

Arsenic accumulation in rice (*Oryza sativa* L.) varieties of Bangladesh: A glass house study

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1 **Arsenic Accumulation in Rice (*Oryza sativa* L.) Varieties of**
2 **Bangladesh: A Glass House Study**

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6 **M. Azizur Rahman^{1,*}; H. Hasegawa¹; M. Mahfuzur Rahman²; M. Nazrul Islam²; M. A. M. Miah³ and A.**
7 **Tasmin⁴**

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12 ¹Graduate School of Natural Science & Technology, Kanazawa University, Kakuma, Kanazawa 920-
13 1192, Japan; ²Department of Botany, Jahangirnagar University, Savar, Dhaka-1342, Bangladesh;
14 ³Bangladesh Rice Research Institute (BRRI), Gazipur, Bangladesh. ⁴Institute of Education and
15 Research (IER), University of Dhaka, Dhaka-1000, Bangladesh.

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18
19
20 *Corresponding author

21 E-mail: arahman@stu.kanazawa-u.ac.jp

22 rahmanmazizur@gmail.com

23 Tel/Fax: +81-76-234-4792

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25

26 **Abstract**

27 A glass house study was conducted to investigate the accumulation of arsenic in tissues of five
28 widely cultivated rice (*Oryza sativa* L.) varieties of Bangladesh namely BRRI dhan 28, BRRI dhan
29 29, BRRI dhan 35, BRRI dhan 36, BRRI hybrid dhan 1. Arsenic concentrations were measured in
30 straw, husk and brown and polish rice grain to see the differential accumulation of arsenic among the
31 rice varieties. The results showed that the concentrations of arsenic in different parts of all rice
32 varieties increased significantly ($p < 0.05$) with the increase of its concentrations in soil. The rice
33 varieties did not showed significant differences in arsenic accumulation in straw, husk, brown and
34 polish grain when the concentrations of arsenic in soil was low. However, at higher concentrations of
35 arsenic in soil, different rice varieties showed significant differences in the accumulations of arsenic
36 in straw, husk and grain. Significantly higher concentrations of arsenic in straw and husk of rice were
37 observed in BRRI hybrid dhan 1 compared to those of other varieties. The BRRI dhan 28 and 35
38 concentrated significantly higher amount of arsenic in brown and polish rice grain compared to those
39 of other rice varieties. The results imply that arsenic translocation from root to shoot (straw) and
40 husk was higher in hybrid variety compared to those of non-hybrid varieties. Arsenic concentrations
41 in brown and polish rice grain of five rice varieties were found to follow the trend: BRRI dhan 28 >
42 BRRI dhan 35 > BRRI dhan 36 > BRRI dhan 29 > BRRI hybrid dhan 1. The order of arsenic
43 contents in tissues of rice was: straw > husk > brown rice grain > polish rice grain.

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46 **Key words:** Arsenic, Accumulation, Translocation, Rice (*Oryza sativa* L.) variety, Rice grain,
47 Bangladesh.

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49

50 **1. Introduction**

51 Arsenic is one of the toxic environmental pollutants which have recently attracted mass attention
52 because of its chronic and epidemic effects on human health. The widespread water and crop
53 contamination through natural release of this toxic element from aquifer rocks has been reported in
54 Bangladesh and West Bengal, India (Fazal et al., 2001; Smith et al., 2000; Nickson et al., 1998;
55 Nickson et al., 2000; Chakraborty et al., 2002; Hopenhayn, 2006; Harvey et al., 2002; Chowdhury et
56 al., 1999; Chakraborti and Das, 1997). Geogenic contamination of arsenic in aquifer rocks has also
57 been reported in Thailand (Visoottiviseth et al., 2002), Vietnam, Inner Mongolia, Greece, Hungary,
58 USA, Ghana, Chile, Argentina and Mexico (Smedley and Kinniburgh, 2002).

59 Bangladesh is one of the major rice growing countries and rice is the staple food crop of the country.
60 Contamination of drinking water by arsenic is a public health emergency in Bangladesh since the
61 populations of arsenic epidemic areas of the country drink underground water which becomes
62 contaminated with very high level of arsenic (Smith et al., 2000). The farmers of Bangladesh also
63 irrigate their crops with this arsenic contaminated ground water. About 33% of total arable land of
64 the country is under irrigation facilities (BBS, 1996). It is estimated that 83% of the total irrigated
65 areas of Bangladesh are used for rice cultivation (Dey et al., 1996). To acquire the self-sufficiency in
66 rice production, the high yielding varieties (HYV) of rice have been cultivated widely in the country
67 throughout the year. The rice cultivation is solely depended on underground water, particularly in the
68 Boro (dry) season since the sources of surface water like river, dam, pond etc. becomes dry in this
69 season. Irrigation is principally performed by a large number of shallow tubewells (STWs) and deep
70 tubewells (DTWs). The water of STWs contained very high level of arsenic (Nickson et al., 2002;
71 McLellan F., 2002; van Geen et al., 2003; Alam et a., 2002). The use of arsenic contaminated
72 underground water in irrigation for a prolong period of time may increase the concentrations of
73 arsenic in agricultural soil and crops (Ullah, 1998; Imamul Huq et al., 2003; Rahman et al., 2007a).

74 In Bangladesh, arsenic concentrations in agricultural soils have been reported to be between 4.0 and
75 8.0 mg kg⁻¹ where the underground irrigation water does not contaminated with high level of arsenic.
76 However, about 83 mg of As kg⁻¹ has been reported in agricultural soils of those areas, where the
77 underground irrigation water is contaminated with very high level of arsenic (Ullah, 1998). Kabata-
78 Pendias and Pendias (1992) recommended 20 mg of As kg⁻¹ soil as the safe level of arsenic in
79 agricultural soil for crops.

80 Consequently, widespread use of arsenic contaminated groundwater for irrigation in rice field could
81 elevate its concentrations in surface soil and eventually into rice plant and rice grain (Abedin et al.,
82 2002; Rahman et al., 2007a; Rahman et al., 2007b). Arsenic uptake and accumulation in rice plant
83 from irrigation water and contaminated soil might depend on cultivars (Xie and Huang, 1998;
84 Meharg and Rahman, 2003). The availability of arsenic to the rice plant might also be subjected to
85 the geographic location, soil properties, redox condition and cropping season (Meharg and Rahman,
86 2003). However, limited literatures are available on arsenic accumulation in different rice varieties.
87 Detail information is needed for the conclusive assessment on arsenic availability and accumulation
88 in rice of different varieties and to find rice varieties which are resistant to the arsenic phytotoxicity.
89 Therefore, a glass house study was conducted with five popular and widely cultivated rice varieties
90 of Bangladesh growing under different soil arsenic concentrations.

91

92 **2. Materials and Methods**

93 Pot experiment was conducted in a glass house and the duration of the experiment was 120 days
94 from transplanting to the harvest. The experimental area was located in sub-tropical and humid
95 region, characterized by high temperature, moderately high rainfall during the rainy season (April -
96 September) and low temperature and rainfall during the dry season (October - March). Though the
97 experiment was conducted in glass house, the environmental conditions inside the glass house were
98 not controlled strictly throughout the experiment. Normal environmental conditions were maintained

99 inside the glass house. The glass house was used only to protect the experiment from some unwanted
100 disturbances. Therefore, the conditions inside the glass house did not differ from that of out side.
101 Thus, the environmental conditions of the experimental area represent the glass house conditions as
102 well, which are shown in [Table 1](#).

103

104 **2.1. Soil and pot preparation**

105 Soil was collected from Bangladesh Rice Research Institute's (BRRI) rice field at a depth of 0-15 cm.
106 After collection, the soil was sun dried for 7 days and massive aggregates were broken by gentle
107 crushing with hammer. The unwanted materials such as dry roots, grasses, hard stones were removed
108 and the soil was mixed thoroughly. About 60, 120, 180, 360 and 540 mg of sodium arsenate
109 ($\text{Na}_2\text{HAsO}_4 \cdot 7\text{H}_2\text{O}$) were taken into 200-ml conical flasks, dissolved in 100 ml deionized (DI) water
110 and spiked in eight-litter plastic pots, respectively containing six kilograms of soil each. The
111 background arsenic in soil was $6.44 \pm 0.24 \text{ mg kg}^{-1}$ ([Table 2](#)). One control treatment was also
112 maintained to compare the results. Pore less plastic pots were used to prevent leaching and
113 absorption of water soluble arsenic from the soil solution. Plastic pots were washed by tap water and
114 sun dried before taking the soil into them. The experiment was arranged following the factorial
115 completely randomized design (CRD) with three replications of each treatment. The physico-
116 chemical properties of initial soil are presented in [Table 2](#).

117

118 **2.2. Selection of rice varieties and seedling transplantation**

119 Five high yielding varieties (HYV) of rice (*Oryza sativa* L.), namely BRRI dhan 28, BRRI dhan 29,
120 BRRI dhan 35, BRRI dhan 36 and BRRI hybrid dhan 1, were selected for the experiment. These rice
121 varieties are popular and widely cultivated throughout the arsenic epidemic areas of Bangladesh.
122 Seedlings of 35 days old were uprooted carefully from seedbed and transplanted on the same day in
123 flooded condition. Four seedlings, six inches apart from each other, were transplanted in each pot.

124 The seedlings, which died within 6 days of transplantation, were discarded and new seedlings were
125 replaced.

126

127 **2.3. Fertilizer application and intercultural operation**

128 After the application of arsenic, soils were left in the pots for 2 days without irrigation. Then, about
129 4.5 liter of tap water was irrigated in each of the pots to make the soil clay, suitable for rice seedling
130 transplantation. About 3-4 cm water from the soil level was maintained in the pot before seedling
131 transplantation. The tap water, used for irrigation, contained 0.001 mg l⁻¹ of arsenic which is much
132 less than the permissible limit (0.05 mg l⁻¹) recommended by the government of Bangladesh.
133 Therefore, addition of arsenic to the soil from irrigation water was negligible.

134 To support plant growth, 1.3, 0.5, 0.6 and 0.4 g pot⁻¹ of urea, triple super phosphate (TSP), murate
135 of potash (MP), and gypsum fertilizer were applied for nitrogen, phosphorus, potassium and sulfur,
136 respectively. The first split (one third of the dose) of urea and full doses of all other fertilizers were
137 incorporated into the soil by hand before 2 days of seedling transplantation. The second and third
138 splits of urea were applied after 35 (maximum tillering stage) and 75 (panicle initiation stage) days
139 of transplantation, respectively.

140 Two insecticides, namely Basudin (solid) and Malathion (liquid), were applied in the soil to kill
141 insects and aphids attacked the rice plants. After transplantation, 3-4 cm water from soil level was
142 maintained in each pot throughout the growth period by irrigating tap water. The pots were infested
143 with some common weeds which were uprooted at their early growth stage by hand carefully.
144 Irrigation was stopped before 10 days of harvest.

145

146 **2.4. Sample collection and preservation**

147 The rice plants were cut at 4 cm above the soil and rice grain was harvested at their maturity stage
148 (120 days after transplantation). Then the collected samples (straw and rice grain) from each pot

149 were tagged properly and sun dried for 3 days putting the samples on a wooden table. The sun dried
150 samples were stored in a drying cabinet at 45 °C. Before taking the final weight, all samples were
151 oven dried at 65 °C for 72 hours.

152

153 **2.5. Arsenic analysis**

154 About 0.5 g of the sample was taken into a dry clean digestion tubes and 5 ml of concentrate nitric
155 acid was added in it. The mixture was allowed to stand over night under fume hood. In the following
156 day, the digestion tubes were placed on a heating block and heated at 60 °C for 2 hours. Then, the
157 tubes were allowed to cool at room temperature. About 2 ml of concentrated perchloric acid was
158 added to the plant samples. For the soil samples (initial soil), 3 ml sulfuric acid was added in addition
159 to 2 ml perchloric acid. Again, the tubes were heated at 160 °C for about 4 to 5 hours. Heating was
160 stopped when the dense white fumes of perchloric acid occurred. The digests were cooled, diluted to
161 25 ml by distilled DI water and filtered through filter paper (Whatman; No.1) and stored in 30-ml
162 polythene bottles.

163 Total arsenic was determined by hydride generation atomic absorption spectrophotometer (HG-AAS)
164 (Perkin-Elmer AAnalyst 100 fitted with flow injection system, FIAS 100, Germany) using matrix-
165 malched standards ([Welsch et al., 1990](#)). The accuracy of the analysis was checked by the certified
166 standard reference material (SRM) 1573a tomato leaf (NIST, USA). The arsenic concentration in
167 certified reference material was $0.112 \pm 0.004 \mu\text{g g}^{-1}$ while the measured arsenic concentration was
168 $0.123 \pm 0.009 \mu\text{g g}^{-1}$. The concentrations detected in all samples were above the instrumental limits of
169 detection ($\geq 0.0008 \text{ mg L}^{-1}$ in water). All glassware and plastic bottles were previously washed by
170 distilled DI water and dried.

171

172 **2.6. Chemicals**

173 Nitric acid (HNO₃) (70%), sulfuric acid (H₂SO₄), perchloric acid (HClO₄) and sodium arsenate
174 (Na₂HAsO₄·7H₂O) were purchased from Mark. Other chemicals were from AnalaR. All the reagents
175 were of analytical grade.

176

177 **2.7. Statistical analysis**

178 The experimental data were statistically analyzed by IRRISTAT 4.0 for windows developed by the
179 Biometrics unit, IRRI, Philippines. Analysis of Variance (ANOVA) was computed for least
180 significant difference (LSD) at 5% level.

181

182 **3. Results and Discussions**

183 **3.1. Arsenic accumulation in rice straw**

184 With the increase of soil arsenic concentrations, arsenic accumulation in straw of all five rice
185 varieties increased significantly ($p < 0.05$) (Fig. 1A). The average straw arsenic concentration in
186 control treatment was 7.07 ± 0.82 mg kg⁻¹ dry weight, which were 19.69 ± 0.90 , 26.85 ± 2.14 and
187 61.65 ± 8.78 mg kg⁻¹ dry weight in soil spiked with 10, 20 and 30 mg of As kg⁻¹, respectively (Fig.
188 2A). [Abedin et al. \(2002\)](#) reported significant increase of arsenic in rice (*Oryza sativa* L.) straw with
189 the increase of arsenate concentrations in irrigation water. [Abedin et al. \(2002\)](#) found 3.9 mg of As
190 kg⁻¹ dry straw at the lowest arsenate treatment (0.05 mg l⁻¹), which increased progressively with
191 increasing the concentration of the element in irrigation water and reached to 91.8 mg kg⁻¹ dry
192 weight at the highest arsenate treatment (8.0 mg l⁻¹). [Tsutsumi \(1980\)](#) observed elevated arsenic
193 concentrations in rice straw (up to 149 mg kg⁻¹ dry weight) when rice (*Oryza sativa* L.) was grown in
194 soil amended with arsenate at different levels (0-312.5 mg kg⁻¹). Other studies ([Marin et al., 1992](#);
195 [Marin et al., 1993](#); [Rahman et al., 2007a](#)) also reported the increase of arsenic in straw of rice (*Oryza*
196 *sativa* L.) with increasing soil arsenic concentrations. However, the present study reports the
197 deferential accumulation of arsenic in straw of five widely cultivated rice (*Oryza sativa* L.) varieties

198 of Bangladesh. Data showed that the average arsenic concentrations in straw of BRRI dhan 28, BRRI
199 dhan 35, BRRI dhan 36 and BRRI hybrid dhan 1 did not differ significantly ($p > 0.05$) from each
200 other though BRRI dhan 29 differed significantly ($p < 0.05$) from other varieties (Figure 2B). At
201 lower soil arsenic concentrations (up to 20 mg kg⁻¹ soil) the arsenic contents in straw of the five rice
202 varieties were statistically identical, though they differed significantly at higher levels of soil arsenic
203 (30 mg kg⁻¹ soil) (Table 3). At 30 mg of As kg⁻¹ soil treatment, the hybrid rice variety accumulated
204 highest amount of arsenic (72.21±5.18 mg kg⁻¹ dry weight) while the non-hybrid BRRI dhan 29
205 accumulated the lowest amount (48.92±4.55 mg kg⁻¹ dry weight). The results indicate that hybrid
206 rice varieties might have higher arsenic accumulation ability and are more tolerant to arsenic
207 phytotoxicity than those of non-hybrid varieties.

208

209 **3.2. Accumulation and translocation of arsenic in husk**

210 Correlation analysis revealed that the increase of arsenic concentrations in soil drastically decreased
211 its translocation from rice straw to husk (Fig. 1B). In control treatment, an average of 0.36±0.06 mg
212 of As kg⁻¹ dry weight was found in husk which was increased significantly with the increase of soil
213 arsenic concentrations (Fig. 3). At 10, 20 and 30 mg of As kg⁻¹ soil treatments, average arsenic
214 contents in husk of five rice varieties were 0.80±0.07, 0.81±0.07 and 1.17±0.22 mg kg⁻¹ dry weight,
215 respectively which were 24, 33 and 52 times less than those of rice straw, respectively. The results
216 imply that a large amount of arsenic had been stored by the straw when the element was translocated
217 to the husk. Significant reduction of arsenic translocation from straw to husk was reported in
218 literatures (Abedin et al., 2002; Rahman et al., 2007a). Abedin et al. (2002) observed increasing
219 concentrations of arsenic in rice husk with the increase of the element in irrigation water. Elevated
220 amount of arsenic in rice husk was also reported by Marin et al. (1992).

221 Arsenic contents in husk were also varied significantly with the variation of rice varieties. The
222 average values of the five rice varieties indicate that BRRI dhan 28 accumulated highest amount of

223 arsenic while BRR I dhan 29 accumulated the lowest amount. The average arsenic contents in husk of
224 BRR I dhan 35, BRR I dhan 36 and BRR I hybrid dhan 1 did not differ significantly from each other
225 (Fig. 4).

226 At 10 mg of As kg⁻¹ soil treatment, the variations of arsenic contents in husk of five rice varieties
227 were not significant though they differed at 20 and 30 mg of As kg⁻¹ soil treatments (Table 3). At 30
228 mg of As kg⁻¹ soil treatment, 1.64±0.12 mg of As kg⁻¹ dry weight was calculated in husk of BRR I
229 dhan 28 followed by 1.45±0.24, 1.28±0.22, 1.24±0.08 and 0.92±0.15 mg kg⁻¹ dry weight in BRR I
230 hybrid dhan 1, BRR I dhan 36, BRR I dhan 35 and BRR I dhan 29, respectively (Table 3). The results
231 imply that translocation of arsenic from straw to husk of BRR I dhan 29 was significantly lower than
232 those of other four varieties. The BRR I dhan 28 accumulated highest amount of arsenic in husk
233 compared to those in other varieties.

234

235 **3.3. Arsenic accumulation in rice grain**

236 Rice grain was considered as the inner most part of raw rice separated from outer layer (husk).
237 Furthermore, the thin brown layer around the rice grain called “barn-polish” was removed to make
238 polish rice. Thus, arsenic concentrations were measured in brown rice (grain with bran-polish) and
239 polish rice (grain without bran-polish).

240 Data indicate that average arsenic concentrations in both brown and polish rice grain were increased
241 significantly ($p < 0.05$) with the increase of soil arsenic concentrations (Fig. 3). Correlation analysis
242 also showed that the arsenic concentrations in soil and rice grain were related antagonistically (Fig.
243 1C, 1D). The lowest average arsenic contents in brown and polish rice grain of the five varieties
244 were 0.28±0.03 and 0.18±0.03 mg kg⁻¹ dry weight, respectively at control treatment, which were
245 0.47±0.05 and 0.35±0.06; 0.56±0.05 and 0.47±0.06; 0.60±0.03 and 0.51±0.06 mg kg⁻¹ dry weight at
246 10, 20 and 30 mg of As kg⁻¹ soil treatments, respectively. Meharg and Rahman (2003) reported
247 elevated (about 10 folds) arsenic content in rice grain of contaminated soil and found 0.058-1.83 µg

248 g⁻¹ dry weight in Bangladeshi rice grain. [Abedin et al. \(2002\)](#) reported 0.15-0.42 mg of As kg⁻¹ dry
249 weight in rice grain (brown rice) when the rice was grown with arsenic contaminated irrigation water.
250 [Schoof et al. \(1999\)](#) reported 0.303 mg of As kg⁻¹ dry weight in rice grain from a market basket
251 survey (they did not mention whether the grain was brown or polish rice). This data is comparable to
252 those found in polish rice at 10 mg of As kg⁻¹ soil treatment of the present study. However, the
253 present study reports for the first time about the arsenic content in brown and polish rice grain
254 independently, which is more informative than the previous reports.

255 Average arsenic concentrations in brown and polish rice grain of BRRI dhan 28, BRRI dhan 35 and
256 BRRI dhan 36 did not differ significantly from each other though they differed significantly ($p >$
257 0.05) from those of BRRI dhan 29 and BRRI hybrid dhan 1. The BRRI dhan 28 contained the
258 highest amount of arsenic in brown and polish rice grain while the BRRI hybrid dhan 1 contained the
259 lowest amount. Regardless of soil arsenic concentrations, arsenic contents in both brown and polish
260 rice grain followed the trend: BRRI dhan 28 > BRRI dhan 35 > BRRI dhan 36 > BRRI dhan 29 >
261 BRRI hybrid dhan 1.

262

263 **4. Conclusions**

264 Although the arsenic uptake into plants has been reported in literature to be associated with plant
265 species, the present study revealed that its uptake into plant might differ with the varieties of same
266 species. Among the five rice (*Oryza sativa* L.) varieties studied in the present experiment, hybrid
267 variety was found to accumulate higher amount of arsenic in their straw compared to non-hybrid rice.
268 But translocation of arsenic into husk and grain of non-hybrid variety BRRI hand 28 was higher than
269 those of other rice varieties. The BRRI dhan 29 was found to uptake lowest amount of arsenic into its
270 straw, husk and grain compared to other four rice varieties. Arsenic uptake increased into the tissues
271 of all rice varieties with the increase of its concentrations in soil. Above 60 mg of As kg⁻¹ soil
272 treatment, rice plant of all varieties died due to the phytotoxicity of arsenic.

273 Though there is no upper standard limit of arsenic in food grain for South and East Asian countries,
274 its content in both brown and polish rice grain have not found to exceed the food hygiene standard
275 level of United Kingdom and Australia (1.0 mg kg^{-1}) (Warren et al., 2003). However, its content in
276 straw was much higher. Regardless of rice varieties, the order of arsenic accumulation in above
277 ground tissues of rice plant was: straw > husk > brown rice grain > polish rice grain. On the other
278 hand, arsenic concentrations in brown and polish rice grain of five rice varieties were found to follow
279 the trend: BRRI dhan 28 > BRRI dhan 35 > BRRI dhan 36 > BRRI dhan 29 > BRRI hybrid dhan 1.

280

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286

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Table 1: Environmental conditions of the experimental area during the experiment ^a

Month	Temperature (°C)		Relative humidity (%)		Average evaporation (mm)	Sunshine (h d ⁻¹)	Solar radiation (cal. cm ⁻²)	Total rainfall (mm)
	Max.	Min.	8:00 AM	2:00 PM				
January '04	24.00	12.70	80.50	53.10	2.00	5.90	261.60	8.00
February '04	28.50	14.40	72.10	40.70	2.70	8.30	373.50	0.00
March '04	32.80	21.60	75.30	44.90	4.60	7.60	403.60	7.40
April '04	32.40	23.50	78.90	55.90	4.10	6.10	376.40	137.40
May '04	33.20	26.00	73.80	56.30	5.50	7.50	429.90	949.40

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^a Source: Plant Physiology Division, Bangladesh. Bangladesh Rice Research Institute (BRRI), Gazipur, Bangladesh.

388 **Table 2:** Physico-chemical properties of initial soil to which arsenic was spiked at different
 389 concentrations

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Soil Properties	Average Value
% Sand (2-0.05 mm)	12.30±0.21
% Silt (0.05-0.002 mm)	53.00±0.04
% Clay (< 0.002 mm)	34.70±0.03
Soil texture	Silty clay loam
Soil pH	7.49±0.07
Total Nitrogen (%)	0.15±0.03
Total Iron (%)	0.22±0.01
Total Manganese (mg kg ⁻¹)	262.08±4.50
Total Arsenic (mg kg ⁻¹)	6.44±0.24
Available Phosphate (mg kg ⁻¹)	4.30±0.03

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406 **Table 3:** Effect of soil arsenic concentrations on arsenic contents on five widely cultivated
 407 rice (*Oryza sativa* L.) varieties of Bangladesh ^a

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Arsenic treatments (mg kg ⁻¹ soil)	Rice varieties	mg of As (kg dry weight) ⁻¹			
		Straw	Husk	Brown rice	Polish rice
Control	BRRRI dhan 28	6.99±0.68a	0.42±0.04a	0.31±0.05a	0.23±0.05a
	BRRRI dhan 29	5.78±0.46a	0.28±0.08b	0.28±0.04a	0.16±0.08ab
	BRRRI dhan 35	7.00±0.88a	0.36±0.06a	0.30±0.08a	0.20±0.03a
	BRRRI dhan 36	7.83±1.05a	0.32±0.07b	0.27±0.07a	0.18±0.05a
	BRRRI hybrid dhan 1	7.74±1.22a	0.40±0.94a	0.24±0.03ab	0.14±0.04b
10	BRRRI dhan 28	19.74±2.31a	0.87±0.14a	0.54±0.08a	0.42±0.09a
	BRRRI dhan 29	18.91±1.54a	0.58±0.08b	0.31±0.04b	0.31±0.04b
	BRRRI dhan 35	18.92±1.22a	0.79±0.16a	0.53±0.05a	0.39±0.05a
	BRRRI dhan 36	19.75±3.44a	0.81±0.13a	0.51±0.3a	0.33±0.04b
	BRRRI hybrid dhan 1	21.12±2.68a	0.84±0.17a	0.32±0.09b	0.28±0.03b
20	BRRRI dhan 28	26.96±2.36a	1.24±0.21a	0.67±0.08a	0.58±0.05a
	BRRRI dhan 29	25.14±3.55a	0.72±0.14d	0.38±0.06b	0.42±0.02b
	BRRRI dhan 35	24.74±3.84a	0.98±0.08b	0.65±0.03a	0.49±0.03a
	BRRRI dhan 36	27.28±1.65a	0.80±0.13cd	0.61±0.05a	0.50±0.02a
	BRRRI hybrid dhan 1	30.12±2.98a	0.87±0.09c	0.44±0.07b	0.32±0.04c
30	BRRRI dhan 28	58.65±3.69b	1.64±0.12a	0.75±0.09a	0.65±0.09a
	BRRRI dhan 29	48.92±4.55c	0.92±0.15d	0.47±0.04c	0.46±0.08bc
	BRRRI dhan 35	61.28±2.87b	1.24±0.08c	0.71±0.02a	0.55±0.07b
	BRRRI dhan 36	66.72±3.47ab	1.28±0.22c	0.59±0.02b	0.54±0.03b
	BRRRI hybrid dhan 1	72.21±5.18a	1.45±0.24b	0.48±0.07c	0.43±0.08bc

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410 ^a Results are presented as mean ± SD (*n* = 3). Data were statistically analyzed for least
411 significant difference (LSD) at 5% level. Different letters in a column of each arsenic
412 treatment indicates significant differences among the five rice varieties. No data were
413 obtained at 60 and 90 mg kg⁻¹ soil arsenic treatments because, all rice plants died at these
414 concentrations due to arsenic phytotoxicity.

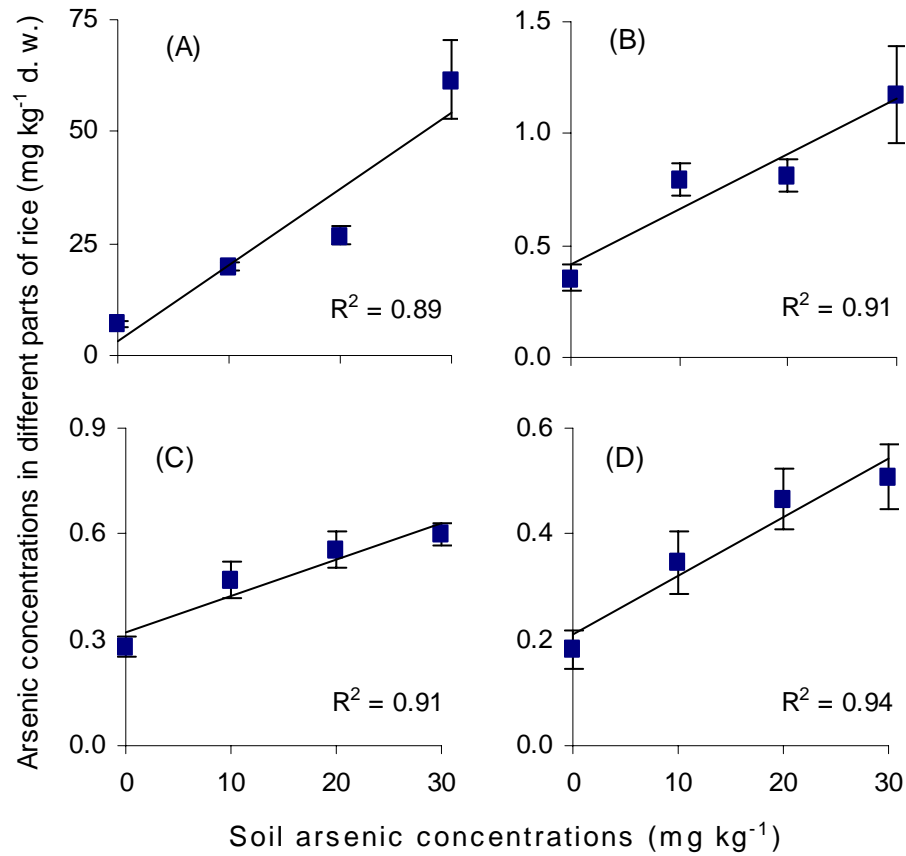
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421 **Figure 1:** Relationship between arsenic concentrations in soil and different parts of rice
 422 (*Oryza sativa* L.). Values are the average of five rice varieties (BRRi dhan 28,
 423 BRRi dhan 29, BRRi dhan 35, BRRi dhan 36 and BRRi hybrid dhan 1). (A)
 424 Straw; (B) Husk; (C) Brown rice and (D) Polish rice. Error bars express mean ±
 425 SD ($n = 3$).

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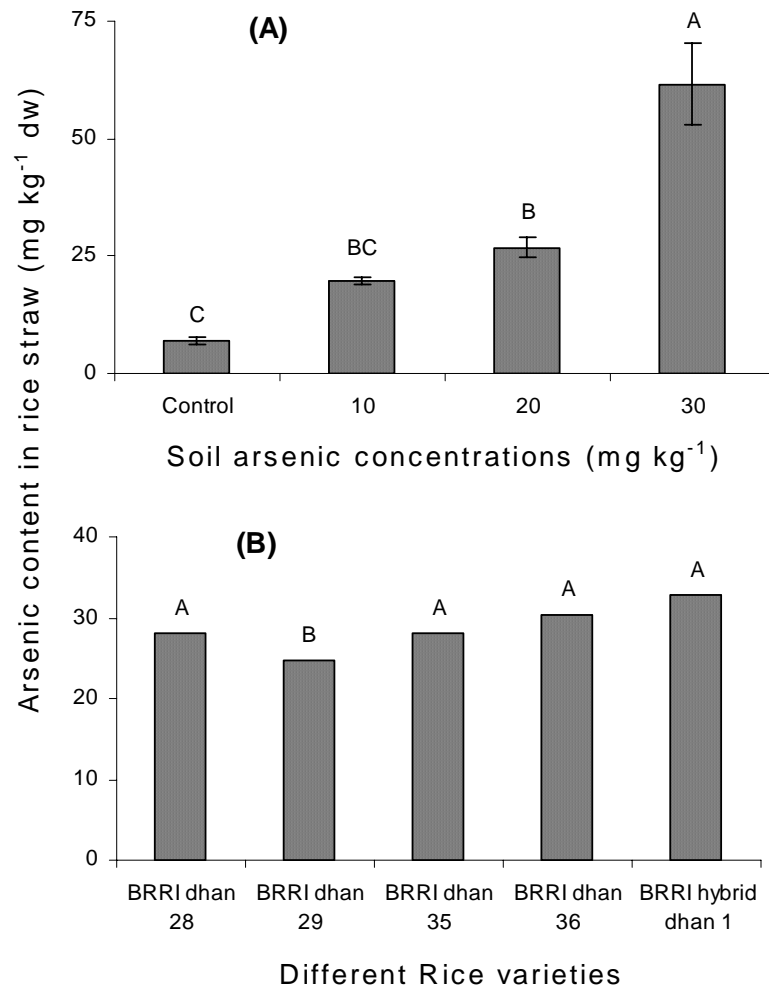
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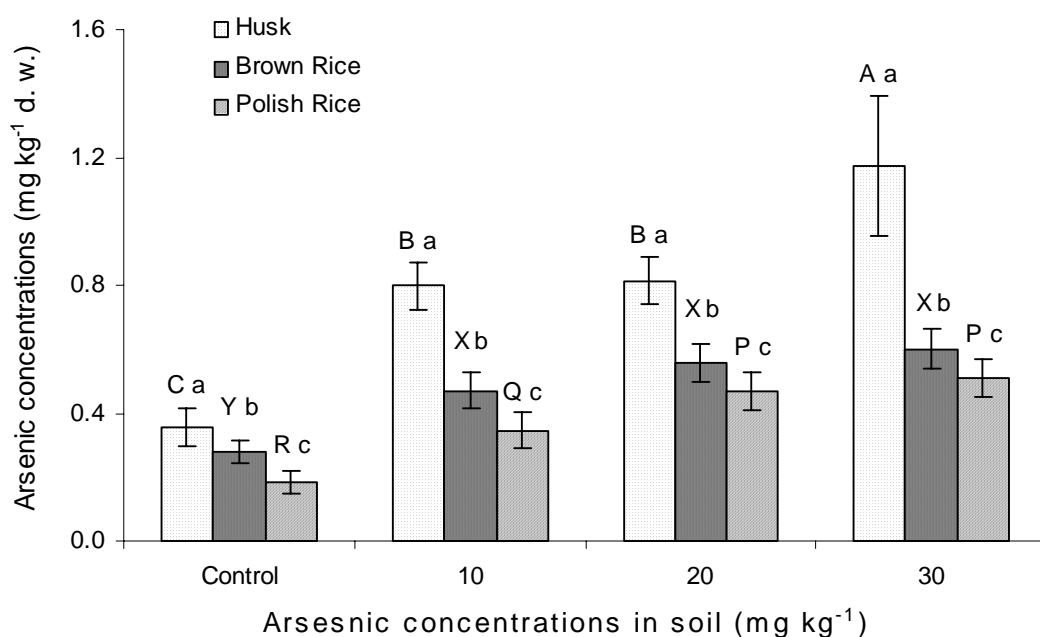
434 **Figure 2:** Arsenic accumulation in straw of rice (*Oryza sativa* L.). **(A)** Values are the average
 435 of five rice varieties (BRRi dhan 28, BRRi dhan 29, BRRi dhan 35, BRRi dhan
 436 36 and BRRi hybrid dhan 1). **(B)** Values are the average of control and three
 437 arsenic treatments (10, 20 and 30 mg of As kg⁻¹ soil). Different letters indicate
 438 significant differences between arsenic treatments **(A)** and between rice varieties
 439 **(B)** at $p < 0.05$. Error bars express mean \pm SD ($n = 3$).

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445 **Figure 3:** Arsenic accumulation in different parts of rice (*Oryza sativa* L.). Values are the
 446 average of five rice varieties (BRR I dhan 28, BRR I dhan 29, BRR I dhan 35,
 447 BRR I dhan 36 and BRR I hybrid dhan 1). Different capital letters indicate
 448 significant differences between arsenic treatments and small letters indicate
 449 significant differences between husk, brown rice and polish rice, at $p < 0.05$. Error
 450 bars express mean \pm SD ($n = 3$).

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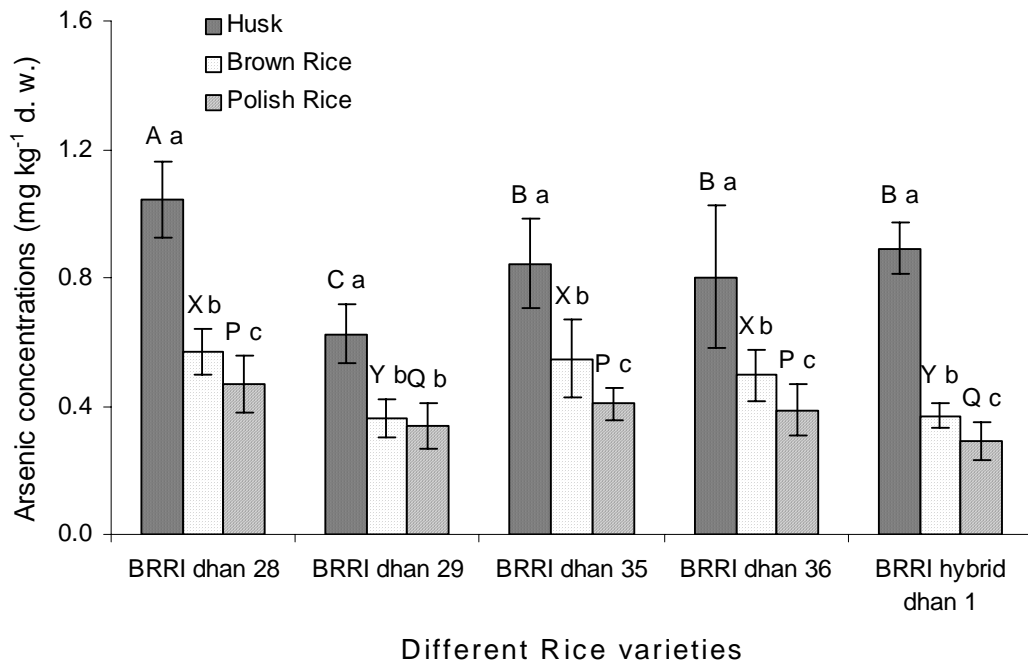
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461 **Figure 4:** Varital differences in arsenic accumulation into rice (*Oryza sativa* L.). Values are
 462 the average of control and the three arsenic treatments (10, 20 and 30 mg of As
 463 kg⁻¹ soil). Different capital letters indicate significant differences between the rice
 464 varieties and small letters indicate significant differences between husk, brown
 465 rice and polish rice, at $p < 0.05$.

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