*Original Research Article*

# Growth, Yield and Grain Arsenic Concentration of Rice Cultivars Under Varying Levels of Soil Arsenic Contamination


## ABSTRACT

Arsenic (As) contamination in groundwater is a severe and widespread problem in Bangladesh and their exposure cause a serious health hazard in human history. A pot experiment was conducted in the net-house of the Department of Soil Science, Bangladesh Agricultural University, Mymensingh using fourteen cultivars of rice (Summer rice) to evaluate the effects of varying levels of As contamination on growth, yield and grain As contents. Arsenic contamination adversely affected tillering, filled grains, grain yield and straw yield of all rice cultivars, however, the effect varied among the cultivars. In As control treatment, the highest grain yield (75.66 g pot$^{-1}$) was observed in BR 11 while the lowest grain yield (8.73 g pot$^{-1}$) was in BRRI dhan4.Application of 20 ppm As to the soil resulted in complete death of BR 11, BRRI dhan30, BRRI dhan33, BRRI dhan34, BRRI dhan41, Binadha-4, Biroy and Kalizeera cultivars. Arsenic contamination significantly increased As concentration in grain for all cultivars of ice. Arsenic concentration on rice grains grown in soils without As contamination ranged from 0.06 ppm in BR 11 to 0.13 ppm in BRRI dhan32 and BRRI dhan41, while such values ranged from 0.231 ppm in Kalizeera with 10 ppm As to 0.743 ppm in BRRI dhan40 with applied 20 ppm As to soils. Among the 14 rice cultivars, BRRI dhan32 BR 11 and Najirshail appeared to be more tolerant to As contamination.



***Key words:*** *Rice, Yield, Arsenic Contamination, Grain Arsenic*

## 1. INTRODUCTION

Arsenic (As) is an important geogenic contaminant found ubiquitously in the earth threatening the health of 150million people worldwide [1-2]. The major sources of As exposure to humans includes drinking water and different food items, especially rice. Exposure of As is associated with various chronic and acute health problems to humans that include skin lesions, cardiovascular diseases, diabetes, cancer, and so on [2]. The envirmental pollutant As is bound to Fe hydroxides, oxyhydroxides, and oxides that released into the groundwater through biogeochemical processes and resulted in widespread As contamination in Bengal delta [3-4]. Geogenic As contaminated groundwater are being used for rice cultivation in West Bengal and Bangladesh. This common practice has resulted in As build-up in soil through the years [5-6]. Background As concentration in Bangladesh soils is in the range of 4-8 mg As $kg^{-1}$. Research studies indicate that, long-term use of As contaminated water for irrigation purposes may result in elevated As concentration in soils and plants, and may lead to crop yield loss and elevated As concentration in cereals, vegetables and other agricultural products [7]. Irrigation using As contaminated groundwater results in significant loading of As in soil and subsequent bioaccumulation in rice grains resulting substantial yield losses [8-9]. Rice can accumulate several-fold higher Asaccumulation than other cereal crops such as wheat and maize [2, 6, 10]. Every year approximately, 36.60 million tons of rice is produced from 11.42 million hectares of land of Bangladesh [11]. The As accumulation in rice grains varies significantly in different rice varieties [12]. The concentrations of As in different parts of all rice varieties increased significantly with the increase of its concentrations in soil. However, the identification of a suitable low As accumulating rice variety and its use in breeding programs for the development of a suitable rice variety is now time demanding. Under these circumstances, a successful solution can be to identify rice varieties that accumulate low As in grains.

## 2. MATERIALS AND METHODS

The experiment was conducted at the net-house of the Department of Soil Science of Bangladesh Agricultural University, Mymensingh, during the Aman season (Summer rice)in 2018.Geographically the net-house stands at 24.750 N latitude and 90.500 E longitude at the height of 18 m above the sea level.The rice cultivars tested were 10 high yielding varieties [BR 11, BRRI dhan30, BRRI dhan31, BRRI dhan32, BRRI dhan33, BRRI dhan34, BRRI dhan39, BRRI dhan40, BRRI dhan41, Binadhan-4], and 4 local varieties [Najirshail, Biroi, Kalizeera,Pajam] were collected from Genetic Resources and Seed Division, BRRI, Gazipur. The soil for the experiment was silt loam in texture, pH 6.7, organic matter 2.0%, total N 0.12%, available P 9.8 ppm, exchangeable K 0.11 me%, available S 10.5 ppm and total As 2.1 ppm. Three levels of As contamination was induced in soil by adding viz. 0, 10 and 20 ppm and tested on 14 rice cultivars (10 modern and 4 local cultivars). The trial was set in a Completely Block Design with three replications. A total of 126 plastic pots were used in the experiment. Each plastic pot had the diameter of 43 cm and height 40 cm receiving 10 of kg soil. Thirty-five days old seedlings were transplanted in the pots and three hills were placed in an equal distance and each hill consisted of 3 seedlings. Urea, Triple Super Phosphate (TSP), Muriate of Potash (MoP), Gypsum and Zinc oxide were applied @ 100 mg $kg^{-1}$ N, 25 mg $kg^{-1}$ P, 50 mg $kg^{-1}$ K, 25 mg $kg^{-1}$ S and 5 mg $kg^{-1}$ Zn, respectively. The entire TSP, MoP, Gypsum and zinc were applied during the final pot preparation. Urea was applied in three equal splits; at 7, 30 and 60 days after transplanting. Intercultural operations were employed as and when necessary. Data were recorded on plant height, effective tillers $pot^{-1}$, panicle length, filled grains $panicle^{-1}$, 1000-grain weight, grain yield $pot^{-1}$ and straw yield $pot^{-1}$. The grain As content was determined after digesting the samples with $HNO_3$ and $H_2O_2$ at120°C followed by flow injection hydride generation atomic absorption spectrophotometer with UNICAM model No. 969 with hydride generator assembly using matrix-matched standards. The analysis of variance for various characters of the crop was done following the MSTATC computer program.

The mean comparison of the treatments was made by the Duncan's Multiple Range Test (DMRT).

## 3. RESULTS AND DISCUSSION

### 3.1 Effective tillers

The effective tillers pot$^{-1}$ decreased significantly due to As contamination to soil. This reduction was significant for all the varieties. The number of effective tillers pot$^{-1}$ in As control condition was 19.31 and that in 10 and 20 ppm As was 8.10 and 1.57, respectively (Table 1). The high yielding and local varieties selected for the experiment showed significant variation in terms of number of effective tillers pot$^{-1}$ (Table 1). The highest number of effective tillers pot$^{-1}$ was obtained in Najirshail with the value of 19.11 which was statistically similar to BRRI dhan32. The interaction of As levels and different high yielding and local varieties selected for the experiment showed remarkable variation in terms of number of effective tillers pot$^{-1}$ (Table 2). Application of 10 and 20 ppm As significantly reduced the number of effective tillers pot$^{-1}$. The highest number of effective tillers pot$^{-1}$ (30.37) was found in BRRI dhan32 with 0 ppm As application. The cultivar BRRI dhan41 failed to produce any effective tillers due to the application of 10 and 20 ppm As and the other seven rice varieties BR 11, BRRI dhan30, BRRI dhan33, BRRI dhan34, Binadhan-4, Biroi and Kalizeera failed to produce plants in 20 ppm As treatment. The corresponding reductions in tiller numbers also reported in Aman rice ranged from 0–22 % [13]. Similarly, a significant effect on plant height and effective tiller numbers has been observed when a different variety of rice is cultivated in soil artificially enriched with arsanilic acid [14].

**Table 1. Effects of added As and varieties on the yield contributing characters, grain and straw yield and their As concentration of different rice cultivars**

| **Factors** | **Number of effective tillers pot$^{-1}$** | **Number of filled grains pot$^{-1}$** | **Grain yield pot$^{-1}$(g)** | **Straw yield pot$^{-1}$(g)** | **Grain As (ppm)** |
|---|---|---|---|---|---|
| **As added (ppm)** | | | | | |
| 0 | 19.31a | 89.54a | 42.27a | 62.54a | 0.10b |
| 10 | 8.10b | 50.12b | 11.30b | 19.47b | 0.45a |
| 20 | 1.33c | 8.75c | 2.12b | 3.80b | 0.64a |
| **S.E. (±)** | **0.41** | **3.52** | **2.73** | **3.04** | **0.05** |

| Cultivars | | | | | |
|---|---|---|---|---|---|
| BR 11 | 14.22b | 48.31b | 33.57a | 39.74ab | 0.31cd |
| BRRI dhan30 | 7.44dc | 57.82ab | 17.58cd | 31.39b | 0.26c |
| BRRI dhan31 | 10.45bc | 67.33a | 24.90b | 29.09bcd | 0.40bc |
| BRRI dhan32 | 15.01ab | 58.71ab | 12.00d | 34.39b | 0.34bcd |
| BRRI dhan33 | 9.00cd | 35.95c | 19.27cd | 23.43d | 0.31d |
| BRRI dhan34 | 5.22d | 49.40b | 8.28d | 14.42d | 0.22e |
| BRRI dhan39 | 10.00bc | 36.00c | 12.33d | 16.69d | 0.48ab |
| BRRI dhan40 | 5.34d | 54.86b | 20.02b | 28.81b | 0.49a |
| BRRI dhan41 | 1.44e | 24.41d | 2.91e | 16.64d | 0.13e |
| Binadhan-4 | 10.00c | 48.86b | 23.93b | 27.21bcd | 0.35bcd |
| Najirshail | 19.11a | 68.38a | 32.55a | 45.43a | 0.35bcd |
| Biroi | 10.00bc | 37.05c | 18.55c | 31.92b | 0.23d |
| Kalizeera | 10.56bc | 54.84b | 19.56c | 28.75b | 0.15e |
| Pajam | 7.45dc | 50.59b | 14.40d | 32.55b | 0.38bcd |
| **S.E. (±)** | **1.21** | **3.78** | **1.52** | **2.07** | **0.05** |

In a column figures having same letters do not differ significantly at 5% level by DMRT

**Table 2. Interaction effects of added As and varieties on the yield contributing characters of different rice cultivars**

| Cultivars | Number of effective tillers pot$^{-1}$(g) | | | Number offilled grains pot$^{-1}$ (g) | | |
|---|---|---|---|---|---|---|
| | As0 | As10 | As20 | As0 | As10 | As20 |
| BR 11 | 28.33ab | 14.33d-g | 0.00m | 93.03b-d | 51.91j-n | 0.00r |
| BRRI dhan30 | 13.66d-h | 8.67g-m | 0.00m | 103.57ab | 69.88g-j | 0.00r |
| BRRI dhan31 | 20.67b-d | 7.00g-m | 3.67i-m | 94.07b-d | 81.85c-h | 26.08o-q |
| BRRI dhan32 | 30.37a | 12.00e-i | 2.67j-m | 102.29ab | 61.12i-l | 12.73qr |
| BRRI dhan33 | 20.67b-d | 6.33g-m | 0.00m | 70.66f-j | 37.20m-o | 0.00r |
| BRRI dhan34 | 10.33e-j | 5.33h-m | 0.00m | 91.81b-e | 56.40i-m | 0.00r |
| BRRI dhan39 | 18.00c-e | 8.00g-m | 4.00i-m | 58.48i-l | 33.56n-p | 15.97p-r |
| BRRI dhan40 | 12.00e-i | 3.33i-m | 0.68lm | 114.31a | 37.39m-o | 12.89qr |
| BRRI dhan41 | 4.33i-m | 0.00m | 0.00m | 73.24d-i | 0.00r | 0.00r |
| Binadhan-4 | 20.68b-d | 9.33f-l | 0.00m | 84.46b-g | 62.13h-k | 0.00r |
| Najirshail | 30.33a | 17.33c | 9.67e-k | 91.11b-f | 70.52f-g | 43.51k-o |
| Biroi | 23.33a-c | 6.68i-m | 0.00m | 84.56b-g | 26.58o-q | 0.00r |
| Kalizeera | 24.00a-c | 7.68g-m | 0.00m | 93.03a-c | 71.50e-j | 0.00r |
| Pajam | 13.68b-h | 7.33g-m | 1.33k-m | 98.88a-c | 41.57l-o | 11.33qr |
| **S.E. (±)** | **1.501** | | | **3.658** | | |

In a column figures having same letters do not differ significantly at 5% level by DMRT

## 3.2 Filled grains

The filled grains pot$^{-1}$ was decreased significantly with addition of As to soil. The number of filled grains pot$^{-1}$ recorded in 0 ppm As was 89.54 and that in 10 and 20 ppm As was 50.12 and 8.75, respectively (Table 1). Higher As concentration causes grain sterility and grains panicle$^{-1}$ were also significantly affected by the As treatments [13, 15]. All the rice cultivars showed significant variation in terms of number of filled grains pot$^{-1}$ (Table 1). The highest number of filled grains pot$^{-1}$ was obtained in Najirshail with the value of 68.38 which was statistically similar to BRRI dhan31 and BRRI dhan30. The interaction of As levels and different high yielding and local varieties selected for the experiment showed remarkable variation in terms of number of filled grains pot$^{-1}$ (Table 2). Application of 10 and 20 ppm As significantly reduced the number of filled grains pot$^{-1}$. The highest number of filled grains pot$^{-1}$ (114.31) was found in BRRI dhan40 with 0 ppm As application.

**3.3 Grain yield**

Grain yield decreased significantly with levels of As application. Grain yield was considered as one of the most important parameters in variety selection in terms of As tolerance or sensitivity. The grain yield of rice cultivars was statistically affected by As contamination (Table 1). The application of 10 and 20 ppm As in soil produced 11.30 g and 2.12 g grain pot$^{-1}$,respectively, whereas in control (0 ppm As) the grain was 42.27 g pot$^{-1}$ i.e. yield reduction was almost 73.31% and 94.98 %, respectively over control. Previously, decreased of rough rice yield from about 7 to 2 t/ha in 2006 and 9 to 3 t/ha in 2007 across the soil As gradient has been reported[9]. A number of authors [16-17] also reported yield reduction as a result of higher levels of As concentrations. Generally higher levels of As addition resulted in greater reduction in yield and the application of As to soil resulted in 80% yield reductions in T. Aman rice (BRRI dhan33), indicating a strong residual effect of added As on the next crop [13]. In winter and summer rice, above ground biomass of rice genotypes progressively decreased because of soil As gradient from 0 to 60 mg/kg [18]. The grain yield of rice varied significantly in different cultivars of Aman rice (Table 3). The highest grain yield (33.57 g pot$^{-1}$) was found in BR 11 which was statistically similar to Najirshail. On the other hand, the lowest grain yield (2.91 g $pot^{-1}$) was found in BRRI dhan41. Almost similar result represents by another study in Bangladesh [17]. The yield markedly declined at 20 mg $kg^{-1}$ As treatment and above. The grain yield was reduced to 93.1% for 50 mg $kg^{-1}$ As treatment, whereas its reduction was only 1.8% in 1.0 mg $kg^{-1}$ As treatment compared to the control. The interaction effect of added As and different rice varieties selected for the experiment significantly affected the grain yield (Table 3). The application of 10 and 20 ppm As reduced the grain yield of all cultivars of rice selected for this experiment. In As control treatment, the highest grain yield (75.66 g $pot^{-1}$) observed in BR 11. The lowest grain yield (8.73 g $pot^{-1}$) in As control treatment was found in BRRI dhan41. The addition of 10 ppm As significantly reduced the grain yield of rice compared to that obtained in As control treatment. The application of 20 ppm As significantly decreased the yield and most of the varieties failed to produce grain yield except BRRI dhan31, BRRI dhan32, BRRI dhan39, BRRI dhan40 and Najirshail. Thus, it can be said that in respect to grain yield Najirshail is the most tolerant variety to As contamination.

**3.4 Straw yield**

Straw yield of rice cultivars was statistically affected by As contamination (Table 1). The yield due to As contamination varied from 62.54 g $pot^{-1}$ in control (0 ppm As) to 19.47 g and 3.80 g $pot^{-1}$ in 10 and 20 ppm As treatment, respectively. Application of 10 and 20 ppm As to soil caused 64.87 % and 93.93 % straw yield reduction of rice, respectively.Similarly straw yield was reduced by 7–64 % in the rice [13]. The straw yield of rice ranged from 14.42 g $pot^{-1}$ in BRRI dhan34 to 45.43 g $pot^{-1}$ in Najirshail (Table 1). The interaction effect of different rates of As and cultivars of rice was significant in producing the straw yield (Table 3). The application of 10 ppm As decreased the straw of all rice varieties but the degree of decrease in straw yield was quite variable. The application of 20 ppm As significantly decreased the yield and some of the varieties failed to produce straw yield viz. BRRI dhan33, BRRI dhan34, BRRI dhan41 and Binadhan-4. Considerable reduction in straw biomass in the higher As treatment recorded in this experiment primarily as a result of lower tillers $pot^{-1}$ and stunted rice plant. The same type of declining As uptake pattern for straw is found for one variety of rice grown in a glasshouse [19]. Exposure to As, causing a reduction in shoot biomass and/ or growth, was also reported by many research findings [20-21].

### 3.5 Grain arsenic

Arsenic concentration is an important consideration for the selection of As tolerant rice genotypes. Arsenic concentration in grains of rice cultivars was significantly increased due to application of different levels of As in soil (Table 1). The rate of increase was significant in all of the cultivars. Arsenic concentration in grain of control pot (0 ppm As) was 0.10 ppm and that in pot receiving 10 and 20 ppm As was 0.45 and 0.64 ppm, respectively. The As concentrations in different cultivars ranged from 0.13 ppm in BRRI dhan41 to 0.49 ppm in BRRI dhan40. There was a significant interaction effect of different rates of As and cultivars of rice on As concentration of rice grains (Table 3). The application of 10 and 20 ppm As increased the grain As concentration of rice. All the varieties selected for the experiment showed higher As concentration in the pots receiving 10 and 20 ppm As in soil compared to As control pot. Among the treatment combinations $As_{20}$ × BRRI dhan40 had the highest As concentration (0.743 ppm) in grain and followed by $As_{20}$ × BRRI dhan39 and $As_{20}$ × BRRI dhan31. The lowest As concentration (0.063 ppm) was found in $As_0$ × BR 11 treatment combination. Cultivation of rice in soils with elevated concentration has been reported a number of authors [22-23]. The As concentrations in rice grain vary widely depending on the cultivars, As status of soil and irrigation water [8, 16]. The grain As concentration increased from values of 0.22–0.32 μg $g^{-1}$ with the As0 treatment to 0.59–0.81 μg $g^{-1}$ with the $As_{20}$ treatment, but varied inconsistently between the varieties.

**Table 3. Interaction effects of added As and cultivars on grain yield, straw yield and grain As concentration of different rice cultivars**

| Cultivars | Grain yield pot$^{-1}$ (g) | | | Straw yield pot$^{-1}$ (g) | | | Grain As (ppm) | | |
|---|---|---|---|---|---|---|---|---|---|
| | As0 | As10 | As20 | As0 | As10 | As20 | As0 | As10 | As20 |
| BR 11 | 75.66a | 25.05f-h | 0.00k | 83.57a | 32.79gh | 2.87m-o | 0.063e | 0.559ab | - |
| BRRI dhan30 | 39.40de | 13.35g-k | 0.00k | 66.62b-e | 25.99hi | 1.57no | 0.095e | 0.417a-d | - |
| BRRI dhan31 | 59.14bc | 10.60g-k | 4.95i-k | 66.64b-e | 14.06i-o | 6.57k-o | 0.105de | 0.458a-c | 0.625ab |
| BRRI dhan32 | 17.25ab | 17.26g-k | 1.48i-k | 80.08a-c | 19.50h-m | 3.58m-o | 0.133d-e | 0.333b-e | 0.550ab |
| BRRI dhan33 | 55.21bc | 2.61i-k | 0.00k | 63.97c-e | 6.31k-o | 0.00o | 0.097e | 0.525a-c | - |
| BRRI dhan34 | 17.54g-i | 7.29i-k | 0.00k | 27.52g-i | 15.75i-o | 0.00o | 0.108de | 0.333b-e | - |
| BRRI dhan39 | 26.19fg | 9.40h-k | 1.39i-k | 32.76gh | 13.49i-o | 3.81l-o | 0.108de | 0.642ab | 0.683ab |
| BRRI dhan40 | 47.06de | 10.01g-k | 2.98i-k | 61.54de | 21.30h-k | 3.59m-o | 0.104de | 0.625ab | 0.743a |
| BRRI dhan41 | 8.73h-k | 0.00k | 0.00k | 42.40fg | 7.53j-o | 0.00o | 0.128de | - | - |
| Binadhan-4 | 56.90bc | 14.90g-k | 0.00k | 63.52de | 18.12h-n | 0.00o | 0.116de | 0.583ab | - |
| Najirshail | 52.78cd | 26.49fg | 18.39g-i | 81.46ab | 34.18gh | 20.65h-l | 0.082e | 0.333b-e | 0.620ab |
| Biroi | 49.24c-e | 6.42i-k | 0.00k | 68.29a-e | 23.78h-j | 3.68m-o | 0.075e | 0.375a-e | - |
| Kalizeera | 52.06cd | 6.63i-k | 0.00k | 64.94c-e | 21.31h-k | 0.00o | 0.071e | 0.231c-e | - |
| Pajam | 34.58ef | 8.18i-k | 0.43jk | 72.25a-d | 18.46h-n | 6.93k-o | 0.078e | 0.450a-c | 0.600ab |
| **S.E. (±)** | **2.845** | | | **2.864** | | | **0.053** | | |

In a column figures having same letters do not differ significantly at 5% level by DMRT

## 4. CONCLUSION

From this experiment, it was found that high level of As contamination to soil significantly affected the yield contributing characters viz. number of effective tillers number of filled grains of rice cultivars. The grain and straw yields of these rice cultivars were also markedly reduced by the artificial introduction of As into soil. A high As uptake in rice grain and rice straw was observed in this experiment. Rice cultivation in the naturally As-contaminated soil of Bangladesh may also reduce the yield of rice grain and straw. Among the fourteen rice cultivars, BRRI dhan32, BR 11 and Najirshail appeared to be tolerant to As contamination. Therefore, at high levels of As contamination, the varieties viz. BRRI dhan32, BR 11 and Najirshail may be considered for cultivation. However, further studies with varying levels of As contamination with different varieties in the field are needed to reach a final conclusion. Therefore, choosing less As-responsive rice genotypes to grow in As affected soil could effectively minimize As bioaccumulation in rice grains, leading to a reduction in health risks caused by As exposure.



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