830 and 900 $\mu g\ kg^{-1}$), potato curry (186 $\mu g\ kg^{-1}$), potato skin fried

377 in oil (617 $\mu g\ kg^{-1}$), leaf of vegetables (578 $\mu g\ kg^{-1}$), mixed vegetable (277.33 $\mu g\ kg^{-1}$),

378 pulses (143 $\mu g\ kg^{-1}$). Das et al. (2004) reported arsenic concentrations exceeding the food

379 safety limits in *Calocasia antiquorum* (between 0.09 and 3.99 $mg\ kg^{-1}$), potato (between

380 0.07 and 1.36 $mg\ kg^{-1}$), *Ipomoea reptoms* (between 0.1 and 1.53 $mg\ kg^{-1}$) collected from an

381 arsenic epidemic area of Bangladesh. Arsenic deposition in cattle body (Bruce et al., 2003;

382 Thornton et al., 1979) and tissues and milk of sheep (Shariatpanahi et al., 1984) has also

383 been reported. Liao and Ling (2003) conducted an experiment on arsenic bioaccumulation

384 in tilapia fish (*Oreochromis mossambicus*) and found that the highest ninety-fifth percentile

385 of potential health risk for inorganic arsenic ranged from 7.36×10^{-4} to 1.12×10^{-3} for the

386 subsistence fishers of Blackfoot disease area of Taiwan. Thus, it is evident that not only

387 "soil-water-human" but also "plant-human" and "plant-animal-human" may be other

388 potential food chain pathways of arsenic accumulation in human body, though arsenic

389 contaminated drinking water is the major and direct source. Adequate emphasis should be

390 given on this matter. To figure out the fact regarding arsenic poisoning in human body

391 through these food chain pathways, intensive investigation on a complete food chain is

392 needed, which is our future interest.

393

401

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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	-	-

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548   [a] The values are mean ± S.D. of three replicates. The data were statistically

549   analyzed by Duncan Multiple Range Test (DMRT) at 5% level. In a column,

550   values having different letters (a - f) indicate significant differences ($p < 0.05$)

551   among them.

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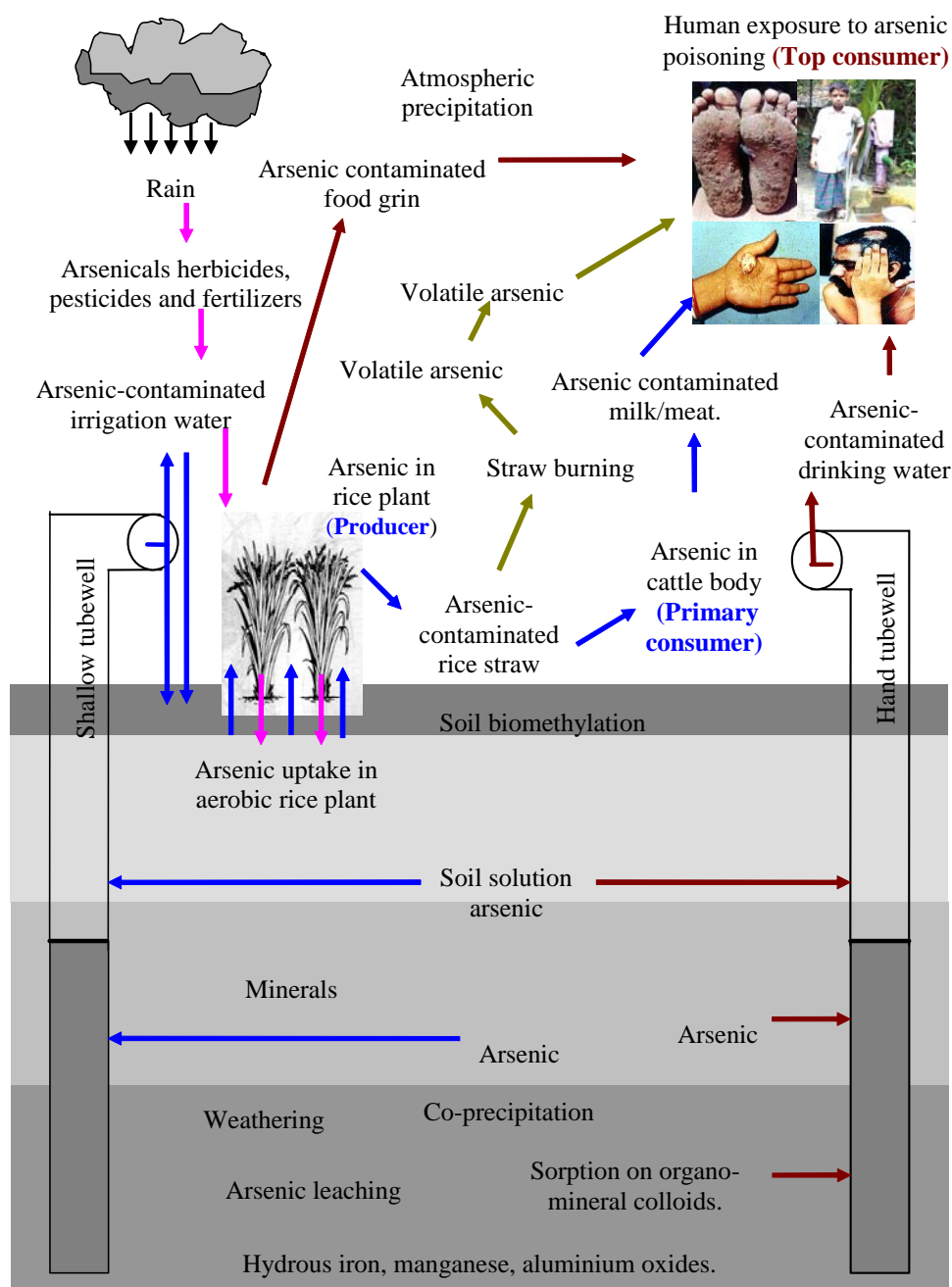
563   Figure 1: Populations of Bangladesh, one of the severely arsenic affected areas of the world,
564   have been exposing arsenic poisoning from drinking water directly. There are
565   some other possible food chain pathways of terrestrial ecosystem through which
566   human may be exposed to arsenic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

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574   **Figure 2:**
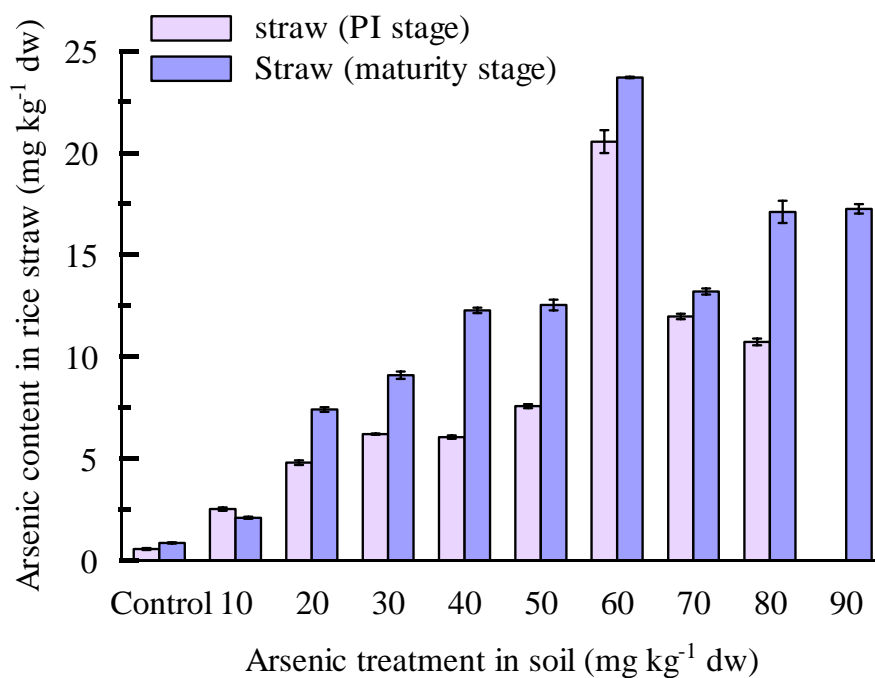
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576   Figure 2: Effect of soil arsenic concentrations on arsenic uptake in rice straw. Error bars

577   represent mean ± SEM of three replicates. Arsenic in straw was measured at two

578   growth stages of rice plant. At the panicle initiation (PI) stage, about 30 days

579   after transplantation and at maturity stage (after harvest).

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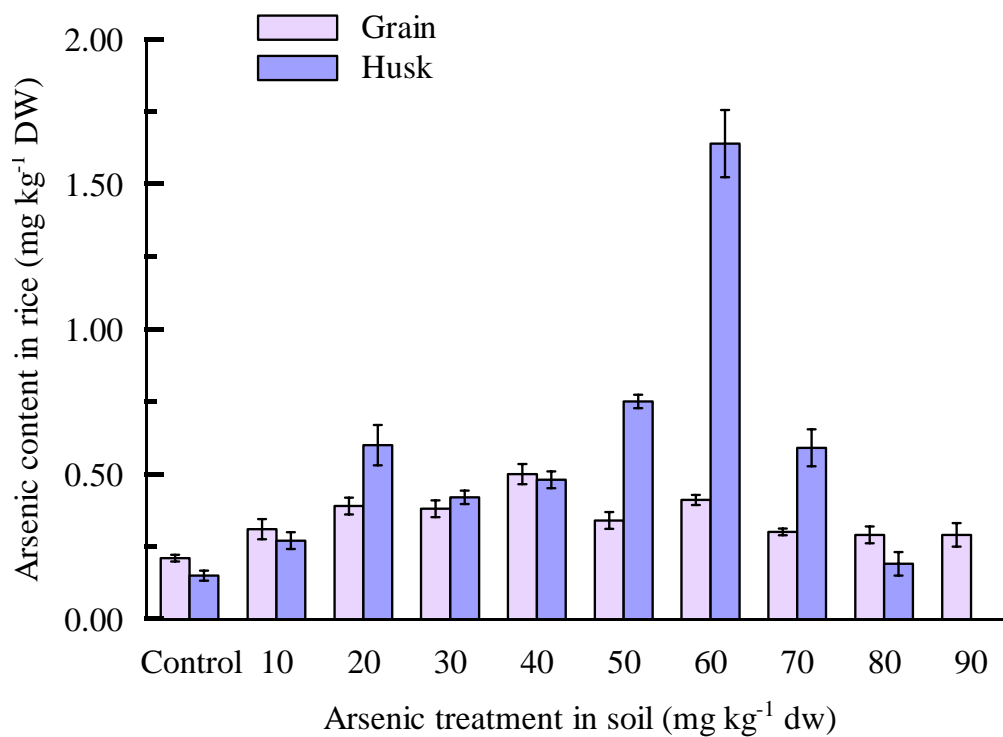
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590   **Figure 3:**

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592   Figure 3: Effect of soil arsenic concentrations on arsenic uptake in rice grain and husk.

593   Error bars represent mean ± SEM of three replicates. Raw rice was sun dried and

594   the husk was removed from rice grain to determine arsenic.

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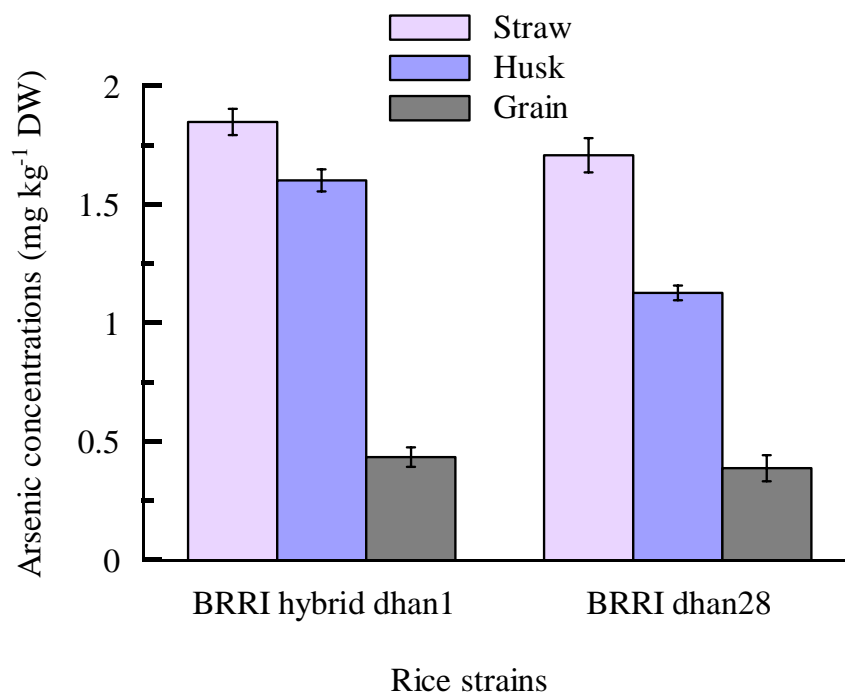
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606   **Figure 4:**

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