EFFECT OF ARSENIC ON GROWTH, YIELD AND NUTRIENTS CONTENT OF FIVE BORO RICE VARIETIES

MD. ASIKUR RAHMAN CHOWDHURY

REGISTRATION NO. 19-10323

DEPARTMENT OF AGRICULTURAL CHEMISTRY

SHER-E-BANGLA AGRICULTURAL UNIVERSITY
DHAKA -1207

DECEMBER, 2021

EFFECT OF ARSENIC ON GROWTH, YIELD AND NUTRIENTS CONTENT OF FIVE BORO RICE VARIETIES

BY

MD. ASIKUR RAHMAN CHOWDHURY

REGISTRATION NO. : 19-10323

ashikur19961996@gmail.com

01799 241768

A Thesis

Submitted to the Department of Agricultural Chemistry
Sher-e-Bangla Agricultural University, Dhaka
In partial fulfillment of the requirements
for the degree of

MASTER OF SCIENCE (MS)

IN

AGRICULTURAL CHEMISTRY

SEMESTER: JULY- DECEMBER, 2021

Approved by:

Prof. Dr. Sheikh Shawkat Zamil
Department of Agricultural Chemistry
SAU, Dhaka
Supervisor

Prof. Dr. Md. Abdur Razzaque
Department of Agricultural Chemistry
SAU, Dhaka
Co-Supervisor

Prof. Dr. Sheikh Shawkat Zamil
Chairman
Examination committee
Department of Agricultural Chemistry

DEPARTMENT OF AGRICULTURAL CHEMISTRY
Sher-e-Bangla Agricultural University
Sher-e-Bangla Nagar, Dhaka-1207

CERTIFICATE

This is to certify that the thesis entitled **“EFFECT OF ARSENIC ON GROWTH, YIELD AND NUTRIENTS CONTENT OF FIVE BORO RICE VARIETIES”** submitted to the Department of Agricultural Chemistry, Faculty of Agriculture, Sher-e-Bangla Agricultural University, Dhaka, in partial fulfillment of the requirements for the degree of **MASTERS OF SCIENCE (M.S.)** in **AGRICULTURAL CHEMISTRY**, embodies the result of a piece of bonafide research work carried out by **MD. ASIKUR RAHMAN CHOWDHURY**, Registration No. 19-10323 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 been duly acknowledged.

October, 2022

Dhaka, Bangladesh

(Dr. Sheikh Shawkat Zamil)
Professor
Department of Agricultural Chemistry
SAU, Dhaka

Dedicated to

My

Beloved Parents

ACKNOWLEDGEMENTS

The author seems it a much privilege to express his enormous sense of gratitude to the almighty Allah for there ever ending blessings for the successful completion of the research work.

*The author wishes to express his gratitude and best regards to his respected Supervisor, **Dr. Sheikh Shawkat Zamil**, Professor, Department of Agricultural Chemistry, Sher-e-Bangla Agricultural University, Dhaka, for his continuous direction, constructive criticism, encouragement and valuable suggestions in carrying out the research work and preparation of this thesis.*

*The author wishes to express his earnest respect, sincere appreciation and enormous indebtedness to his reverend Co-supervisor, **Dr. Md. Abdur Razzaque**, Professor, Department of Agricultural Chemistry, Sher-e-Bangla Agricultural University, Dhaka, for his scholastic supervision, helpful commentary and unvarying inspiration throughout the research work and preparation of the thesis.*

*The author feels to express his heartfelt thanks to the honorable Chairman, **Prof. Dr. Sheikh Shawkat Zamil,** Department of Agricultural Chemistry along with all other teachers; Prof. Dr. Rokeya Begum, Prof. Dr. Noorjahan Begum, Prof. Dr. Mohammed Ariful Islam, Prof. Dr. Sirajul Islam Khan, Prof. Dr. Md. Tazul Islam Chowdhury, Assoc. Prof. Abdul Kaium, Assist. Prof.Mominul Haque Rabin Assistant Prof. Marzia Habib, Assist. Prof. Mahbuba Siddika, and also all staff members of the Department of Agricultural Chemistry, Sher-e-Bangla Agricultural University, Dhaka, for their co-operation during the period of the study. Again, the author feels to express his especial thanks to Assist. Prof. Mahbuba Siddika for her special help to complete the experimental works from beginning to end.*

The author feels proud to express his deepest and endless gratitude to all of his course mates and friends to cooperate and help him during taking data from the field and preparation of the thesis. The author wishes to extend his special thanks to his lab mates, class mates and friends for their keen help as well as heartiest co-operation and encouragement.

The author expresses his heartfelt thanks to his beloved parents, Elder Sister and Brother and all other family members for their prayers, encouragement, constant inspiration and moral support for his higher study. May Almighty bless and protect them all.

The Author

EFFECT OF ARSENIC ON GROWTH, YIELD AND NUTRIENTS CONTENT OF FIVE BORO RICE VARIETIES

ABSTRACT

A pot experiment was conducted at the net house of Agro-environmental chemistry laboratory of department of Agricultural Chemistry, Sher-e-Bangla Agricultural University, Dhaka, Bangladesh during the period from December 2020 to March 2021 to study the effect of arsenic on the growth, yield and nutrients content in straw and grain of rice varieties. Five rice varieties *viz.* V_1 (BR-16), V_2 (BRRI dhan-28), V_3 (BRRI dhan-29), V_4 (BRRI dhan-55) and V_5 (BRRI hybrid dhan-5) were comprised with five arsenic treatment *viz.* As_0 (control; no arsenic added), As_1 (2 mg As kg^{-1} soil), As_2 (10 mg As kg^{-1} soil), As_3 (20 mg As kg^{-1} soil) and As_4 (40 mg As kg^{-1} soil) for the present study. The experiment was laid out in Completely Randomized Design (CRD) with four replications. Among different rice varieties, V_5 showed better performance on growth and yield contributing parameters except plant height, leaf length and number of leaves $hill^{-1}$. Maximum grain and straw yield (19.5 g $hill^{-1}$ and 24.70 g $hill^{-1}$, respectively) were obtained from V_5 variety whereas minimum grain yield (12.76 g $hill^{-1}$) from V_2 and straw yield (13.79 g $hill^{-1}$) from V_4 was obtained. Arsenic had significant effect on growth and yield contributing parameters of rice and it was observed that higher doses of As showed lower performance on yield and higher As content in grain and straw. In terms of treatment combinations, V_5As_0 showed highest number of panicles $hill^{-1}$ (10.25), filled grain $panicle^{-1}$ (143.40), 1000 grain weight (28.63 g), grain yield $hill^{-1}$ (28.60 g) and straw yield $hill^{-1}$ (41.00 g) whereas V_3As_4 showed minimum results. In case of nutrient content, V_5As_0 gave maximum K (0.259%) content in grain but V_5As_4 showed maximum S content (0.197%) whereas in straw, the maximum P (0.215%), K (1.057%) and S content (0.330%) were recorded from V_1As_0, V_2As_0 and V_5As_4, respectively. Increased doses of As adversely affected the growth and yield of rice variety. But V_1 (BR-16) up took minimum As than other varieties and As content increased with increasing doses of it. In terms of treatment combinations, V_3As_4 gave maximum As content in straw (230 mg/kg) and this treatment combination showed no grain yield that is why the maximum As content in grain (270.00 mg/kg) was found from V_3As_3. In case of As uptake, V_2, V_3, V_4 and V_5 was increased with the increasing amount of As addition in soil but in case of variety V_1 was not that much increased like other varieties in grain and straw. So, it was found that low or no As was recommended for successful rice cultivation.

LIST OF CONTENTS

LIST OF CONTENTS (Cont'd)

LIST OF TABLES

LIST OF APPENDICES

ABBREVIATIONS AND ACRONYMS

AEZ	=	Agro-Ecological Zone
BBS	=	Bangladesh Bureau of Statistics
BCSRI	=	Bangladesh Council of Scientific Research Institute
cm	=	Centimeter
CV %	=	Percent Coefficient of Variation
DAS	=	Days After Sowing
DAT	=	Days After Transplanting
DMRT	=	Duncan's Multiple Range Test
et al.,	=	And others
e.g.	=	exempli gratia (L), for example
etc.	=	Etcetera
FAO	=	Food and Agricultural Organization
g	=	Gram (s)
i.e.	=	id est (L), that is
Kg	=	Kilogram (s)
LSD	=	Least Significant Difference
m^2	=	Meter squares
ml	=	MiliLitre
M.S.	=	Master of Science
No.	=	Number
SAU	=	Sher-e-Bangla Agricultural University
var.	=	Variety
^oC	=	Degree Celceous
%	=	Percentage
NaOH	=	Sodium hydroxide
GM	=	Geometric mean
mg	=	Miligram
P	=	Phosphorus
K	=	Potassium
Ca	=	Calcium
L	=	Litre
μg	=	Microgram
USA	=	United States of America
WHO	=	World Health Organization

CHAPTER I

INTRODUCTION

Rice (*Oryza sativa* L.) (2n=24) belongs to the family Gramineae (Poaceae). The genus *Oryza* contains 24 recognized species, of which 22 are wild species and two cultivated (*O. sativa* and *O. glaberrima*) (Singh *et al*., 2019). Rice is one of the three most important cereal food grain crop of the world and forms the staple diet of 2.7 billion people. India's share in the world rice production is 21.6%. India holds second and China holds the first position in rice production in the world (FAO, 2011). This caloric contribution varies from 29.5% for China to 72.0% for Bangladesh (Calpe and Prakash, 2007).

For being a staple food, its production is considered as the key factor for food security in Bangladesh. In the last 30 years, rice production has doubled with the development of high yielding, short duration, stress-tolerant, resource responsive and semi-dwarf varieties (Chowhan *et al*., 2021). Bangladesh ranks 4th in both area and production and 6th in per hectare production of rice (Sarkar *et al*., 2016). Rice occupied an area of 28,213 thousand acres in 2018-2019, with a yield of 36,603 thousand metric tons. Bangladesh's average rice output is roughly 3.21 t ha^{-1} (BBS, 2020), which is quite low when compared to other rice-growing nations such as China (7.056 t ha^{-1}), Japan (6.82 t ha^{-1}), and Korea (6.87 t ha^{-1}) (FAO, 2021).

In Bangladesh about 11422 hectare land is under rice cultivation with a production of 36,603 thousand metric tons. In 2019-2020, total land under rice cultivation in *Aus* season was 1095 thousand hectare which produced 2756 metric tons rice, accordingly 5562 and 4763 thousand hectares of land was in *Aman* and *Boro* season, respectively which produced 14204 and 19646 metric tons rice, respectively (BBS, 2020). Besides, based on the rice cultivation, Bangladesh is the 5th largest country of the world (BBS, 2016). According to the latest estimation made by BBS, per capita rice consumption is about 166 kg $year^{-1}$. Rice alone provides 76% of the calorie intake and 66% of total protein requirement and shares about 95% of the total cereal food supply (Alam *et al*., 2012).

Variety plays an important role for successful crop production. Significant variation was found due to varietal difference on yield of rice. HYV and hybrid rice varieties have 15-30% yield advantage over local inbred (Julfiquar *et al*., 2009; Abou Khalifa, 2009). Slow senescence and more strong photosynthetic capability of flag leaf, higher LAI at grain filling period and higher post heading-CGR plays major role for higher yield formation in modern rice. Greater biomass accumulation before heading and higher shoot reserve translocation are the decisive factors of higher yield in HYV rice (Haque *et al*., 2015).

Arsenic is a potent environmental pollutant that has caused one of the largest public health poisonings in the history of human civilization (Islam and Hossain 2019). Arsenic contamination of paddy soils irrigated with arsenic-rich groundwater in Bangladesh is well documented (Meharg and Rahman, 2003, Huq and Naidu, 2003) and the risk of soil contamination is higher in the areas where the groundwater has elevated arsenic (Meharg and Rahman 2003, Lu *et al*., 2009). The people of Bangladesh are not only drink the arsenic contaminated groundwater but also irrigate their crops. About 33% of total arable land of the country is under irrigation facilities. Irrigation is principally performed in dry season for boro rice cultivation. The agricultural soil of arsenic noncontaminated areas of Bangladesh contain 4 to 8 mg As kg^{-1} while that irrigated with arsenic contaminated groundwater, contain up to 83 mg As kg^{-1}. The maximum acceptable concentration of arsenic in agricultural soil is 20 mg kg^{-1} (Khan *et al*., 2010). Chowdhury *et al.* (2017) observed that the concentration of arsenic was higher in paddy soils compared to non-paddy soils, with soils irrigated with groundwater being higher in arsenic than those irrigated with surface water. At higher concentration, arsenic is toxic to most plants. It interferes with metabolic processes and inhibits plant growth and development through arsenic induced phytotoxicity. 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 *et al*., 2002a), decrease in plant height (Abedin *et al*., 2002b, Jahan *et al*., 2003), depress in tillering (Rahman *et al*., 2004), reduction in root growth (Abedin *et al*., 2002a), decrease in shoot growth (Khan *et al*., 2010), lower fruit and grain yield (Abedin *et al*., 2002b; Panaullah *et al*., 2009) and sometimes, leads to death (Howladar *et al*., 2019).

Therefore, keeping these points in view, the present investigation was undertaken to evaluate the effect of arsenic on the growth, yield and nutrient content in straw and grain of rice varieties in order to fulfill following objectives:

1. To study the effect of arsenic (As) on growth and yield of different rice varieties
2. To find out the suitable rice variety against As contamination on growth and yield of rice
3. To evaluate the effect of As on P, S, K and As content in grain and straw of rice

CHAPTER II

REVIEW OF LITERATURE

Varietal performance is one of the major reasons of yield reduction of rice. So, varieties are the most important factor needed to be considered in rice production. Again, arsenic (As) contamination in paddy soils is one of the most serious problems facing rice production in Asian countries. In Bangladesh, out of 64 districts, 61 districts are reported to have considerable levels of As in groundwater (BGS, 2001). Some of the important and informative works and research findings related to the variety and arsenic effect done at home and abroad have been reviewed under the following headings:

2.1 Effect of variety

Rahman *et al.* (2020) conducted an experiment to study the effects of crop establishment methods on the growth and yield of boro rice. The experiment comprised of methods of crop establishment *viz*., dry direct seeding, unpuddle transplanting, alternate wetting and drying (AWD) and puddle transplanting with rice cultivars *viz*., BRRI dhan28, BRRI dhan58, BRRI dhan74 and BRRI hybrid dhan3. Among the varieties the highest grain yield was obtain in BRRI hybrid dhan3 due to highest number of grains panicle^{-1} and 1000-grain weight. The highest grain yield (6.21 t ha^{-1}) was found in puddle transplanting with BRRI dhan28, while the lowest grain yield (2.80 t ha^{-1}) was produced in dry direct seeding with BRRI dhan28. Therefore, puddle transplanting with BRRI dhan28 might be recommended due to best physiological performance and obtaining highest grain yield of *boro* rice.

Khatun (2020) conducted a field experiment with six rice varieties to determine their growth and yield performance. Maximum number of filled spikelet observed in Binadhan-17 (164.89/ penical) and that was significantly different from other varieties. Percent of sterile spikelet was highest in BRRI dhan39

(12.9%) and that was statistically similar with Binadhan-16 (11.96%) and BRRI dhan33 (12.36%). Maximum 1000-seed weight was observed in Binadhan-17 (27.25 g). Highest grain yield was obtained from Binadhan-17 (6.13 t ha^{-1}) that was significantly different from other varieties. Lowest grain yield observed in BRRI dhan39 (4.49 t ha^{-1}) that was statistically similar to BRRI dhan33 (4.57 t ha^{-1}) and Binadhan-7 (4.86 t ha^{-1}).

Salam *et al*. (2019) carried out an experiment in Boro season in two experiment field with the objective of testing agronomic status and adaptability of four modern rice varieties in comparison with the popular mega variety BRRI dhan28. The varieties were BRRI dhan67, BRRI dhan81, BRRI dhan84 and BRRI dhan86. BRRI dhan28 was chosen as a control due to its wide acceptability among the farmers. It was observed that germination rate, plant height, effective tiller number were significantly higher in BRRI dhan67 than the other varieties but insignificant with BRRI dhan28 ($p \leq 0.05$). All the yield components spikelets per panicle, filled grain and 1000-grain weight were also significantly higher in BRRI dhan67 in compared to the other varieties. The highest grain yield was observed in BRRI dhan67 in both plots (7.89 and 7.29 t ha^{-1}). Harvest Index of BRRI dhan67 (51.02±4.2, 57.84±8.6)% indicated that this variety is the best yielder among the varieties.

Singh *et al*. (2019) conducted a field experiment to find the performance of 40 hybrids. The experiment finding revealed that the variety T38 (KR 38) has performed significantly better than all other hybrids *viz*; Germination (96%), plant height (115.14 cm), number of tillers per m^2 (381.00), panicle length (30.70 cm), number of filled grains $plant^{-1}$ (307.66), number of un-filled grains $plant^{-1}$ (22.56), test weight (29.89 g), grain yield $plant^{-1}$ (0.041 kg), grain yield (13.96 t ha^{-1}), straw yield (19.98 t ha^{-1}), biological yield (33.94 t ha^{-1}). However variety T35 (KR 35), T25 (KR 25), T36 (KR 36) and T16 (KR 16) were statistically at par with treatment T38 (KR 38) respectively.

Mahmood *et al*. (2019) conducted an experiment to evaluate the performance of hybrid *boro* rice (genotypes) in coastal area of Bangladesh. The experiment consisted of five rice varieties as treatment such as Arize Tej, Tea Sakti, Shathi and BRRI Dhan 28. Among the five varieties the Arize Tej gave the highest performance. From the above investigated results, it was observed that the Arize Tej was the most efficient for better growth and higher yield of hybrid boro rice genotypes grown in coastal area of Bangladesh.

Murshida *et al.* (2017) conducted an experiment with three varieties (cv. BRRI dhan28, BRRI dhan29 and Binadhan-14) and four water management systems to examine the effect of variety and water management system on the growth and yield performance of boro rice. At 100 DAT, the highest plant height, maximum number of tillers hill^{-1}, dry matter of shoot hill^{-1} and dry matter of root hill^{-1} were obtained from BRRI dhan29 and the lowest values were found in Binadhan-14. Variety had significant effect on all the crop characters under study except 1000-grain weight. The highest grain yield was obtained from BRRI dhan29 and the lowest value was recorded from Binadhan-14.

Mia (2018) carried out a field experiment consisted of three rice varieties *viz.* (i) V_1 = BRRI dhan45, (ii) V_2 = BRRI dhan63 and (iii) V_3 = BRRI hybrid dhan3 with four Zn application methods *viz.* (i) F_0 = No zinc application, (ii) F_1 = Zn application through root soaking, (iii) F_2 = Zn application through foliar spray and (iv) F_3 = Zn application through soil application. The result revealed that BRRI hybrid dhan3 produced the highest yield (8.47 t ha^{-1}) because of its higher panicle length (23.48 cm), grains panicle^{-1} (100.33), weight of 1000-seeds (29.33g), straw yield (9.10 t ha^{-1}) and the lowest unfilled grains panicle^{-1} (6.84).

Sarkar *et al.* (2016) conducted an experiment to check the performance of five hybrid rice varieties namely Shakti 2, Suborna 8, Tia, Aloron and BRRI hybrid dhan 2 where inbred BRRI dhan 33 was used as check variety. The highest TDM hill^{-1} (84.0 g), maximum leaf area hill^{-1} (1787cm^2), average highest CGR and RGR (40.63 g m^{-2} d^{-1} and 17.9 mg g^{-1} d^{-1}) were observed Tia and lowest TDM hill^{-1} (70.10 g), minimum leaf area hill^{-1} (1198 cm^2), average lowest CGR and RGR (27.26 g m^{-2} d^{-1} and 13.35 mg g^{-1} d^{-1}) were observed in BRRI dhan

33. These hybrid varieties also showed higher yield attributes *viz*. effective tillers hill^{-1}, 1000-grain weight, biological yield and harvest index (HI) over the inbred. The highest grain yield was achieved from Tia (7.82 t ha^{-1}), which was closely followed by Shakti 2 (7.65 t ha^{-1}). These two hybrid varieties produced 24.0% higher yield over the inbred BRRI dhan 33. Effective tillers hill^{-1} and higher filled grains panicle^{-1} mainly contributed to the higher grain yield of hybrid varieties.

Huang and Yan (2016) conducted a field test of 41 entries, 32 new hybrids, 8 male parents restore lines and 1 inbred variety. The only inbred Francis in this experiment was used as the check. Results showed that the yields of 7 hybrids were 25.7%-30.7% higher than check Francis. Hybrid 28s/BP23R had the highest yield, 10846.6 kg ha^{-1} and over check by 30.7%. The yield of hybrid 28s/PB-24, was 10628.9 kg ha^{-1} and over check by 28.1%. The yields of hybrid 28s/PB-22 and 33A/PB24 were 10549.8 and 10539.8 kg ha^{-1} and over check by 27.1% and 27.0%, respectively. The sterile lines 28s, 29s, 30s and 33A have good combinability. PB2, PB5, PB12, PB22, PB23, PB24, and PB25 are good restorers and most of their hybrids were over check more than 17%.

Haque *et al.* (2015) evaluated the two popular *indica* hybrids (BRRI hybrid dhan2 and Heera2) and one elite inbred (BRRI dhan45) rice varieties. Both hybrid varieties out yielded the inbred. However, the hybrids and inbred varieties exhibited statistically identical yield in late planting. Filled grain (%) declined significantly at delayed planting in the hybrids compared to elite inbred due to increased temperature impaired- inefficient transport of assimilates. Results suggest that greater remobilization of shoot reserves to the grain rendered higher yield of hybrid rice varieties.

Chamely *et al*. (2015) conducted an experiment with three varieties *viz*., BRRI dhan28 (V_1), BRRI dhan29 (V_2) and BRRI dhan45 (V_3); and five rates of nitrogen *viz*., control (N_0), 50 kg (N_1), 100 kg (N_2), 150 kg (N_3) and 200 kg (N_4) N ha^{-1} to study the effect of variety and rate of nitrogen on the performance of Boro rice. The growth analysis results indicate that the tallest plant (80.88 cm) and the highest number of total tillers hill^{-1} (13.80) were observed in BRRI dhan29 at 70 DATs and the highest total dry matter (66.41 g m^{-2}) was observed in BRRI dhan45. The shortest plant (78.15 cm) and the lowest number of tillers hill^{-1} (12.41) were recorded from BRRI dhan45 and the lowest dry matter (61.24 g) was observed in BRRI dhan29. The harvest data reveal that variety had significant effect on total tillers hill^{-1}, effective tillers hill^{-1}, non-effective tillers hill^{-1}, panicle length, grain yield, straw yield and harvest index. The highest grain yield (4.84 t ha^{-1}) was recorded from BRRI dhan29.

Jisan *et al*. (2014) carried out an experiment to examine the yield performance of some transplant aman rice varieties as influenced by different levels of nitrogen. The experiment consisted of four varieties *viz*. BRRI dhan49, BRRI dhan52, BRRI dhan56, BRRI dhan57. Among the varieties, BRRI dhan52 produced the tallest plant (117.20 cm), highest number of effective tillers hill^{-1} (11.28), grains panicle^{-1} (121.5) and 1000-grain weight (23.65 g) whereas the lowest values of these parameters were produced by BRRI dhan57. Highest grain yield (5.69 t ha^{-1}) was obtained from BRRI dhan52 followed by BRRI dhan49 (5.15 t ha^{-1}) and the lowest one (4.25 t ha^{-1}) was obtained from BRRI dhan57.

Shiyam *et al.* (2014) conducted an experiment to evaluate the performance of four Chinese hybrid rice varieties where it was showed comparative superiority of FARO 15 to the hybrids in all growth and yield components assessed. FARO 15 was taller (140 cm) with more productive tillers (11.0), higher spikelets plant^{-1} (166.0), higher filled grains panicle^{-1} (156.17), higher filled grains (92.17%), highest 100-grain weight of 2.63 g and the higher paddy yield (5.021 t ha^{-1}) than others. Despite the comparative poor performance of the hybrids, Xudao151 came close to FARO 15 with grain yield of 2.987 t ha^{-1}.

Sarkar *et al*. (2014) conducted an experiment to study the yield and quality of aromatic fine rice as affected by variety and nutrient management. The experiment comprised three aromatic fine rice varieties *viz*. BRRI dhan34, BRRI dhan37 and BRRI dhan38. The tallest plant (142.7 cm), the highest number of effective tillers hill^{-1} (10.02), number of grains panicle^{-1} (152.3), panicle length (22.71cm), 1000-grain weight (15.55g) and grain yield (3.71 t ha^{-1}) were recorded in BRRI dhan34.

Masum *et al*. (2014) conducted a study to investigate the influence of population density on growth and yield of inbred and hybrid boro rice. The treatments consisted of four varieties *viz*., BRRI Dhan 28, BRRI dhan 29, BRRI Hybrid Dhan 2 and ACI Hybrid Dhan 2 and four population density *viz*. 1, 2, 3 and 4 seedlings hill^{-1}. The effect of variety, population density hill^{-1} and their interaction showed significant variation in respect of yield contributing parameters and yield. ACI Hybrid Dhan 2, 2 seedlings hill^{-1} and their combination increased yield attributing parameters, grain and straw yield for *boro* season.

Islam *et al*. (2013) conducted an experiment to study the yield and quality of aromatic fine rice as affected by variety and nutrient management. The experiment comprised three aromatic fine rice varieties viz. BRRI dhan34, BRRI dhan37 and BRRI dhan38. The tallest plant (142.7 cm), the highest number of effective tillers hill^{-1} (10.02), number of grains panicle^{-1} (152.3), panicle length (22.71cm), 1000-grain weight (15.55g) and grain yield (3.71 t ha^{-1}) were recorded in BRRI dhan34. The highest grain protein content (8.17%) was found in BRRI dhan34 whereas the highest aroma was found in BRRI dhan37 and BRRI dhan38.

Haque *et al.* (2013) conducted an experiment to evaluate some physiological traits and yield of three hybrid rice varieties (BRRI hybrid dhan 2, Heera 2, and Tia) in comparison to BRRI dhan48 in *Aus* season. Compared to BRRI dhan 48, hybrid varieties accumulated greater shoot dry matter at anthesis, higher flag leaf chlorophyll at 2, 9, 16 and 23 days after flowering (DAF), flag leaf photosynthetic rate at 2 DAF and longer panicles. Heera 2 and BRRI hybrid dhan 2 maintained significantly higher chlorophyll a, b ratio over Tia and BRRI dhan 48 at 2, 9, 16 and 23 DAF in their flag leaf. Shoot reserve remobilization to grain exhibited higher degree of sensitivity to rising of minimum temperature in the studied hybrids compared to the inbred. Inefficient photosynthetic activities of flag leaf and poor shoot reserve translocation to grain resulted poor grain filling percentage in the test hybrids. Consequently the studied hybrids showed significantly lower grain yield (36.7%) as compared to inbred BRRI dhan48, irrespective of planting date in *Aus* season.

Sritharan and Vijayalakshmi (2012) evaluated the physiological traits and yield potential of six rice cultivars *viz.,* PMK 3, ASD 16, MDU 3, MDU 5, CO 47 and RM 96019. The plant height, total dry matter production and the growth attributes like leaf area index, crop growth rate and R:S ratio were found to be higher in the rice cultivar PMK 3 that showed significant correlation with yield. Yield and yield components like number of productive tillers, fertility co-efficient, panicle harvest index, grain weight and harvest index were found to be higher in PMK 3.

Abou-Khalif (2009) conducted an experiment for physiological evaluation of some hybrid rice varieties in different sowing dates. Four hybrid rice H_1, H_2, GZ 6522 and GZ 6903 were used. Results indicated that H1 hybrid rice variety surpassed other varieties for number of tillers m^{-2}, chlorophyll content, leaf area index, sink capacity, number of grains panicle^{-1}, panicle length (cm), 1000-grain weight (g), number of panicles m^{-1}, panicle weight (g) and grain yield (ton ha^{-1}).

Islam *et al*. (2009) conducted a pot experiments with Hybrid variety Sonarbangla-1 and inbred modern variety BRRI dhan 31 and BRRI hybrid dhan-l to compare the growth and yield behavior of hybrid and inbred rice varieties under controlled condition. BRRI dhan 3l had about 10-15% higher plant height, very similar tillers hill^{-1}, 15-25% higher leaf area compared to Sonarbangla-1. Sonarbangla-1 had about 40% higher dry matter production at 25 DAT but had very similar dry matter production at 50 and 75 DAT, 4-11% higher rooting depth at all DATs, about 22% higher root dry weight at 25 DAT, but 5-10% lower root dry weight at 50 and 75 DAT compared to BRRI dhan31. The photosynthetic rate was higher (20 μ mol m^{-2} sec^{-1}) in BRRI dhan3l at 35 DAT (maximum tillering stage) but at 65 DAT, Sonarbangla-l had higher photosynthetic rate of 19.5 μ mol m^{-2} sec^{-1}. BRRI dhan3l had higher panicles $plant^{-1}$ than Sonarbangla-1, but Sonarbangla-1 had higher number of grains $panicle^{-1}$, 1000-grain weight and grain yield than BRRI dhan 31.

Razzaque *et al.* (2009) studied on salt tolerant genotypes PVSB9, PVSB19, PNR381, PNR519, Iratom24 and salt sensitive genotype NS15 along with one standard check salt tolerant rice cultivar Pokkali. The different morphological characters studied include plant height, total number of tillers, Root Dry Weight (RDW), Shoot Dry Weight (SDW) and Total Dry Matter (TDM) content of the selected rice genotypes in view to evaluate their response at different salinity levels. The genotypes Pokkali, PVSB9, PVSB19 showed significantly higher values and the lowest value of all these characters were recorded in NS15.

Kamal (2007) conducted an experiment to determine the effect of variety and planting method on the yield of *boro* rice. Four varieties *viz*., BINADHAN-5, BINADHAN-6, BRRI dhan28 and BRRI dhan29, and three planting methods *viz*., transplanting method, drum seeding and line sowing were included as experimental treatments. BINADHAN-5 produced the highest grain yield (4.61 t ha^{-1}) which was the consequence of highest number of effective tillers $hill^{-1}$ and highest number of grains $panicle^{-1}$. In case of effect of interaction of BINADHAN-5 and transplanting method produced the highest grain (5.20 t ha^{-1}) yield.

Chowdhury *et al*. (2005) conducted an experiment to study their effect on the yield and yield components of rice varieties BR23 and Pajam with 2, 4 and 6 seedlings $hill^{-1}$ during the *Aman* season. They reported that the cv. BR23 showed superior performance over Pajam in respect of yield and yield contributing characters i.e. number of productive tillers $hill^{-1}$, length of panicle, l000-grain weight, grain yield and straw yield. On the other hand, the cultivar

Pajam produced significantly the tallest plant, total number of grains panicle^{-1}, number of filled grains panicle^{-1} and number of unfilled grains panicle^{-1}.

Murthy *et al.* (2004) conducted an experiment with six varieties of rice genotypes Mangala, Madhu, J-13, Sattari, CR 666-16 and Mukti and observed that Mukti (5268 kg ha^{-1}) out yielded the other genotypes and recorded the maximum number of filled grains and had lower spikelet sterility (25.85%) compared to the others.

Sumit *et al.* (2004) worked with newly released four commercial rice hybrids (DRRH 1, PHB 71, Pro-Agro 6201, KHR 2, ADTHR 1, UPHR 1010 and Pant Sankar dhan1) and two high yielding cultivars (HYV) as controls (Pant dhan 4 and Pant dhan 12) and reported that KHR 2 gave the best yield (7.0 t/ha) among them.

Anwar and Begum (2004) reported that time of tiller separation of rice significantly influenced plant height, total number of tiller hill^{-1}, number of bearing tillers and panicle length but grain and straw yields were unaffected. Therefore, Sonarbangla-1 appeared to be tolerant to tiller separation and separation should be done between 20 to 40 DAT without hampering grain yield.

Siddiquee *et al.* (2002) conducted a study to evaluate the difference between hybrid and inbred rice in respect of their growth duration, yield and quality. Among the varieties, Aalok 6201 had the highest grain yield followed by BRRI dhan29 and IR68877H but statistically they were similar. BRRI dhan28 had the lowest grain yield, which was statistically similar to Loknath503. BRRI dhan28 and the tested hybrid rice had lower growth duration than BRRI dhan29.

Rahman *et al.* (2002) carried out an experiment with 4 varieties of transplant *Aman* rice *viz.,* BR1l, BR22, BR23 and Tuishimala and 6 structural arrangement of rows *viz.,* 25 cm + 25 cm, 30 cm + 20 cm, 35 cm + 1 5 cm, 40 cm + 10 cm) 45 cm + 05 cm and haphazard planting at the Agronomy Field Laboratory, Bangladesh Agricultural University, Mymensingh. Thousand grains weight and grain yield were highest in BR23 and these were lowest in Tulshirnaia.

Bhowmick and Nayak (2000) conducted an experiment with two hybrids (CNHR2 and CNHR3) and two high yielding varieties (IR36 and IR64) of rice and five levels of nitrogenous fertilizers. They observed that CNHR2 produced more number of productive tillers (413.4 m^{-2}) and filled grains $panicle^{-1}$ (111.0) than other varieties, whereas IR36 gave the highest 1000- grain weight (21.07 g) and number of panicles m^{-} than other tested varieties.

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.

Julfiquar *et al.* (1998) evaluated 23 hybrids along with three standard checks during *Boro* season 1994-95 as preliminary yield trial at Gazipur and 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 *Boro* season of 1995-96. Two hybrids out yielded the check variety of same duration by more than 1 t ha^{-1}.

2.2 Occurrence of arsenic in soils of different regions

Patel *et al*. (2016) studied the arsenic concentration in Kaudikasa village of Ambagarh Chowki block, Rajnandgoan Chhattisgarh. They collected 20 ground water irrigation sources and 20 field soil samples and analyzed for arsenic content. They found that arsenic concentration in water varied from 34 to 90 mg L^{-1}. While in soil concentration of arsenic was ranged from 44 – 270 mg kg^{-1} with mean value 126 ± 28 mg kg^{-1}. The arsenic concentration in the soil of studied area was found to be higher than reported in other regions of the country and world (Brammer, 2009).

According to Sahoo and Mukherjee (2014) arsenic is naturally present in the soil. Its average concentration in non-contaminated soils is 5 mg kg^{-1}; however, the concentration can increase up to 27,000 mg kg^{-1} or more than that in contaminated soil. Arsenic concentration in paddy field occurs naturally via. weathring processes, and/or by anthropogenic activities such as mining, pesticides use, fertilizer application and irrigation with arsenic contaminated groundwater. In the long term, use of this arsenic contaminated irrigation water can cause elevated arsenic concentration in soil and crops.

Ahsan and Del Valls (2011) studied the arsenic concentration of soil in different locations of Bangladesh and reported that arsenic concentration in noncontaminated soils range from 0.1 to 10 mg kg^{-1}. However, the arsenic content in some parts of Bangladesh soils are more than 30 mg kg^{-1}. In Srinagar thana, Bangaldesh, arsenic concentration in top soil layer of paddy field varied 7 to 27.5 mg kg^{-1} whereas at the Sonargaon area of Bangladesh arsenic concentration in the top soil layer of paddy field varied from about 3.2 to 19 mg kg^{-1}. Mean arsenic concentration in soils of two up-zilas (Daudkandi and Begumganj) of Bangladesh was 15.676 ppm which was 1.5 times higher than worldwide natural concentration of 10 ppm. On other hand, in Dhamrai region the level of soil arsenic is 6.10 mg kg^{-1} which is lower than world limit.

Hue (2010) carried out a field study to study the total arsenic content in some soil orders, sediments and stream waters of Hawaii. According to him, arsenic levels in Hawaii soils are quite variable, ranging from 15 to 950 mg kg^{-1}. Andisols contains more arsenic (mean 163 mg kg^{-1}) than the other soil orders followed by Oxisols (mean 72 mg kg^{-1}) and Ultisols (mean 60 mg kg^{-1}). He also reported that arsenic level in some stream waters are likely relaetd to arsenic impacted soil.

The impact of arsenic contaminated irrigation water on soil arsenic content and rice productivity was studied by Panaullah *et al*. (2009) in the commond area of a single tubewell in Faridpur district, Bangladesh. After 16-17 years of use of the tubewell, a spatially variable build up of arsenic and other chemical constituents of the water (Fe, Mn and P) was observed over the command area, with soil-arsenic levels ranging from about 10 to 70 mg kg^{-1}. A simple mass balance calculation using the current water arsenic level of 0.13 mg L^{-1} suggested that 96 percent of the added arsenic was retained in the soil.

Ali *et al*. (2005) studied the arsenic profile of the rice field and canal soil samples collected from Srinagar and Sonargoan site of Bangladesh which was irrigated with arsenic rich irrigation water. They found that arsenic accumulation is the canal samples were relatively high compared to the field samples. Field samples of Srinagar had mean arsenic concentration from 14.5 mg kg^{-1} in top layer and 4.9 mg kg^{-1} in sub soil layer. At the Sonargoan site, the mean arsenic concentration in the top soil layer was 8.9 mg kg^{-1}, while that at the bottom layer was 6.07 mg kg^{-1}. The higher accumulation of arsenic at the Srinagar site is probably partly related to higher arsenic concentration in the irrigation water in Srinagar site.

2.3 Status of arsenic in rice plant

2.3.1 Bioaccumulation and distribution of arsenic in rice plant

Patel *et al*. (2016) studied the Distribution of arsenic in rice grain, husk, straw and root. The concentration of arsenic in the rice grain, husk, straw and root (n = 20) was ranged from 0.17 - 0.72, 0.40 - 1.58, 2.5 - 5.9 and 204 - 354 mg kg^{-1} with mean value of 0.47 ± 0.07, 0.83 ± 0.15, 4.2 ± 0.5 and 276 ± 21 mg kg^{-1}, respectively. The arsenic content in husk was found to be higher than the rice grain, may be due to external contamination from the environment. The high yield rice varieties i.e. Kalinga, IR-64, G. Gurmatia, Shyamla, Ek Hazar Das, M2, etc. were found to be more sensitive to the As-accumulation. The concentration of arsenic in the rice of the studied area was found to be higher than reported in the other region of the country and World (Jayasumana *et al*. 2015).

Kabir *et al*. (2016) performed a study in shallow tube well command areas in Faridpur, Bangladesh, where both soil and irrigation water arsenic was high. Both arsenic contaminated irrigation water and the soils were responsible for accumulation of arsenic in rice straw, husk, and grain. The accumulation of arsenic was higher in water followed by soil, straw, husk, and grain. Arsenic concentration varied widely within command areas. The extent and propensity of arsenic concentration were higher in areas where high concentration of arsenic existed in groundwater and soils. The average arsenic content in grain was 0.08–0.45 mg kg^{-1} while in groundwater arsenic level it ranged from 138.0 to 191.3 ppb.

Manirul *et al*. (2016) conducted an experiment at the Horticultural Farm, Sher-e-Bangla Agricultural University, Dhaka, Bangladesh to evaluate the arsenic accumulation by the rice plant during july 2012 following CRD with three replications each. Rice plant (BRRI dhan-29) grown at soil treated with different arsenic concentration viz. A_0: 0 ppm; A_1: 500 ppm; A_2: 1000 ppm and A_3: 2000 ppm. Numbers of leaves, plant height, leaf area, tiller numbers, number of panicle, plant biomass and grain biomass were decreased significantly while the arsenic contamination level in soil increased. Rice plant biomass accumulated 206.0, 195.0 82.9, 54.5 ppm and grain accumulated 61.6, 36.5, 29.9, 14.9 ppm arsenic respectively from 2000, 1000, 500 and 0 ppm arsenic contaminated soil.

Biswas *et al*. (2014) studied the arsenic concentration in rice plant parts grown in different season at West Bengal. The results showed that median arsenic concentration in rice starw grown in summer season was 0.96 mg kg^{-1}, while in winter it was 0.85. Similarly, the median arsenic concentration in rice husk was 0.75 mg kg1 and 0.72 mg kg^{-1} respectively, in summer and winter season. In rice grain arsenic concentration ranged from 0.23 to 0.61 mg kg^{-1} in the summer and 0.16 to 0.38 mg kg^{-1} in winter.

Williams *et al*. (2006) studied the arsenic level in ground water and rice grains in different districts of Bangladesh. They reported that arsenic concentration in groundwater was ranges from 3 to 366 ppb and rice obtained from districts with more contaminated with water (>50 ppb) were more elevated with arsenic than rice from less contaminated districts (<50ppb). They also found that arsenic content in Boro rice (0.15 to 0.38 mg kg^{-1}) could be 1.5 times than higher than the Aman rice (0.11 to 0.32 mg kg^{-1}).

Ali *et al*. (2005) analyzed the arsenic concentration in paddy plants collected from Srinagar and Sonargoan site of Bangladesh which were irrigated with arsenic rich irrigation water. They found that plants roots accumulated the higher amount of arsenic followed by stem and then grains. Arsenic concentration in roots of rice plant samples collected from the Srinagar site varied from 2.81 to 16.8 mg kg^{-1} while that in the rice grain varied from 0.05 to 1.52 mg kg^{-1}. For the samples collected from the Srinagar site, arsenic in root varied from 2.88 to 26.1 mg kg^{-1}, while that in the rice grain varied from 0.05 to 1.23 mg kg^{-1}.

Islam *et al*. (2004) carried out a pot culture experiment at Bangladesh to see the effects of arsenic irrigation water on Boro rice and then residual effect on Aman rice. There were eight treatments consisting of control, 0.10, 0.25, 0.50, 0.75, 1.00, 1.50 and 2.00 ppm arsenic added through irrigation water. After the harvest of Boro rice, Aman rice (cv. BRRI dhan 33) was grown in the same pot with monsson rain. Nutreint such as N, P, K and S @ 100, 25, 40 and 25 ppm respectively were applied in both the season. Excluding the 0.25 ppm of arsenic concentration in irrigation water, further doses significantly depressed the plant growth, yield and yield components. The concentartion of arsenic in grain and straw in Boro rice increased significantly with increasing arsenic concentration in irrigation water. Application of arsenic added to the first crop also had significant residual effetc on the second crop in respect of growth and yield components. Arsenic concentration were always higher in Boro rice grain and straw compared to Aman rice.

2.3.2 Varietal effect in bioaccumulation of arsenic in rice plant

It is established by various studies that As accumulation in rice grains differs with the rice varieties (Williams *et al*., 2007; Rahman *et al*., 2007; Bhattacharya *et al*., 2010; Norton *et al*., 2010). Nearly 20 fold variation in arsenic accumulation capacity in grain was found in more than 1700 rice varieties investigated worldwide (Pinson *et al*., 2015). Based on preliminary shreds of evidence from the experiment of Bhattacharyya *et al*. (2012), few cultivars, namely, Gobindabhog, Badshabhog, Satika, Choli 60, Satika, Khitish, and Satabdi were identified as As-excluder (low accumulator) as far as As-content in the grain is concerned. Whereas, IR-36, IR 50, White Minikit, and Red Minikit were reported to be efficient accumulators of arsenic (0.24–0.31 mg kg^{-1}) as compared to Nayanmani, Jaya, Ratna, Ganga-kaveri, and Lal Sarna (0.14–0.20 mg kg^{-1}) (Bhattacharya *et al*. 2010). Distribution of As in different plant parts is an important aspect, which determines the impact of As accumulation to a great extent. According to Patra *et al*. (2016), the concentration of As in grain, husk, straw, and root of 20 popular rice varieties of West Bengal varied from 0.3±0.02 to 0.5±0.13, 0.63±0.19 to 0.98±0.21, 0.56±0.06 to 1.4±0.57 and 20.24±1.99 to 29.79±0.81 mg kg^{-1}, respectively, where Gontra Bidhan-1 and CN 1719-1 were identified as the highest and lowest accumulators of As in grain, respectively. Translocation of arsenic is generally higher in the high yielding varieties (0.194–0.393) compared to that in the traditional rice varieties (0.099– 0.161) (Bhattacharya *et al*., 2010).

Singh *et al*. (2014) carried out an experiment to study the arsenic accumulation in rice genotype in India. All rice genotype seeds were germinated and grown in hydroponic medium in the presence of two concentrations of arsenic 500 uM and 250 uM with control. The results revealed that arsenic concentration in all genotypes increased significantly with the increase in arsenic treatment.

According to results Ndr359 genotype accumulated highest concentration of arsenic and Swarn sub-1 accumulated low arsenic.

A green pot experiment was conducted by Bhattacharya *et al*. (2009) on four widely cultivated variety of rice (namely Ratna, IR 50, Gangakaveri and Tulsa) of West Bengal to investigate the uptake and distribution of arsenic phytotoxicity in different fractions of rice plant. 5.0, 10.0, 20.0, 30.0 and 40.0 mg kg^{-1} dry weight of arsenic dosing was applied to study the arsenic phyto toxicity in rice. The result showed that the uptake of arsenic in rice plant varied with the different rice varieties. With the increasing concentration of arsenic added to pot soil, the accumulation of arsenic in rice grain was found to increase, but on necessarily in the same rate. The high yielding rice varieties were found to be higher accumulator of arsenic as compared to the studied local rice variety, Tulsa. Irrespective of rice varieties, arsenic accumulated mostly in the root of the rice plant, followed by accumulation in the straw, husk and grain parts. In most of the rice varieties, the accumulation of arsenic in the rice grain was found to exceed the WHO recommendation permissible limit in rice (1 mg kg^{-1} of dry weight) at 20.0 mg kg^{-1} of arsenic dosing in pot.

Huq *et al*. (2006) studied the arsenic content in various rice varieties collected from different districts of Bangladesh. They found that rice variety BR-28 had the maximum arsenic content ranged from 0.1 to 1.8 mg kg^{-1} (mean, 0.81 mg kg^{-1}), depends on the arsenic content in irrigation water and soil. While the average arsenic content of BR-14, IRRI-532 and BR-76 were 0.24, 0.21 and 0.19 mg kg^{-1} of dry weight, respectively.

Alam and Rahman (2003) selected 21 field sites in Comilla district Bangladesh for analysis of arsenic content in groundwater, soil and rice plant samples. Arsenic content in irrigation groundwater was varied from 62 to 364 ppb while in soil it was ranged from 2.0 to 12.0 mg kg^{-1}. They also reported that arsenic accumulation in rice varies from variety to variety. Arsenic accumulation in rice Purbachi variety was more than the other varieties such as BR 28, BR 29, BR 14 and IR 50. Arsenic was detected in all the grain samples of Purbachi variety of rice tested (0.022 to 0.094 mg kg^{-1}) and in few samples of BR 28 and BR 29 varieties. But no arsenic accumulation was found in the grain samples of BR 14 and IR 50 rice varieties. Root samples were found to have the highest accumulation of arsenic.

2.4 Toxic effect of arsenic in rice

Jahan *et al*. (2020) conducted a study to elucidate the effect of soil As contamination on rice and its management through water regimes. Two water management practices *viz*. alternate wetting and drying (AWD) and continuous flooding (CF) in combination with different concentration of AS (0, 20 and 40 mg kg^{-1}) were initiated as treatment using BRRI dhan47 rice variety. Pots were filled with 10 kg soil with background soil As 3.73 mg kg^{-1}. Results showed that As contamination significantly reduced growth and yield of rice. The grain and straw arsenic concentrations were 0.55 and 17.31 mg kg^{-1}, respectively in soil treated with As 40 mg kg^{-1} while 0.18 mg kg^{-1} grain As and 2.41 mg kg^{-1} straw As were found in As 0 mg kg^{-1} treatment.

Howladar *et al*. (2019) carried out a pot experiment with arsenic (As) *viz*. 0, 0.1, 1 and 2 mg L^{-1} as sodium arsenite and phosphorus *viz*, 0, 15 and 30 µg L^{-1} as ammonium dihydrogen phosphate to evaluate their effects on dry matter yield and nutrients concentration in rice plants (*Oryza sativa* L.) in the net house. Arsenic toxicity caused more damage to root than to shoot. As reduced plant height and dry matter yields but lower level increased the same significantly. A maximum diminution of 26.70% shoot weight and 32.30% root weights were observed where 2 mg L^{-1}As and 0 µg L^{-1} P were applied. The lowest concentration of most of the nutrients were found at 2 mg L^{-1} As and 0 µg L^{-1} P.

Alam and Islam (2011) reported that arsenic contamination resulted in less tillering, shorter plants, uneven plant growth and finally, decreased yield. Land degradation due to continued use of arsenic contaminated irrigation was reported. Due to the application of extra fertilizer and labour, the cost of modern Boro rice production in the more arsenic contaminated plots was 5% higher compared to that in less contaminated plots. Yields of MV (Modern variety) boro rice in more contaminated plots were significantly low resulting in lower gross return and profitability.

Investigation of arsenic level in rice grains from Bangladesh was done by Meharg and Rahman (2002). Three rice grain samples were grown in the regions where arsenic is build up in the soil had high arsenic concentrations having levels above 1.7 µg g^{-1}. These typical grain arsenic levels contributed considerably to 0.1 mg L^{-1} arsenic. Arsenic accumulation in rice can be further elevated in rice growing on arsenic contaminated soils, potentially increasing the risk of arsenic exposure of the Bangladesh population.

Montenegro and Mejia (2001) conducted field and greenhouse experiments in rice to investigate the effect of irrigation water containing Cd and As on soils and on the physiological parameters of rice growth, the amount of As accrued in different parts of rice plants, and the yield and other aspects of rice crop. The results showed that when none of the element was present in the irrigation waters rice reached its maximum height. Increasing As content of irrigation waters reduced panicles $hill^{-1}$, panicle length and grains per panicle. Significant yield reduction was found when irrigation waters contained the highest concentration of Cd and As. Accumulation of Cd and As was increased in rice plants with the increase of both elements in the irrigation waters.

Dilday *et al*. (2000) reported that physiological disorder of rice called straighthead is influenced by arsenic which results in blank florets and distorted lemma and palea and in extreme cases, can result in almost a total yield loss. Twelve cultivars were grown in the southern United States among them ten cultivars are more popular and used to observe arsenic responses (i.e. monosodium methanearsenate, MSMA). The most susceptible cultivars to straighthead were Cocodrie, Kaybonnet, Bengal, and Mars at the rate of 6 lb acre^{-1} level of MSMA based on a scale of low to high susceptibility. Arsenic (As) tolerant cultivars also showed strong tolerance against straight head.

CHAPTER III

MATERIALS AND METHODS

The experiment was conducted to find out the effect of arsenic on the growth, yield and nutrient content in straw and grain of rice varieties. This chapter deals with a brief description on experimental site, climate, soil, land preparation, layout, experimental design, intercultural operations, data recording and their analyses. The details of experimental materials and methods are described below:

3.1 Site description

The experiment was conducted at the Net house of Agro-environmental Chemistry Laboratory under the Department of Agricultural Chemistry, Sher-e-Bangla Agricultural University, Dhaka. The site belongs to Agro-ecological zone of Modhupur Tract, AEZ-28. The land area is situated at 23°41′ N latitude and 90°22′ E longitude at an altitude of 8.6 meter above sea level. The experimental site is shown in the AEZ map of Bangladesh in Appendix I.

3.2 Climate

The experimental area is under the sub-tropical climate that is characterized by high temperature, high humidity and heavy rainfall with occasional gusty winds in kharif season (April-September) and less rainfall associated with moderately low temperature during the Rabi season (October-March). The weather data during the study period of the experimental site is shown in Appendix II.

3.3 Soil

The soil of the experimental area that used in the pot for rice grown belongs to “The Modhupur Tract”, AEZ 28. Pot soil was silty clay in texture. Soil pH was 5.6 and has organic carbon 0.45%.

3.4 Treatment of the experiment

The experiment consisted of two factors:

Factor A: Variety – 5 varieties of rice

1. V_1 = BR-16
2. V_2 = BRRI dhan-28
3. V_3 = BRRI dhan-29
4. V_4 = BRRI dhan-55
5. V_5 = BRRI hybrid dhan-5

Factor B: Arsenic (As) doses – 5 doses

1. As_0 = Control (No arsenic)
2. As_1 = 2 mg As kg^{-1} soil
3. As_2 = 10 mg As kg^{-1} soil
4. As_3 = 20 mg As kg^{-1} soil
5. As_4 = 40 mg As kg^{-1} soil

There were total 25 (5×5) combination as a whole *viz.*, V_1As_0, V_1As_1, V_1As_2, V_1As_3, V_1As_4, V_2As_0, V_2As_1, V_2As_2, V_2As_3, V_2As_4, V_3As_0, V_3As_1, V_3As_2, V_3As_3, V_3As_4, V_4As_0, V_4As_1, V_4As_2, V_4As_3, V_4As_4, V_5As_0, V_5As_1, V_5As_2, V_5As_3 and V_5As_4.

3.5 Experimental design and layout

The two factors experiment was laid out in Completely Randomized Design (CRD) with four replications. 25 treatment combinations were assigned randomly with four replications. The total number of unit pot was 100 (25×4). One pot was considered as each replication.

3.6 Growing of crops

3.6.1 Seed collection and sprouting

This seeds of each variety were obtained from the Bangladesh Rice Research Institute (BRRI) in Gazipur, Bangladesh. Clean seeds were soaked in water in a pail for 24 hours to produce seedlings. The imbibed seeds were then removed from the water and placed in gunny bags. After 48 hours, the seeds sprouted and were ready for planting in the seed bed in 72 hours.

3.6.2 Preparation of nursery bed and seed sowing

As per BRRI recommendation seedbed was prepared with 1 m wide adding nutrients as per the requirements of soil. Sprouted seeds were sown in the seed bed on November, 2020 in order to transplant the seedlings in the main field.

3.6.3 Raising of seedlings

The sprouted seeds were sown on beds as uniformly as possible at 30th November, 2020. Irrigation was gently provided to the bed when needed. No fertilizer was used in the nursery bed.

3.6.4 Pot preparation

The pot for the experiment was filled up with soil at 18th December, 2020. Weeds and stubble were removed from the soil and finally obtained a desirable condition of soil for transplanting of seedlings.

3.6.5 Fertilizers and As application

The fertilizers N, P, K, S and B in the form of Urea, TSP, MoP, gypsum and borax, respectively. The following doses of fertilizer were applied for cultivation of crop as recommended by BRRI, 2020.

Fertilizer	Recommended doses ha^{-1}
Urea	150 kg
TSP	100 kg
MOP	100 kg
Gypsum	60 kg

The fertilizers N, P, K, S, Zn and B in the form of urea, TSP, MoP, gypsum, zinc sulphate and borax, respectively were applied. The entire amount of TSP, MoP, gypsum, zinc sulphate and borax were applied during the final pot preparation. Arsenic was applied to the soil during final pot preparation according to the treatment. Urea was applied in three equal installments at after recovery, tillering and before panicle initiation. Arsenic was applied to the soil during final pot preparation according to treatments.

3.6.6 Uprooting and transplanting of seedling

Seedlings were carefully uprooted from the nursery bed and transplanted in the pot on 4th January, 2021. One seedling was transplanted in each hill and two hills were in each pot. After one week of transplanting all pots were checked for any missing hill, which was filled up with extra seedlings of the same source whenever required.

3.7 Intercultural operations

Intercultural operations were done to ensure normal growth of the crop. Plant protection measures were followed as and when necessary. The following intercultural operations were done.

3.7.1 Irrigation and drainage

Irrigation was given to maintain a consistent level of standing water up to 6 cm during the early phases of seedling establishment, and thereafter the quantity of drying and wetting was maintained throughout the whole vegetative period. There was no water stress during the reproductive and ripening phases.

3.7.2 Weeding

Weeding was done to keep the plots weed-free, which resulted in enhanced seedling growth and development. The weeds were mechanically pulled at 20 DAT (days after transplanting) and 40 days after transplanting (DAT).

3.7.3 Insect and pest control

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

3.8 Harvesting, threshing and cleaning

Depending on the variety, the crop was harvested after 80-90% of the grains had become straw in colour. The harvested crop was wrapped individually, correctly labelled, and sent to the threshing floor. For each pot, the grains were dried, washed, and weighed. The grains were cleaned and finally the weight was adjusted to a moisture content of 13%. The straw was sun dried and the yields of grain and straw pot^{-1} were recorded.

3.9 Recording of data

The following data were collected during the study period:

3.9.1. Growth characters

1. Plant height (cm)
2. Number of leaves hill^{-1}
3. Leaf length (cm)
4. Number of total tillers hill^{-1}
5. Number of effective tillers hill^{-1}

3.9.2 Yield contributing parameters

1. Panicle length (cm)
2. Number of panicles hill^{-1}
3. Number of grain panicle^{-1}
4. Number of filled grains panicle^{-1}
5. Number of unfilled grains panicle^{-1}
6. Dry weight of straw hill^{-1} (g)

3.9.3 Yield parameters

1. 1000 grain weight (g)
2. Grain yield hill^{-1} (g)
3. Straw yield hill^{-1} (g)

3.9.4 Nutrient content

1. P, K, S, As content in grain
2. P, K, S, As content in straw

3.10 Procedures of recording data

A brief outline of the data recording procedure is given below:

3.10.1 Plant height

The height of plant was recorded in centimeter (cm) at the time of harvest. The height was measured from the ground level to the tip of the plant.

3. 10.2 Number of leaves hill^{-1}

The number of leaves hill^{-1} was recorded at the time of harvest by counting total leaves in a hill.

3. 10.3 Leaf length

Leaf length hill^{-1} was measured in centimeter (cm) using meter scale. The length was measured from the base to the tip of the leaf.

3. 10.4 Number of total tillers hill^{-1}

The number of tillers hill^{-1} was recorded at the time of harvest by counting total tillers in a hill.

3. 10.5 Number of effective and ineffective 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. 10.6 Panicle length (cm)

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

3.10.7 Number of panicles hill^{-1}

The number of total panicle per pot were counted.

3. 10.8 Number of grains panicle^{-1}

The total number of grains was collected randomly from selected 5 panicles of a hill and then average number of grains panicle^{-1} was recorded.

3.10.9 Number of filled grains panicle^{-1}

The total number of filled grains was collected randomly from selected 5 panicles of a hill and then average number of filled grains panicle^{-1} was recorded.

3.10.10 Number of unfilled grains panicle^{-1}

The total number of unfilled grains was collected randomly from selected 5 panicle of a hill and then average number of unfilled grains panicle^{-1} was recorded.

3.10.11 Dry weight hill^{-1}

Dry matter hill^{-1} was recorded at harvest. Collected hill were oven dried at 70°C for 72 hours then transferred into desiecator and allowed to cool down at room temperature, final weight was taken and converted into dry matter content hill^{-1}.

3.10.12 Weight of 1000 grain (g)

One thousand cleaned dried grains were counted randomly from each plot and weighed by using a digital electric balance when the grains retained 13% moisture and the mean weight was expressed in gram.

3. 10.13 Grain yield

Grain yield was determined from each hill of each pot and expressed as g on 13% moisture basis. Grain moisture content was measured by using a digital moisture tester.

3.10.14 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.

3.10.15 Chemical analysis (P, K, S and As content) in grain and straw

P and S content in grain and straw were determined by Spectrophotometer. K content in grain and straw was determined by flame emission Spectrophotometer and As content in grain and straw was determined by ICP-MS (Agilent-7850) (BRiCM, Bangladesh Reference Institute for Chemical Mesearments, 75 Laboratory Road, Dhaka).

Rice grain and straw were dried in an oven at 70°C to obtain constant weight. Oven dried grain and straw samples were grounded in a Wiley Hammer Mill, passed through 40 mesh screen, mixed well and stored in plastic vials. Exactly 1 g oven-dried samples of rice were taken in digestion tube. About 20 mL of di-acid mixture (2:1) ration of HNO_3 and $HClO_4$ digestion tube and left to stand for 20 minutes and then transferred to a digestion block and continued heating at 100°C. The temperature was increased to 365°C gradually to prevent frothing (50°C steps) and left to digest until yellowish color of the solution turned to whitish color. Then the digestion tubes were removed from the heating source and allowed to cool to room temperature. About 40 mL of de-ionised water was carefully added to the digestion tubes and the contents filtered through Whatman no. 40 filter paper into a 100 mL volumetric flask and the volume was made up to the mark with de-ionised water. The samples were stored at room temperature in clearly marked containers. After digestion, approximately 100 mL of each digest samples was stored in a plastic bottle for determination of the P, K and S. After that, the percent values were also calculated from concentration of P, K and S. in the samples.

3.11 Statistical analysis

The data collected on different parameters were statistically analyzed with Completely Randomized Design (CRD) using the MSTAT computer package program. 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 present investigation included the response of different rice varieties to different levels of arsenic (As). The results presented in tables and figures are discussed systematically under the following heads:

4.1 Growth parameters

4.1.1 Plant height

Effect of variety

Plant height was significantly varied due to varietal effect of rice (Table 4.1 and Appendix IV). The highest plant height (91.28 cm) was recorded from the variety V_2 (BRRI dhan-28) that was statistically same to the variety V_3 (BRRI dhan-29) and V_5 (BRRI hybrid dhan-5) whereas the lowest plant height (76.95 cm) was recorded from the variety V_1 (BR-16). Similar result was also observed by Salam *et al*. (2019) and Singh *et al*. (2019) who observed variation on plant height of rice due to varietal difference.

Effect of arsenic

Significant variation was observed on plant height of rice as influenced by different arsenic levels (Table 4.1 and Appendix IV). Results showed that lower levels of arsenic gave higher plant height and the maximum plant height (92.15 cm) of rice was obtained in As_1 which was statistically same to As_0 control whereas increased arsenic levels gave lower plant height and maximum arsenic level As_4 (40 mg As kg^{-1} soil) showed minimum plant height (80.43 cm). Jahan *et al*. (2020) and Howladar *et al*. (2019) showed similar result with the present study and reported that As contamination significantly reduced plant height of rice.

Table 4.1. Effect of variety and arsenic on growth parameters of rice

Treatments	Growth parameters				
	Plant height (cm)	Leaf length (cm)	Number of leaves $hill^{-1}$	Number of total tillers $hill^{-1}$	Number of effective tillers $hill^{-1}$
Effect of variety					
V_1	76.95 c	26.33 c	55.55 a	10.00 b	9.05 c
V_2	91.28 a	44.94 a	44.80 c	8.20 c	8.10 c
V_3	90.60 a	43.45 a	38.00 d	11.35 b	10.10 b
V_4	84.28 b	38.33 b	44.15 c	6.65 d	6.25 d
V_5	89.25 a	39.58 b	51.75 b	12.85 a	12.35 a
$LSD_{0.05}$	2.217	1.543	1.703	1.387	0.9514
CV(%)	11.23	12.71	13.51	10.43	12.55
Effect of arsenic					
As_0	90.05 a	48.92 a	57.70 a	12.55 a	11.95 a
As_1	92.15 a	39.31 b	49.15 b	10.25 b	9.10 b
As_2	86.72 b	37.04 c	46.95 c	9.45 b	9.05 b
As_3	83.00 c	35.44 c	40.95 d	8.55 c	8.35 bc
As_4	80.43 d	31.91 d	39.50 d	8.25 c	7.40 c
$LSD_{0.05}$	2.217	1.782	1.703	0.855	0.951
CV(%)	11.23	12.71	13.51	10.43	12.55

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

V_1 = BR-16, V_2 = BRRI dhan-28, V_3 = BRRI dhan-29, V_4 = BRRI dhan-55, V_5 = BRRI hybrid dhan-5
As_0 = Control (No arsenic), As_1 = 2 mg As kg^{-1} soil, As_2 = 10 mg As kg^{-1} soil, As_3 = 20 mg As kg^{-1} soil, As_4 = 40 mg As kg^{-1} soil

Combined effect of variety and arsenic

There was a significant variation on plant height of rice due to treatment combination of different rice varieties and arsenic levels (Table 4.2 and Appendix IV). Data showed that the highest plant height (99.63 cm) was observed from the treatment combination of V_2As_0 which was statistically similar to the treatment combination of V_2As_1, V_3As_0 and V_3As_1. Similarly, the lowest plant height (72.25 cm) was observed from the treatment combination of V_1As_4 that was statistically similar to V_4As_4 and V_1As_3.

Table 4.2. Combined effect of variety and arsenic on growth parameters of rice

Treatment combination	Growth parameters				
	Plant height (cm)	Leaf length (cm)	Number of leaves hill^{-1}	Number of total tillers hill^{-1}	Number of effective tillers hill^{-1}
V_1As_0	82.25 def	28.25 fgh	64.00 a	14.00 b	13.50 ab
V_1As_1	78.75 fgh	26.25 h	58.50 c	13.75 b	13.00 bc
V_1As_2	76.00 ghi	25.70 h	57.75 c	12.25 bcd	11.25 cd
V_1As_3	75.50 hi	25.90 h	56.50 cd	10.25 efg	8.75 efg
V_1As_4	72.25 i	25.58 h	42.00 hi	6.75 ij	5.50 ij
V_2As_0	99.63 a	57.38 a	56.25 cd	14.00 b	12.75 bc
V_2As_1	97.50 ab	52.25 bc	53.75 de	13.00 bc	12.50 bc
V_2As_2	95.88 abc	51.75 bc	50.75 ef	10.00 efg	9.50 def
V_2As_3	86.75 d	39.13 de	45.25 gh	9.25 fgh	7.75 fgh
V_2As_4	77.00 ghi	27.05 h	38.75 ij	5.75 jk	5.50 ij
V_3As_0	99.25 a	54.50 ab	63.00 ab	14.00 b	13.75 ab
V_3As_1	97.75 ab	52.13 bc	41.75 hi	7.00 ij	6.75 ghi
V_3As_2	92.88 bc	40.13 d	35.25 j	6.75 ij	6.75 ghi
V_3As_3	86.25 d	36.42 e	23.50 k	5.75 jk	5.00 ij
V_3As_4	76.50 ghi	31.20 fg	22.00 k	4.50 k	0.00 k
V_4As_0	95.50 abc	53.33 bc	48.25 fg	11.25 cde	11.25 cd
V_4As_1	93.00 bc	52.50 bc	44.50 gh	10.50 def	10.25 de
V_4As_2	83.00 def	31.25 fg	39.00 ij	9.50 efgh	8.50 efg
V_4As_3	76.25 ghi	28.00 gh	36.25 j	7.75 hi	7.00 ghi
V_4As_4	73.63 i	26.58 h	35.50 j	6.75 ij	6.25 hij
V_5As_0	95.50 abc	52.00 bc	59.50 bc	16.75 a	15.25 a
V_5As_1	93.75 bc	50.45 c	55.75 cd	9.75 efg	9.75 def
V_5As_2	92.50 c	36.00 e	49.50 f	9.00 fgh	8.25 efgh
V_5As_3	84.00 de	31.55 f	47.00 fg	8.50 ghi	8.00 fgh
V_5As_4	80.50 efg	27.88 gh	47.00 fg	8.50 ghi	8.00 fgh
$LSD_{0.05}$	4.957	3.450	3.809	1.912	2.128
CV(%)	11.23	12.71	13.51	10.43	12.55

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

V_1 = BR-16, V_2 = BRRI dhan-28, V_3 = BRRI dhan-29, V_4 = BRRI dhan-55, V_5 = BRRI hybrid dhan-5

As_0 = Control (No arsenic), As_1 = 2 mg As kg^{-1} soil, As_2 = 10 mg As kg^{-1} soil, As_3 = 20 mg As kg^{-1} soil, As_4 = 40 mg As kg^{-1} soil

4.1.2 Leaf length

Effect of variety

Significant variation was recorded for leaf length which was influenced by different of rice varieties (Table 4.1 and Appendix IV). The maximum leaf length (44.94 cm) was recorded from the variety V_2 (BRRI dhan-28) that was statistically similar to V_3 (BRRI dhan-29) whereas the minimum leaf length (26.33 cm) was recorded from the variety V_1 (BR-16). Similar result was also observed by Mahmood (2019) who found variation in leaf area among the varieties.

Effect of arsenic

Different arsenic levels showed significant variation on leaf length of rice (Table 4.1 and Appendix IV). The maximum leaf length (48.92 cm) was found from the control treatment As_0 (no arsenic produced) and the second highest (39.31 cm) was recorded from As_1 (2 mg As kg^{-1} soil) whereas the minimum leaf length (31.91 cm) was found from the maximum arsenic level As_4 (40 mg As kg^{-1} soil). Manirul *et al*. (2016) also found similar result with the present study

Combined effect of variety and arsenic

Treatment combination of different rice varieties and arsenic levels gave significant influence on leaf length of rice (Table 4.2 and Appendix IV). Results showed that the maximum leaf length (57.38 cm) was observed from the treatment combination of V_2As_0 which was statistically similar to V_3As_0. The minimum leaf length (25.58 cm) was observed from the treatment combination of V_1As_4 that was statistically similar to V_1As_1, V_1As_2, V_1As_3, V_2As_4, V_4As_3, and V_4As_4.

4.1.3 Number of leaves hill^{-1}

Effect of variety

Different varieties of rice showed significant variation on number of leaves hill^{-1} (Table 4.1 and Appendix IV). Results showed that the variety V_1 (BR-16) gave the maximum number of leaves hill^{-1} (55.55) followed by V_5 (BRRI hybrid dhan-5) whereas the variety V_3 (BRRI dhan-29) gave the minimum number of leaves hill^{-1} (38.00). The result obtained from the present study was similar with the findings of Sarker *et al.* (2013) and they reported significant variation of leaf number due to varietal difference.

Effect of arsenic

Significant variation was observed on number of leaves hill^{-1} of rice as influenced by different arsenic levels (Table 4.1 and Appendix IV). The control treatment As_0 (no arsenic produced) gave the maximum number of leaves hill^{-1} (57.70) whereas the lowest number of leaves hill^{-1} (39.50) was given by the treatment As_4 (40 mg As kg^{-1} soil) which was statistically similar with As_3 (20 mg As kg^{-1} soil).

Combined effect of variety and arsenic

Significant influence was achieved on number of leaves hill^{-1} of rice due to treatment combination of different rice varieties and arsenic levels (Table 4.2 and Appendix IV). Results indicated that the highest number of leaves hill^{-1} (64.00) was observed from the treatment combination of V_1As_0 that was statistically similar to V_3As_0 whereas the lowest number of leaves hill^{-1} (22.00) was observed from the treatment combination of V_3As_4 that was significantly same to the treatment combination of V_3As_3.

4.1.4 Number of total tillers hill^{-1}

Effect of variety

Significant variation was recorded for number of total tillers hill^{-1} which was influenced by different of rice varieties (Table 4.1 and Appendix IV). Results revealed that the maximum number of total tillers hill^{-1} (12.85) was recorded from the variety V_5 (BRRI hybrid dhan-5) followed by V_3 (BRRI dhan-29) and V_1 (BR-16) whereas the minimum number of total tillers hill^{-1} (6.65) was recorded from the variety V_4 (BRRI dhan-55). Supported result was also observed by the findings of Rashid *et al*. (2017) and Haque *et al.* (2013); they reported that variety had significant variation on tillers $hill^{-1}$.

Effect of arsenic

Different arsenic levels showed significant variation on number of total tillers $hill^{-1}$ of rice (Table 4.1 and Appendix IV). It was observed that lower levels of arsenic showed comparatively higher number of tillers $hill^{-1}$ and gradually decreased tiller number was observed due to higher arsenic levels. The maximum number of total tillers $hill^{-1}$ (12.55) that was statistically similar to As_2 (10 mg As kg^{-1} soil). The minimum number of total tillers $hill^{-1}$ (8.25) was found from the treatment As_4 (40 mg As kg^{-1} soil) which was statistically similar with As_3 (20 mg As kg^{-1} soil). Alam and Islam (2011) reported that arsenic contamination resulted in less tillering of rice plant which resulted decreased yield of rice w.

Combined effect of variety and arsenic

Treatment combination of different rice varieties and arsenic levels gave significant influence on number of total tillers $hill^{-1}$ of rice (Table 4.2 and Appendix IV). The maximum number of total tillers $hill^{-1}$ (16.75) was observed from the treatment combination of V_5As_0 whereas the minimum number of total tillers $hill^{-1}$ (4.50) was observed from the treatment combination of V_3As_4.

4.1.5 Number of effective tillers $hill^{-1}$

Effect of variety

Number of effective tillers $hill^{-1}$ was significantly varied due to varietal different of rice (Table 4.1 and Appendix IV). Results indicated that the highest number of effective tillers $hill^{-1}$ (12.35) was recorded from the variety V_5 (BRRI hybrid dhan-5) followed by V_3 (BRRI dhan-29) whereas the lowest number of effective tillers $hill^{-1}$ (6.25) was recorded from the variety V_4 (BRRI dhan-55). Supported result on effective tillers $hill^{-1}$ due to varietal difference was also observed by the findings of Chamely *et al*. (2015), Sarker *et al.* (2013) and Abou-Khalif (2009).

Effect of arsenic

Significant variation was observed on number of effective tillers hill^{-1} of rice as influenced by different arsenic levels (Table 4.1 and Appendix IV). It was observed that the highest number of effective tillers hill^{-1} (11.95) was found from the control treatment As_0 (no arsenic produced) and the second highest was recorded from arsenic dose As_1 (2 mg As kg^{-1} soil) and gradually decreased effective tillers was found with increasing arsenic levels. The lowest number of effective tillers hill^{-1} (7.40) was found from the maximum levels of arsenic As_4 (40 mg As kg^{-1} soil). Supported result was also observed by Alam and Islam (2011) who found decreased tillering due to As contamination.

Combined effect of variety and arsenic

There was a significant variation on number of effective tillers hill^{-1} of rice due to treatment combination of different rice varieties and arsenic levels (Table 4.2 and Appendix IV). The highest number of effective tillers hill^{-1} (15.25) was observed from the treatment combination of V_5S_0 while the treatment combination of V_3As_4 showed no effective tillers whereas V_3As_3 gave least number of effective tillers hill^{-1} (5.00) compared to other treatment combinations which was significantly similar to V_1As_4 and V_2As_4.

4.2 Yield contributing parameters

4.2.1 Panicle length (cm)

Effect of variety

Different varieties of rice showed significant variation on panicle length (Table 4.3 and Appendix V). Results showed that the variety V_3 (BRRI dhan-29) gave the maximum panicle length (24.65 cm) which was statistically similar to V_5 (BRRI hybrid dhan-5). The variety V_4 (BRRI dhan-55) gave the minimum panicle length (22.90 cm) which was statistically same to the variety V_1 (BR-16). Chamely *et al*. (2015) and Islam *et al*. (2013) found similar result which supported the present study.

Effect of arsenic

Significant variation was observed on panicle length of rice as influenced by different arsenic levels (Table 4.3 and Appendix V). The control treatment S_0 (no arsenic produced) gave the maximum panicle length (26.45 cm) whereas different doses showed lower panicle length and it was decreased with increasing of arsenic levels; the second highest panicle length (24.97 cm) was found from As_1 (2 mg As kg^{-1} soil) whereas the lowest panicle length (21.50 cm) was given by the treatment As_4 (40 mg As kg^{-1} soil) that was statistically similar to As_3 (20 ppm As kg^{-1} soil). Montenegro and Mejia (2001) also found reduced panicle length due to As contamination through irrigation water which supported the present study.

Combined effect of variety and arsenic

Significant influence was achieved on panicle length of rice due to treatment combination of different rice varieties and arsenic levels (Table 4.4 and Appendix V). Results indicated that the highest panicle length (27.50 cm) was observed from the treatment combination of V_5S_0 and the lowest panicle length (20.75 cm) was observed from the treatment combination of V_3s_4 that was significantly same to the treatment combination of V_1As_4, V_2As_4, V_3As_3 and V_4As_4.

Table 4.3. Effect of variety and arsenic on yield contributing parameters of rice

Treatments	Yield contributing parameters				
	Panicle length (cm)	Number of panicles $hill^{-1}$	Number of grains $panicle^{-1}$	Number of filled grain $panicle^{-1}$	Dry weight of straw $hill^{-1}$ (g)
Effect of variety					
V_1	23.00 b	6.80 c	92.71 d	85.17 c	8.15 b
V_2	23.55 ab	7.90 b	105.5 c	82.83 c	8.00 bc
V_3	24.65 a	7.90 b	132.4 b	100.2 b	8.35 b
V_4	22.90 b	5.10 d	91.81 d	72.59 d	7.75 c
V_5	24.23 a	8.60 a	135.4 a	112.9 a	10.15 a
$LSD_{0.05}$	1.224	0.202	2.659	3.280	0.378
CV(%)	6.94	7.38	12.73	11.24	12.71
Effect of arsenic					
As_0	26.45 a	8.60 a	124.3 a	105.5 a	9.25 a
As_1	24.97 b	7.35 b	124.0 a	100.4 b	8.80 b
As_2	23.65 c	7.15 b	119.8 b	92.96 c	8.45 bc
As_3	21.75 d	6.75 c	112.3 c	92.92 c	8.10 cd
As_4	21.50 d	6.45 d	77.18 d	61.94 d	7.80 d
$LSD_{0.05}$	0.8392	0.203	2.659	3.280	0.375
CV(%)	5.62	9.16	14.45	14.35	11.46

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

V_1 = BR-16, V_2 = BRRI dhan-28, V_3 = BRRI dhan-29, V_4 = BRRI dhan-55, V_5 = BRRI hybrid dhan-5
As_0 = Control (No arsenic), As_1 = 2 mg As kg^{-1} soil, As_2 = 10 mg As kg^{-1} soil, As_3 = 20 mg As kg^{-1} soil, As_4 = 40 mg As kg^{-1} soil

4.2.2 Number of panicles $hill^{-1}$

Effect of variety

Significant variation was recorded for number panicles $hill^{-1}$ which was influenced by different of rice varieties (Table 4.3 and Appendix V). Results revealed that the maximum number panicles $hill^{-1}$ (8.60) was recorded from the variety V_5 (BRRI hybrid dhan-5) whereas the minimum number panicles $hill^{-1}$ (5.10) was recorded from the variety V_4 (BRRI dhan-55). Islam *et al*. (2009)

also observed variation on panicles $hill^{-1}$ due to varietal difference which supported the present study.

Effect of arsenic

Different arsenic levels showed significant variation on number panicles $hill^{-1}$ of rice (Table 4.3 and Appendix V). It was observed that lower levels of arsenic showed comparatively higher number panicles $hill^{-1}$ and gradually decreased panicle number was observed due to higher arsenic levels. The maximum number panicles $hill^{-1}$ (8.60) was found from the control treatment As_0 (no arsenic produced) and the second highest (7.35) was found from As_1 (2 mg As kg^{-1} soil). The minimum number panicles $hill^{-1}$ (6.45) was found from the treatment As_4 (40 mg As kg^{-1} soil).

Combined effect of variety and arsenic

Treatment combination of different rice varieties and arsenic levels gave significant influence on number panicles $hill^{-1}$ of rice (Table 4.4 and Appendix V). The maximum number panicles $hill^{-1}$ (10.25) was observed from the treatment combination of V_5As_0 which was statistically similar with V_3As_0 whereas the minimum number panicles $hill^{-1}$ (4.00) was observed from the treatment combination of V_3As_4 which was significantly different from other treatment combinations. Similar result was also observed by Montenegro and Mejia (2001).

4.2.3 Number of grains panicle^{-1}

Effect of variety

Number of grains $panicle^{-1}$ was significantly varied due to varietal different of rice (Table 4.3 and Appendix V). Results indicated that the highest number of grains $panicle^{-1}$ (135.4) was recorded from the variety V_5 (BRRI hybrid dhan-5) which was significantly different to other varieties followed by V_3 (BRRI dhan-

29) whereas the lowest number of grains panicle^{-1} (91.81) was recorded from the variety V_4 (BRRI dhan-55) that was significantly same to V_1 (BR-16).

Effect of arsenic

Significant variation was observed on number of grains panicle^{-1} of rice as influenced by different arsenic levels (Table 4.3 and Appendix V). It was observed that the highest number of grains panicle^{-1} (124.3) was found from the control treatment As_0 (no arsenic produced) which was significantly same to arsenic dose As_1 (2 mg As kg^{-1} soil) and gradually decreased number of grains panicle^{-1} was found with increasing arsenic levels. The lowest number of grains panicle^{-1} (77.18) was found from the maximum levels of arsenic As_4 (40 mg As kg^{-1} soil) which was significantly different from other arsenic levels. Similar result was also observed by Montenegro and Mejia (2001) and reported that increasing As content of irrigation waters reduced 10% of grains per panicle.

Combined effect of variety and arsenic

There was a significant variation on number of grains panicle^{-1} of rice due to treatment combination of different rice varieties and arsenic levels (Table 4.4 and Appendix V). The highest number of grains panicle^{-1} (160.20) was observed from the treatment combination of V_5As_0 that was statistically similar to V_2As_0 and V_3As_0 while the treatment combination of V_3As_4 showed no grains panicle^{-1} whereas V_3As_3 gave least number of grains panicle^{-1} (46.30) which was significantly different to other treatment combinations.

4.2.4 Number of filled grains panicle^{-1}

Effect of variety

Number of filled grains panicle^{-1} was significantly varied due to varietal different of rice (Table 4.3 and Appendix V). Results indicated that the highest number of filled grains panicle^{-1} (112.9) was recorded from the variety V_5 (BRRI hybrid dhan-5) which was significantly different to other varieties whereas the lowest number of filled grains panicle^{-1} (72.79) was recorded from the variety V_4 (BRRI dhan-55) that was significantly different to other varieties. The result obtained from the present study was similar with the findings of Rashid *et al*. (2017) and Sarker *et al.* (2013).

Effect of arsenic

Significant variation was observed on number of filled grains panicle^{-1} of rice as influenced by different arsenic levels (Table 4.3 and Appendix V). It was observed that the highest number of filled grains panicle^{-1} (105.5) was found from the control treatment As_0 (no arsenic produced) and the second highest (100.4) was found from arsenic dose As_1 (2 mg As kg^{-1} soil) and gradually decreased number of filled grains panicle^{-1} was found with increasing arsenic levels. The lowest number of filled grains panicle^{-1} (61.94) was found from the maximum levels of arsenic As_4 (40 mg As kg^{-1} soil) which was significantly different from other arsenic levels. Montenegro and Mejia (2001) also found reduced grains per panicle due to As contamination through irrigation water which supported the present study.

Combined effect of variety and arsenic

There was a significant variation on number of filled grains panicle^{-1} of rice due to treatment combination of different rice varieties and arsenic levels (Table 4.4 and Appendix V). The highest number of filled grains panicle^{-1} (143.4) was observed from the treatment combination of V_5As_0 that was significantly different to other treatment combinations followed by V_2As_0 while the treatment combination of V_3As_4 showed no grains panicle^{-1} whereas V_3As_3 gave least number of filled grains panicle^{-1} (24.46) which was significantly different to other treatment combinations.

4.2.5 Dry weight of straw hill^{-1}

Effect of variety

Significant variation was recorded for dry weight of straw hill^{-1} which was influenced by different of rice varieties (Table 4.3 and Appendix V). Results revealed that the maximum dry weight of straw hill^{-1} (10.15 g) was recorded from the variety V_5 (BRRI hybrid dhan-5) followed by V_1 (BR-16) and V_3 (BRRI dhan-29) whereas the minimum dry weight of straw hill^{-1} (7.75 g) was recorded from the variety V_4 (BRRI dhan-55). Murshida *et al*. (2017) also found similar result with the present study.

Effect of arsenic

Different arsenic levels showed significant variation on dry weight of straw hill^{-1} of rice (Table 4.3 and Appendix V). It was observed that lower levels of arsenic showed comparatively higher dry weight of straw hill^{-1} and gradually decreased dry weight was observed due to higher arsenic levels. The maximum dry weight of straw hill^{-1} (9.25 g) was found from the control treatment As_0 (no arsenic produced) that was followed by and the second highest (8.80 g) was found from As_1 (2 mg As kg^{-1} soil). The minimum dry weight of straw hill^{-1} (7.80 g) was found from the treatment As_4 (40 mg As kg^{-1} soil). Similar result was also observed by Howladar *et al*. (2019) and they reported reduced dry matter production due to As contamination in plants.

Combined effect of variety and arsenic

Treatment combination of different rice varieties and arsenic levels gave significant influence on dry weight of straw hill^{-1} of rice (Table 4.4 and Appendix V). The maximum dry weight of straw hill^{-1} (14.50 g) was observed from the treatment combination of V_5S_0 whereas the minimum dry weight of straw hill^{-1} (4.75 g) was observed from the treatment combination of V_3As_4.

Table 4.4. Combined effect of variety and arsenic on yield contributing parameters of rice

Treatment combination	Yield contributing parameters				
	Panicle length (cm)	Number of panicles $hill^{-1}$	Number of grain $panicle^{-1}$	Number of filled grain $panicle^{-1}$	Dry weight of straw $hill^{-1}$ (g)
V_1As_0	26.63 ab	9.50 b	146.5 c	103.00 f	11.00 b
V_1As_1	24.10 cd	9.25 bc	116.2 e	121.70 bc	9.25 de
V_1As_2	23.38 de	8.00 ef	87.68 ij	114.40 cde	9.00 e
V_1As_3	23.25 def	7.75 f	80.37 kl	92.27 g	6.50 gh
V_1As_4	20.78 h	6.25 jk	77.54 l	64.99 kl	6.00 h
V_2As_0	26.50 ab	9.50 b	156.40 ab	127.30 b	11.00 b
V_2As_1	25.75 abc	9.00 c	112.40 ef	85.54 gh	9.00 e
V_2As_2	25.50 bc	7.25 g	108.10 fg	84.50 h	7.25 fg
V_2As_3	22.38 defgh	7.00 gh	104.30 g	73.08 ij	7.00 fg
V_2As_4	20.88 h	7.00 gh	97.24 h	67.96 jkl	7.00 fg
V_3As_0	26.00 ab	10.0 a	159.30 a	120.00 bc	11.00 b
V_3As_1	25.63 abc	6.75 hi	152.70 b	116.00 cd	10.25 bc
V_3As_2	25.50 bc	6.50 ij	122.40 d	71.03 ijk	6.00 h
V_3As_3	20.88 h	4.75 l	46.30 n	24.46 n	5.75 h
V_3As_4	20.75 h	4.00 m	0.00 o	0.00 o	4.75 i
V_4As_0	26.00 ab	8.25 de	126.60 d	89.89 gh	11.00 b
V_4As_1	23.38 de	6.00 k	123.40 d	83.26 h	9.00 e
V_4As_2	23.25 def	6.00 k	108.80 fg	105.30 f	7.75 f
V_4As_3	21.38 fgh	4.75 l	97.91 h	63.62 l	7.25 fg
V_4As_4	21.00 h	4.50 l	70.81 m	32.96 m	7.00 fg
V_5As_0	27.50 a	10.25 a	160.20 a	143.40 a	14.50 a
V_5As_1	25.63 abc	8.25 de	146.50 c	119.90 c	10.00 cd
V_5As_2	23.00 defg	8.50 d	142.70 c	109.40 def	10.00 cd
V_5As_3	21.50 efgh	6.50 ij	92.50 hi	107.90 ef	7.75 f
V_5As_4	21.13 gh	6.00 k	67.13 m	71.04 ijk	7.00 fg
$LSD_{0.05}$	1.876	0.452	5.946	7.335	0.845
CV(%)	5.62	9.16	14.45	14.35	11.46

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

V_1 = BR-16, V_2 = BRRI dhan-28, V_3 = BRRI dhan-29, V_4 = BRRI dhan-55, V_5 = BRRI hybrid dhan-5

As_0 = Control (No arsenic), As_1 = 2 mg As kg^{-1} soil, As_2 = 10 mg As kg^{-1} soil, As_3 = 20 mg As kg^{-1} soil, As_4 = 40 mg As kg^{-1} soil

4.3 Yield data

4.3.1 1000 grain weight

Effect of variety

Weight of 1000 grains was significantly varied due to varietal different of rice (Table 4.5 and Appendix VI). The highest 1000 grain weight (28.47g) was recorded from the variety V_5 (BRRI hybrid -5) followed by the variety V_3 (BRRI dhan-29) and V_4 (BRRI dhan-55) whereas the lowest 1000 grain weight (22.04 g) was recorded from the variety V_2 (BRRI dhan-28) which is statistically similar with V_1 (BR-16). Supported result was also observed by the findings of Rashid *et al*. (2017).

Effect of arsenic

Non-significant variation was observed on 1000 grain weight of rice as influenced by different arsenic levels (Table 4.5 and Appendix VI). However, results showed that the control treatment As_0 (no arsenic produced) gave the maximum 1000 grain weight (24.48 g) and As_4 (40 mg As kg^{-1} soil) showed minimum 1000 seed weight (24.10 g).

Combined effect of variety and arsenic

There was a significant variation on 1000 grain weight of rice due to treatment combination of different rice varieties and arsenic levels (Table 4.6 and Appendix VI). Data showed that the highest 1000 grain weight (28.63 g) was observed from the treatment combination of V_5As_0 which was statistically same to the treatment combination of V_5As_1, V_5As_2, V_5As_3 and V_5As_4. The lowest performance on 1000 grain weight was performed by V_3S_4 which showed no seeds at harvesting time and also V_2As_4 showed least performance on 1000 grain weight (21.80 g) that was statistically similar to V_1As_4.

4.3.2 Grain yield hill^{-1}

Effect of variety

Significant variation was recorded for grain yield hill^{-1} which was influenced by different of rice varieties (Table 4.5 and Appendix VI). Results revealed that the maximum grain yield hill^{-1} (19.51 g) was recorded from the variety V_5 (BRRI hybrid dhan-5) whereas the minimum grain yield hill^{-1} (10.98 g) was recorded from the variety V_4 (BRRI dhan-55). The result obtained from the present study was similar with the findings of Rashid *et al*. (2017), Chamely *et al*. (2015), Sarker *et al.* (2013) and Islam *et al*. (2013).

Effect of arsenic

Different arsenic levels showed significant variation on grain yield hill^{-1} (Table 4.5 and Appendix VI). It was observed that lower levels of arsenic showed comparatively higher grain yield hill^{-1} and gradually decreased grain weight was observed due to higher arsenic levels. The maximum grain yield hill^{-1} (20.00 g) was found from the control treatment As_0 (no arsenic produced) and the second highest grain yield hill^{-1} (15.76 g) was found from As_1 (2 mg As kg^{-1} soil) that was significantly different to other treatments. The minimum grain yield hill^{-1} (13.60 g) was found from the treatment As_4 (40 mg As kg^{-1} soil). Jahan *et al*. (2020) reported that As contamination significantly reduced the yield of rice which supported the present study. Howladar *et al*. (2019) also found similar result with the present study.

Combined effect of variety and arsenic

Treatment combination of different rice varieties and arsenic levels gave significant influence on grain yield hill^{-1} of rice (Table 4.6 and Appendix VI). The maximum grain yield hill^{-1} (28.60 g) was observed from the treatment combination of V_5As_0 whereas the treatment combination of V_3As_4 showed no grain yield and also V_1As_4 gave lowest grain yield hill^{-1} (10.88 g) compared to other treatment combinations which was significantly same to V_2As_4, V_3As_3, V_2As_4 and V_5As_4.

Table 4.5. Effect of variety and arsenic on yield parameters of rice

Treatments	Yield parameters		
	1000 grain weight (g)	Grain yield hill^{-1} (g)	Straw yield hill^{-1} (g)
Effect of variety			
V_1	22.07 c	16.25 b	19.71 b
V_2	22.04 c	12.76 c	18.36 c
V_3	24.52 b	17.14 b	19.83 b
V_4	24.47 b	10.98 d	13.79 d
V_5	28.47 a	19.51 a	24.70 a
$LSD_{0.05}$	0.899	1.010	0.8717
CV(%)	7.63	13.38	12.09
Effect of arsenic			
As_0	24.48	20.00 a	27.98 a
As_1	24.42	15.76 b	19.68 b
As_2	24.28	14.49 c	17.22 c
As_3	24.22	14.79 c	17.33 c
As_4	24.10	13.60 d	16.19 d
$LSD_{0.05}$	0.354^{NS}	0.805	0.8717
CV(%)	7.63	13.38	12.09

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

V_1 = BR-16, V_2 = BRRI dhan-28, V_3 = BRRI dhan-29, V_4 = BRRI dhan-55, V_5 = BRRI hybrid dhan-5
As_0 = Control (No arsenic), As_1 = 2 mg As kg^{-1} soil, As_2 = 10 mg As kg^{-1} soil, As_3 = 20 mg As kg^{-1} soil, As_4 = 40 mg As kg^{-1} soil

4.1.5 Straw yield hill^{-1}

Effect of variety

Straw yield hill^{-1} was significantly varied due to varietal different of rice (Table 4.5 and Appendix VI). Results indicated that the highest straw yield hill^{-1} (24.70 g) was recorded from the variety V_5 (BRRI hybrid dhan-5) which was followed by V_1 (BR-16) and V_3 (BRRI dhan-29) whereas the lowest straw yield hill^{-1} (13.79 g) was recorded from the variety V_4 (BRRI dhan-55). Similar result was also observed by Chamely *et al*. (2015).

Effect of arsenic

Significant variation was observed on straw yield of rice as influenced by different arsenic levels (Table 4.5 and Appendix VI). It was observed that the highest straw yield hill^{-1} (27.98 g) was found from the control treatment As_0 (no arsenic produced) and the second highest was recorded from arsenic dose As_1 (2 mg As kg^{-1} soil) and gradually decreased straw yield was found with increasing arsenic levels. The lowest number straw yield hill^{-1} (16.19 g) was found from the maximum levels of arsenic As_4 (40 mg As kg^{-1} soil). Similar result was also observed by Jahan *et al*. (2020).

Combined effect of variety and arsenic

There was a significant variation on rice straw yield hill^{-1} due to treatment combination of different rice varieties and arsenic levels (Table 4.6 and Appendix VI). The highest straw yield hill^{-1} (41.00 g) was observed from the treatment combination of V_5As_0 that was significantly different to other treatment combinations while the treatment combination of V_3As_4 showed minimum stover yield hill^{-1} (8.50 g) that was significantly different compared to other treatment combinations.

Table 4.6. Combined effect of variety and arsenic on yield parameters of rice

Treatment combination	Yield parameters		
	1000 seed weight (g)	Grain yield $hill^{-1}$ (g)	Straw Yield $hill^{-1}$ (g)
V_1As_0	22.30 c	19.30 c	23.65 d
V_1As_1	22.21 cd	15.55 fgh	22.58 d
V_1As_2	22.03 cde	14.60 ghi	21.80 de
V_1As_3	21.93 de	12.60 jk	17.48 ghi
V_1As_4	21.86 e	10.88 k	13.68 j
V_2As_0	22.27 c	18.90 c	22.00 de
V_2As_1	22.20 cd	17.52 cde	20.50 ef
V_2As_2	22.00 cde	16.08 efg	19.15 fgh
V_2As_3	21.94 de	13.63 ij	16.57 i
V_2As_4	21.80 e	11.60 k	13.60 j
V_3As_0	24.64 b	26.52 b	34.50 b
V_3As_1	24.57 b	17.90 cd	19.30 fg
V_3As_2	24.48 b	14.50 ghi	16.92 i
V_3As_3	24.45 b	10.95 k	12.20 j
V_3As_4	0.00 f	0.00 l	8.50 k
V_4As_0	24.58 b	17.00 def	25.75 c
V_4As_1	24.55 b	16.92 def	27.05 c
V_4As_2	24.45 b	15.77 efg	19.70 f
V_4As_3	24.41 b	13.85 hij	17.35 hi
V_4As_4	24.37 b	7.425 l	12.00 j
V_5As_0	28.63 a	28.60 a	41.00 a
V_5As_1	28.55 a	19.20 c	20.25 ef
V_5As_2	28.44 a	14.97 ghi	17.75 ghi
V_5As_3	28.39 a	12.60 jk	16.00 i
V_5As_4	28.36 a	11.63 k	12.75 j
$LSD_{0.05}$	0.307	1.797	1.949
CV(%)	7.63	13.38	12.09

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

V_1 = BR-16, V_2 = BRRI dhan-28, V_3 = BRRI dhan-29, V_4 = BRRI dhan-55, V_5 = BRRI hybrid dhan-5

As_0 = Control (No arsenic), As_1 = 2 mg As kg^{-1} soil, As_2 = 10 mg As kg^{-1} soil, As_3 = 20 mg As kg^{-1} soil, As_4 = 40 mg As kg^{-1} soil

4.4 Nutrient content in grain and straw

4.4.1 Phosphorus (P) content in grain

Effect of variety

Different variety showed non-significant variation on P content in grain (Table 4.7 and Appendix VII). However, the maximum P content (0.286%) was found in V_1 (BR-16) whereas the lowest P content (0.185%) was recorded in V_3 (BRRI dhan-29) variety.

Effect of arsenic

Different arsenic levels showed non-significant variation on P content in rice grain (Table 4.7 and Appendix VII). However, the maximum P content (0.269%) was found from the control treatment As_0 (no arsenic produced) followed by As_1 (2 mg As kg^{-1} soil) whereas the lowest P content (0.154%) was recorded in arsenic level of As_4 (40 mg As kg^{-1} soil).

Combined effect of variety and arsenic

Significant variation was found on P content in rice grain due to treatment combination of different rice varieties and arsenic levels (Table 4.8 and Appendix VII). The highest P content (0.286%) was observed from the treatment combination of V_1As_0 while the treatment combination of V_2As_4 gave least performance of P content (0.137%) and obtained no P found of V_3As_4 i.e. there is no grain.

Table 4.7. Effect of variety and arsenic on nutrient content of rice grain

Treatments	Nutrient content of grain			
	%P	%K	%S	As (mg/kg)
Effect of variety				
V_1	0.286	0.205	0.132	1.96 d
V_2	0.233	0.173	0.152	4.67 c
V_3	0.185	0.121	0.111	56.95 a
V_4	0.225	0.151	0.151	43.43 b
V_5	0.255	0.216	0.175	44.20 b
$LSD_{0.05}$	NS	NS	NS	3.142
CV(%)	3.42	2.56	3.73	4.88
Effect of arsenic				
As_0	0.269	0.227	0.132	0.00 e
As_1	0.251	0.184	0.151	1.64 d
As_2	0.241	0.162	0.152	4.63 c
As_3	0.231	0.141	0.155	57.96 b
As_4	0.154	0.089	0.142	86.98 a
$LSD_{0.05}$	NS	NS	NS	2.712
CV(%)	3.42	2.56	3.73	4.88

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

V_1 = BR-16, V_2 = BRRI dhan-28, V_3 = BRRI dhan-29, V_4 = BRRI dhan-55, V_5 = BRRI hybrid dhan-5
As_0 = Control (No arsenic), As_1 = 2 mg As kg^{-1} soil, As_2 = 10 mg As kg^{-1} soil, As_3 = 20 mg As kg^{-1} soil, As_4 = 40 mg As kg^{-1} soil

4.4.2 Potassium (K) content in grain

Effect of variety

Different variety showed non-significant variation on K content in grain (Table 4.7 and Appendix VII). However, the maximum K content (0.216%) was found in V_5 (BRRI hybrid dhan-5) whereas the lowest K content (0.121%) was recorded in V_3 (BRRI dhan-29) variety.

Effect of arsenic

Different arsenic levels showed non-significant variation on K content in rice grain (Table 4.7 and Appendix VII). However, the maximum K content (0.227%) was found from the control treatment As_0 (no arsenic produced) followed by As_1 (2 mg As kg^{-1} soil) whereas the lowest K content (0.089%) was recorded in arsenic level of As_4 (40 mg As kg^{-1} soil).

Combined effect of variety and arsenic

Significant variation was found on K content in rice grain due to treatment combination of different rice varieties and arsenic levels (Table 4.8 and Appendix VII). The highest K content (0.259%) was observed from the treatment combination of V_5As_0, V_5As_1 and V_2As_0. The treatment combination of V_1As_3, V_1As_4, V_2As_4 and V_3As_3 gave least performance of K content (0.097%) and no K was found at this treatment combination V_3As_4 i.e. there is no grain.

4.4.3 Sulphur (S) content in grain

Effect of variety

Different variety showed non-significant variation on S content in grain (Table 4.7 and Appendix VII). However, the maximum S content (0.175%) was found in V_5 (BRRI hybrid dhan-5) whereas the lowest S content (0.111%) was recorded in V_3 (BRRI dhan-29) variety.

Effect of arsenic

Different arsenic levels showed non-significant variation on S content in rice grain (Table 4.7 and Appendix VII). However, the maximum S content (0.155%) was found from the arsenic level of As_3 (20 mg As kg^{-1} soil) whereas the lowest S content (0.132%) was recorded in control treatment As_0 (no arsenic produced).

Combined effect of variety and arsenic

Significant variation was found on S content in rice grain due to treatment combination of different rice varieties and arsenic levels (Table 4.8 and Appendix VII). The highest S content (0.197%) was observed from the treatment combination of V_5As_4 which was statistically similar to V_2As_4, V_3As_1, V_4As_4, V_5As_2 and V_5As_3. The treatment combination of V_3As_3 gave least performance of S content (0.111%) and no S was found at treatment combination V_3As_4 i.e. there is no grain.

4.4.4 Arsenic (As) content in grain

Effect of variety

Different variety showed significant variation on As content in grain (Table 4.7 and Appendix VII). The maximum As content (56.95 mg/kg) was found in the variety V_3 (BRRI dhan-29) followed by V_5 (BRRI hybrid dhan-5) and V_4 (BRRI dhan-55) whereas the V_1 (BR-16) showed minimum As content. Bhattacharya *et al*. (2010) and Patra *et al*. (2016) also observed similar result as the present study and found As content in grain varied due to varietal difference.

Effect of arsenic

Different arsenic levels showed significant variation on As content in rice grain (Table 4.7 and Appendix VII). The maximum As content (86.98 mg/kg) was found from the arsenic level of As_4 (40 mg As kg^{-1} soil) followed by As_3 (20 mg As kg^{-1} soil) whereas the control treatment As_0 (no arsenic produced) showed no As content in grain. Patra *et al*. (2016) found similar result with present study and observed higher concentration of As in grain with higher dose applied of As in the soil.

Combined effect of variety and arsenic

Significant variation was found on As content in rice grain due to treatment combination of different rice varieties and arsenic levels (Table 4.8 and Appendix VII). The highest As content (270.00 mg/kg) was observed from the treatment combination of V_3As_3 followed by V_4As_4 and V_5As_4. The treatment combination of V_1As_0, V_2As_0, V_3As_0, V_4As_0 and V_5As_0 showed no As content in grains. The treatment combination of V_3As_4 produced no grain.

Table 4.8. Combined effects of variety and arsenic on nutrient content of rice grain

Treatment combination	Nutrient content of grain			
	%P	%K	%S	As (mg/kg)
V_1As_0	0.286 a	0.205 ab	0.132 c	0.00 j
V_1As_1	0.259 a	0.151 b	0.138 c	1.21 hi
V_1As_2	0.244 a	0.151 b	0.141 bc	1.62 h
V_1As_3	0.233 a	0.097 c	0.149 bc	3.07 f
V_1As_4	0.218 b	0.097 c	0.159 ab	3.91 ef
V_2As_0	0.273 a	0.259 a	0.138 c	0.00 j
V_2As_1	0.255 a	0.205 ab	0.143 bc	1.80 h
V_2As_2	0.253 a	0.151 b	0.149 bc	4.44 e
V_2As_3	0.249 a	0.151 b	0.159 ab	6.15 d
V_2As_4	0.137 b	0.097 c	0.170 a	10.98 c
V_3As_0	0.253 a	0.205 ab	0.122 c	0.00 j
V_3As_1	0.237 b	0.151 b	0.176 a	2.56 fg
V_3As_2	0.218 a	0.151 b	0.146 bc	12.21 c
V_3As_3	0.215 b	0.097 c	0.111 c	270.00 a
V_3As_4	0.000 c	0.000 d	0.000 d	0.00 j
V_4As_0	0.257 a	0.205 ab	0.122 c	0.00 j
V_4As_1	0.235 a	0.151 b	0.138 c	1.70 h
V_4As_2	0.233 a	0.151 b	0.149 bc	2.54 fg
V_4As_3	0.211 b	0.151 b	0.165 ab	2.91 f
V_4As_4	0.187 ab	0.097 b	0.181 a	210.00 b
V_5As_0	0.277 a	0.259 a	0.149 bc	0.00 j
V_5As_1	0.266 a	0.259 a	0.159 ab	0.94 i
V_5As_2	0.257 a	0.205 ab	0.176 a	2.36 fg
V_5As_3	0.244 a	0.205 ab	0.192 a	7.69 d
V_5As_4	0.229 b	0.151 b	0.197 a	210.00 b
$LSD_{0.05}$	0.052	0.046	0.032	1.172
CV(%)	3.42	2.56	3.73	4.88

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

V_1 = BR-16, V_2 = BRRI dhan-28, V_3 = BRRI dhan-29, V_4 = BRRI dhan-55, V_5 = BRRI hybrid dhan-5

As_0 = Control (No arsenic), As_1 = 2 mg As kg^{-1} soil, As_2 = 10 mg As kg^{-1} soil, As_3 = 20 mg As kg^{-1} soil, As_4 = 40 mg As kg^{-1} soil

4.4.5 Phosphorus (P) content in straw

Effect of variety

Different variety showed significant variation on P content in straw (Table 4.9 and Appendix VIII). The maximum P content (0.215%) was found in V_1 (BR-16) whereas the lowest P content (0.056%) was recorded in V_5 (BRRI hybrid dhan-5) variety that was statistically same toV_2 (BRRI dhan-28), V_3 (BRRI dhan-29) and V_4 (BRRI dhan-55).

Effect of arsenic

Different arsenic levels showed non-significant variation on P content in rice straw (Table 4.9 and Appendix VIII). However, the maximum P content (0.132%) was found from the control treatment As_0 (no arsenic produced) followed by As_1 (2 mg As kg^{-1} soil) whereas the lowest P content (0.0.060%) was recorded in arsenic level of As_4 (40 mg As kg^{-1} soil).

Combined effect of variety and arsenic

Significant variation was found on P content in rice straw due to treatment combination of different rice varieties and arsenic levels (Table 4.10 and Appendix VIII). The highest P content (0.215%) was observed from the treatment combination of V_1As_0 whereas the treatment combination ofV_5As_3 and V_5As_4 gave least performance of P content (0.046%).

4.4.6 Potassium (K) content in straw

Effect of variety

Different variety showed significant variation on K content in straw (Table 4.9 and Appendix VIII). However, the maximum K content (0.669%) was found in V_2 (BRRI dhan-28) variety whereas the lowest K content (0.303%) was recorded in V_1 (BR-16) that was statistically same to V_3 (BRRI dhan-29), V_4 (BRRI dhan-55) and V_5 (BRRI hybrid dhan-5).

Effect of arsenic

Different arsenic levels showed significant variation on K content in rice straw (Table 4.9 and Appendix VIII). The maximum K content (0.540%) was found from the control treatment As_0 (no arsenic produced) followed by S_1 (2 mg As kg^{-1} soil), S_2 (10 mg As kg^{-1} soil) and As_3 (20 mg As kg^{-1} soil) whereas the lowest K content (0.260%) was recorded in arsenic level of As_4 (40 mg As kg^{-1} soil).

Combined effect of variety and arsenic

Significant variation was found on K content in rice straw due to treatment combination of different rice varieties and arsenic levels (Table 4.10 and Appendix VIII). The highest K content (1.057%) was observed from the treatment combination of V_2S_0. The treatment combination of V_1As_1, V_1As_1, V_1As_2, V_1As_3, V_1As_4, V_3As_4, V_4As_4 and V_5As_4 gave least performance of K content (0.195%).

4.4.7 Sulphur (S) content in straw

Effect of variety

Different variety showed significant variation on S content in straw (Table 4.9 and Appendix VIII). The maximum S content (0.0.297%) was found in V_5 (BRRI hybrid dhan-5) whereas the lowest S content (0.138%) was recorded in V_1 (BR-16) variety which was statistically same to V_2 (BRRI dhan-28), V_3 (BRRI dhan-29) and V_4 (BRRI dhan-55).

Effect of arsenic

Different arsenic levels showed non-significant variation on S content in rice straw (Table 4.9 and Appendix VIII). However, the maximum S content (0.217%) was found from the arsenic level of As_4 (40 mg As kg^{-1} soil) whereas the lowest S content (0.158%) was recorded in control treatment As_0 (no arsenic produced).

Combined effect of variety and arsenic

The significant variation was found on S content in rice straw due to treatment combination of different rice varieties and arsenic levels (Table 4.10 and Appendix VIII). However, the highest S content (0.330%) was observed from the treatment combination of V_5As_4. The treatment combination V_3As_4 and V_4As_0 gave least performance of S content (0.111%).

Table 4.9. Effect of variety and arsenic on nutrient content of rice straw

Treatments	Nutrient content of straw			
	%P	%K	%S	As (mg/kg)
Effect of variety				
V_1	0.215 a	0.303 b	0.138 b	2.80 d
V_2	0.110 b	0.669 a	0.163 b	51.93 b
V_3	0.071 b	0.346 b	0.154 b	89.58 a
V_4	0.078 b	0.367 b	0.144 b	49.72 b
V_5	0.056 b	0.305 b	0.297 a	7.03 c
$LSD_{0.05}$	0.089	0.154	0.087	3.471
CV(%)	3.28	3.14	2.68	5.72
Effect of arsenic				
As_0	0.132	0.540 a	0.158	2.53 e
As_1	0.088	0.389 b	0.185	4.11 d
As_2	0.074	0.389 b	0.196	9.25 c
As_3	0.065	0.324 b	0.198	50.58 b
As_4	0.060	0.260 c	0.217	139.66 a
$LSD_{0.05}$	0.089^{NS}	0.108	0.089^{NS}	1.634
CV(%)	3.28	3.14	2.68	5.72

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

V_1 = BR-16, V_2 = BRRI dhan-28, V_3 = BRRI dhan-29, V_4 = BRRI dhan-55, V_5 = BRRI hybrid dhan-5

As_0 = Control (No arsenic), As_1 = 2 mg As kg^{-1} soil, As_2 = 10 mg As kg^{-1} soil, As_3 = 20 mg As kg^{-1} soil, As_4 = 40 mg As kg^{-1} soil

4.4.8 Arsenic (As) content in straw

Effect of variety

Different variety showed significant variation on As content in straw (Table 4.9 and Appendix VIII). The maximum As content (89.58 mg/kg) was found in the variety V_3 (BRRI dhan-29) followed by V_2 (BRRI dhan-28) and V_4 (BRRI dhan-55) whereas the variety V_1 (BR-16) showed minimum As content (2.80 mg/kg). Bhattacharya *et al*. (2010) and Patra *et al*. (2016) also observed similar result with the present study and found As content in straw varied due to varietal difference.

Effect of arsenic

Different arsenic levels showed significant variation on As content in rice straw (Table 4.9 and Appendix VIII). The maximum As content (139.66 mg/kg) was found from the arsenic level of As_4 (40 mg As kg^{-1} soil) followed by As_3 (20 mg As kg^{-1} soil) whereas the control treatment As_0 (no arsenic produced) showed minimum As content in straw (2.53 mg/kg). Patra *et al*. (2016) found similar result with present study and observed higher concentration of As in straw with higher dose applied of As in the soil.

Combined effect of variety and arsenic

Significant variation was found on As content in rice straw due to treatment combination of different rice varieties and arsenic levels (Table 4.10 and Appendix VIII). The highest As content (230.00 mg/kg) was observed from the treatment combination of V_3As_4. The treatment combination of V_3As_0 showed minimum As content (0.821 mg/kg) in straw.

Table 4.10. Combined effects of variety and arsenic on nutrient content of rice straw

Treatment combination	Nutrient content of straw			
	%P	%K	%S	As (mg/kg)
V_1As_0	0.215 a	0.303 de	0.138 bc	2.800 i
V_1As_1	0.099 bc	0.195 e	0.176 abc	4.456 gh
V_1As_2	0.077 c	0.195 e	0.197 abc	7.634 fg
V_1As_3	0.066 c	0.195 e	0.214 abc	8.953 f
V_1As_4	0.062 c	0.195 e	0.262 abc	15.47 d
V_2As_0	0.171 ab	1.057 a	0.138 bc	3.250 h
V_2As_1	0.112 bc	0.626 b	0.149 bc	6.246 fg
V_2As_2	0.108 bc	0.626 b	0.165 abc	13.56 e
V_2As_3	0.086 bc	0.518 bc	0.176 abc	16.61 d
V_2As_4	0.074 c	0.518 bc	0.189 abc	220.00 b
V_3As_0	0.079 c	0.410 cd	0.138 bc	0.821 j
V_3As_1	0.079 c	0.410 cd	0.192 abc	2.100 i
V_3As_2	0.068 c	0.410 cd	0.181 abc	7.766 fg
V_3As_3	0.066 c	0.303 de	0.149 bc	7.892 fg
V_3As_4	0.060 c	0.195 e	0.111 c	230.00 a
V_4As_0	0.112 bc	0.518 bc	0.111 c	2.680 i
V_4As_1	0.090 bc	0.410 cd	0.132 bc	3.454 h
V_4As_2	0.068 c	0.410 cd	0.138 bc	11.78 e
V_4As_3	0.062 c	0.303 de	0.146 bc	210.00 c
V_4As_4	0.057 c	0.195 e	0.192 abc	220.00 b
V_5As_0	0.082 bc	0.410 cd	0.268 abc	3.110 h
V_5As_1	0.058 c	0.303 de	0.278 abc	4.275 gh
V_5As_2	0.049 c	0.303 de	0.300 ab	5.504 g
V_5As_3	0.046 c	0.303 de	0.308 ab	9.436 f
V_5As_4	0.046 c	0.195 e	0.330 a	12.81 e
$LSD_{0.05}$	0.089	0.154	0.178	1.736
CV(%)	3.28	3.14	2.68	5.72

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

V_1 = BR-16, V_2 = BRRI dhan-28, V_3 = BRRI dhan-29, V_4 = BRRI dhan-55, V_5 = BRRI hybrid dhan-5

As_0 = Control (No arsenic), As_1 = 2 mg As kg^{-1} soil, As_2 = 10 mg As kg^{-1} soil, As_3 = 20 mg As kg^{-1} soil, As_4 = 40 mg As kg^{-1} soil

CHAPTER V

SUMMARY AND CONCLUSION

Different rice varieties showed significant variation on different studied parameters. Variety V_2 (BRRI dhan-28) gave the highest plant height (91.28 cm) and leaf length (44.94 cm) whereas the lowest (76.95 cm and 26.33 cm, respectively) were found from V_1 (BR-16) but the maximum number of leaves hill^{-1} (55.55) was achieved from V_1 (BR-16) while the highest number of total tillers hill^{-1} (12.85) and number of effective tillers hill^{-1} (12.35) were achieved from V_5 (BRRI hybrid dhan-5) whereas the minimum number of leaves hill^{-1} (38.00) was recorded from V_3 (BRRI dhan-29) but the minimum number of total tillers hill^{-1} and number of effective tillers hill^{-1} (6.65 and 6.25, respectively) were recorded from V_4 (BRRI dhan-55).

Similarly, the highest panicle length (24.23 cm), number of panicles hill^{-1} (8.60), number of grains panicle^{-1} (135.40), number of filled grain panicle^{-1} (112.90), dry weight of straw hill^{-1} (10.15 g), 1000 grain weight (28.47 cm), grain yield hill^{-1} (19.51 g) and straw yield hill^{-1} (24.70 g) were recorded from V_5 (BRRI hybrid dhan-5) whereas the lowest results for the respected parameters (22.90 cm, 5.10, 91.81, 72.59, 7.75 g, 28.47 g, 10.98 g and 13.79 g, respectively) were achieved from V_4 (BRRI dhan-55).

Different variety showed significant variation on P, K and S content of rice grain but As content was significant. V_3 (BRRI dhan-29) showed highest As content in grain (56.95 mg/kg) followed by V_4 (BRRI dhan-55) and V_5 (BRRI hybrid dhan-5) whereas V_1 (BR-16) showed no As content in grain. Different variety showed significant variation on P, K and S and As content of rice in straw. The maximum percent P (0.215%), K (0.669%), S (0.297%) and As (89.58 mg/kg) were recorded from the variety V_1 (BR-16), V_2 (BRRI dhan-28), V_5 (BRRI hybrid dhan-5) and V_3 (BRRI dhan-29), respectively.

In case of arsenic (As) treatments, all the studied parameters showed better performance at lower As level and control treatment (no arsenic produced) performed best but gradually increased As level showed lower performance on studied parameters. The maximum plant height (90.05 cm), leaf length (48.92 cm), number of leaves hill^{-1} (57.70), number of total tillers hill^{-1} (12.55), number of effective tillers hill^{-1} (11.95), panicle length (26.45 cm), number of panicles hill^{-1} (8.60), number of grains panicle^{-1} (124.30), number of filled grain panicle^{-1} (105.50), dry weight of straw hill^{-1} (9.25 g), 1000 seed weight (24.48 g), grain yield hill^{-1} (20.00 g) and straw yield hill^{-1} (27.98 g) were recorded from control treatment S_0 (no arsenic produced) followed by As_1 (2 mg As kg^{-1} soil) (92.15 cm, 39.31 cm, 49.15, 10.25, 9.10, 24.97 cm, 7.35, 124.00, 100.40, 8.80 g, 24.42 g, 15.76 g and 19.68 g, respectively) whereas the maximum As level As_4 (40 mg As kg^{-1} soil) showed minimum plant height (80.43 cm), leaf length (31.91 cm), number of leaves hill^{-1} (39.50), number of total tillers hill^{-1} (8.25), number of effective tillers hill^{-1} (7.40), panicle length (21.50 cm), number of panicles hill^{-1} (6.45), number of grains panicle^{-1} (77.18), number of filled grain panicle^{-1} (61.94), dry weight of straw hill^{-1} (7.80 g), 1000 seed weight (13.28 g), grain yield hill^{-1} (13.60 g) and straw yield hill^{-1} (16.19 g). Nutrient content in grain and straw influenced by As treatment, non-significant variation was found for P, K and S in grain and for P and S in straw whereas As content in grain and straw and K content in straw was significant. Maximum As content in grain and straw (86.98 mg/kg and 139.66 mg/kg, respectively) was recorded from maximum As level As_4 (40 mg As kg^{-1} soil) whereas decreased As content in grain and straw was found with lower As treatments and control treatment As_0 (no arsenic produced) gave minimum As content (0 and 2.53 mg/kg, respectively).

Different parameters affected significantly due to treatment combinations of variety and arsenic. V_2As_0 showed highest plant height (99.63 cm) and leaf length (57.38 cm) whereas V_1As_4 showed minimum result (72.25 cm and 25.58 cm, respectively) but V_1As_0 showed highest number of leaves hill^{-1} (64.00) but

V_5As_0 showed highest number of total tillers hill^{-1} (16.75) and number of effective tillers hill^{-1} (15.25) whereas V_3As_4 gave least performance (22.00, 4.50 and 0, respectively). Treatment combination of V_5S_0 also showed highest number of panicles hill^{-1} (10.25), number of grain panicle^{-1} (160.20), number of filled grain panicle^{-1} (143.40), dry weight of straw hill^{-1} (14.50 g), 1000 grain weight (28.63 g), grain yield hill^{-1} (28.60 g) and straw yield hill^{-1} (41.00 g) whereas V_3As_4 gave least performance for the respected parameters and showed no grain yield. Again, V_3As_4 gave maximum As content in straw (230 mg/kg) and this treatment combination showed no grain yield due to As effect but the maximum As content in grain (270.00 mg/kg) was found from V_3As_3.

From the above result, it may be concluded that the V_5 (BRRI hybrid dhan-5) showed better performance on yield and yield contributing parameters and nutrient uptake against arsenic contamination in soil. The experiment showed that the addition of As to soil significantly and adversely affected the plant height, total tillers per hill^{-1}, effective tillers per hill^{-1}, panicle length, filled grains per panicle, 1000-grain weight, and grain and straw yield. Generally, the values for most of the parameters drastically decreased as the doses of As increased. The grain and straw yields were markedly affected by As addition to soil. In case of nutrient content, V_1As_0 gave maximum P (0.286%) and V_5As_0 and V_5As_1 gave maximum K (0.259%) content in grain but V_5As_4 showed maximum S content (0.197%) which was statistically identical with V_5As_3 and V_5As_2 and minimum P, K, S were found from V_3As_4 i.e. there is no grain in case of straw, the maximum P (0.215%) content was found in V_1As_0, K (1.057%) content was inV_2As_0 and S content (0.330%) was in V_5As_4 and minimum P, K, S were found from V_3As_4. The variety V_1 (BR-16) up took minimum amount of As in grain and straw. As uptake was increased with increasing addition of As in soil. In case of variety, V_2 (BRRI dhan-28), V_3 (BRRI dhan-29), V_4 (BRRI dhan-55), V_5 (BRRI hybrid dhan-5) As uptake was increased with the increasing amount of As addition in soil but in case of variety V_1 (BR-16) As uptake in grain and straw was not that much increased like other varieties.

Recommendations

1. Further research works at different regions of the country are needed to be carried out for the confirmation of the present findings.

2. Some other rice varieties including present plant materials with other As doses might be included for further experiment.

REFERENCES

Abedin, M.J. and Meharg, A.A. (2002a). Relative toxicity of arsenite and arsenate on germination and early seedling growth of rice (Ory*za sativa* L.). *Plant Soil*. **243**: 57-66.

Abedin, M.J., Cottep-Howells, J. and Meharg, A.A. (2002b). Arsenic uptake and accumulation in rice (*Oryza sativa* L.) irrigated with contaminated water. *Plant Soil*. **240**: 311-319.

Abou-Khalif, A.A.B. (2009). Evaluation of some hybrid rice varieties in under different sowing times. *Afr. J. Plant Sci.* **3**(4): pp. 053-058.

Ahsan, D.A. and Del-Valls, T.A. (2011). Impact of arsenic contaminated irrigation water in food chain: An overview from Bangladesh. *Int. J. Environ. Res*., **5**(3): 627:638.

Alam, A. and Rahman, A. (2003). Accumulation of arsenic from arsenic contaminated irrigation water and effect on nutrient content. Fate of arsenic in environment. Proceeding of the international symposium on the fate of arsenic in the environment, ITN centre, BUET, Dhaka.

Alam, M.S. and Islam, M.A. (2011). Assessing the effect of arsenic contamination on modern rice production: evidences from a farm level study. *Bangladesh J. Agric. Econs*. **34**(1&2): 15-28.

Alam, M.S., Baki, M.A., Sultana, M.S., Ali, K.J. and Islam, M.S. (2012). Effect of variety, spacing and number of seedlings per hill on the yield potentials of transplant aman rice. *Int. J. Agron. Agric. Res*. **2**(12): 10–15.

Ali, M.A., Badruzzaman, A.B.M., Jalil, M.A., Hossain, M.D., Ahmed, M.F., Masud, A.A. and Rahman, A. (2005). Arsenic in plants-soil environment in Bangladesh. *Environ. Sci. Technol*., **34**: 85-110.

BBS. (2016). Yearbook of Agricultural Statistics. Bangladesh Bureau of Statistics, Statistics and Informatics Division (SID), Ministry of Planning, Government of the People's Republic of Bangladesh.

BBS. (2020). Statistical yearbook of Bangladesh. Bangladesh Bureau of Statistics. Statistics Division, Ministry of Planning, Govt. of Peoples Republic of Bangladesh.

Bhattacharya, P., Samal, A.C., Majumdar, J. and Santra, S.C. (2010). Uptake of arsenic in rice plant varieties cultivated with arsenic rich groundwater. *Environ. Asia*. **3**: 34-37.

Bhattacharyya, S., Chatterjee, M., Debnath, S., Sarkar, S. and Mukherjee, A. (2012). Genetics and physiology of elevated arsenic in grain and straw of rice. In Arsenic Contamination in Water and Food Chain: Proceedings of International Workshop on "Arsenic in Food Chain: Cause, Effect and Mitigation", (D.N. Guha Mazumder and S. Sarkar, Eds.), DNGM Research Foundation, Kolkata, India, 99-110.

Bhowmick, N. and Nayak, R.L. (2000). Response of hybrid rice *(Oryza sativa* L.) varieties to nitrogen, phosphorus and potassium fertilizers during dry *(Boro)* season in West Bengal. *Indian J. Agron.* **45**(2): 323-326.

Biswas, A., Biswas, S. and Santra, S.C. 2014. Arsenic in irrigated water, soil and rice: perspective of the cropping season. *Paddy Water Environ*. **12**: 407- 412.

Brammer, H. (2009). Mitigation of arsenic contamination in irrigated paddy soils in South and South-East Asia. *Environ. Int*. **35**: 856-863.

Calpe, C. and Prakash, A. (2007). Sensitive and Special Products-a rice perspective. Commodity Market Review, FAO. p. 49-71.

Chamely, S.G., Islam, N., Hoshain, S., Rabbani, M.G., Kader, M.A. and Salam, M.A. (2015). Effect of variety and nitrogen rate on the yield performance of boro rice. *Progressive Agric*. **26** (1): 6-14.

Chowdhury, M.T.A., Deacon, C.M., Jones, G.D., Huq, S.M.I., Williams, P.N., Winkel, L.H.E., Price, A.H., Norton G.J. and Meharg, A.A. (2017). Arsenic in Bangladesh soils related to physiographic region, paddy management, and micro- and macro-elemental status. *Sci. Total Environ*. pp. 406- 415.

Chowdhury, U.M.J., Sacker, U.A., Sarkar, R.M.A. and Kashem, A.M. (2005). Effect of variety and number of seedlings hill's on the yield and its components on late transplanted *Aman* rice. *Bangladesh J. Agril. Sci.* **20**(2): 311-316.

Chowhan, S., Ali, M.K.J., Nahar, K., Rahman, M.M., Ali, M.I. and Islam, M. (2021). Yield and morpho physical characters of some modern aus rice varieties at Khagrachari. *Plant Sci. Today*. **8**(1): 155-160.

Dilday, R.H., Slaton, N.A., Gibbhons, J.W., Moldenhouer, K.A., and Yan, W.G. (2000). Straightheadot rice as influenced by arsenic and nitrogen. Research Series Arkansas Agricultural Experiment Station. **476**: 201-214.

FAO (2011). Directorate of economics and statistics: Ministry of Agriculture.

FAO (Food and Agriculture Organization). (2021). Retrieved from: http://www.fao.org/faostat/en/#data/QCL.

Gomez, K. A. and Gomez, A. A. (1984). Statistical Procedure for Agricultural Research (2nd edn.). Int. Rice Res. Inst., *A Willey Int. Sci*., pp. 28-192.

Haque, M.M., Pramanik, H.R. and Biswas, J.K. (2015). Physiological behavior and yield performances of hybrid rice at different planting dates in *Aus* Season. *Bangladesh Rice J.* **17**(1&2): 7-14.

Haque, M.M., Pramanik, H.R. and Biswas, J.K. (2013). Physiological behavior and yield performances of hybrid rice at different planting dates in *Aus* Season. *Bangladesh Rice J.* **17**(1&2): 7-14.

Howladar, M.M., Uddin, M.J., Islam, M.M., Parveen, Z. and Rahman, M.K. (2019). Effects of arsenic and phosphorus on the growth and nutrient concentration in rice plant. *J. Biodivers. Conserv. Bioresour. Manag*. **5**(1): 31-38.

Huang, B. and Yan, Z. (2016). Performance of 32 Hybrid Rice Varieties at Pine Bluff of Arkansas. *American J. Plant Sci*. **7**: 2239-2247.

Hue, V.N. (2010). Arsenic levels, chemistry and bio-availability in Hawaii soils. World Congress of Soil Science, soil solution for a changing world. Brisbane, Austrilia, 9-12.

Huq, S.M.I. and Naidu, R. (2003). Arsenic in ground water of Bangladesh: contamination in the food chain. In: M. F. Ahmed (ed.). Arsenic contamination: Bangladesh perspective. ITN-Bangladesh; Centre for water supply and management. BUET, Dhaka, Bangladesh.

Huq, S.M.I., Joardar, J.C. Parvin, S., Corell, R. and Naidu, R. (2006). Arsenic contamination in food-chain: Transfer of arsenic into food material through groundwater irrigation. *J. Health Popul. Nutr*. **24**(3): 305-316.

Islam, K. and Hossain, K. (2019). Association between arsenic exposure and organ dysfunction- a population based study in Bangladesh. Abstract. 1st International Conference on Environmental Science and Resource Management. 2019: Safe Environment for Better Living, February 08- 09, 2019. *Mawlana Bhashani Sci. Technol. Univ*., ICESRM 2019. pp. 43-44.

Islam, M.S., Parvin, S. and Sarkar, M.A.R. (2009). Yield of fine rice varieties as influenced by integrated management of poultry manure, urea super granules and prilled urea. *J. Environ. Sci. Nat. Res.,* **5**(1): 203-212.

Islam, M.R., Islam, S., Jahiruddin, M. and Islam, M.A. (2004). Effect of irrigation water arsenic in rice-rice cropping system. *J. Biol. Sci*. **4**(4): 542-556.

Islam, N., Kabir, M.Y., Adhikary, S.K. and Jahan, M.S. (2013). Yield Performance of Six Local Aromatic Rice Cultivars. *IOSR J. Agric. Vet. Sci. (IOSR-JAVS)*. **6**(3): 58-62

Jahan, I., Islam, M.R., Hoque, T.S., Hossain, M., Abedin, M.A. (2020). Influence of Soil arsenic in Rice and its Mitigation Through Water Management. *J. Bangladesh Agric. Univ*. **18**(3): 1–6.

Jahan, I., Ullah, S.M., Hoque, S. and Ullah, T.K. (2003). Effects of arsenic on the mineral nutrition of rice plant. Dhaka. *Univ. J. Biol. Sci*. **12**(2): 165-175.

Jisan, M.T., Paul, S.K. and Salim, M. (2014). Yield performance of some transplant aman rice varieties as influenced by different levels of nitrogen. *J. Bangladesh Agril. Univ*. **12**(2): 321–324.

Julfiquar, W.A., Haque, M.M., Haque, E.K.G.M.A. and Rashid, A.M. (2009). Current status of Hybrid Rice Research and Future Program in Bangladesh. Proc. Workshop on use and development of hybrid rice in Bangladesh, held at BARC, 18-19, May, 2009.

Julfiquar,W.A., Haque, M.M., Haque, E.K.G.M.A. and Rashid, A.M. (1998). Current status of Hybrid Rice Research and Future Program in Bangladesh. Proc. Workshop on use and development of hybrid rice in Bangladesh, held at BARC, 22-23, April, 1998.

Kabir, M.S., Salam, M.A., Paul, D.N.R., Hossain, M.I., Rahman, N.M.F., Aziz, A., and Latif, M.A. (2016). Spatial variation of arsenic in soil, irrigation water, and plant parts: A Microlevel Study. *The Sci. World J*. pp. 1-12.

Kamal, M.M. (2007). Performance of modern boro rice varieties under different planting methods. *J. Bangladesh Agril. Univ*. **5**(1): 43-47, 2007.

Khan, M.A., Stroud, J., Zhu, Y.G., McGrath S.P. and Zhao, F.J. (2010). Arsenic bioavailability to rice is elevated in Bangladeshi paddy soils. *Environ. Sci. Technol*. **44**: 8515-8521.

Khatun, S. (2020). Growth and Yield Performance of Six Aman Rice Varieties of Bangladesh. *Asian Res. J. Agric*. **12**(2): 1-7

Lu, Y., Adomako, E.E., Solaiman, A.R.M., Islam, M.R., Deacon, C., Williams, P. N., Rahman, G. K. M. M. and Meharg, A. A. (2009). Baseline soil variation is a major factor in arsenic accumulation in Bengal Delta paddy rice. *Environ. Sci. Technol*. **43**(6): 1724-1729.

Mahmood, R., Howlader, M.H.K. and Haque, M.Z. (2019). Performance of hybrid Boro rice in coastal area of Bangladesh. *Prog. Agric*. **30** (2): 186-193.

Masum, S.M., Ali, M.H., Hasanuzzaman, M., Chowdhury, I.F., Mandal, M.S.H. and Jerin, R. (2014). Response of variety and population density on yield attributes and yield of boro rice (*Oryza sativa*). *Ann. Agric. Res. New Series*. **35**(4): 355-361.

Meharg, A.A. and Rahman, M.M. (2003). Arsenic Contamination of Bangladesh Paddy Field Soils: Implications for Rice Contribution to Arsenic Consumption. *Environ. Sci. Tech*. **37**: 229-234.

Meharg, A.A., and Rahman, M.M. (2002). Arsenic Contamination of Bangladesh Paddy Field Soils: Implications for Rice Contribution to Arsenic Consumption. *Environ. Sci. Technol*. pp. 42-47.

Mia, M.B. (2018). Influence of zinc application methods on growth and yield of *Boro* rice. M.S. thesis, Dept. Agronomy, Sher-e-bangla Agricultural University, Dhaka-1207.

Montenegro, O. and Mejia, L. (2001). Contamination of rice (*Oryza sativa* L.) with cadmium and arsenic by irrigation with water of the Bogota River in rice soils of the lower basin. *Suelos Ecuatoriales*. **31**(1): 26-31.

Murshida, S., Uddin, M.R., Anwar, M.P., Sarker, U.K., Islam, M.M. and Haque, M.M.I. (2017). Effect of variety and water management on the growth and yield of Boro rice. *Prog. Agric*. **28**(1): 26-35.

Murthy, K.N.K., Shankaranarayana, V., Murali, K., Jayakumar, B.V. (2004). Effect of different dates of planting on spikelet sterility in rice genotypes *(Oryza sativa* L.). *Res. Crops.* **5**(2/3): 143-147.

Norton, G.J., Deacon, C.M., Xiong, L., Huang, S., Meharg, A.A. and Price, A.H. (2010) Genetic mapping of the rice ionome in leaves and grain: identification of QTLs for 17 elements including arsenic, cadmium, iron and selenium. *Plant Soil*, **329**: 139-153.

Panaullah, G.M., Alam, T., Hossain, M.B., Loppert, R.H., Lauren, J.G., Meisner, C.A., Ahmed, Z.U. and Duxbury, J.M. (2009). Arsenic toxicity to rice (*Oryza sativa* L.) in Bangladesh. *Plant Soil*. **317**(1-2): 31-39.

Patel, J.R. (2000). Effect of water regime, variety and blue green algae on rice *(Oryza sativa). Indian J. Agron.* **45**(1): 103-106.

Patel, K.S., Sahu, B.L., Ramteke, S. and Bontempi, E. (2016). Contamination of paddy soil and rice with arsenic. *J. Environ. Protec*. **7**: 689-698.

Patra, P.K., Sarkar, S., Pal, S., Roy, A. and Dhara, M.C. (2016). Interim progress report on "Screening of low arsenic accumulating rice varieties and hybrids for West Bengal", Government of West Bengal, 1-47.

Pinson, S.R., Tarpley, L., Yan, W., Yeater, K., Lahner, B., Yakubova, E. and Salt, D.E. (2015). Worldwide genetic diversity for mineral element concentrations in rice grain. *Crop Sci*. **55**: 294-311.

Rahman, A., Salam, M.A., Kader, M.A., Islam, M.S. and Perveen, S. (2020). Growth and yield of *boro* rice (*Oryza sativa* L.) in response to crop establishment methods and varieties. *Arch. Agric. Environ. Sci*. **5**(2): 137-143.

Rahman, M.A., Rahman, M.M., Miah, M.A.M. and Khaled, H.M. (2004). Influence of soil arsenic concentrations in rice (*Oryza sativa* L.). *J. Sub-trop. Agric. Res. Dev*. **2**: 24-31.

Rahman, M.A., Hasegawa, H., Rahman, M.M., Rahman, M.A. and Miah, M.A.M. (2007) Accumulation of arsenic in tissues of rice plant (*Oryza sativa* L.) and its distribution in fractions of rice grain. Chemosphere, **69**: 942-948.

Rahman, M.A., Hossain, S.M.A., Sarkar, N.A.R., Hossain, M.S. and Islam, M.S. (2002). Effect of variety and structural arrangement of rows on the yield and yield components of transplant *Aman* rice. *Bangladesh .J. Agril. Sci.* **29**(2): 303-307.

Rashid, M.M., Ghosh, A.K., Roni, M.N., Islam, M.R and Alam, M.M. (2017). Yield performance of seven aromatic rice varieties of Bangladesh. *Int. J. Agric. Environ. Res.* **3**(2): 2637.

Razzaque, M.A., Talukder, N.M., Islam, M.S., Bhadra, A.K. and Dutta, R.K. (2009). The effect of salinity on morphological characteristics of seven rice (*Oryza sativa*) genotypes differing in salt tolerance. *Pak. J. Biol. Sci*. **12**(5): 406-412.

Sahoo, P.K. and Mukherjee, A. (2014). Arsenic fate and transport in groundwatersoil- plant system: An understanding of suitable rice paddy cultivation arsenic enriched areas. Treands in Modelling of Environmental Contaminants, **10**: 21-32.

Salam, T.B., Karmakar, B., Hossain, S.M.T., Robin, M.H., Mariam, M.Z. and Hossain, M. (2019). Agronomic Performance of Modern Rice Varieties in South-west Bangladesh. *Plant Sci. Today*. **6**(4):528-532.

Sarkar, S.K., Sarkar, M.A.R., Islam, N. and Paul, S.K. (2014). Yield and quality of aromatic fine rice as affected by variety and nutrient management. *J. Bangladesh Agril. Univ*. **12**(2): 279–284.

Sarkar, S.C., Akter, M., Islam, M.R. and Haque, M.M. (2016). Performance of Five Selected Hybrid Rice Varieties in *Aman* Season. *J. Plant Sci.,* **4**(2): 72-79.

Shiyam, J.O., Binang, W.B. and Ittah, M.A. (2014). Evaluation of growth and yield attributes of some lowland chinese hybrid rice *(Oryza sativa* L.) varieties in the Coastal Humid Forest Zone of Nigeria. *J. Agric. Vet. Sci.* **7**(2): 70-73.

Siddiquee, M.A., Biswas, S.K., Kabir, K. A., Mahbub, A.A., Dipti, S.S., Ferdous, N., Biswas, J.K. and Banu, B. (2002). A Comparative Study Between Hybrid and Inbred Rice in Relation to Their Yield and Quality. *Pakistan J. Biol. Sci.* **5**: 550-552.

Singh, S., Singh, V., Khanna, R., Kumar, P. and Shukla, R. (2019). Effect of nitrogen and sulphur fertilization on growth and yield of rice (*Oryza sativa* L.). *Prog. Res. Int. J. Soc. Sci. Dev*. 14 (Special-I): 526-530.

Sinha, B. and Bhattacharya, K. (2014). Arsenic accumulation and speciation in transplanted autumn rice as influenced by source of irrigation and organic manures. *Int. J. Bio-res. Stress Manag*. **5**(3):363:368.

Sritharan, N. and Vijayalakshmi, C. (2012). Physiological basis of rice genotypes under aerobic condition. *Plant Archives.* **12**(1): 209-214.

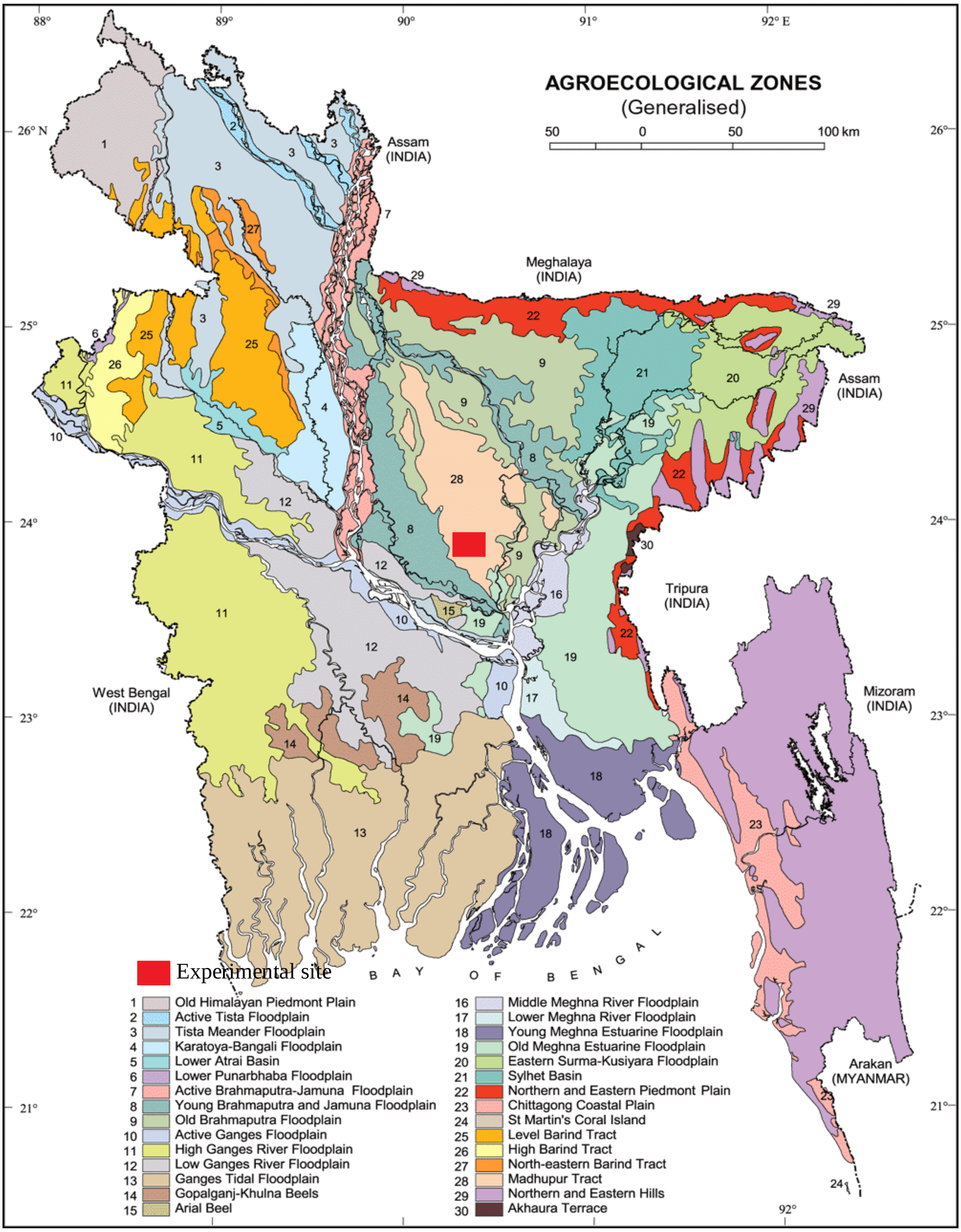
Sumit, C., Pyare, L., Singh, A.P. and Tripathi, M.K. (2004). Agronomic and morpho-physiological analysis of growth and productivity in hybrid rice *(Oryza sativa* L.). *Ann. Biol.* **20**(2): 233-238.

Williams, P.N., Islam, M.R., Adomokao, E.E., Raab, A., Hossain, S.A., Zhu, Y.G., Feldman, J. and Mehrag, A.A. (2006). Increase in rice grain arsenic for regions of Bangladesh irrigating paddies with elevated arsenic in ground waters. *Environ. Sci. Technol*., **40**: 4903-4908.

Williams, P.N., Raab, A., Feldmann, J. and Meharg, A.A. (2007). Market basket survey shows elevated levels of As in South Central US processed rice compared to California: consequences for human dietary exposure. *Environ. Sci. Technol*. **41**: 2178-2183.

APPENDICES

Appendix I. Agro-Ecological Zone of Bangladesh showing the experimental location



Appendix II. Monthly records of air temperature, relative humidity and rainfall during the period from December 2020 to May 2021.

Year	Month	Air temperature (°C)			Relative humidity (%)	Rainfall (mm)
		Max	*Min*	*Mean*		
2020	December	25.50	6.70	16.10	54.80	0.0
2021	January	23.80	11.70	17.75	46.20	0.0
2021	February	22.75	14.26	18.51	37.90	0.0
2021	March	35.20	21.00	28.10	52.44	20.4
2021	April	34.70	24.60	29.65	65.40	165.0
2021	May	32.64	23.85	28.25	68.30	182.2

Source: Bangladesh Meteorological Department (Climate division), Agargaon, Dhaka-1212.

Appendix III. Characteristics of experimental soil analyzed at Soil Resources Development Institute (SRDI), Farmgate, Dhaka.

A. Morphological characteristics of the experimental field

Morphological features	**Characteristics**
Location	Agronomy Farm, SAU, Dhaka
AEZ	Modhupur 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
Cropping pattern	Not Applicable

Source: Soil Resource Development Institute (SRDI)

B. Physical and chemical properties of the initial soil

Characteristics	**Value**
Partical size analysis % Sand	27
%Silt	43
% Clay	30
Textural class	Silty Clay Loam (ISSS)
pH	5.6
Organic carbon (%)	0.45
Organic matter (%)	0.78
Total N (%)	0.03
Available P (ppm)	20
Exchangeable K (me/100 g soil)	0.1
Available S (ppm)	45

Source: Soil Resource Development Institute (SRDI)

Appendix IV. Effect of variety and arsenic on growth parameters of rice

Sources of variation	Degrees of freedom	Growth parameters				
		Plant height (cm)	Leaf length (cm)	Number of leaves hill^{-1}	Number of total tillers hill^{-1}	Number of effective tillers hill^{-1}
Factor A	4	716.60*	1075.4*	947.57*	121.13*	103.31*
Factor B	4	468.63*	821.34*	1059.2*	59.260*	57.765*
AB	16	211.65**	353.89*	254.63*	15.191**	15.44**
Error	72	12.368	5.991	7.302	1.840	2.278

* = Significant at 5% level ** = Significant at 1% level

Appendix V. Effect of variety and arsenic on yield contributing parameters of rice

Sources of variation	Degrees of freedom	Yield contributing parameters				
		Panicle length (cm)	Number of panicles hill^{-1}	Number of grains panicle^{-1}	Number of filled grain panicle^{-1}	Dry weight of straw hill^{-1} (g)
Factor A	4	11.66*	37.46*	8939.18*	5019.62*	18.39*
Factor B	4	89.07*	13.66**	7874.39*	5748.19*	6.515**
AB	16	4.825**	6.204**	1887.18*	2327.71*	24.08*
Error	72	1.772	0.103	17.795	27.076	0.359

* = Significant at 5% level ** = Significant at 1% level

Appendix VI. Effect of variety and arsenic on yield parameters of rice

Sources of variation	Degrees of freedom	Yield parameters		
		1000 seed weight (g)	Grain yield hill^{-1} (g)	Straw yield hill^{-1} (g)
Factor A	4	34.475*	164.826*	210.711*
Factor B	4	87.649*	126.068*	463.270*
AB	16	32.077*	1.629**	133.156*
Error	72	0.316	2.565	1.912

* = Significant at 5% level ** = Significant at 1% level

Appendix VII. Effect of variety and arsenic on nutrient content of rice grain

Sources of variation	Degrees of freedom	Nutrient content of grain			
		%P	%K	%S	As (mg/kg)
Factor A	4	NS	NS	NS	7.362 *
Factor B	4	NS	NS	NS	3.812 **
AB	16	0.385**	0.221**	0.143**	11.44 *
Error	72	0.225	0.151	0.151	0.103

NS = Non-significant * = Significant at 5% level ** = Significant at 1% level

Appendix VIII. Effect of variety and arsenic on nutrient content of rice straw

Sources of variation	Degrees of freedom	Nutrient content of straw			
		%P	%K	%S	As (mg/kg)
Factor A	4	NS	NS	NS	11.463*
Factor B	4	NS	NS	NS	105.24*
AB	16	NS	NS	NS	46.24 *
Error	72	0.102	0.117	0.144	1.204

NS = Non-significant * = Significant at 5% level ** = Significant at 1% level