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

M. Azizur Rahman[1,*]; H. Hasegawa[1]; M. Mahfuzur Rahman[2]; M. Nazrul Islam[2]; M. A. M. Miah[3] and A. Tasmin[4]

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

<u>*Corresponding author</u>

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

rahmanmazizur@gmail.com

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

Abstract

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

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

1. Introduction

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

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

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

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

2. Materials and Methods

Pot experiment was conducted in a glass house and the duration of the experiment was 120 days from transplanting to the harvest. The experimental area was located in sub-tropical and humid region, characterized by high temperature, moderately high rainfall during the rainy season (April - September) and low temperature and rainfall during the dry season (October - March). Though the experiment was conducted in glass house, the environmental conditions inside the glass house were not controlled strictly throughout the experiment. Normal environmental conditions were maintained inside the glass house. The glass house was used only to protect the experiment from some unwanted disturbances. Therefore, the conditions inside the glass house did not differ from that of out side. Thus, the environmental conditions of the experimental area represent the glass house conditions as well, which are shown in Table 1.

2.1. Soil and pot preparation

Soil was collected from Bangladesh Rice Research Institute's (BRRI) rice field at a depth of 0-15 cm. After collection, the soil was sun dried for 7 days and massive aggregates were broken by gentle crushing with hammer. The unwanted materials such as dry roots, grasses, hard stones were removed and the soil was mixed thoroughly. About 60, 120, 180, 360 and 540 mg of sodium arsenate ($Na_2HAsO_4 \cdot 7H_2O$) were taken into 200-ml conical flasks, dissolved in 100 ml deionized (DI) water and spiked in eight-litter plastic pots, respectively containing six kilograms of soil each. The background arsenic in soil was 6.44±0.24 mg kg^{-1} (Table 2). One control treatment was also maintained to compare the results. Pore less plastic pots were used to prevent leaching and absorption of water soluble arsenic from the soil solution. Plastic pots were washed by tap water and sun dried before taking the soil into them. The experiment was arranged following the factorial completely randomized design (CRD) with three replications of each treatment. The physico-chemical properties of initial soil are presented in Table 2.

2.2. Selection of rice varieties and seedling transplantation

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

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

2.3. Fertilizer application and intercultural operation

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

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

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

2.4. Sample collection and preservation

The rice plants were cut at 4 cm above the soil and rice grain was harvested at their maturity stage (120 days after transplantation). Then the collected samples (straw and rice grain) from each pot were tagged properly and sun dried for 3 days putting the samples on a wooden table. The sun dried samples were stored in a drying cabinet at 45 ºC. Before taking the final weight, all samples were oven dried at 65 ºC for 72 hours.

2.5. Arsenic analysis

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

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

2.6. Chemicals

Nitric acid (HNO_3) (70%), sulfuric acid (H_2SO_4), perchloric acid ($HClO_4$) and sodium arsenate ($Na_2HAsO_4 \cdot 7H_2O$) were purchased from Mark. Other chemicals were from AnalaR. All the reagents were of analytical grade.

2.7. Statistical analysis

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

3. Results and Discussions

3.1. Arsenic accumulation in rice straw

With the increase of soil arsenic concentrations, arsenic accumulation in straw of all five rice varieties increased significantly ($p < 0.05$) (Fig. 1A). The average straw arsenic concentration in control treatment was 7.07±0.82 mg kg^{-1} dry weight, which were 19.69±0.90, 26.85±2.14 and 61.65±8.78 mg kg^{-1} dry weight in soil spiked with 10, 20 and 30 mg of As kg^{-1}, respectively (Fig. 2A). Abedin et al. (2002) reported significant increase of arsenic in rice (*Oryza sativa* L.) straw with the increase of arsenate concentrations in irrigation water. Abedin et al. (2002) found 3.9 mg of As kg^{-1} dry straw at the lowest arsenate treatment (0.05 mg l^{-1}), which increased progressively with increasing the concentration of the element in irrigation water and reached to 91.8 mg kg^{-1} dry weight at the highest arsenate treatment (8.0 mg l^{-1}). Tsutsumi (1980) observed elevated arsenic concentrations in rice straw (up to 149 mg kg^{-1} dry weight) when rice (*Oryza sativa* L.) was grown in soil amended with arsenate at different levels (0-312.5 mg kg^{-1}). Other studies (Marin et al., 1992; Marin et al., 1993; Rahman et al., 2007a) also reported the increase of arsenic in straw of rice (*Oryza sativa* L.) with increasing soil arsenic concentrations. However, the present study reports the deferential accumulation of arsenic in straw of five widely cultivated rice (*Oryza sativa* L.) varieties of Bangladesh. Data showed that the average arsenic concentrations in straw of BRRI dhan 28, BRRI dhan 35, BRRI dhan 36 and BRRI hybrid dhan 1 did not differ significantly ($p > 0.05$) from each other though BRRI dhan 29 differed significantly ($p < 0.05$) from other varieties (Figure 2B). At lower soil arsenic concentrations (up to 20 mg kg^{-1} soil) the arsenic contents in straw of the five rice varieties were statistically identical, though they differed significantly at higher levels of soil arsenic (30 mg kg^{-1} soil) (Table 3). At 30 mg of As kg^{-1} soil treatment, the hybrid rice variety accumulated highest amount of arsenic (72.21±5.18 mg kg^{-1} dry weight) while the non-hybrid BRRI dhan 29 accumulated the lowest amount (48.92±4.55 mg kg^{-1} dry weight). The results indicate that hybrid rice varieties might have higher arsenic accumulation ability and are more tolerant to arsenic phytotoxicity than those of non-hybrid varieties.

3.2. Accumulation and translocation of arsenic in husk

Correlation analysis revealed that the increase of arsenic concentrations in soil drastically decreased its translocation from rice straw to husk (Fig. 1B). In control treatment, an average of 0.36±0.06 mg of As kg^{-1} dry weight was found in husk which was increased significantly with the increase of soil arsenic concentrations (Fig. 3). At 10, 20 and 30 mg of As kg^{-1} soil treatments, average arsenic 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, respectively which were 24, 33 and 52 times less than those of rice straw, respectively. The results imply that a large amount of arsenic had been stored by the straw when the element was translocated to the husk. Significant reduction of arsenic translocation from straw to husk was reported in literatures (Abedin et al., 2002; Rahman et al., 2007a). Abedin et al. (2002) observed increasing concentrations of arsenic in rice husk with the increase of the element in irrigation water. Elevated amount of arsenic in rice husk was also reported by Marin et al. (1992).

Arsenic contents in husk were also varied significantly with the variation of rice varieties. The average values of the five rice varieties indicate that BRRI dhan 28 accumulated highest amount of arsenic while BRRI dhan 29 accumulated the lowest amount. The average arsenic contents in husk of BRRI dhan 35, BRRI dhan 36 and BRRI hybrid dhan 1 did not differ significantly from each other (Fig. 4).

At 10 mg of As kg^{-1} soil treatment, the variations of arsenic contents in husk of five rice varieties were not significant though they differed at 20 and 30 mg of As kg^{-1} soil treatments (Table 3). At 30 mg of As kg^{-1} soil treatment, 1.64±0.12 mg of As kg^{-1} dry weight was calculated in husk of BRRI 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 BRRI hybrid dhan 1, BRRI dhan 36, BRRI dhan 35 and BRRI dhan 29, respectively (Table 3). The results imply that translocation of arsenic from straw to husk of BRRI dhan 29 was significantly lower than those of other four varieties. The BRRI dhan 28 accumulated highest amount of arsenic in husk compared to those in other varieties.

3.3. Arsenic accumulation in rice grain

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

Data indicate that average arsenic concentrations in both brown and polish rice grain were increased significantly ($p < 0.05$) with the increase of soil arsenic concentrations (Fig. 3). Correlation analysis also showed that the arsenic concentrations in soil and rice grain were related antagonistically (Fig. 1C, 1D). The lowest average arsenic contents in brown and polish rice grain of the five varieties were 0.28±0.03 and 0.18±0.03 mg kg^{-1} dry weight, respectively at control treatment, which were 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 10, 20 and 30 mg of As kg^{-1} soil treatments, respectively. Meharg and Rahman (2003) reported elevated (about 10 folds) arsenic content in rice grain of contaminated soil and found 0.058-1.83 µg g^{-1} dry weight in Bangladeshi rice grain. Abedin et al. (2002) reported 0.15-0.42 mg of As kg^{-1} dry weight in rice grain (brown rice) when the rice was grown with arsenic contaminated irrigation water. Schoof et al. (1999) reported 0.303 mg of As kg^{-1} dry weight in rice grain from a market basket survey (they did not mention whether the grain was brown or polish rice). This data is comparable to those found in polish rice at 10 mg of As kg^{-1} soil treatment of the present study. However, the present study reports for the first time about the arsenic content in brown and polish rice grain independently, which is more informative than the previous reports.

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

4. Conclusions

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

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

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6. References

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

Month	Temperature (°C)		Relative humidity (%)		Average evaporation	Sunshine	Solar radiation	Total rainfall
	Max.	Min.	8:00 AM	2:00 PM	(mm)	(h d^{-1})	(cal. cm^{-2})	(mm)
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

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

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

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

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

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

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

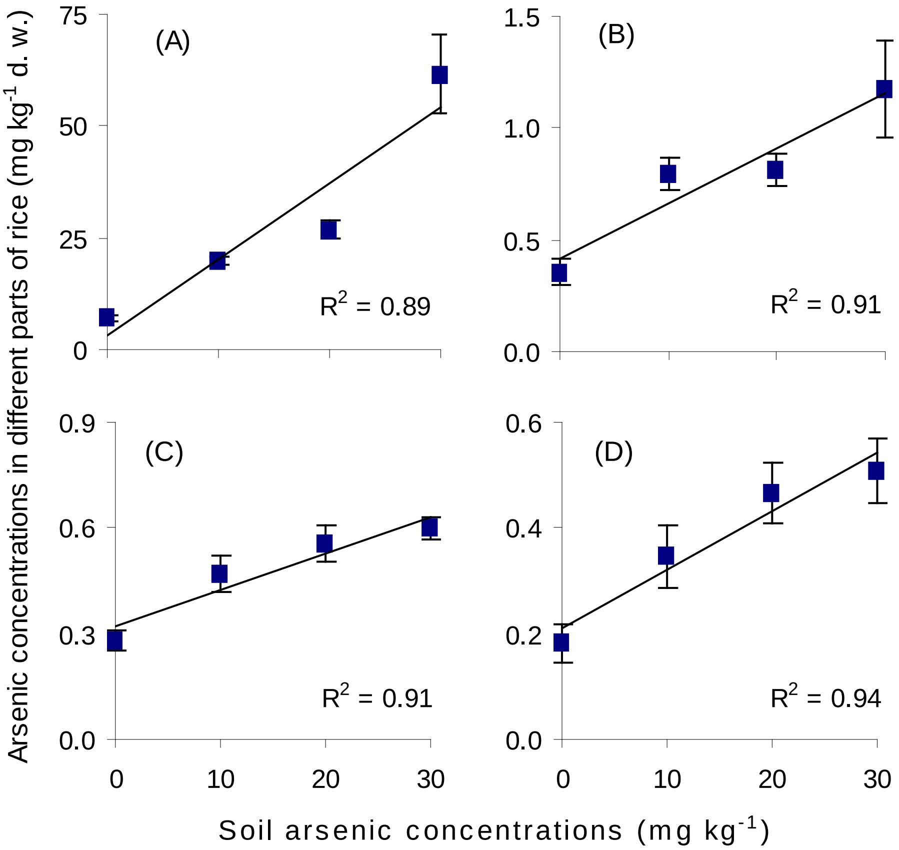

Figure 1: Relationship between arsenic concentrations in soil and different parts of rice (*Oryza sativa* L.). Values are the average of five rice varieties (BRRI dhan 28, BRRI dhan 29, BRRI dhan 35, BRRI dhan 36 and BRRI hybrid dhan 1). **(A)** Straw; **(B)** Husk; **(C)** Brown rice and **(D)** Polish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

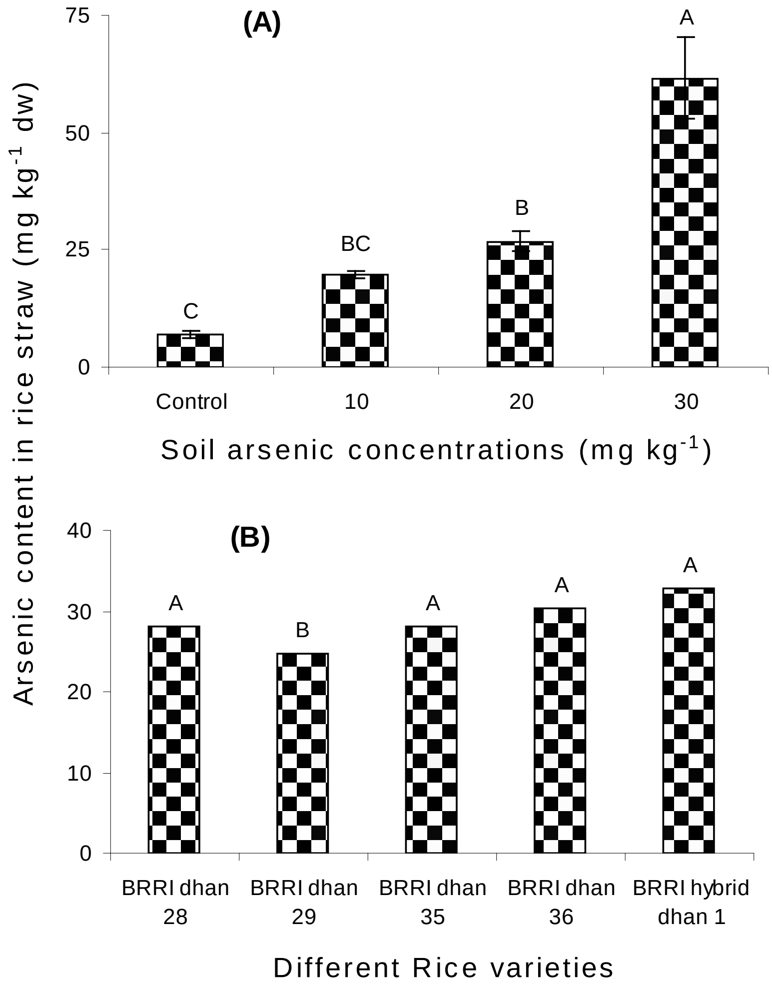

Figure 2: Arsenic accumulation in straw of rice (*Oryza sativa* L.). **(A)** Values are the average of five rice varieties (BRRI dhan 28, BRRI dhan 29, BRRI dhan 35, BRRI dhan 36 and BRRI hybrid dhan 1). **(B)** Values are the average of control and three arsenic treatments (10, 20 and 30 mg of As kg^{-1} soil). Different letters indicate significant differences between arsenic treatments **(A)** and between rice varieties **(B)** at $p < 0.05$. Error bars express mean ± SD ($n = 3$).

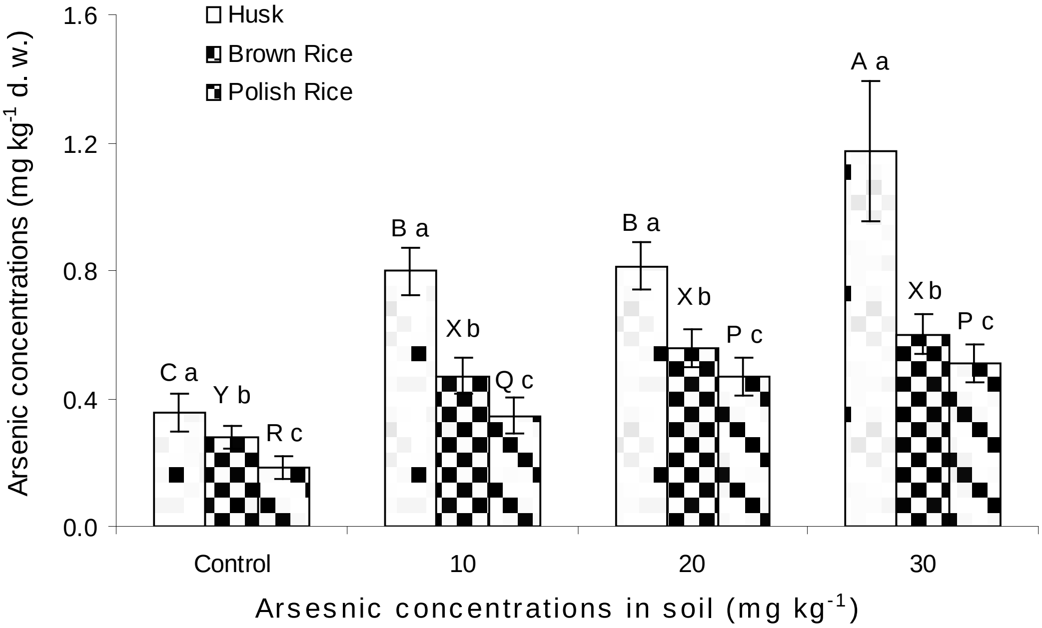

Figure 3: Arsenic accumulation in different parts of rice (*Oryza sativa* L.). Values are the average of five rice varieties (BRRI dhan 28, BRRI dhan 29, BRRI dhan 35, BRRI dhan 36 and BRRI hybrid dhan 1). Different capital letters indicate significant differences between arsenic treatments and small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

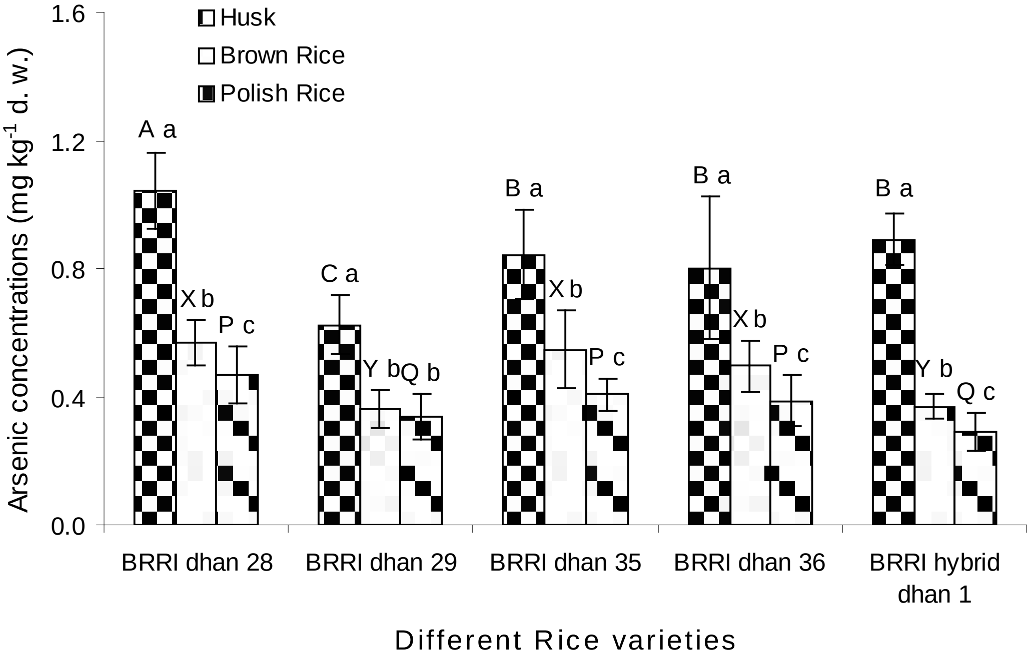

Figure 4: Varital differences in arsenic accumulation into rice (*Oryza sativa* L.). Values are the average of control and the three arsenic treatments (10, 20 and 30 mg of As kg^{-1} soil). Different capital letters indicate significant differences between the rice varieties and small letters indicate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