EFFECT OF ARSENIC ON GROWTH AND YIELD OF RICE

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TO

MY BELOVED PARENTS

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CERTIFICATE

This is to certify that the thesis entitled **"Effect of Arsenic on Growth and Yield of Rice"** submitted to the Faculty of Agriculture, Sher-e-Bangla Agricultural University, Dhaka, in partial fulfilment of the requirements for the degree of **Master of Science** in **Agronomy**, embodies the result of a piece of bonafide research work carried out by **Md. Mizanur Rahman**, Registration number: **03-01034** under my supervision and guidance. No part of the thesis has been submitted for any other degree or diploma.

I further certify that any help or source of information, received during the course of this investigation has duly been acknowledged.

Dated:
Dhaka, Bangladesh

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ABSTRACT

The pot experiment was conducted at the Sher-e-Bangla Agricultural University, Dhaka, Bangladesh during the period from December 2010 to May 2011 to study the effect of arsenic on growth and yield of rice. The experiment comprised of two factors. Factor A: Arsenic level (4 levels): As_0: Control (No arsenic); As_1: 20 ppm As kg soil^{-1}, As_2: 40 ppm As kg soil^{-1} and As_3: 60 ppm As kg soil^{-1}. Factor B: Rice variety: (4 Nos.); V_1: BRRI dhan28; V_2: BRRI dhan29; V_3: BRRI hybrid dhan-1 and V_4: Chamak. The experiment was laid out in Randomized Complete Block Design (RCBD) with three replications. In case of arsenic, at 30, 50, 70, 90 DAT and harvest the longest plant (17.59 cm, 32.53 cm, 56.64 cm, 77.04 and 84.09 cm), maximum length of panicle (23.10 cm), highest number of filled grains panicle^{-1} (92.52), highest grain yield (3.91 t ha^{-1}) and highest straw yield (7.52 t ha^{-1}) was recorded in As_0, whereas the shortest plant (16.44 cm, 28.88 cm, 53.40 cm, 72.53 cm and 80.85 cm), minimum length of panicle (22.05), lowest number of filled grains panicle^{-1} (79.35), lowest grain yield (3.39 t ha^{-1}) and lowest straw yield (7.16 t ha^{-1}) was recorded in As_3. In case of variety, at 30, 50, 70, 90 DAT and at harvest, the tallest plant (18.61 cm, 34.68 cm, 58.59 cm, 81.69 cm and 92.40 cm) was observed in V_4, again the shortest plant (15.01 cm, 24.74 cm, 47.47 cm, 60.05 cm and 63.10 cm) from V_1. The maximum length of panicle (23.80 cm) was recorded in V_3, whereas the minimum length (21.01 cm) from V_1. The highest number of filled grains panicle^{-1} (88.46) was observed in V_4, whereas the lowest number (79.83) from V_1. The highest grain yield (4.91 t ha^{-1}) was found in V_3 and the lowest grain yield (2.66 t ha^{-1}) from V_1. The highest straw yield (8.08 t ha^{-1}) was observed in V_4, whereas the lowest straw yield (6.66 t ha^{-1}) from V_1. In case of the interaction effect of arsenic and variety, at 30, 50, 70, 90 DAT and at harvest the tallest plant (20.34 cm, 39.96 cm, 64.15 cm, 89.03 cm and 99.43 cm, respectively) was observed from As_0V_4, while the shortest (13.46 cm, 20.38 cm, 42.91 cm, 53.78 cm and 54.43 cm, respectively) from As_3V_1. The maximum length of panicle (24.28 cm) was attained from As_0V_3 and the minimum length (20.82 cm) from As_3V_1. The highest number of filled grains panicle^{-1} (95.63) was observed from As_0V_2 and the lowest number (71.90) from As_3V_1. The highest grain yield (5.30 t ha^{-1}) was attained from As_0V_3, while the lowest grain yield (2.20 t ha^{-1}) from As_3V_1. The highest straw yield (8.23 t ha^{-1}) was recorded from As_0V_4, whereas the lowest straw yield (6.40 t ha^{-1}) from As_3V_1.

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CHAPTER I

INTRODUCTION

Rice is the most important food around the world and the staple food approximately more than two billion people in Asia (Hien *et al.,* 2006). The geographical, climatic and edaphic conditions are favorable for year round rice cultivation for Bangladesh but the national average rice yield (2.34 t ha^{-1}) is very low compared to that of other rice growing countries. For instance, the average rice yield in China is about 6.30 t ha^{-1}, Japan is 6.60 t ha^{-1} and Korea is 6.30 t ha^{-1} (FAO, 2002).

The population of Bangladesh is increasing at an alarming rate and the cultivable land is reducing due to urbanization and industrialization resulting in more shortage of food. Horizontal expansion of rice area, rice yield $unit^{-1}$ area should be increased to meet this ever-increasing demand of food in the country. Management practices also can help for horizontal expansion of rice area and yield $unit^{-1}$ area. There should be need to develop appropriate management technique. Arsenic (As) is a widespread natural element and it is not a bio-organic element to plants and animals. The increased soil content of arsenic is a result of the technologic contamination and it is transport in the environment have become a matter of great concern in Bangladesh and several other countries. The maximum acceptable concentration of arsenic in agricultural soil is 20 mg kg^{-1} (Abedin and Meharg, 2002).

Arsenic (As) is not essential for plant growth because of chemical similarities to P, As is able to replace P in many cell reactions and it shows many harmful toxicities to plants including wilting of new-cycle leaves and retardation of root and top growth. All the growth and yield parameters of Boro rice responded positively at lower concentrations of up to 0.25 mg As L^{-1} in irrigation water but decreased sharply at concentrations more than 0.5 mg As L^{-1}. At higher concentration of As interferes with metabolic processes and inhibit plant growth and development through arsenic induced phytotoxicity (Marin *et al*., 1992). When plants are exposed to excess arsenic either in soil or in solution culture, they exhibits toxicity symptoms such as: inhibition of seed germination (Abedin and Meharg, 2002); decrease in plant height (Jahan *et al*., 2003); depress in tillering (Kang *et al.*, 1996); reduction in root growth (Abedin and Meharg, 2002); decrease in shoot growth; lower grain yield (Kang *et al*., 1996); and sometimes, leads to death (Marin *et al*., 1992). However, little is known about the effect of arsenic on the effect of different rice variety. Under these circumstances, the proposed study will be undertaken to examine the effect of As on sustainable rice production in Bangladesh.

In Bangladesh, rice dominates over all other crops and covers 75% of the total cropped area of which around 79% is occupied by high yielding rice varieties (BBS, 2008). Improvement of rice grain yield is the main target of breeding program to develop rice varieties for diverse ecosystems. However, grain yield is a complex trait, controlled by many genes and highly affected by environment (Jennings *et al*., 1979). In addition, grain yield also related with other characters such as plant type, growth duration, and yield components (Yoshida, 1981). Consumer demand for the fine rice varieties is high due to its good nutritional quality, palatability and due to special flavor and taste. Very recently various new rice varieties were developed and available as BRRI dhan and maximum of them is exceptionally high yielding. On the other hand compared with conventional cultivars, the hybrids had larger panicles, heavier seeds, resulting in an average yield increase of 7.27%. This variety however, needs further test under different adaptive condition to interact with different environmental conditions and hazards materials. Considering these matters this research work was under taken with the following objectives:

a. To observe the effects of different levels of arsenic on growth and yield of rice,
b. To study the performance of different rice varieties regarding yield and yield contributing characters, and
c. To find the interaction effects of different levels of arsenic and rice varieties on growth and yield perspective.

CHAPTER II

REVIEW OF LITERATURE

Yield and yield contributing characters of rice are considerably depended on manipulation of basic ingredients of agriculture. The basic ingredients include variety, environment, agronomic practices and hazards factors. Among the above factors As is now a considerable matter for rice growing in context of production and also health hazards. Varieties in respect of local, MV and hybrid are generally more adaptive to appropriate and they greatly affect the return of rice cultivation. But the available relevant reviews related to As and variety in respect of their performance is very limited in the context of Bangladesh as well as the World. Some of the recent past information on As and variety performance on rice have been reviewed under the following headings:

2.1 Performance of As on rice

Field experiments were conducted by Talukder *et al*. (2011) to examine the effects of water management (WM) and Phosphorus (P) rates on As uptake, rice growth, yield and yield attributes of winter (boro) and monsoon (aman) rice in an As contaminated soil-water at Gobindagonj, Gaibandha, Bangladesh in 2004 and 2005. Significantly, the highest average grain yields (6.88+or-0.07 t ha^{-1} in boro 6.38+or-0.06 t ha^{-1} in aman) were recorded in permanent raised bed (PRB; aerobic WM: Eh=+360 mV) plus 100% P amendment. There was a 12% yield increase over conventional till on flat (CTF; anaerobic WM: Eh=-56 mV) at the same P level. In boro, the As content in grain and As content in straw were about 3 and 6 times higher in CTF compared to PRB, respectively. The highest total As content (0.646+or-0.01 ppm in grain and 10.93+or-0.19 ppm in straw) was recorded under CTF, and the lowest total As content (0.247+or-0.01 and 1.554+or-0.09 ppm in grain and straw, respectively) was recorded under PRB (aerobic WM). The results suggest that grain and straw As are closely associated in boro rice. The furrow irrigation approach of the PRB treatments consistently reduced irrigation input by 29-31% for boro and 27-30% for aman rice relative to CTF treatments in 2004 and 2005, respectively, thus reducing the amount of As added to the soil from the As-contaminated irrigation water.

Khan *et al*. (2010a) reported that shallow tube well (STW) water, often contaminated with arsenic (As), is used extensively in Bangladesh for irrigating rice fields in the dry season, leading to potential As accumulation in soils. In the current study the consequences of arsenic from irrigation water and direct surface (0-15 cm) soil application were studied under field conditions with wetland rice culture over 2 years. Treatments included irrigation-water As concentrations of 0, 1 and 2 mg L^{-1} (Boro season only) and soil-As concentrations of 10 and 20 mg kg^{-1}. These results indicate the relatively low mobility of applied As and the likely continued detrimental accumulation of As within the rooting zone. Arsenic addition in either irrigation water or as soil-applied As resulted in yield reductions from 21 to 74% in Boro rice and 8 to 80% in T. Aman rice, the latter indicating the strong residual effect of As on subsequent crops. The As concentrations in rice grain (0.22 to 0.81 micro g g^{-1}), straw (2.64 to 12.52 micro g g^{-1}) and husk (1.20 to 2.48 micro g g^{-1}) increased with increasing addition of As. A critical need exists for the development of crop and water management strategies to minimize potential As hazard in wetland rice production.

A study was conducted by Bhattacharya *et al*. (2010) with aims at assessing the level of arsenic in irrigation water and soil and to investigate the seasonal bioaccumulation of arsenic in the various parts (straw, husk and grain) of the rice plant of different varieties in the arsenic affected two blocks (Chakdaha and Ranaghat-I) of Nadia district, West Bengal. It was found that the arsenic uptake in rice during the pre-monsoon season is more than that of the post-monsoon season. The accumulation of arsenic found to vary with different rice varieties; the maximum accumulation was in White minikit (0.31+or-0.005 mg/kg) and IR 50 (0.29+or-0.001 mg/kg) rice varieties and minimum was found to be in the Jaya rice variety (0.14+or-0.002 mg/kg). In rice plant maximum arsenic accumulation occurred in the straw part (0.89+or-0.019-1.65+or-0.021 mg/kg) compared to the accumulation in husk (0.31+or-0.011-0.85+or-0.016 mg/kg) and grain (0.14+or-0.002-0.31+or-0.005 mg/kg) parts. For any rice sample concentration of arsenic in the grain did not exceed the WHO recommended permissible limit in rice (1.0 mg/kg).

Arsenic (As) is now regarded as one of the most serious contaminants as a typical noxious element-especially inorganic arsenic reported by Wang *et al*. (2010). Indeed, arsenic has a chronic poisoning effect in human body. Recent studies have shown that rice is much more efficient in assimilating arsenic into its straw and grains than other staple cereal crops, and consumption of rice constitutes a large proportion of dietary intake of arsenic. Therefore, scientists pay a high degree of attention to arsenic in rice. In rice total As content varies from 0.005 to 0.710 mg/kg. Arsenic speciation in rice grain is dominated by inorganic As (III+V) and dimethylarsinic (DMA). The inorganic As content in rice varies from 10% to 90% of total As.

The study was conducted by Dittmar *et al*. (2010) investigated the As contents of rice straw and grain over three consecutive harvest seasons (2005-2007) in a paddy field in Munshiganj, Bangladesh, which exhibits a documented gradient in soil As caused by annual irrigation with As-rich groundwater since the early 1990s. The field data revealed that straw and grain As concentrations were elevated in the field and highest near the irrigation water inlet, where As concentrations in both soil and irrigation water were highest. On the basis of a recently published scenario of long-term As accumulation at the study site, it was estimated that, under unchanged irrigation practice, average grain As concentrations increase from currently ~0.15 mg As kg^{-1} to 0.25-0.58 mg As kg^{-1} by the year 2050. This translates to a 1.5-3.8 times higher As intake by the local population via rice, possibly exceeding the provisional tolerable As intake value defined by FAO/WHO.

Khan *et al*. (2010b) reported that some paddy soils in the Bengal delta are contaminated with arsenic (As) due to irrigation of As-laden groundwater, which may lead to yield losses and elevated As transfer to the food chain. Whether these soils have a higher As bioavailability than other soils containing either geogenic

As or contaminated by mining activities was investigated in a pot experiment. Fourteen soils varying in the source and the degree (4-138 mg As kg^{-1}) of As contamination were collected, 10 from Bangladeshi paddy fields (contaminated by irrigation water) and two each from China and the UK (geogenic or mining impacted), for comparison. Bangladeshi soils had higher percentages of the total As extractable by ammonium phosphate (specifically sorbed As) than other soils and also released more As into the porewater upon flooding. Porewater As concentrations increased with increasing soil As concentrations more steeply in Bangladeshi soils, with arsenite being the dominant As species. Rice growth and grain yield decreased markedly in Bangladeshi soils containing >13 mg As kg^{-1}, but not in the other soils.

A solution culture experiment was conducted by Guo *et al.* (2005) to investigate the effect of silicate on the yield and arsenate uptake by rice. Rice seedlings (*Oryza sativa* L. cv. Weiyou 77) were cultured in modified Hoagland nutrient solution containing three arsenate levels (0, 0.5 and 1.0 mg L^{-1} As) and four silicate levels (0, 14, 28 and 56 mg L^{-1} Si). Addition of Si significantly increased shoot dry weight (P=0.001) but had little effect on root dry weight (P=0.43). Addition of As had no significant effect on shoot dry weight (P=0.43) but significantly increased root dry weight (P=0.01). Silicon concentrations in shoots and roots increased proportionally to increasing amounts of externally supplied Si (P<0.001). The presence of As in the nutrient solution had little effect on shoot Si concentration (P=0.16) but significantly decreased root Si concentration

(P=0.005). Increasing external Si concentration significantly decreased shoot and root As concentrations and total As uptake by rice seedlings ($P<0.001$).

Delowar *et al*. (2005) reported that to ensure food security, the Bangladesh government has supported the cultivation of a number of high yielding rice varieties which require a large volume of irrigation water. The use of groundwater for irrigation has increased abruptly over the last couple of decades. About 80% of pumped groundwater is utilized in the agricultural sector, but the groundwater in many areas of Bangladesh is severely contaminated with arsenic. So, there is a possibility of arsenic accumulation in rice and rice plants from arsenic-contaminated irrigation water. This study aims at assessing the extent of accumulation of arsenic in rice plants and its effects on growth and yield of rice. Arsenic concentrations in paddy soils (irrigated with 0, 2.5, 5, 10, 15 and 20 mgL^{-1} of arsenic water) were 0-0.2, 0-0.95 and 0-0.27 mg kg^{-1} at tillering, heading and ripening stages. Rice grains accumulated arsenic from soil/water and arsenic accumulation varied greatly in the two rice varieties studied. Arsenic concentrations in rice grains were 0-0.07 and 0-0.14 mg kg-1 dry weight in rice varieties BRRI dhan28 and Iratom 24, respectively. The growth and yield of rice plants were reduced significantly with increased doses of arsenic but the grain weight was not affected. Among the different yield components, the number of tillers per pot, number of effective tillers per pot and grain yield per pot reduced greatly with the higher dose (20 mgL^{-1}) of arsenic applied. Yield reduction of more than 60 and 40% for Iratom-24 and BRRI dhan28, was found with 20 mg L^{-1} of arsenic as compared to control. The reduction in straw yield was also significantly higher for both of rice varieties with the 20 mg L^{-1} arsenic application.

A pot culture experiment was carried out at Bangladesh Agricultural University (BAU), Mymensingh by Islam *et al*. (2004) to see the effects irrigation water arsenic (As) on Boro rice (February to June) and the residual effect on T. Aman rice (August-November). There were eight treatments consisting of Control, 0.10, 0.25, 0.50, 0.75, 1.00, 1.50 and 2.00 ppm As added through irrigation water. A total of 56 L of irrigation water having different concentrations of As was needed for the Boro rice (cv. BRRI dhan 29). After harvest of Boro rice, T. Aman rice (cv. BRRI dhan 33) was grown in the same pots with monsoon rain. Nutrients such as N, P, K and S @ 100, 25, 40 and 25 ppm, respectively were added to sustain normal growth of both Boro and T. Aman rice. The irrigation water added As up to 0.25 ppm enhanced the plant height, panicle length, filled grains/panicle, 1000-grain weight and finally the grain yield of Boro rice and the further doses of depressed the plant growth, yield and yield components. The concentration of As in rice grain or straw of Boro rice increased significantly with increasing As concentrations in the irrigation water, the values for grain As for every As treatment were below the Maximum permissible level (1.0 ppm).

A pot experiment was conducted on rice cv. IET-4094 by Ghoshal *et al*. (2003) to study the effect of irrigation water, contaminated with arsenic, on the uptake of phosphorus and arsenic by the different parts of the crop. The treatments comprised irrigation with arsenic-free deionized water and arsenic-contaminated irrigation water containing 0.29 ppm arsenic. Each treatment was divided into two series, namely, uncovered and covered (glazed black polythene sheet). Arsenic accumulation and concentration significantly increased in the straw and roots of the plants grown on soil irrigated with arsenic-contaminated water. Similar results were obtained with covered treatments. Arsenic concentration and accumulation was greater in the root than the straw. Phosphorus uptake was reduced with the increase in soil arsenic concentration and covering further reduced the same, indicating a significant arsenic-phosphorus interaction.

Elevated soil arsenic levels resulting from long-term use of arsenic contaminated ground for irrigation in Bangladesh may inhibit seed germination and seedling establishment of rice, the country's main food crop was reported by Abedin and Meharg (2002). A germination study on rice seeds and a short-term toxicity experiment with different concentrations of arsenite and arsenate on rice seedlings were conducted. Percent germination over control decreased significantly with increasing concentrations of arsenite and arsenate. Arsenite was found to be more toxic than arsenate for rice seed germination. There were varietal differences among the test varieties in response to arsenite and arsenate exposure. The performance of the dry season cultivar Purbachi was the best among the cultivars. Germination of Purbachi was not inhibited at up to 4 mg l^{-1} arsenite and 8 mg l^{-1} arsenate treatment. Root tolerance index (RTI) and relative shoot height (RSH) for rice seedlings decreased with increasing concentrations of arsenite and arsenate. Reduction of RTI caused by arsenate was higher than that of arsenite. In general, dry season varieties have more tolerance to arsenite or arsenate than the wet season varieties.

Field and greenhouse experiments were simultaneously carried out by Montenegro and Mejia (2001) in rice (*Oryza sativa* cv. Oryzica) planted in soils of the Bogota river (Colombia) lower basin, to evaluate the effect of the Cd and As content in irrigation waters on soils, and on: (1) the physiological parameters of rice growth; (2) the amount of Cd and As accumulated in the different parts of rice plants; and (3) the yield and other aspects and properties of rice crop. The results of the experiment led to the following conclusions: (1) rice reached its maximum height when neither element was present in the irrigation waters; (2) the gradual increase of Cd in the irrigation waters decreased by 12.5% the number of grains per panicle, while an increase in As content induced a 10% reduction in the same parameter; (3) when irrigation waters used contained the highest concentration of Cd and As, yields were significantly reduced; maximum yield were obtained when Cd and As were absent from the irrigation waters; (4) at any concentration of As in irrigation waters, the highest concentration of Cd accumulated in the rice leaves when the concentration of Cd in irrigation water was 2 mg/litre; above this value, Cd accumulation in leaves decreased with the gradual increase of As concentration; (5) accumulation of Cd and As in rice grains increased with the gradual increment in concentration of both elements in the irrigation waters; amounts of Cd and As accumulated in the rice grains were 50 and 150 times, respectively, higher than the maximum critical levels.

In pot experiments rice was grown by Kang *et al*. (1996) on loam paddy soil with available arsenic contents of 1.3, 6.0, 7.8 or 10.3 mg/kg and total arsenic contents of 1.3, 27.7, 36.6 and 56.0 mg/kg, respectively. Increasing the level of arsenic decreased plant height, number of effective tillers, dry weight of aboveground parts and 1000-grain weight. Yields decreased from 48.7 g/pot with the lowest rate of arsenic to 17.9 g with the highest rate. Content of arsenic was higher in roots than in stems plus leaves or in grain, but in all parts the content increased as soil arsenic increased. The contents of arsenic in stems plus leaves were more closely related to soil total and available arsenic than those of roots or grain..

Pot and field experiments were conducted by Chen and Liu (1993) to investigate the effect of pH in the movement of arsenic (As) in the plant-soil system. Increasing the soil pH decreased As adsorption and thereby increased the As concn in the soil solution. Therefore as the soil pH rose As availability to rice increased and toxicity problems became more serious. They also reported that from a pot experiments, low levels of arsenite (As^{3+}) added to the soil increased growth due to inhibition of photorespiration unnecesary for growth, which led to less depletion of photosynthates. High levels of arsenite caused phytotoxicity due to inhibition of necessary respiration.

2.2 Performance of rice cultivars

Amin *et al.* (2006) conducted a field experiment to find out the influence of variable doses of N fertilizer on growth, tillering and yield of three traditional rice varieties (*viz.* Jharapajam, Lalmota, Bansful Chikon) was compared with that of a modern variety (*viz.* KK-4) and reported that traditional varieties accumulated higher amount of vegetative dry matter than the modern variety.

Wang *et al.* (2006) studied the effects of plant density and row spacing (equal row spacing and one seedling $hill^{-1}$, equal row spacing and 3 seedlings $hill^{-1}$, wide-narrow row spacing and one seedling $hill^{-1}$, and wide-narrow row spacing and 3 seedlings $hill^{-1}$) on the yield and yield components of hybrids and conventional cultivars of rice. Compared with conventional cultivars, the hybrids had larger panicles, heavier seeds, resulting in an average yield increase of 7.27%.

Xu and Wang (2001) evaluated ten restorer and ten maintainer lines. They observed that the restorer lines showed more spikelet fertility than maintainer lines. They studied growth duration, number of effective tillers, number of spikelets per panicle and adaptability.

Patel (2000) studied that the varietal performance of Kranti and IR36. He observed that Kranti produced significantly higher grain and straw yield than IR36. The mean yield increased with Kranti over IR36 was 7.1 and 10.0% for grain and straw, respectively. Molla (2001) reported that Pro-Agro6201 (hybrid) had a significant higher yield than IET4786 (HYV), due to more mature panicles m^{-2}, higher number of filled grains $panicle^{-1}$ and greater seed weight.

Chen-Liang *et al*. (2000) showed that the cross between Peiai 64s and the new plant type lines had strong heterosis for filled grains per plant, number of spikes per plant and grain weight per plant, but heterosis for spike fertility was low.

Improving rice (*Oryza sativa* L.) grain yield per unit land area is the only way to achieve increased rice production because of the reduction in area devoted to rice production (Cassman, 1999).

Julfiquar *et al*. (1998) reported that BRRI evaluated 23 hybrids along with three standard checks during *boro* season 1994-95 as preliminary yield trial at Gazipur and it was reported that five hybrids (IR58025A/IR54056, IR54883, PMS8A/IR46R) out yielded the check varieties (BR14 and BR16) with significant yield difference. They also reported that thirteen rice hybrids were evaluated in three locations of BADC farm during the boro season of 1995-96. Two hybrids out yielded the check variety of same duration by more than 1 t ha^{-1}. Rajendra *et al.* (1998) carried out an experiment with hybrid rice cv. Pusa 834 and Pusa HR3 and observed that mean grain yields of Pusa 834 and Pusa HR3 were 3.3 t ha^{-1} and 5.6 t ha^{-1}, respectively.

Mishra and Pandey (1998) evaluated standard heterosis for seed yield in the range of 44.7 to 230.9% and 42.4 to 81.4%, respectively. Plant height, panicle per plant, grain per panicle and 1000 grain weight increase the yield in modern varieties. Xu and Li (1998) observed that the maintainer lines were generally shorter than restorer line.

Son *et al.* (1998) reported that dry matter production of four inbred lines of rice (low-tillering large panicle type), YR15965ACP33, YR17104ACP5, YR16510-B-B-B-9, and YR16512-B-B-B-10, and cv. Namcheonbyeo and Daesanbyeo, were evaluated at plant densities of 10 to 300 plants m^{-2} and reported that dry matter production of low-tillering large panicle type rice was lower than that of Namcheonbyeo regardless of plant density.

Devaraju *et al.* (1998) in a study with two rice hybrids such as Karnataka Rice Hybrid 1 (KRH1) and Karnataka Rice Hybrid-2(KRI42) using HYV IR20 as the check variety and found that KRH2 out yielded than IR20. In IR20, the tiller number was higher than that of KRH2.

Ahmed *et al.* (1997) conducted an experiment to compare the grain yield and yield components of seven modern rice varieties (BR4, BR5, BR10, BR11, BR22, BR23, and BR25) and a local improved variety, Nizersail and respectively for all the varieties and found that percent filled grain was the highest in Nizersail followed by BR25 and the lowest in BR11 and BR23.

Islam (1995) in an experiment with four rice cultivars *viz.* BR10, BR11, BR22 and BR23 found that the highest number of non bearing tillers $hill^{-1}$ was produced by cultivar BR11 and the lowest number was produced by the cultivar BR10.

BRRI (1994) studied the performance of BR14, BR5, Pajam, and Tulsimala and reported that Tulsimala produced the highest number of filled grains $panicle^{-1}$ and BR14 produced the lowest number of filled grains $penicle^{-1}$.

Rice tillering is a major determinant for panicle production (Miller *et al*., 1991) and as a consequence affects total yield. The high tillering capacity is considered as a desirable trait in rice production, since number of tillers per plant is closely related to number of panicles per plant. To some extent, yield potential of a rice variety may be characterized by tillering capacity. On the other hand, it was reported that the plants with more tillers showed a greater inconsistency in mobilizing assimilates and nutrients among tillers. Moreover, grain quality could be also affected by tillering ability due to different grain development characteristics. It has been well documented that either excessive or insufficient tillering is unfavorable for high yield. Hossain and Alam (1991) also found that the growth characters like total tillers $hill^{-1}$ differed significantly among BR3, BR11, Pajam and Jaguli varieties in *boro* season.

Miah *et al.* (1990) conducted an experiment where rice cv. Nizersail and mutant lines Mut. NSI and Mut. NSS were planted and found that plant height were greater in Mut. NSI than Nizersail.

Patnaik *et al*. (1990) found that hybrids with intermediate to tall plant height having non-lodging habit could be developed gave more than 20% grain yield than the standard checks. They also reported that in hybrids, yield was primarily influenced by effective tillers per plant and fertile grains per panicle, whereas in parents it was panicle length, maturity and effective tillers per plant. Number of effective tillers per plant and fertile grains per panicle remained constant and common in explaining heterosis for yield of most of the hybrids. The heterosis for grain yield was mainly due to the significant heterosis for the number of spikelets/panicle, test weight and total dry matter accumulation.

Saha *et al*. (1989) studied the characteristics of CMS lines V20A, 279A, V41A and P203A with their corresponding maintainer (B) lines and two restorer (R) lines IR50 and IR54 and in maintainer lines tiller number were recorded highest.

Ghosh and Hossain (1988) reported that effective tillers/plant, number of grains/panicle and grain weight as the major contributory characters for grain yield it had positive correlations with number of productive tillers/plant.

Shamsuddin *et al*. (1988) conducted a field trial with nine different rice varieties and observed that plant height differed significantly among varieties. Sawant *et al.* (1986) conducted an experiment with the new rice lines R-73-1-1, R-711 and the traditional cv. Ratna and reported that the traditional cv. Ratna was the shortest.

Dwarfness may be one of the most important agronomic characters, because it is often accompanied by lodging resistance and thereby adapts well to heavy fertilizer application (Futsuhara and Kikuchi, 1984).

In addition, grain yield also related with other characters such as plant type, growth duration, and yield components (Yoshida, 1981). Rice yield is a product of number of panicles per unit area, number of spikelets per panicle, percentage of filled grains and weight of 1000 grains (Yoshida, 1981; De Datta, 1981).

CHAPTER III

MATERIALS AND METHODS

The pot experiment was conducted at the Sher-e-Bangla Agricultural University, Dhaka, Bangladesh during the period from December 2010 to May 2011 to study the effect of arsenic on growth, yield and quality of rice. The details of the materials and methods have been presented below:

3.1 Description of the experimental site

3.1.1 Location

The present piece of research work in pot was conducted in the experimental area of Sher-e-Bangla Agricultural University, Sher-e-Bangla Nagar, Dhaka. The location of the site is $23^{0}74^{/}$N latitude and $90^{0}35^{/}$E longitude with an elevation of 8.2 meter from sea level.

3.1.2 Soil

The soil of the experimental area that used in the pot for rice cultivation belongs to "The Modhupur Tract", AEZ – 28 (FAO, 1988). Top soil was silty clay in texture, olive-gray with common fine to medium distinct dark yellowish brown mottles. Soil pH was 5.6 and has organic carbon 0.45%. The experimental area was flat having available irrigation and drainage system. The details of the pot soil have been presented in Appendix I.

3.1.3 Climate

The geographical location of the experimental site was under the subtropical climate, characterized by three distinct seasons, winter season from November to

February and the pre-monsoon period or hot season from March to April and monsoon period from May to October (Edris *et al*., 1979). Details of the meteorological data of air temperature, relative humidity, rainfall and sunshine hour during the period of the experiment was collected from the Weather Station of Bangladesh, Sher-e Bangla Nagar, Dhaka and has been presented in Appendix II.

3.2 Experimental details

3.2.1 Treatments

The experiment comprised of two factors.

Factor A: Arsenic level (4 levels):

i. As_0: Control (No arsenic)

ii. As_1: 20 ppm As kg $soil^{-1}$

iii. As_2: 40 ppm As kg $soil^{-1}$

iv. As_3: 60 ppm As kg $soil^{-1}$

Factor B: Rice variety: (4 Nos.)

i. V_1: BRRI dhan28

ii. V_2: BRRI dhan29

iii. V_3: BRRI hybrid dhan-1

iv. V_4: Chamak

As such there were 16 treatments combinations viz. As_0V_1, As_0V_2, As_0V_3, As_0V_4, As_1V_1, As_1V_2, As_1V_3, As_1V_4, As_2V_1, As_2V_2, As_2V_3, As_2V_4, As_3V_1, As_3V_2, As_3V_3 and As_3V_4.

3.2.2 Experimental design and layout

The experiment was laid out in Randomized Complete Block Design (RCBD) with three replications. There were 48 pots for 48 treatment combination in each of 3 replications. The 16 treatment combinations of the experiment were assigned at random in 16 pots of each replication.

3.3 Growing of crops

3.3.1 Raising seedlings

3.3.1.1 Seed collection

The seeds of the test crop i.e. BRRI dhan28, BRRI dhan29, BRRI hybrid dhan-1 and Chamak were collected from Bangladesh Rice Research Institute (BRRI), Joydevpur, Gazipur and local market**.**

3.3.1.2 Seed sprouting

Healthy seeds were selected by specific gravity method and then immersed in water bucket for 24 hours and then they were kept tightly in gunny bags. The seeds started sprouting after 48 hours and were sown after 72 hours.

3.3.1.3 Preparation of seedling nursery bed and seed sowing

As per BRRI recommendation seed bed was prepared with 1 m wide seed bed adding nutrients as per the requirements of soil. Seeds were sown in the seed bed on December 20, 2010, in order to transplant the seedlings in the pot as per experimental treatment.

3.3.2 Preparation of the pot

The pot for the experiment was filled up with soil at 15 January, 2011. Weeds and stubble were removed from the soil and finally obtained a desirable tilth of soil for transplanting of seedlings.

3.3.3 Fertilizers and manure application

The fertilizers N, P, K, S, Zn and B in the form of urea, TSP, MP, gypsum, zinc sulphate and borax, respectively were applied. The entire amount of TSP, MP, gypsum, zinc sulphate and borax were applied during the final preparation of pot land. Urea was applied in two equal installments at tillering and before panicle initiation. Different concentration of As was mixed the soil as per treatment. The dose and method of application of fertilizers are shown in Table 1.

Table 1. Dose and method of application of fertilizers

Fertilizers	Dose (kg/ha)	Application (%)		
		Basal	1st installment	2nd installment
Urea	150	33.33	33.33	33.33
TSP	100	100	--	--
MP	100	100	--	--
Gypsum	60	100	--	--
Borax	10	100	--	--

Source: Anon., 2010, BRRI, Joydevpur, Gazipur

3.3.4 Uprooting of seedlings

The nursery bed was made wet by application of water one day before uprooting of the seedlings. The seedlings were uprooted on January 20, 2011 without causing much mechanical injury to the roots.

3.3.5 Transplanting of seedlings in the pots

The rice seedlings were transplanted in the pot at 21 January, 2011 and 2 healthy seedlings were transplanted in the pot in a hill.

3.3.6 After care

After establishment of seedlings, various intercultural operations were accomplished for better growth and development of the rice seedlings.

3.3.6.1 Irrigation and drainage

Sprinkler irrigation was provided to maintain a constant level of standing water upto 6 cm in the early stages to enhance tillering and 10-12 cm in the later stage to discourage late tillering. The pot was finally dried out at 15 days before harvesting.

3.3.6.2 Gap filling

First gap filling was done for all of the pots at 10 days after transplanting (DAT) by planting same aged seedlings.

3.3.6.3 Weeding

Weedings were done to keep the pots free from weeds, which ultimately ensured better growth and development. The newly emerged weeds were uprooted carefully at tillering stage and at panicle initiation stage by mechanical means.

3.3.6.4 Top dressing

After basal dose, the remaining doses of urea were top-dressed in 2 equal installments and were applied on both sides of seedlings rows in the soil.

3.3.6.5 Plant protection

Furadan 57 EC was applied at the time of final land preparation and later on other insecticides were applied as and when necessary.

3.4 Harvesting, threshing and cleaning

The rice was harvested depending upon the maturity of plant and harvesting was done manually from each pot. The harvested crop of each pot was bundled separately, properly tagged and brought to threshing floor. Enough care was taken during harvesting, threshing and also cleaning of rice seed. Fresh weight of grain and straw were recorded pot wise. The grains were cleaned and finally the weight was adjusted to a moisture content of 14%. The straw was sun dried and the yields of grain and straw pot^{-1} were recorded and converted to t ha^{-1}.

3.5 Data recording

3.5.1 Plant height

The height of plant was recorded in centimeter (cm) at the time of 30, 50, 70, 90 DAT (Days after transplanting) and at harvest. The height was measured from the ground level to the tip of the tiller.

3.5.2 Number of tillers hill^{-1}

The number of tillers hill^{-1} was recorded at the time of 30, 50, 70 and 90 DAT by counting total tillers in a hill.

3.5.3 Total tillers hill^{-1} (at harvest)

The total number of total tillers hill^{-1} was counted as the number of panicle bearing and non bearing tillers hill^{-1}. Data on total tillers hill^{-1} were counted at harvest and value was recorded.

3.5.4 Effective tillers hill^{-1}

The total number of effective tillers hill^{-1} was counted as the number of panicle bearing tillers plant^{-1}. Data on effective tiller hill^{-1} were counted and value was recorded.

3.5.5 Length of panicle

The length of panicle was measured with a meter scale from 5 selected panicles and the average value was recorded.

3.5.6 Filled grains panicle^{-1}

The total number of filled grains was collected randomly from selected 3 panicles of a pot on the basis of grain in the spikelet and then average number of filled grains panicle^{-1} was recorded.

3.5.7 Unfilled grains panicle^{-1}

The total number of unfilled grains was collected randomly from the same 3 panicles where filled grains were counted of a pot on the basis of no grain in the spikelet and then average number of unfilled grains panicle^{-1} was recorded.

3.5.8 Weight of 1000 seeds

One thousand seeds were counted randomly from the total cleaned harvested seeds of each individual pot and then weighed in grams and recorded.

3.5.9 Grain yield

Grains obtained from each unit pot were sun-dried and weighed carefully. The dry weight of grains of each pot was measured and grain yield pot^{-1} and converted to t ha^{-1}.

3.5.10 Straw yield

Straw obtained from each unit pot were sun-dried and weighed carefully. The dry weight of the straw of each pot was measured and straw yield m^{-1} and finally converted to t ha^{-1}.

3.5.11 Harvest index

Harvest index was calculated from the grain and straw yield of rice for each pot and expressed in percentage.

$$HI = \frac{\text{Economic yield (grain weight)}}{\text{Biological yield (Total dry weight)}} \times 100$$

3.6 Statistical Analysis

The data obtained for different characters were statistically analyzed using MSTAT software to observe the significant difference among the treatments. The mean values of all the characters were calculated and factorial analysis of variance was performed. The significance of the difference among the treatment means was estimated by the Least Significant Difference Test (LSD) test at 5% level of probability (Gomez and Gomez, 1984).

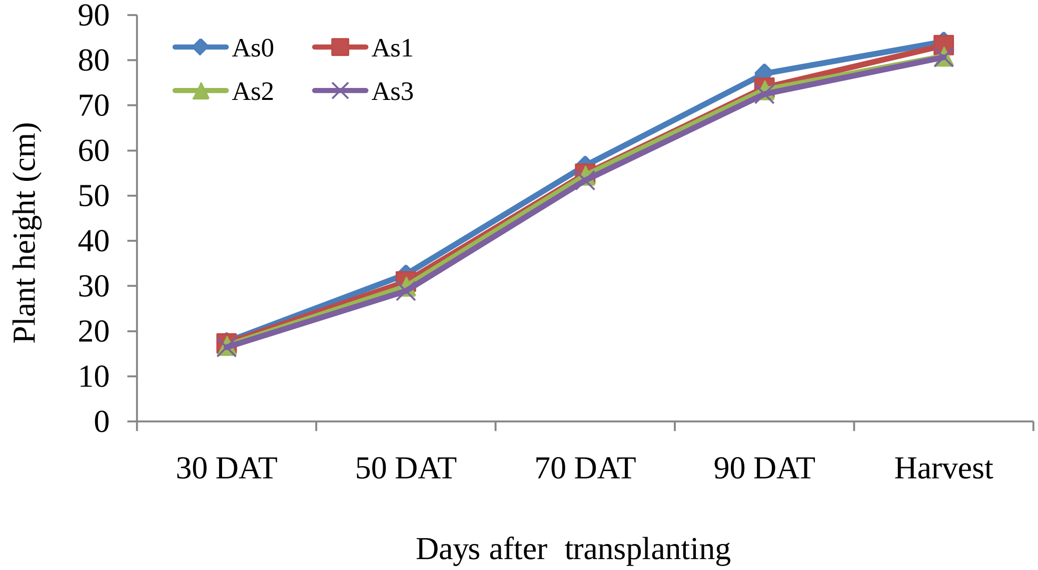
CHAPTER IV

RESULTS AND DISCUSSION

The experiment was conducted to study the effect of arsenic on growth and yield of rice. Data on different yield contributing characters and yield were recorded. The analyses of variance (ANOVA) of the data on different parameters are presented in Appendix III-VI. The results have been presented with the help of table and graphs and possible interpretations given under the following headings:

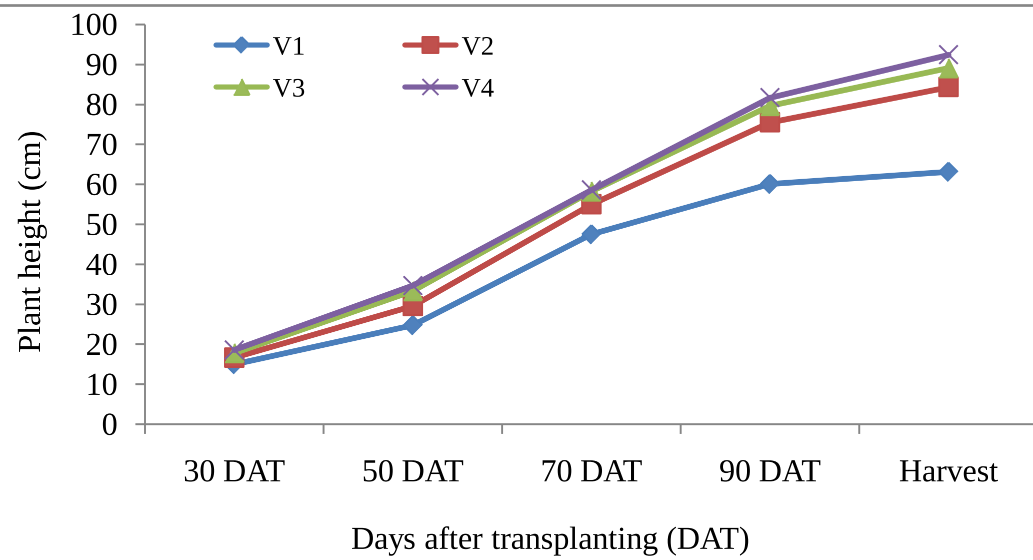
4.1 Plant height

Plant height varied non-significantly at 30, 50, 70, 90 DAT and at harvest due to the application of different levels of arsenic under the present trial (Figure 1). At 30, 50, 70, 90 DAT and harvest the longest plant (17.59 cm, 32.53 cm, 56.64 cm, 77.04 and 84.09 cm) was recorded in As_0 (0 ppm As/kg soil i.e. control condition), whereas the shortest plant (16.44 cm, 28.88 cm, 53.40 cm, 72.53 cm and 80.85 cm) in As_3 (60 ppm As/kg soil). Marin *et al*. (1992) reported that at higher concentration of As interferes with metabolic processes and inhibit plant growth and development through arsenic induced phytotoxicity. Delowar *et al*. (2005) reported that growth and yield of rice plants were reduced significantly with increased doses of arsenic. Among the different yield components plant height reduced greatly with the higher dose of arsenic applied. Islam *et al*. (2004) reported that the irrigation water added As up to 0.25 ppm enhanced the plant height and the further doses of depressed the plant growth.



As_0: Control (No arsenic)
As_1: 20 ppm As/kg soil
As_2: 40 ppm As/kg soil
As_3: 60 ppm As/kg soil

Figure 1. Effect of different level of arsenic on plant height



V_1: BRRI dhan28
V_2: BRRI dhan29
V_3: BRRI hybrid dhan-1
V_4: Chamak

Figure 2. Effect of different rice variety on plant height [LSD(0.05) = 1.039, 2.847, 3.319, 4.467 and 5.570 at

Different rice variety showed significant variation on plant height at 30, 50, 70, 90 DAT and at harvest (Figure 2). At 30, 50, 70, 90 DAT and at harvest, the tallest plant (18.61 cm, 34.68 cm, 58.59 cm, 81.69 cm and 92.40 cm) was observed in V_4 (Chamak), which was statistically similar (17.78 cm, 33.28 cm, 58.25 cm, 79.60 cm and 89.05 cm) with V_3 (BRRI hybrid dhan-1). Again the shortest plant (15.01 cm, 24.74 cm, 47.47 cm, 60.05 cm and 63.10 cm) was recorded in V_1 (BRRI dhan28) and closely followed (16.68 cm, 29.55 cm, 55.02 cm, 75.51 cm and 84.31 cm) by V_2 (BRRI dhan29) at same DAT. Xu and Li (1998) observed that the maintainer lines were generally shorter than restorer line. Miah *et al.* (1990) conducted an experiment where rice cv. Nizersail and mutant lines Mut. NSI and Mut. NSS were planted and found that plant height were greater in Mut. NSI than Nizersail. Sawant *et al.* (1986) conducted an experiment with the new rice lines R-73-1-1, R-711 and the traditional cv. Ratna and reported that the traditional cv. Ratna was the shortest.

Interaction effect of arsenic and rice variety showed significant differences on plant height at 30, 50, 70, 90 DAT and at harvest (Table 1). At 30, 50, 70, 90 DAT and at harvest the tallest plant (20.34 cm, 39.96 cm, 64.15 cm, 89.03 cm and 99.43 cm) was observed in As_0V_4 (0 ppm As/kg soil in Chamak), while the shortest (13.46 cm, 20.38 cm, 42.91 cm, 53.78 cm and 54.43 cm) in As_3V_1 (60 ppm As/kg soil in BRRI dhan28).

Table 1. Interaction effect of arsenic and variety on plant height of rice

Treatments	Plant height (cm) at				
	30 DAT	50 DAT	70 DAT	90 DAT	Harvest
As_0V_1	15.12 ef	24.81 ef	45.90 fg	58.61 fg	64.35 d
As_0V_2	17.65 b-d	32.72 b-d	58.24 a-d	80.24 a-c	89.48 ab
As_0V_3	18.90 ab	37.07 ab	61.27 ab	85.10 ab	95.01 ab
As_0V_4	20.34 a	39.96 a	64.15 a	89.03 a	99.43 a
As_1V_1	16.48 b-e	29.10 c-e	52.08 d-f	61.21 e-g	65.06 d
As_1V_2	16.83 b-e	29.64 c-e	54.81 b-e	76.96 bc	88.11 a-c
As_1V_3	17.09 b-e	30.81 b-e	55.51 b-e	78.20 bc	89.03 ab
As_1V_4	18.73 ab	34.27 a-d	56.82 a-d	79.18 a-c	90.90 ab
As_2V_1	14.98 ef	24.69 ef	48.98 e-g	66.61 d-f	70.55 d
As_2V_2	15.98 de	27.90 de	53.06 c-f	70.46 c-e	76.03 cd
As_2V_3	18.57 a-c	35.50 c-c	60.17 a-c	78.42 bc	86.58 a-c
As_2V_4	17.55 b-d	31.46 b-d	55.67 b-e	78.11 bc	89.40 ab
As_3V_1	13.46 f	20.38 f	42.91 g	53.78 g	54.43 e
As_3V_2	16.26 c-e	27.92 de	53.98 b-e	74.40 cd	83.60 bc
As_3V_3	16.55 b-e	29.74 c-e	56.04 b-e	76.66 bc	85.57 bc
As_3V_4	17.83 b-d	33.03 b-d	57.70 a-d	80.44 a-c	89.89 ab
$LSD_{(0.05)}$	2.079	5.639	6.637	8.934	11.14
CV(%)	7.32	11.17	7.26	5.22	8.13

DAT: Days after transplanting

In a column means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly as per 0.05 level of probability

As_0: Control (No Arsenic)

As_1: 20 ppm As/kg Soil

As_2: 40 ppm As/kg Soil

As_3: 60 ppm As/kg Soil

V_1: BRRI dhan28

V_2: BRRI dhan29

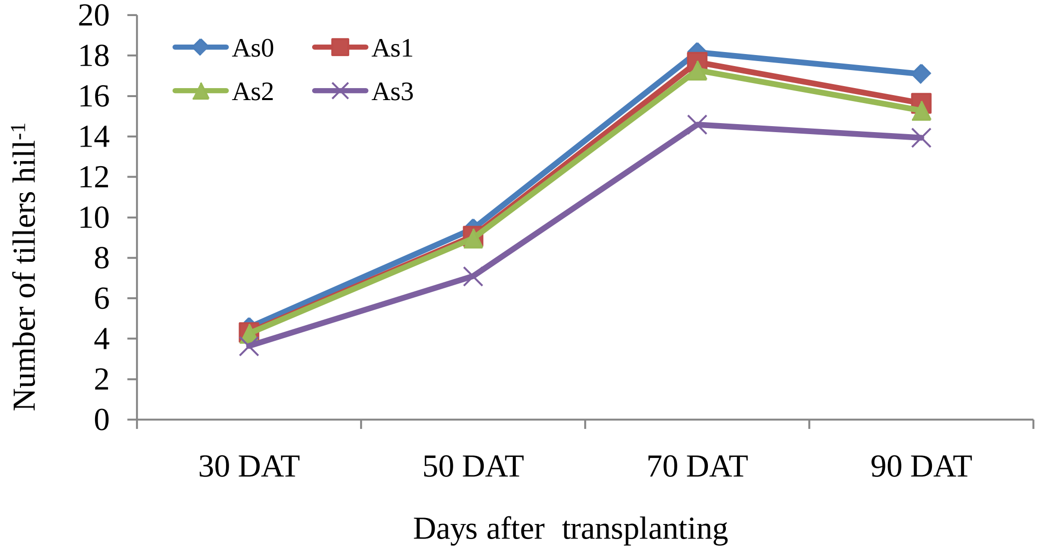
V_3: BRRI hybrid dhan-1

V_4: Chamak

4.2 Number of tillers hill^{-1}

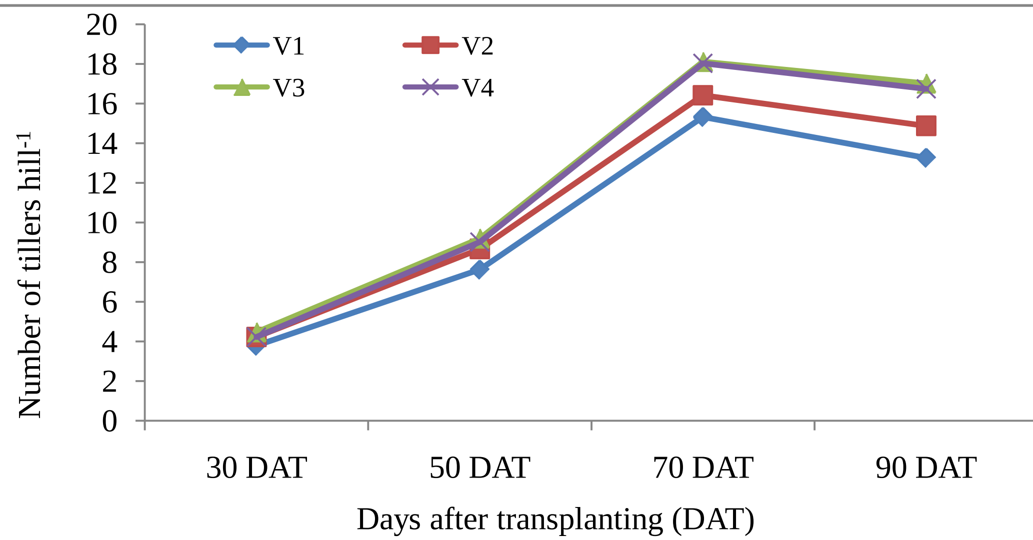
Application of different level of arsenic showed significant variation on number of tillers hill^{-1} at 30, 50, 70 and 90 DAT (Figure 3). At 30, 50, 70 and 90 DAT the highest number of tillers hill^{-1} (4.55, 9.43, 18.15 and 17.08) was found in As_0 (0 ppm As/kg soil) which was statistically similar (4.33, 9.00, 17.67 and 15.67) with As_1 (20 ppm As/kg soil). On the other hand, while the lowest number (3.67, 7.00, 14.67 and 13.93) in As_4 (60 ppm As/kg soil). Delowar *et al*. (2005) reported that growth and yield of rice plants were reduced significantly with increased doses of arsenic. The number of tillers per pot reduced greatly with the higher dose of arsenic applied. Yield reduction of more than 60 and 40% for Iratom-24 and BRRI dhan28, was found with 20 mg L^{-1} of arsenic as compared to control. The reduction in straw yield was also significantly higher for both of rice varieties with the 20 mg L^{-1} arsenic application.

Significant variation was recorded on number of tillers hill^{-1} at 30, 50, 70 and 90 DAT (Figure 4). At 30, 50, 70 and 90 DAT, the highest number of tillers hill^{-1} (4.48, 9.21, 18.12 and 17.03) was obtained in V_3 (BRRI hybrid dhan-1), which was statistically similar (4.23, 9.02, 18.03 and 16.74) with V_4 (Chamak), again the lowest number (3.79, 7.63, 15.33 and 13.27) was found in V_1 (BRRI dhan28) at same DAT.



As_0: Control (No arsenic) As_1: 20 ppm As/kg soil
As_2: 40 ppm As/kg soil As_3: 60 ppm As/kg soil

Figure 3. Effect of different level of arsenic on number of tillers hill^{-1} [LSD(0.05) =0.089, 0.216, 0.337 and 0.364 at 30, 50, 70 and 90 DAT , respectively]



V_1: BRRI dhan28 V_2: SBRRI dhan29
V_3: BRRI hybrid dhan-1 V_5: Chamak

Figure 4. Effect of different rice variety on number of tillers hill^{-1} [LSD(0.05) =0.089, 0.216, 0.337 and 0.364 at 30, 50, 70 and 90 DAT , respectively]

Number of tillers $hill^{-1}$ at 30, 50, 70 and 90 DAT showed significant variation due to the interaction effect of arsenic and rice variety (Table 2). At 30, 50, 70 and 90 DAT the highest number of tillers $hill^{-1}$ (5.00, 10.33, 19.67 and 19.67) was recorded in As_0V_3 (0 ppm As/kg soil in BRRI hybrid dhan-1) and the lowest number (3.33, 6.33, 13.67 and 12.67) in As_3V_1 (60 ppm As/kg soil in BRRI dhan28).

4.3 Total tillers $hill^{-1}$

Number of total tillers $hill^{-1}$ at harvest showed significant variation due to the application of different level of arsenic under the present trial (Table 3). The highest number of total tillers $hill^{-1}$ (11.53) was found in As_0 (0 ppm As/kg soil) which was statistically similar (11.31) with As_1 (20 ppm As/kg soil) and closely followed (11.03) by As_2 (40 ppm As/kg soil), whereas the lowest number (10.88) in As_3 (60 ppm As/kg soil).

Number of total tillers $hill^{-1}$ at harvest showed significant differences for different varity (Table 3). The highest number of total tillers $hill^{-1}$ (12.16) was attained in V_3 (BRRI hybrid dhan-1), which was closely followed (12.29 and 11.20) by V_2 (BRRI dhan29) and V_4 (Chamak), while the lowest number (10.10) was recorded in V_1 (BRRI dhan28). Hossain and Alam (1991) also found that the growth characters like total tillers $hill^{-1}$ differed significantly among BR3, BR11, Pajam and Jaguli varieties in *boro* season.

Table 2. Interaction effect of arsenic and variety on number of tillers hill^{-1} of rice

Treatments	Number of tillers hill^{-1} at			
	30 DAT	50 DAT	70 DAT	90 DAT
As_0V_1	3.67 f-h	7.33 cd	14.67 g	12.67 f
As_0V_2	4.33 b-d	9.33 ab	17.00 d-f	15.00 d-f
As_0V_3	4.67 ab	10.33 a	19.33 ab	18.33 ab
As_0V_4	4.33 b-f	9.67 a	19.33 a-c	16.67 b-d
As_1V_1	4.00 d-g	8.00 bc	15.67 e-g	14.00 ef
As_1V_2	4.67 a-c	9.67 a	17.67 b-e	16.33 b-e
As_1V_3	5.00 a	10.33 a	19.67 a	19.67 a
As_1V_4	4.67 a-c	9.67 a	19.33 a-c	18.33 a-c
As_2V_1	3.67 e-h	7.67 cd	15.67 e-g	13.33 f
As_2V_2	3.67 gh	6.67 cd	13.67 g	13.67 f
As_2V_3	4.33 c-f	9.33 a	18.33 a-d	16.33 b-e
As_2V_4	4.00 d-g	7.67 cd	15.00 fg	16.00 c-e
As_3V_1	3.33 h	6.33 d	13.67 g	12.67 f
As_3V_2	4.33 b-e	9.00 ab	17.33 c-f	14.67 d-f
As_3V_3	4.67 a-c	9.67 a	18.33 a-d	17.00 b-d
As_3V_4	3.67 e-h	7.67 cd	15.33 fg	13.00 f
$LSD_{(0.05)}$	0.180	0.432	0.673	0.728
CV(%)	7.42	8.68	6.89	8.14

DAT: Days after transplanting

In a column means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly as per 0.05 level of probability

As_0: Control (No Arsenic)
As_1: 20 ppm As/kg Soil
As_2: 40 ppm As/kg Soil
As_3: 60 ppm As/kg Soil

V_1: BRRI dhan28
V_2: BRRI dhan29
V_3: BRRI hybrid dhan-1
V_4: Chamak

Table 3. Effect of arsenic and variety on total tillers, effective tillers, filled grains and unfilled grains per plants of rice

Treatments	Total tillers hill^{-1} (No.)	Effective tiller hill^{-1} (No.)	Filled grains plant^{-1} (No.)	Unfilled grains plant^{-1} (No.)
Level of arsenic				
As_0	11.53 a	10.97 a	92.52 a	23.88 bc
As_1	11.31 ab	10.81 a	86.82 b	25.13 b
As_2	11.03 bc	10.62 ab	82.80 c	22.17 c
As_3	10.88 c	10.22 b	79.35 d	27.70 a
$LSD_{(0.05)}$	0.408	0.406	3.002	2.143
Variety				
V_1	10.10 c	9.10 c	79.83 c	26.72 a
V_2	11.29 b	10.77 b	85.05 b	24.02 b
V_3	12.16 a	11.79 a	88.15 a	23.63 b
V_4	11.20 b	10.95 b	88.46 a	24.52 b
$LSD_{(0.05)}$	0.408	0.406	3.002	2.143
CV(%)	6.37	4.57	8.22	10.40

In a column means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly as per 0.05 level of probability

As_0: Control (No Arsenic)

As_1: 20 ppm As/kg Soil

As_2: 40 ppm As/kg Soil

As_3: 60 ppm As/kg Soil

V_1: BRRI dhan28

V_2: BRRI dhan29

V_3: BRRI hybrid dhan-1

V_4: Chamak

Significant variation was recorded due to the interaction effect of arsenic and rice variety on number of total tillers $hill^{-1}$ at harvest (Table 4). The highest number of total tillers $hill^{-1}$ (13.00) was recorded in As_0V_3 (0 ppm As/kg soil in BRRI hybrid dhan-1), again the lowest number (9.33) in As_3V_1 (60 ppm As/kg soil in BRRI dhan28).

4.4 Effective tillers $hill^{-1}$

Number of effective tillers $hill^{-1}$ at harvest varied significantly due to the application of different level of arsenic under the present trial (Table 3). The highest number of effective tillers $hill^{-1}$ (10.97) was observed in As_0 (0 ppm As/kg soil) which was statistically similar (10.81 and 10.62) with As_1 (20 ppm As/kg soil) and As_2 (40 ppm As/kg soil). On the other hand, the lowest number (10.22) was recorded in As_4 (60 ppm As/kg soil). Delowar *et al*. (2005) reported that growth and yield of rice plants were reduced significantly with increased doses of arsenic. Number of effective tillers per pot and grain yield per pot reduced greatly with the higher dose of arsenic applied.

Different rice variety showed significant variation on number of effective tillers $hill^{-1}$ at harvest (Table 3). The highest number of effective tillers $hill^{-1}$ (11.79) was found in V_3 (BRRI hybrid dhan-1), which was closely followed (10.95 and 10.77) by V_4 (Chamak) and V_2 (BRRI dhan29) and they were statistically similar, whereas the lowest number (9.10) was recorded in V_1 (BRRI dhan28).

Table 4. Interaction effect of arsenic and variety total tillers, effective tillers, filled grains and unfilled grains per plants of rice

Treatments	Total tillers hill^{-1} (No.)	Effective tiller hill^{-1} (No.)	Filled grains plant^{-1} (No.)	Unfilled grains plant^{-1} (No.)
As_0V_1	10.67 ef	9.67 fg	86.63 b-d	23.63 d-g
As_0V_2	11.67 b-d	10.67 c-e	95.63 a	33.17 a
As_0V_3	13.00 a	12.67 a	95.40 a	13.10 i
As_0V_4	11.00 c-f	10.67 c-e	92.40 ab	25.63 c-f
As_1V_1	10.33 f	9.00 g	80.77 d-f	28.13 b-d
As_1V_2	11.67 b-d	11.00 b-d	83.73 c-e	21.83 f-h
As_1V_3	12.00 b	12.00 ab	84.47 c-e	27.27 b-e
As_1V_4	11.33 b-d	11.33 b-d	98.33 a	23.30 e-g
As_2V_1	10.33 ef	9.67 fg	80.03 df	20.27 gh
As_2V_2	11.33 b-e	11.00 c-e	83.90 c-e	17.60 h
As_2V_3	11.67 bc	11.67 bc	88.17 bc	22.43 fg
As_2V_4	10.67 d-f	10.33 d-f	79.10 ef	28.40 bc
As_3V_1	9.33 g	8.88 h	71.90 g	34.83 a
As_3V_2	11.00 c-f	10.33 ef	76.93 fg	23.50 d-g
As_3V_3	11.67 bc	11.00 b-d	84.57 c-e	31.73 ab
As_3V_4	11.67 b-d	11.33 bc	84.00 de	20.73 gh
$LSD_{(0.05)}$	0.815	0.812	6.003	4.287
CV(%)	6.37	4.57	8.22	10.40

In a column means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly as per 0.05 level of probability

As_0: Control (No Arsenic)

As_1: 20 ppm As/kg Soil

As_2: 40 ppm As/kg Soil

As_3: 60 ppm As/kg Soil

V_1: BRRI dhan28

V_2: BRRI dhan29

V_3: BRRI hybrid dhan-1

V_4: Chamak

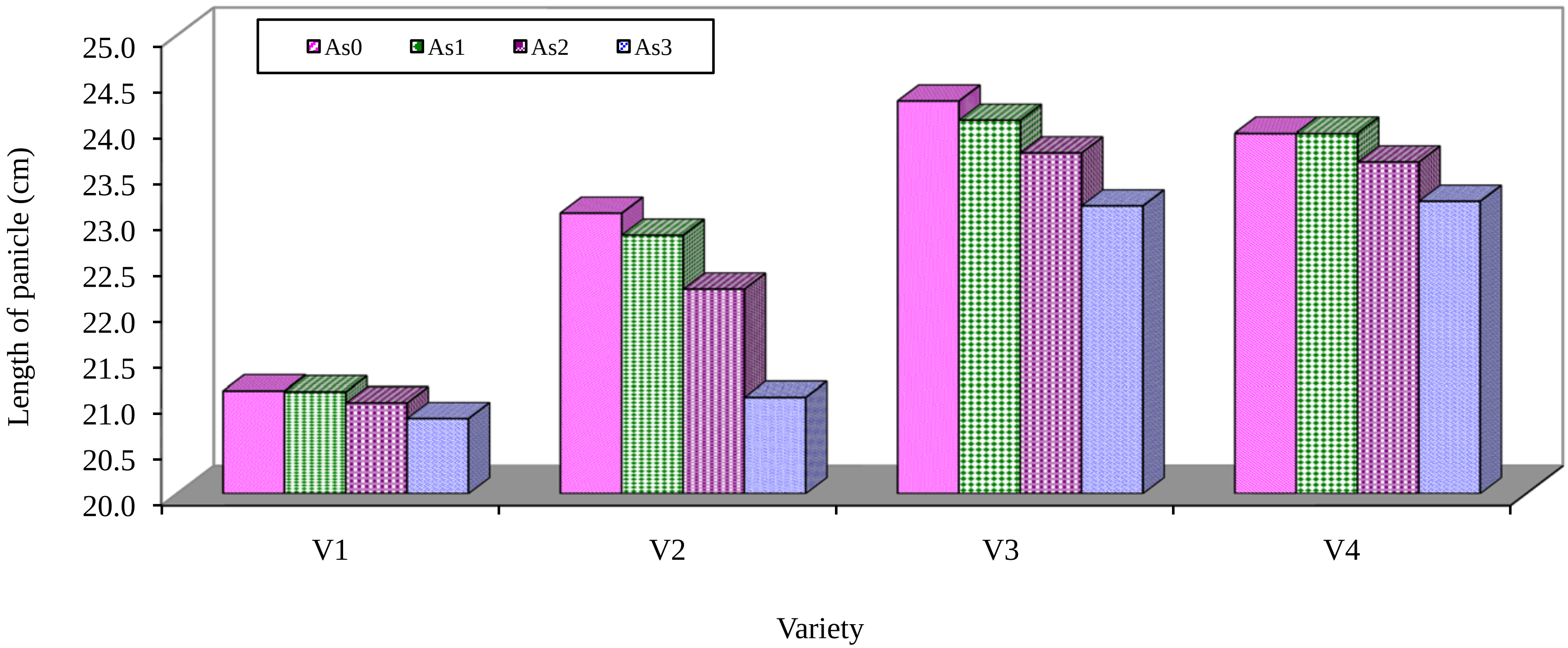
Interaction effect of arsenic and rice variety showed significant differences on number of effective tillers $hill^{-1}$ at harvest (Table 4). The highest number of effective tillers $hill^{-1}$ (12.67) was found in As_0V_3 (0 ppm As/kg soil in BRRI hybrid dhan-1), while the lowest number (8.00) in As_4V_1 (60 ppm As/kg soil in BRRI dhan28).

4.5 Length of panicle

Application of different level of arsenic showed significant variation for length of panicle under the present trial (Figure 5). The maximum length of panicle (23.10 cm) was recorded in As_0 (0 ppm As/kg soil) which was statistically similar (22.90 cm and 22.64 cm) with As_1 (20 ppm As/kg soil) and As_2 (40 ppm As/kg soil), again the minimum length (22.05) found in As_0 (0 ppm As/kg soil). Islam *et al.* (2004) reported that the irrigation water added As up to 0.25 ppm enhanced the panicle length and the further doses of depressed the length of panicle.

Statistically significant variation was recorded for different rice variety in terms of length of panicle (Figure 6). The maximum length of panicle (23.80 cm) was recorded in V_3 (BRRI hybrid dhan-1), which statistically similar (23.67 cm) with by V_4 (Chamak) and closely followed (22.29 cm) by V_2 (BRRI dhan29), whereas the minimum length (21.01 cm) was found in V_1 (BRRI dhan28).

Interaction effect of arsenic and rice variety showed non-significant differences on length of panicle (Figure 7). The maximum length of panicle (24.28 cm) was attained in As_0V_3 (0 ppm As/kg soil in BRRI hybrid dhan-1) and the minimum length of panicle (20.82 cm) in As_3V_1 (60 ppm As/kg soil in BRRI dhan28).



As_0: Control (No arsenic)
As_2: 40 ppm As/kg soil

As_1: 20 ppm As/kg soil
As_3: 60 ppm As/kg soil

V_1: BRRI dhan28
V_3: BRRI hybrid dhan-1

V_2: BRRI dhan29
V_4: Chamak

Figure 7. Interaction effect of arsenic and variety on length of panicle of rice [LSD(0.05) = 0.834

4.6 Filled grains panicle^{-1}

Number of filled grains panicle^{-1} varied significantly due to the application of different level of arsenic under the present trial (Table 3). The highest number of filled grains panicle^{-1} (92.52) was recorded in As_0 (0 ppm As/kg soil) which was closely followed (86.82) by As_1 (20 ppm As/kg soil), again the lowest number (79.35) was recorded in As_3 (60 ppm As/kg soil) which was closely followed (82.80) by As_2 (40 ppm As/kg soil). Islam *et al*. (2004) reported that the irrigation water added As up to 0.25 ppm enhanced the filled grains and the further doses of depressed number of filled grains.

Different rice variety showed significant variation in terms of number of filled grains panicle^{-1} (Table 3). The highest number of filled grains panicle^{-1} (88.46) was observed in V_4 (Chamak), which statistically similar (88.15) with by V_3 (BRRI hybrid dhan-1) and closely followed (85.05) by V_2 (BRRI dhan29), whereas the lowest number (79.83) was recorded in V_1 (BRRI dhan28).

Interaction effect of arsenic and rice variety varied significantly on number of filled grains panicle^{-1} (Table 4). The highest number of filled grains panicle^{-1} (95.63) was observed in As_0V_2 (0 ppm As/kg soil in BRRI dhan29) and the lowest number (71.90) in As_3V_1 (60 ppm As/kg soil in BRRI dhan28).

4.7 Unfilled grains panicle^{-1}

Number of unfilled grains panicle^{-1} varied significantly due to the application of different level of arsenic under the present trial (Table 3). The lowest number of unfilled grains panicle^{-1} (22.17) was attained in As_0 (0 ppm As/kg soil) which was statistically similar (23.88) with As_2 (40 ppm As/kg soil), while the highest number (27.70) was found in As_3 (60 ppm As/kg soil) which was closely followed (25.13) by As_1 (20 ppm As/kg soil) and.

Different rice variety showed significant variation on number of unfilled grains panicle^{-1} (Table 3). The lowest number of unfilled grains panicle^{-1} (23.63) was found in V_3 (BRRI hybrid dhan-1), which statistically similar (24.02 and 24.52) with by V_1 (BRRI dhan29) and V_2 (Chamak), while the highest number (26.72) was observed in V_1 (BRRI dhan28)

Interaction effect of arsenic and rice variety showed significant differences on number of unfilled grains panicle^{-1} (Table 4). The lowest number of unfilled grains panicle^{-1} (13.10) was recorded in As_0V_3 (0 ppm As/kg soil in Chamak), whereas the highest number (34.83) in As_3V_1 (60 ppm As/kg soil in BRRI dhan28).

4.8 Weight of 1000 seeds

Application of different level of arsenic under the present trial varied non-significantly in terms of weight of 1000 seeds (Table 5). The highest weight of 1000 seeds (24.25 g) was found in As_0 (0 ppm As/kg soil). On the other hand, the lowest weight (23.23 g) was observed in As_3 (60 ppm As/kg soil). Islam *et al.* (2004) reported that the irrigation water added As up to 0.25 ppm enhanced the 1000-grain weight and the further doses of depressed.

Different rice variety showed non significant variation on weight of 1000 seeds (Table 5). The highest weight of 1000 seeds (24.17 g) was observed in V_3 (BRRI hybrid dhan-1), while the lowest weight (23.10 g) in V_1 (BRRI dhan28).

Weight of 1000 seeds showed non significant differences due to interaction effect of arsenic and rice variety (Table 6). The highest weight of 1000 seeds (24.80 g) was found in As_0V_2 (0 ppm As/kg soil in BRRI dhan29), again the lowest weight (22.17 g) in As_3V_1 (60 ppm As/kg soil in BRRI dhan28).

4.9 Grain yield

Application of different level of arsenic showed significant variation on grain yield per hectare (Table 5). The highest grain yield (3.91 t ha^{-1}) was recorded in As_0 (0 ppm As/kg soil) which was closely followed (3.69 t ha^{-1} and 3.51 t ha^{-1}) by As_1 (20 ppm As/kg soil) and As_3 (60 ppm As/kg soil), while the lowest grain yield (3.39 t ha^{-1}) was observed in As_3 (60 ppm As/kg soil). Delowar *et al*. (2005) reported that growth and yield of rice plants were reduced significantly with increased doses of arsenic and the grain weight was also affected. Yield reduction of more than 60 and 40% for Iratom-24 and BRRI dhan28, was found with 20 mg L^{-1} of arsenic as compared to control. The reduction in straw yield was also significantly higher for both of rice varieties with the 20 mg L^{-1} arsenic application. Islam *et al*. (2004) reported that the irrigation water added As up to 0.25 ppm enhanced the plant height, panicle length, filled grains/panicle, 1000-grain weight and finally the grain yield of Boro rice and the further doses of depressed yield.

Table 5. Effect of arsenic and variety on weight of 1000 seeds, grain and straw yield of rice

Treatments	Weight of 1000 seeds (g)	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})
Level of arsenic			
As_0	24.25	3.91 a	7.52 a
As_1	23.63	3.69 b	7.34 b
As_2	24.19	3.51 bc	7.47 ab
As_3	23.23	3.39 c	7.16 c
$LSD_{(0.05)}$	--	0.194	0.158
Variety			
V_1	23.10	2.66 c	6.66 d
V_2	24.05	3.47 b	7.02 c
V_3	24.17	4.91 a	7.72 b
V_4	23.98	3.47 b	8.08 a
$LSD_{(0.05)}$	--	0.194	0.158
CV(%)	7.73	6.43	8.58

In a column means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly as per 0.05 level of probability

As_0: Control (No Arsenic)
As_1: 20 ppm As/kg Soil
As_2: 40 ppm As/kg Soil
As_3: 60 ppm As/kg Soil

V_1: BRRI dhan28
V_2: BRRI dhan29
V_3: BRRI hybrid dhan-1
V_4: Chamak

Table 6. Interaction effect of arsenic and variety on weight of 1000 seeds, grain and straw yield of rice

Treatment	Weight of 1000 seeds (g)	Grain yield ($t\ ha^{-1}$)	Straw yield ($t\ ha^{-1}$)
As_0V_1	23.50	3.07 gh	6.75
As_0V_2	24.80	4.00 d	7.07
As_0V_3	24.50	5.30 a	8.04
As_0V_4	24.20	3.27 fg	8.23
As_1V_1	22.67	2.73 hi	6.69
As_1V_2	23.67	3.37 fg	6.99
As_1V_3	24.17	5.00 ab	7.62
As_1V_4	24.00	3.67 d-f	8.04
As_2V_1	24.07	2.63 i	6.79
As_2V_2	24.17	3.43 e-g	7.11
As_2V_3	24.40	4.87 b	7.82
As_2V_4	24.13	3.10 gh	8.15
As_3V_1	22.17	2.20 j	6.40
As_3V_2	23.57	3.07 gh	6.91
As_3V_3	23.60	4.47 c	7.42
As_3V_4	23.57	3.83 de	7.91
$LSD_{(0.05)}$	--	0.388	--
CV(%)	7.73	6.43	8.58

In a column means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly as per 0.05 level of probability

As_0: Control (No Arsenic)
As_1: 20 ppm As/kg Soil
As_2: 40 ppm As/kg Soil
As_3: 60 ppm As/kg Soil

V_1: BRRI dhan28
V_2: BRRI dhan29
V_3: BRRI hybrid dhan-1
V_4: Chamak

Significant variation was recorded for different rice variety on grain yield per hectare (Table 5). The highest grain yield (4.91 t ha^{-1}) was found in V_3 (BRRI hybrid dhan-1), which was closely followed (3.47 t ha^{-1}) by V_2 (BRRI dhan-29) and V_4 (Chamak). On the other hand, the lowest grain yield (2.66 t ha^{-1}) was recorded in V_1 (BRRI dhan28). Wang *et al.* (2006) reported that compared with conventional cultivars, the hybrids had larger panicles, heavier seeds, resulting in an average yield increase of 7.27%.

Arsenic and rice variety showed significant interaction effect on grain yield per hectare (Table 6). The highest grain yield (5.30 t ha^{-1}) was attained in As_0V_3 (0 ppm As/kg soil in BRRI hybrid dhan-1), while the lowest grain yield (2.20 t ha^{-1}) in As_3V_1 (60 ppm As/kg soil in BRRI dhan28).

4.9 Straw yield

Straw yield per hectare varied significantly due to the application of different level of arsenic under the present trial (Table 5). The highest straw yield (7.52 t ha^{-1}) was attained in As_0 (0 ppm As/kg soil) which was statistically similar (7.47 t ha^{-1}) by As_2 (40 ppm As/kg soil) and closely followed (7.34 t ha^{-1}) by As_1 (20 ppm As/kg soil), again the lowest straw yield (7.16 t ha^{-1}) was recorded in As_3 (60 ppm As/kg soil). Delowar *et al*. (2005) reported that growth and yield of rice plants were reduced significantly with increased doses of arsenic. The reduction in straw yield was also significantly higher for both of rice varieties with the 20 mg L^{-1} arsenic application.

Different rice variety showed significant variation on straw yield per hectare (Table 5). The highest straw yield (8.08 t ha^{-1}) was observed in V_4 (Chamak), which was closely followed (7.72 t ha^{-1}) by V_3 (BRRI hybrid dhan-1), whereas the lowest straw yield (6.66 t ha^{-1}) was found in V_1 (BRRI dhan28) which was closely followed (7.02 t ha^{-1}) by V_2 (BRRI dhan29).

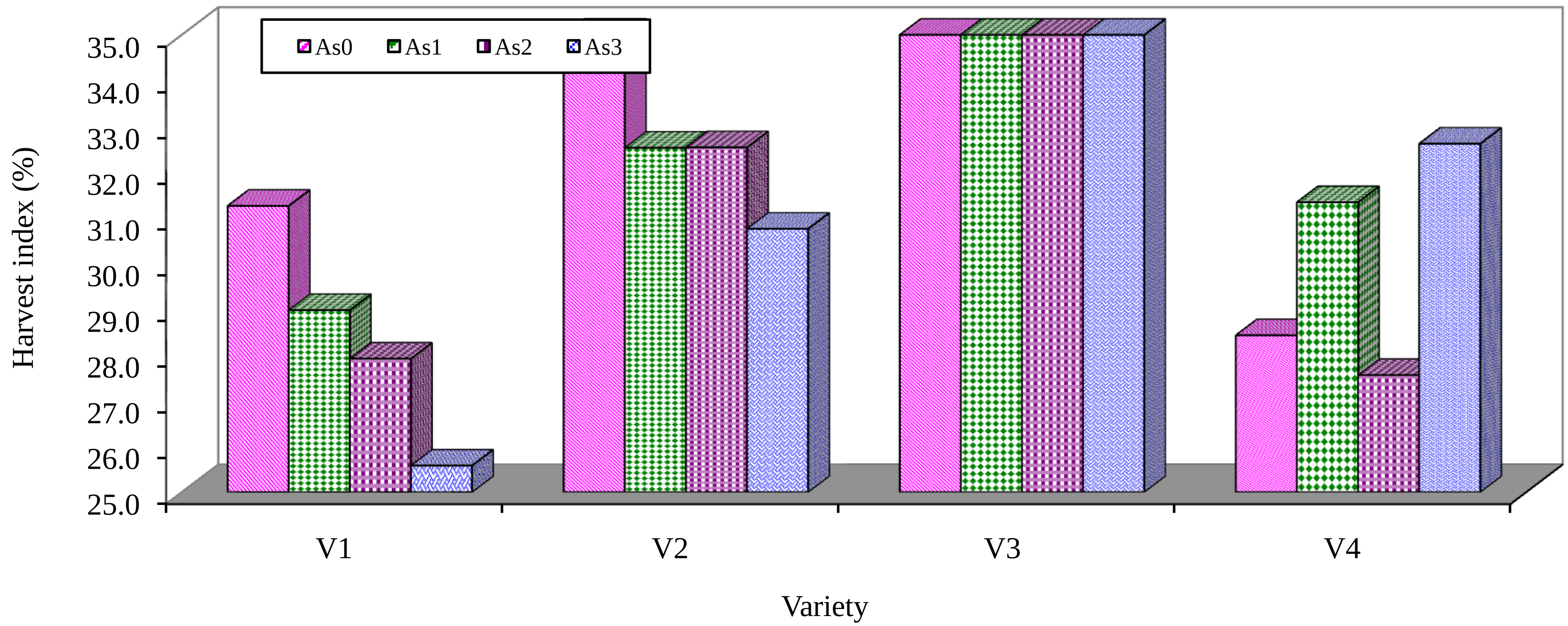
Interaction effect of arsenic and rice variety showed non significant differences on straw yield per hectare (Table 6). The highest straw yield (8.23 t ha^{-1}) was recorded in As_0V_4 (0 ppm As/kg soil in Chamak), whereas the lowest straw yield (6.40 t ha^{-1}) in As_3V_1 (60 ppm As/kg soil in BRRI dhan28).

4.10 Harvest index

Harvest index showed non significant variation due to the application of different level of arsenic (Figure 8). The highest harvest index (33.89%) was observed in As_0 (0 ppm As/kg soil) and the lowest harvest index (31.60%) was found in As_3 (60 ppm As/kg soil).

Different rice variety showed non significant variation on harvest index (Figure 9). The highest harvest index (38.83%) was attained in V_3 (BRRI hybrid dhan-1), while the lowest harvest index (28.44%) was recorded in V_1 (BRRI dhan28).

Harvest index showed non significant interaction effect of arsenic and rice variety (Figure 10). The highest harvest index (39.73%) was recorded in As_0V_3 (0 ppm As/kg soil in BRRI hybrid dhan-1), while the lowest harvest index (25.58%) in As_3V_1 (60 ppm As/kg soil in BRRI dhan28).



As_0: Control (No arsenic)
As_2: 40 ppm As/kg soil

As_1: 20 ppm As/kg soil
As_3: 60 ppm As/kg soil

V_1: BRRI dhan28
V_3: BRRI hybrid dhan-1

V_2: BRRI dhan29
V_4: Chamak

Figure 10. Interaction effect of arsenic and variety on harvest index of rice

CHAPTER V

SUMMARY AND CONCLUSION

The pot experiment was conducted at the Sher-e-Bangla Agricultural University, Dhaka, Bangladesh during the period in December 2010 to May 2011 to study the effect of arsenic on growth and yield of rice. The experiment comprised of two factors. Factor A: Arsenic level (4 levels): As_0: Control (No arsenic); As_1: 20 ppm As kg soil^{-1}, As_2: 40 ppm As kg soil^{-1} and As_3: 60 ppm As kg soil^{-1}. Factor B: Rice variety: (4 Nos.); V_1: BRRI dhan28; V_2: BRRI dhan29; V_3: BRRI hybrid dhan-1 and V_4: Chamak. The experiment was laid out in Randomized Complete Block Design (RCBD) with three replications.

In case of arsenic, at 30, 50, 70, 90 DAT and harvest the longest plant (17.59 cm, 32.53 cm, 56.64 cm, 77.04 and 84.09 cm) was recorded in As_0, whereas the shortest plant (16.44 cm, 28.88 cm, 53.40 cm, 72.53 cm and 80.85 cm) in As_3. At 30, 50, 70 and 90 DAT the highest number of tillers hill^{-1} (4.67, 9.33, 18.00 and 17.00) was found in As_0 and while the lowest number (3.67, 7.00, 14.67 and 13.93) in As_3. The highest number of total tillers hill^{-1} at harvest (11.53) was found in As_0, whereas the lowest number (10.88) in As_3. The highest number of effective tillers hill^{-1} at harvest (10.97) was observed in As_0 and the lowest number (10.22) in As_3. The maximum length of panicle (23.10 cm) was recorded in As_0, again the minimum length (22.05) in As_3. The highest number of filled grains panicle^{-1} (92.52) was recorded in As_0, again the lowest number (79.35) in As_3. The lowest number of unfilled grains panicle^{-1} (22.17) was attained in As_0, while the highest number (27.70) in As_3. The highest weight of 1000 seeds (24.25 g) was found in As_0 and the lowest weight (23.23 g) in As_3. The highest grain yield (3.91 t ha^{-1}) was recorded in As_0, while the lowest grain yield (3.39 t ha^{-1}) in As_3. The highest straw yield (7.52 t ha^{-1}) was attained in As_0, again the lowest straw yield (7.16 t ha^{-1}) in As_3. The highest harvest index (33.89%) was observed in As_0 and the lowest harvest index (31.60%) in As_3.

At 30, 50, 70, 90 DAT and at harvest, the tallest plant (18.61 cm, 34.68 cm, 58.59 cm, 81.69 cm and 92.40 cm) was observed in V_4 again the shortest plant (15.01 cm, 24.74 cm, 47.47 cm, 60.05 cm and 63.10 cm) in V_1. At 30, 50, 70 and 90 DAT, the highest number of tillers $hill^{-1}$ (4.48, 9.21, 18.12 and 17.03) was obtained in V_3, again the lowest number (3.79, 7.63, 15.33 and 13.27) in V_1 at same DAT. The highest number of total tillers $hill^{-1}$ at harvest (12.16) was attained in V_3, while the lowest number (10.10) in V_1. The highest number of effective tillers $hill^{-1}$ at harvest (11.79) was found in V_3, whereas the lowest number (9.10) in V_1. The maximum length of panicle (23.80 cm) was recorded in V_3, whereas the minimum length (21.01 cm) in V_1. The highest number of filled grains $panicle^{-1}$ (88.46) was observed in V_4, whereas the lowest number (79.83) in V_1. The lowest number of unfilled grains $panicle^{-1}$ (23.63) was found in V_3, while the highest number (26.72) in V_1. The highest weight of 1000 seeds (24.17 g) was observed in V_3, while the lowest weight (23.10 g) in V_1. The highest grain yield (4.91 t ha^{-1}) was found in V_3 and the lowest grain yield (2.66 t ha^{-1}) in V_1. The highest straw yield (8.08 t ha^{-1}) was observed in V_4, whereas the lowest straw yield (6.66 t ha^{-1}) in V_1. The highest harvest index (38.83%) was attained in V_3, while the lowest harvest index (28.44%) in V_1.

At 30, 50, 70, 90 DAT and at harvest the tallest plant (20.34 cm, 39.96 cm, 64.15 cm, 89.03 cm and 99.43 cm) was observed in As_0V_4, while the shortest (13.46 cm, 20.38 cm, 42.91 cm, 53.78 cm and 54.43 cm) in As_3V_1. At 30, 50, 70 and 90 DAT the highest number of tillers $hill^{-1}$ (5.00, 10.33, 19.67 and 19.67) was recorded in As_0V_3 and the lowest number (3.33, 6.33, 13.67 and 12.67) in As_3V_3. The highest number of total tillers $hill^{-1}$ at harvest (13.00) was recorded in As_0V_3, again the lowest number (9.33) in As_3V_1. The highest number of effective tillers $hill^{-1}$ at harvest (12.67) was attained in As_0V_3, while the lowest number (8.00) in As_3V_1. The maximum length of panicle (24.28 cm) was attained in As_0V_3 and the minimum length of panicle (20.82 cm) in As_3V_1. The highest number of filled grains $panicle^{-1}$ (95.63) was observed in As_0V_2 and the lowest number (71.90) in As_3V_1. The lowest number of unfilled grains $paniclet^{-1}$ (13.10) was recorded in As_0V_3, whereas the highest number (34.83) in As_3V_1. The highest weight of 1000 seeds (24.80 g) was found in As_0V_2, again the lowest weight (22.17 g) in As_3V_1. The highest grain yield (5.30 t ha^{-1}) was attained in As_0V_3, while the lowest grain yield (2.20 t ha^{-1}) in As_3V_1. The highest straw yield (8.23 t ha^{-1}) was recorded in As_0V_4, whereas the lowest straw yield (6.40 t ha^{-1}) in As_3V_1. The highest harvest index (39.73%) was recorded in As_0V_3, while the lowest harvest index (25.58%) in As_3V_1.

It may be concluded that growth, yield and yield contributing characters of rice were influenced by different levels of arsenic and variety. Among the treatment combination applications of 0 ppm As/kg soil in BRRI hybrid dhan produced longest plant, highest number of tillers, longest panicle, maximum number of filled grains panicle^{-1} and highest 1000 grains weight and ultimately provides maximum grain and straw yields.

Considering the situation of the present experiment, further studies in the following areas may be suggested:

1. Such study is needed in different agro-ecological zones (AEZ) of Bangladesh for regional compliance and other performance.
2. More experiments may be carried out with other rice varieties.

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APPENDICES

Appendix I. Characteristics of experimental pot soil as analyzed by Soil Resources Development Institute (SRDI), Khamarbari, Farmgate, Dhaka

A. Morphological characteristics of the experimental field

Morphological features	Characteristics
Location	Exprimental field , SAU, Dhaka
AEZ	Madhupur Tract (28)
General Soil Type	Shallow red brown terrace soil
Land type	High land
Soil series	Tejgaon
Topography	Fairly leveled
Flood level	Above flood level
Drainage	Well drained

B. Physical and chemical properties of the initial soil

Characteristics	Value
% Sand	27
% Silt	43
% clay	30
Textural class	Silty-clay
pH	5.6
Organic carbon (%)	0.45
Organic matter (%)	0.78
Total N (%)	0.03
Available P (ppm)	20.00
Exchangeable K (me/100 g soil)	0.10
Available S (ppm)	45

Source: SRDI

Appendix II. Monthly record of air temperature, relative humidity, rainfall, and sunshine hour of the experimental site during the period from December 2010 to May 2011

Month	*Air temperature (ºc)		*Relative humidity (%)	*Rainfall (mm) (total)	*Sunshine (hr)
	Maximum	Minimum			
December, 2010	22.4	13.5	74	00	6.3
January, 201	24.5	12.4	68	00	5.7
February, 2011	27.1	16.7	67	30	6.7
March, 2011	31.4	19.6	54	11	8.2
April, 2011	33.6	23.6	69	163	6.4
May, 2011	32.4	27.2	71	134	7.1

* Monthly average,

Source: Bangladesh Meteorological Department (Climate & weather division) Agargoan, Dhaka-1212

Appendix III. Analysis of variance of the data on plant height of rice as influenced by levels of arsenic and variety

Source of variation	Degrees of freedom	Mean square				
		Plant height (cm) at				
		30 DAT	50 DAT	70 DAT	90 DAT	Harvest
Replication	2	0.392	0.928	4.020	0.887	6.749
Levels of arsenic (A)	3	2.264	1.918	3.497	4.255	3.469
Rice variety (B)	3	20.025**	47.151**	50.631**	101.392**	122.187**
Interaction (A×B)	9	4.701*	9.396**	12.031**	14.537**	18.341**
Error	30	1.692	2.599	3.678	4.400	5.400

**: Significant at 0.01 level of probability: *: Significant at 0.05 level of probability

Appendix IV. Analysis of variance of the data on number of tillers hill^{-1} of rice as influenced by levels of arsenic and variety

Source of variation	Degrees of freedom	Mean square			
		Number of tillers hill^{-1} at			
		30 DAT	50 DAT	70 DAT	90 DAT
Replication	2	0.072	0.952	0.311	0.331
Levels of arsenic (A)	3	3.591**	7.360**	7.088**	11.710**
Rice variety (B)	3	8.664**	11.737**	20.349**	47.153**
Interaction (A×B)	9	2.509**	2.930**	4.570*	9.456**
Error	30	0.548	0.823	1.576	2.391

**: Significant at 0.01 level of probability: *: Significant at 0.05 level of probability

Appendix V. Analysis of variance of the data on total tillers hill^{-1}, effective tillers hill^{-1}, unfilled & total grains and weight of 1000 seeds of rice as influenced by levels of arsenic and variety

Source of variation	Degrees of freedom	Mean square				
		Total tillers hill^{-1} (No.)	Effective tillers hill^{-1} (No.)	Length of panicle (cm)	Filled grains panicle^{-1} (No.)	Unfilled grains panicle^{-1} (No.)
Replication	2	0.013	1.193	16.358	1.918	6.398
Levels of arsenic (A)	3	14.673**	59.235**	126.395**	98.901**	87.129**
Rice variety (B)	3	4.965**	9.832**	38.058**	17.015**	17.182**
Interaction (A×B)	9	5.436**	12.412**	3.284	9.173**	5.164**
Error	30	0.496	1.208	5.319	3.015	2.007

**: Significant at 0.01 level of probability: *: Significant at 0.05 level of probability

Appendix VI. Analysis of variance of the data on weight of 1000 seeds, grain yield, straw yield and harvest index of rice as influenced by levels of arsenic and variety

Source of variation	Degrees of freedom	Mean square			
		Weight of 1000 seeds (g)	Grain yield (t/ha)	Straw yield (t/ha)	Harvest index (%)
Replication	2	0.019	0.041	0.373	0.018
Levels of arsenic (A)	3	0.317	16.876**	30.907**	0.285
Rice variety (B)	3	0.043	6.986**	9.554**	0.791
Interaction (A×B)	9	0.489	2.663**	3.707**	0.430
Error	30	0.401	0.743	0.680	0.177

**: Significant at 0.01 level of probability: *: Significant at 0.05 level of probability