EFFECTS OF CADMIUM ON GROWTH, YIELD AND NUTRIENTS CONTENT OF BRRI dhan29, BRRI dhan60 AND BRRI dhan61

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CERTIFICATE

This is to certify that the thesis entitled" EFFECTS OF CADMIUM ON GROWTH, YIELD AND NUTRIENTS CONTENT OF BRRI dhan29, BRRI dhan60 AND BRRI dhan61"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 (M.S.) in AGRICULTURAL CHEMISTRY, embodies the results of a piece of bona fide research work carried out by MD. LUTFEY AL MUEEZ, Registration. No.10-03993, under my supervision and guidance. No part of this thesis has been submitted for any other degree or diploma in any other institution.

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

Dated:
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Dedicated to

My

Beloved Parents

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The Author

ABSTRACT

A pot experiment was conducted at the net house of the Department of Agricultural Chemistry of Sher-e-Bangla Agricultural University, Dhaka-1207 during the Boro season from November, 2015 to May, 2016 to evaluate the effects of cadmium on growth, yield and nutrients content of three different Boro rice cultivars. The two factorial experiment was laid out in a completely randomized design (CRD) with three replications. Factor A: three varieties [V_1-BRRI dhan29, V_2-BRRI dhan60 and V_3-BRRI dhan61] and factor B: five doses of cadmium [T_0= No cadmium applied), T_1= 20 ppm Cd, T_2=40 ppm Cd, T_3=60 ppm Cd, T_4=80 ppm Cd]. Cadmium was added from cadmium sulphate ($3CdSO_4.8H_2O$). Soils were treated with Cd as per treatments before transplanting. The cultivar BRRI dhan29 showed better performance than BRRI dhan60 and BRRI dhan61. Treatment with no cadmium (T_0) gave higher results in most growth, yield and yield related parameters. In case of interaction, BRRI dhan29 and the treatment with no cadmium (T_0) gave longer panicle (29.80 cm), the highest number of filled grains panicle^{-1} (220.7) and grain yield (6.543 t ha^{-1}). K, Na and Ca content in grain showed statistically non-significant difference due to the varietal effect in most cases. The treatment with no cadmium (T_0) gave higher K, Na and Ca content in grain, straw and root. Interaction of BRRI dhan61 and the treatment with no cadmium (T_0) gave higher K content in grain (0.4353 %), straw (5.137 %) and root (0.8133 %). Interaction of BRRI dhan61 and the treatment with no cadmium (T_0) gave higher Na content in grain (0.22 %) while interaction of BRRI dhan60 and the treatment with no cadmium (T_0) gave higher Na content in straw (1.833 %) and root (1.430 %). In case of Ca content in grain, there was statistically non-significant difference due to the interaction of variety and cadmium doses. Interaction of BRRI dhan61 and the treatment with no cadmium (T_0) gave higher Ca content in straw (0.559 %) while interaction of BRRI dhan60 and the treatment with no cadmium (T_0) gave higher Ca content in root (0.346 %). Cadmium contamination significantly decreased almost all the growth, yield & yield contributing characters and nutrients content. The Cd concentration in grain, straw and root of three rice varieties increased with increasing rate of Cd addition. BRRI dhan29 had the lowest grain Cd concentration (15.35 mg kg^{-1}) and BRRI dhan60 showed the highest Cd concentration (24.43 mg kg^{-1}) in grain but BRRI dhan29 had the maximum Cd content in straw (26.16 mg kg^{-1}) and root (77.29 mg kg^{-1}) while BRRI dhan60 and BRRI dhan61 had comparatively lower in straw and root.

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LIST OF ABBREVIATIONS AND ACRONYMS

AEZ	=	Agro- Ecological Zone
@	=	At the rate
BARI	=	Bangladesh Agricultural Research Institute
BAU	=	Bangladesh Agricultural University
BBS	=	Bangladesh Bureau of Statistics
BINA	=	Bangladesh Institute of Nuclear Agriculture
BRRI	=	Bangladesh Rice Research Institute
Cd	=	Cadmium
cm	=	Centi-meter
CV	=	Coefficient of Variance
cv.	=	Cultivar (s)
DAT	=	Days After Transplanting
^{0}C	=	Degree Centigrade
et al.	=	And others
FAO	=	Food and Agriculture Organization
g	=	Gram (s)
IRRI	=	International Rice Research Institute
hr	=	Hour(s)
Kg	=	Kilogram (s)
LSD	=	Least Significant Difference
m	=	Meter
m^2	=	Meter squares
mm	=	Millimeter
MOP	=	Muriate of Potash
N	=	Nitrogen
No.	=	Number
NS	=	Non significant
%	=	Percentage
SAU	=	Sher-e- Bangla Agricultural University
t ha^{-1}	=	Ton per hectare
TSP	=	Triple Super Phosphate
var.	=	Variety
Wt.	=	Weight

Chapter I

Introduction

CHAPTER 1

INTRODUCTION

Rice is the seed of the grass species *Oryza sativa* (Asian rice) or *Oryza glaberrima* (African rice) and belongs to the cereal crops under Poaceae family. As a cereal grain, it is the most widely consumed staple food for a large part of the world's human population, especially in Asia. It is the agricultural commodity with the third-highest worldwide production, after sugarcane and maize (FAOSTAT, 2012). It is one of the world's most widely consumed grains which play a unique role in combating global hunger. It is the staple food of Bangladesh. Almost all the people depend on rice and have tremendous influence on agrarian type of economy of Bangladesh. Rice is intensively cultivated in Bangladesh covering about 80% of arable land. Rice alone constitutes 95% of the food grain production in Bangladesh. Unfortunately, the yield of rice is low in Bangladesh as compared to that of other rice growing countries like South Korea and Japan where the average yield is 7.00 and 6.22 t/ha, respectively (FAO, 2015). Bangladesh is an agro-based country with population of about 160 millions living in 14.84 million hectares of land. According to the estimate of World Bank, the population will have possibly increased to 230 million by the year 2030 with almost half of the people living in cities and towns. Rice is the staple dietary item for the people and per capita rice consumption in Bangladesh is about 166 kg/year (BBS, 2015). Rice alone provides 76% of the calorie intake and 66% of total protein requirement (Bhuiyan *et al.*, 2002). It employs about 43.6% of total labor forces (BBS, 2015, HIES, 2009). Rice covers about 75% of the total cropped area (BRKB, 2017). Rice alone shares about 96% of the total cereal food supply. Furthermore, rice alone contributes about 9.5 % of the total agricultural GDP in the country. Among all crops, rice is the driving force of Bangladesh agriculture (MoFDM, 2012). On the other hand, the need for increasing rice production is mounting up to feed the ever-increasing population of this country.

Rice is grown in three seasons namely Aus (mid-March to mid-June), Aman (mid-June to mid-November) and Boro (Mid-November to mid-May) in Bangladesh. The largest part of the total production of rice comes from Boro season. The total production in Boro season is 19001.10 thousand metric tons while in the Aus season production is 2468 thousand metric tons and Aman season production is 13591thousand metric tons (BBS, 2016). The Agro ecological condition of this country favours the large-scale production of Boro rice.

In Bangladesh, total cultivable land is 10 million hectare and near about 70 per cent of this land is occupied by rice cultivation. In the year 2015-2016, the total production of rice was 38.99 million metric ton (BBS, 2016). Hybrid rice varieties were cultivated in 0.698 million hectares of land and total production was 3.31 million metric ton in the year of 2014-2015. On the other hand, HYV (High Yielding Varieties) was cultivated in 8.94 million hectares land and the total production of rice was 28.7 million metric ton. The average rice production of hybrid varieties was 4.41 metric ton and HYV varieties were 3.84 metric ton in the year 2014–2015 (BBS, 2015).

Variety is the most important factor in rice production. Yield components are directly related to the variety and neighboring environments in which it grows. Variety is the key component to produce higher yield of rice depending upon their differences in genotypic characters, input requirements and response, growth process and off course the prevailing environmental conditions during the growing season. The growth process of rice plants under a given agro-climatic condition differs with variety. In the year 2015-2016 among the Boro rice varieties modern varieties covered 98.29% and yield was 2.44 t ha^{-1} on the other hand local varieties covered 1.71% and yield was 1.37 t ha^{-1} (BBS, 2016). It was the farmers who have gradually replaced the local indigenous low yielding rice varieties by HYV of rice developed by BRRI only because of getting 20% to 30 % more yield $unit^{-1}$ land area (Shahjahan, 2007).

There are many abiotic factors that affect rice production each year in huge scale. Contamination by heavy metals is one of them. In recent years there has been increasing awareness and concern over heavy metal contamination of soils and their effects on the food chain. The uptake of toxic heavy metals from contaminated soils by food and forage plants comprises a prominent path for such elements to enter into the food chain and finally be ingested by humans. Cadmium is one of these heavy metals. It is estimated that around 30,000 tones cadmium (Cd) are released into the environment annually, of which 13,000 tones resulted from human activity (Gallego *et al.,* 2012). Cd is one of the most readily uptake and rapidly transported heavy metals in higher plants. The level of Cd uptake in higher plants is determined by the Cd concentration of the soil. It was assumed that for Cd being a non-essential element, there would be no specific uptake mechanisms. Instead, Cd would enter plant cells via uptake systems for essential elements. In other words, the uptake of Cd ions takes place in competition with that of essential elements such as K, Mg, Ca, and Fe, across the same trans-membrane transporter (Das *et al.,* 1997, Sanita di Toppi and Gabbrielli, 1999, Pál *et al.,* 2006). Such competition results in a decrease in the uptake of essential elements. Thus, the possibility that toxic effect of Cd may be attributable to the decline of essential elements cannot be excluded.

Cadmium is a class one carcinogenic element in nature and is non-degradable contaminant which can be transferred from soil to plants (Meharg *et al.,* 2013, Satarug *et al.,* 2003). Its accretion in crops and soils is an increasing concern to crop production (Hall, 2002). A part of agricultural soils, all over the world are slightly to moderately polluted by Cd due to industrial pollution, metal mining, manufacture and disposal as well as some agricultural practices such as extended use of superphosphate fertilizers, pesticides, sewage sludge and smelters dust spreading leads to dispersion of Cd (Angelova and Atanassov., 2009). Cadmium is a relatively rare metal with no biological function, and is highly toxic to plants and animals (Alloway, 1995). Plants often accumulate a huge quantity of Cd without poisoning symptoms, which inters into the food chain (Fergusson, 1991).

The cadmium treatment led to an inhibition of growth rate, transpiration and ion uptake by wheat seedlings; the rapid inhibition of root function was evident in terms of reductions in both ion and water uptake and the decrease in transpiration of Cd - treated plants is likely to be due to stomata closure (Veselov *et al.,* 2003). Cd-induced reduction in stomata conductivity is in accordance with the literature (Pearson and Kirkham, 1981). Its physiological significance might be in limiting water losses when water uptake by roots is reduced by Cd. A beneficial effect of decreased stomata conductivity was assumed to be in limiting Cd transported with the transpiration flow (Salt *et al*., 1995). Free Cd ions in the cytosol can be toxic to plant cells. In plant cells, cadmium tends to be stored in the apoplast and in vacuoles, which may contribute to Cd tolerance in hyper accumulator plants and common crops (Boominathan and Doran, 2003; Liu *et al*., 2007). Cadmium may cause growth inhibition related to reduction of mitotic activity, induction of chromosome aberrations, toxicity to nucleoli in apical meristems (Qin *et al*., 2010), damage of macromolecules, mainly proteins and lipids (Liu *et al*., 2005), and disturbance of the organization of the microtubular cytoskeleton in interphase and mitotic cells (Jiang *et al*., 2009; Liu *et al*., 2009). Cataldo *et al*. (1983) reported that, the normally cadmium ions are mainly retained in the roots and only small amounts are transported to the shoots. Roots of the plant acts as a barrier against heavy metal translocation and this may be a potential tolerance mechanism operating in the roots. (Ernst *et al*., 1992).

Cadmium is highly toxic to human, animals and plants. In plants exposure to Cd causes reductions in photosynthesis, water and nutrient uptake (Sanita di Toppi and Gabbrielli, 1999). As a consequence, Cd-exposed plants show various symptoms of injury such as chlorosis, growth inhibition, browning of root tips and finally death (Kahle, 1993). Moderate Cd contamination of arable soils can result in considerable Cd accumulation in edible parts of crops (Arao and Ae, 2003; Wolnik *et al*., 1983). Such levels of Cd in plants are not toxic to crops but can cause to substantial Cd nutritional intake by humans (Wagner, 1993). In the case of "Itai-itai disease", Cd-polluted rice was the major source of Cd intake in the patients (Yamagata and Shigematsu, 1970). This is the earliest case of chronic Cd toxicity in general populations without specific industrial exposure. Even in recent general populations in Japan, the internal Cd level is higher than those of other countries and this is largely because of daily consumption of Japanese rice which contains relatively high Cd (Watanabe *et al*., 1996; Watanabe *et al*. 2000; Tsukahara *et al*., 2003). Cd concentrations of recent Japanese rice have been continuously higher compared to those of other countries (Watanabe *et al*., 1996), although the values are much lower than the limit established by the Codex Alimentarius Commission of FAO/WHO (0.4 mg/kg). In some areas in China and Thailand, production of highly Cd-polluted rice and renal dysfunctions among populations were reported (Nordberg *et al*., 2007; Jin *et al*., 2002; Honda *et al*., 2010). Earlier it has been reported that the uptake and accumulation rate of Cd changes among plant species and genotypes of a given species (Dunbar *et al*., 2003). Recently Hassan *et al*. (2005a) have observed differences between rice cultivars in their ability to absorb and accumulate Cd in roots and shoots. However, the mechanisms of its uptake and translocation in plants have not yet been sufficiently studied to date. The maximum acceptable intake of Cd for humans, recommended by FAO/WHO is 0.83 μg day^{-1} in body weight (Nakashima *et al*. 1997). In Bangladesh, there are very few reports regarding Cd contamination in soil. Haque *et al*. (2006) reported Cd concentration in Chapai Nawabganj soil <1 mg kg^{-1}. Cadmium contamination in rice grain is a serious threat to human health especially for those with a rice based food diet. Therefore, defensive measures are needed to decrease uptake of Cd to reduce the risk of health hazards in response to Cd-polluted field. The changes in antioxidant enzymes activities, photosynthetic rate and growth of rice cultivars as affected by Zn, S and N fertilizers on the improvement of Cd toxicity has been reported by Hassan *et al*. (2005b). The differences in acceptance of different cultivars against Cd toxicity provide a base to study the mechanisms of Cd tolerance in rice.

In the light of the above discussion, the present study was under taken with the following objectives:

a. To make comparative study on growth and yield of three rice cultivars due to cadmium accumulation from soil

b. To evaluate the amount of Cd, K, Na and Ca in grain, straw and root

c. To find out the variety with lower Cd accumulation in grain, straw and root.

Chapter II

Review of Literature

CHAPTER 2

REVIEW OF LITERATURE

Growth and development and yield of rice plants are greatly influenced by the environmental factors i.e. air, day length or photoperiod, temperature, variety and agronomic practices like transplanting time, spacing, number of seedlings, depth of planting, fertilizer management etc. and abiotic stresses like salinity, drought, flood, contamination by heavy metals etc. Yield and yield contributing characters of rice are considerably influenced by different levels of contamination by heavy metals like Cadmium, Arsenic, and Lead etc. Cadmium is one the most widespread and toxic heavy metals in several parts of the world. It is one of the main pollutants in paddy fields near industrial areas and highly toxic to plant growth and development. Several strategies have been proposed for the successful management of the Cd contamination in crops.

Varieties also play an important role in rice production by affecting the growth, yield and yield components of rice.

In this chapter, an attempt has been made to review some of the research findings in Bangladesh and elsewhere related to the effect of Cd on rice.

2.1. Sources of cadmium in the environment

The uptake of heavy metal by plants depends on their concentration in soils. But these metal ions are not always in available forms for plants. It was reported that once the metals are in the soil they are held by soil particle and there is little removal by plants uptake. The availability of such metals depends on some factors like, pH of soil, organic matter, clay content, cation exchange capacity from other external sources (McGrath *et al.*, 2008).

A report of OECD (1995) indicates that cadmium in soils is derived from both natural and anthropogenic sources. Natural sources include underlying bedrock or transported parent material such as glacial till and alluvium. Anthropogenic input of cadmium to soils occurs by aerial deposition and sewage sludge, manure and phosphate fertilizer application. Cadmium is much less mobile in soils than in air and water. The major factors governing cadmium speciation, adsorption and distribution in soils are pH, soluble organic matter content, hydrous metal oxide content, clay content and type, presence of organic and inorganic legends, and competition from other metal ions.

Streppler (1991) highlighted that Cd in plants as well as soil and water. Notably, after 1945, great volumes of Cd were released into the atmosphere either as an effluent or as dust, subsequently being deposited into fresh water. In addition, notable levels of Cd entered soil as a direct result of agricultural and industrial activities.

Thornton (1992) reported that cadmium is only found in very low levels (less than 1 μgL^{-1} in contaminated waters, although soils, on the other hand, are believed to contain up to 5 $mgkg^{-1}$. Such levels increase as a result of human activities, resulting in significant contamination around the world.

WHO (1992a) indicated that, thus producing cadmium oxide in the air, reacting with water vapor, carbon dioxide and other gases to produce various cadmium salts, including CdS and $CdCO_3$. Such salts are not able to dissolve in water, but, with the passing of time, change form and become water soluble, namely through converting into $Cd(NO_3)_2$ and $CdCl_2$. With this in mind, a number of different human industrial activities are recognized as adding to the environmental contamination of cadmium.

WHO (1992b) Also reported that with the presence of $CdSO_4$ in soil demonstrating that lettuce leaves have Cd levels amounting to 800 $mgkg^{-1}$. Furthermore, Cd contamination is also recognized as stemming from fertilizers.

Non-polluted soil solutions contain Cd concentrations ranging from 0.04 to 0.32 mM. Soil solutions that have a Cd concentration varying from 0.32 to about 1 mM can be regarded as polluted to a moderate level. Because Cd is a naturally occurring component of all soils, all food stuffs will contain some Cd and therefore all humans are exposed to natural levels of Cd was reported by Wagner (1993).

Cook and Morrow (1995) showed that the average natural abundance of Cd in the earth's crust has most often been reported from 0.1 to 0.5 $mgkg^{-1}$, but much higher and much lower values have also been cited depending on a large number of factors. Igneous and metamorphic rocks tend to show lower values, from 0.02 to 0.2 $mgkg^{-1}$, whereas sedimentary rocks have much higher values, from 0.1to 25 $mgkg^{-1}$. Fossil fuels contain 0.5 to 1.5 $mgkg^{-1}$ Cd, but phosphate fertilizers contain from 10 to 200 $mgkg^{-1}$ Cd.

Dudka *et al.* (1996) found that heavy metal accumulation in crops is a function of complex interaction among soil, plant and environmental factors. It has been well documented that the contents of heavy metals in crop plants are closely associated with their levels in soil. Moreover, the uptake and accumulation of heavy metal by plants are largely dependent on the available rather than total level of metals in soil.

Watanabe *et al.* (1996) stated that the people who take rice (*Oryza sativa*) as staple food for daily energy, are inevitably exposed to significant amounts of Cd via rice, rice cropped even from non-polluted areas may contain Cd.

Mench *et al.* (1998) reported that leafy vegetables and potato tubers naturally accumulate higher levels of Cd than do fruits and cereals. Moreover, tillage and crop rotation practices similarly have a greater impact upon the Cd content of food than does the concentration of Cd in soils.

Heavy metals are found ubiquitously in both polluted and unpolluted soils. Although these heavy metals occur naturally in the Earth's crust, they tend to be concentrated in agricultural soil because of irrational application of commercial fertilizers, manures and sewage sludge containing heavy metals and of contamination caused by mining and industry was stated by McLaughlin and Singh (1999).

Unwin (1999) found in his report that the metals are deposited in agricultural lands primarily by atmospheric deposition, the use of organic and inorganic fertilizers and the disposal of sewage sludge and other waste materials. Apart from atmospheric deposition, phosphate fertilizers are the major source of cadmium.

An experiment was conducted by Sultana (2000) on the effect of intensive fertilization heavy metal concentration in soils and plants. She found that Cd, Pb and Zn concentration were 0.20, 1.30 and 12 $mgkg^{-1}$ respectively, in rice plant treated with NPKS. Heavy metal concentrations in rice plant treated with NFYM were 0.20, 1.26, 12.00 mg kg^{-1} for Cd, Pb and Zn, respectively.

Zhang and Huang (2000) reported from a recent soil survey from 11 provinces in China, at least 13,330 ha farmland has been contaminated by Cd.

Simmons *et al*. (2005) mentioned that the mean value of Cd concentrations in soil samples for weight with the average of 0.64 mg $Cdkg^{-1}$ dry weight, which was 3.5 times of the Thai standard safety limit of 0.15 mg $Cdkg^{-1}$ dry weight. It indicated that a soil sample from Mae Sot district is a Cd-contaminated soil. So, rice grains are always exposed to the threat of Cd contamination because of high levels of Cd in the soil.

Bhattacharya *et al*. (2006) highlighted those anthropogenic activities, such as mining and smelting of ores have increased the occurrence of heavy metal contamination of soil and water sources.

Mico *et al*. (2007) observed that total concentrations of heavy metals in the LVB paddy soils were generally similar to values in agricultural soils in the Mediterranean region.

Liu *et al*. (2007) mentioned that by the early 1990s, the worldwide annual release of Cd reached 22,000 tons, which was mostly distributed in the water and soil.

SCHER (2006) reported that phosphate rocks of igneous origin normally contain less than 15 mg $Cdkg^{-1}$ P_2O_5 (phosphate fertilizer) compared with 20 to 245 mg Cd in sedimentary counterparts. Therefore, European fertilizer producers had put forward a limit of 60 mg $Cdkg^{-1}$ for importing phosphate fertilizers by the year 2005 and the Czech Republic has notified the

European Commission it wishes to maintain its precession upper limit of 50 mg $Cdkg^{-1}$ P_2O_5 for phosphate fertilizers in 2005.

Navarro, Silvera and Rohan (2007) reported that the Cd content of the soil and the plants grown on it, are principally derived from natural sources, air born particles, phosphate fertilizers and sewage sludge.

Afshar *et al.* (2000) reported that the most important anthropogenic sources of soil pollution to Cd are industrial sludge sewage discharging, applying super phosphate fertilizers, burying the nonferrous wastes in land and closing the agricultural fields to lead and zinc mines or refining factories.

Nigam *et al.* (2001) mentioned that soil acidification (e.g. by acid rain) can lead to an increased content of Cd in food.

FAO/WHO (2002) reported that the results indicated that LVB rice had acceptable concentrations of Cd, however, rice from Mwanza City paddy fields need attention because the concentration is close to the limit of allowable concentration.

Yi-Chu Chang *et al.* (2012) conducted an experiment and found that the changes in Fe concentration in Cd-treated rice (*Oryza sativa* L.) seedlings. Exogenous addition of excess Fe-citrate decreased Cd concentration and Cd toxicity of rice seedlings. This study suggests that the improvement of Fe status is able to reduce toxicity of rice seedlings to $CdCl_2$.

Meharg *et al.* (2013) found from a survey conducted in 12 countries of four continents that cadmium level in rice grain were the highest in Bangladesh and Sri Lanka where the per capita rice intakes is also high. In Bangladesh, the minimum, maximum and average concentration of Cd in rice was 0.0005, 1.31 and 0.099 mg kg^{-1}, respectively.

Adriano *et al.* (2005) argue that in general, chloride can be expected to form a soluble complex with Cd^{2+} as $CdCl^{+}$, thereby decreasing the adsorption of Cd^{2+} to soil particles. In contrast to inorganic ligand ions, Cd^{2+} adsorption by kaolinite, a variable-charge mineral, could be enhanced by the presence of organic matter via the formation of an adsorbed organic layer on the clay surface.

Williams *et al.* (2009) reported that areas of agricultural soils contaminated by Cd have been widely increasing in many countries as a result of anthropogenic activities, such as disposal of industrial effluent, mining waste, and sewage sludge, and application of phosphate fertilizers. Cadmium sources to paddy soils can be primarily natural, from base mining contamination (Honda *et al.*, 2010; Williams *et al.*, 2009), industrial discharge or from phosphate fertilizers (Osborn, 1982).

Haynes *et al*. (2007) reported that in most developing countries, biosolids are still major source of heavy metal input to soils.

Li *et al*. (2009) reported that the mean Cd concentration in the 0–20cm soil layer in Zhangshi irrigation area (ceased in 1992) is still 1.75 mg/kg and the highest Cd value is up to 10 mg/kg in some sampling points.

Naser *et al*. (2012) determined the levels of lead, cadmium and nickel in roadside soils and vegetables along a major highway in Gazipur, Bangladesh were investigated. Soil samples were collected at distances of 0, 50, 100, and 1000 m (meter) from the road. The concentrations of Pb and Ni in soil and vegetables (bottle gourd and pumpkin) decreased with distance from the road, indicating their relation to traffic and automotive emissions. The concentration of Cd was found to be independent of distance from road.

Moradi *et al*. (2005) reported that Cd in soils is derived from both natural and anthropogenic sources. Naturally a very large amount of Cd is released into the environment, about 25,000 t a year. About half of this Cd is released into rivers through weathering of rocks and some Cd is released into the air through forest fires and volcanoes. The main anthropogenic input of Cd to soils occurs by industrial waste from processes. Even domestic sewage sludge, which originated from the strictest control sources, contains Cd and adds it to pollution. From the sewage systems, Cd enters into rivers and streams. The addition of Cd in metal rich sewage sludge may also result in contamination of groundwater.

Mico *et al*. (2007) reported that plants absorb heavy metals from the soil, the surface 25 cm depth zone of soil is the most affected by such pollutants resulting from anthropogenic activities. Heavy metals accumulated in this soil layer due to the relatively high organic matter content. This depth zone is also where roots of most cereal crops are located wetland soils are fertile, rich in organic matter and favours accumulation of heavy metals such as Cd.

Kikuchi *et al*. (2008) mentioned that in agricultural soils, atmospheric deposition (Keller and Schulin, 2003) is known as a major source of Cd input. In paddy fields, irrigation water is another Cd source which continuously loads Cd into soils.

2.2 Cadmium availability to plants

Matusik *et al.* (2008) showed that several plant nutrients have many direct as well as indirect effects on Cd availability and toxicity. Direct effects include decreased Cd solubility in soil by favoring precipitation and adsorption.

Romkens *et al.* (2009) reported that irrespective of rice cultivars, the combination of elevated total Cd concentrations in soil, a low pH, and low soil OM content results in an increased availability of Cd in soil, this result in a high uptake of Cd by rice plants.

Li *et al.* (2009) investigated the effects of pig manure on the distribution and accumulation of Cd in a soil–rice system using a pot experiment. Results showed that application of pig manure decreased the concentrations of Cd in rice roots by 35.6%. They observed that pig manure not only decreased uptake of Cd by rice but also restrained the transfer of Cd from the rice root to the stem and grain. The application of amendments increased soil pH and resulted in the reduction of Cd concentrations in soil solutions, which were significantly correlated to the uptake of Cd by the rice stem and grain.

Riffaldi *et al.* (1983) obtained significant correlations between Cd sorption and phenolic hydroxyl groups and carboxyl groups of fulvic acids.

Lu *et al.*, (1992) reported that under low Eh in soil, H_2S is produced in Mae Sot district, Tak province ranged from 0.5-0.8 mg $Cdkg^{-1}$ dry and then Cd reacts with S^{-2} forming insoluble CdS; thus Cd is not easily absorbed by crops.

Del Castilho *et al.* (1993) observed that low-molecular fractions, such as hydrophilic bases, have a strong affinity to form soluble Cd complexes.

Naidu *et al.* (1994) found that three possible reasons have been advanced for this phenomenon First, in variable-charge soils, a decrease in pH causes a decrease in surface negative charge, lowering cation adsorption. Second, a decrease in soil pH is likely to decrease hydroxyl species of metal cations, which are adsorbed preferentially over mere metal cations. And third, acidification causes the dissolution of metal compounds, increasing the concentration of metals in soil solution.

Hernandez *et al.*, (1996) mentioned that meanwhile, the presence of plentiful Fe^{3+} and Mn^{4+} is competitive with Cd^{2+} thereby reducing plant absorption. For instance, Cd absorption and accumulation was significantly reduced with diminishing Eh in reductive conditions formed by flooding rice field.

Li *et al.*, (1997) reported that Cd also reduced the absorption of nitrate and its transport from roots to shoots, by inhibiting nitrate reductase activity in the shoots indicating the potential possibility of reducing grain Cd accumulation by means of genetic improvement. Breeding for low Cd accumulating cultivars has been undertaken in sunflower and durum wheat.

Das *et al.* (1997) reported that uptake, transport, and subsequent distribution of nutrient elements by the plants can be affected by the presence of Cd ions. In general, Cd has been shown to interfere with the uptake, transport, and use of several elements (Ca, Mg, P, and K) by plants.

Sauve *et al*. (2000) investigated that in soils containing large amounts of OM, such as pasture soils and organic manure-amended soils, only a small proportion of the Cd in soil solution remains as free Cd^{2+} and a large portion is complexed with soluble organic carbon Addition of manure and composted biosolids has been found to increase the complexation of Cd in soils, the extent of which is related to the amount of DOC.

Bakhtiarian *et al.* (2001) reported that the effect of the Kor river's pollution on the Pb and Cd content of the Korbal rice samples. A study on the comparison of the pollution level of the Korbal and Gilan rice samples showed that the lead and Cd content of the hybrid, prolific and late rice sample types were greater than that of unprolific and early types, such that the amount of these two elements were highest in the Hassani type (the lead content was 0.925 ppm and the content was (0.0793ppm), whereas the Gasroddashti type which blooms earlier and is long seeded has the lowest amount of these two elements

Bolan *et al.* (2003) reported that large number of soil factors, atmospheric factors and plant factors are usually influencing Cd uptake by plants, moreover plant variety plays an important role in Cd partitioning between roots and shoots of plants.

Kumpiene *et al.* (2007) found the data from laboratory and glasshouse experiments have clearly demonstrated that P addition enhances the immobilization of Cd in soils, thereby alleviating its phytotoxicity. They suggested that polished rice produced from Cd-contaminated fields may be safer for consumers than brown rice.

Shi-Jing *et al.* (2007) found in an experiment that uptake of Cd by the plant was significantly affected by soil type, plant cultivar, and soil Cd dosage.

Pichtel and Bradway (2008) found in an experiment that FYM, including cow or pig manure, decreases bioavailability of heavy metals in soil and crop plants.

2.3. Effects of cadmium on plants

Zhang and Ge (2008) reported that an increase of glutathione-S-transferases (GST) activity was found in rice shoots, while in roots the activity of the enzyme was inhibited by Cd treatments. Compared with shoots, rice roots had higher GST activity, indicating that the ability of Cd detoxification was much higher in roots than in shoots.

Seth *et al.* (2008) added that, damage to the DNA in root-cap cells has been found in rice.

Zhu *et al.* (2008) observed that in China, large areas of agricultural soils and many tons of crops such as rice (*Oryza sativa* L.) have been highly polluted by Cd in some provinces, including Hunan.

Arao *et al.* (2009) reported that once the field is drained, the soil becomes an oxidative condition and CdS in the soil is changed to Cd^{2+} which is much available to plants. This flooding water management before and after heading drastically reduces grain Cd concentrations, but on the contrary, this treatment increases As concentration in grains.

Herawati *et al.* (2000) mentioned that Cd concentration above 20 μgg^{-1} in soil reduces rice plant biomass by poisoning the roots and restricting growth.

Mohammad Anwar Hossain *et al.* (2012) observed that heavy metals are toxic to higher plants by causing oxidative stress, displacing other essential metals in plant pigments or enzymes, leading to disruption of function of these molecules and of many metabolic processes, and finally reducing growth and yield.

Wang *et al.* (2001) investigated Cd levels in soils and rice or wheat in contaminated areas throughout 15 provinces of China. The results indicated that the levels of Cd, Hg and Pb in some crops were greater than the Governmental standards. Cadmium level in rice was 7 mg kg^{-1} in the wide area of the country. For rice and wheat, the latter seemed to have much higher concentrations of Cd and Pb than the former grown in the same area. For examples, 6.9 Pb mg kg^{-1} was in cortex of wheat compared to 0.65 $mgkg^{-1}$ in the same parts of rice.

Hu and Kao (2003) observed that in second leaves of rice plants decreased in chlorophyll content of cv. Tainung 67 (TNG 67) was less than cv. Taichung Native-1 after Cd treatment, while the decrease in photosynthetic rate and chlorophyll content due to Cd toxicity is genotypic dependent.

Zhou *et al.* (2003) found that rice plant height and grain yield were decreased by about 4 to 5 cm and 20 to 30%, respectively due to the effect of Cd concentrations in rice plants.

Zhou *et al.* (2003) also found that percolation pattern is one of the important factors together with soil pH, temperature, anaerobic bacteria, heavy metal concentration, gravel size and soil fertility for the growth and development of rice plants. Percolation pattern controls the oxidation-reduction status of soil, consequently the uptake of Cd by rice plants. A closed system percolation pattern can be considered a tool to reduce Cd uptake by rice plants, growing in Cd polluted paddy fields.

Kyuma (2004) mentioned that flooding of paddy fields is effective in reducing grain levels of Cd.

Chamon *et al.* (2005) conducted pot and field studies including with the contaminated soils to see heavy metal accumulation in rice and wheat at harvest. They observed that wheat varieties accumulated significant amount of different heavy metals.

Chen *et al.* (2005) reported that Cd stress significantly reduced grain yield and panicle number $plant^{-1}$, spikelets $panicle^{-1}$, filled spikelet rate and grain weight, and shoot dry weight at various growth stages.

Hassan *et al.* (2005) also found that the toxic effect of Cd on rice varied with the form of nitrogen fertilizer, and application of $(NH_4)_2SO_4$ to Cd stressed rice plants, compared to NH_4NO_3 or $Ca(NO_3)_2$, would be beneficial to mitigate detrimental effect of Cd and to reduce Cd accumulation in plants.

Liu *et al.* (2005) showed that there were great differences in Cd concentrations in straw, brown rice and grain chaff among the rice cultivars grown in a soil containing a Cd concentration of 100 $mgkg^{-1}$. The great genotypic differences in Cd concentrations indicated that it is possible to lower the Cd content of rice through cultivar selection and breeding. There were significant correlations between straw and brown rice in Cd concentration and in the total amount of Cd accumulated. These results indicated that Cd concentration in rice grain is governed by the transport of Cd from root to shoot and also from shoot to grain.

He *et al.* (2006) investigated Cd concentrations in the 19 paddy fields where the soil pH, CEC, and soil organic matter varied widely. Cadmium concentrations in rice grains were quite different among cultivars even though they were planted in soils with comparable soil properties and total soil Cd levels. Overall, median Cd concentrations in rice grains of *Indica* variety were 2-3 times higher than that of Japonica variety no matter if the rice is planted in low or high Cd-contaminated fields or in different climates. The results indicated that Cd accumulation in brown rice of *Indica* was 1.54 times higher than that of *Japonica.*

Liu *et al.* (2007) reported that Cd was not evenly distributed in different parts of rice grain. The results of their pot experiments planting six rice cultivars (include Indica, Japonica, hybrid *Indica,* and New Plant type) in artificially Cd-contaminated soil showed that the average percentage of Cd quantity accumulated in chaff, cortex (embryo), and polished rice were about 15%, 40%, and 45%, respectively. The cortex occupied only 9% of the grain dry weight in average but the polished rice occupied 71% so Cd concentration in cortex is significantly higher than that in polished rice.

Inahara *et al.* (2007) and Li *et al.* (2009) reported that the same water-management regime could cause different changes in the redox potentials for various types of soils because of differences in the properties of the soils, such as aggregate development. It may therefore be difficult to maintain low Cd concentrations in grain by means of water management alone. Silicon fertilization decreases Cd concentrations in rice grain.

Williams *et al.* (2009) found that 65% of the field rice in Hunan province of China exceeded the national food standard for Cd.

Popova *et al.* (2009) found that Cd also produces alterations in the functionality of membranes by inducing changes in their lipid and fatty acid composition.

Farooqi *et al.* (2009) and Shafi *et al.* (2010) reported that germination and growth of plants can be adversely affected by Cd.

Lee *et al.* (2010) and Rodriguez-Celma *et al.* (2010) reported that Cd affected the synthesis of 36 proteins in rice. In roots, the synthesis of 16 proteins was increased, while the synthesis of

1 protein was reduced. In leaves, the synthesis of 16 proteins was up-regulated, while the synthesis of 3 proteins was down-regulated. Treatment of tomato plants with a low Cd concentration (10 µM) induced changes in 36 polypeptides, while higher Cd concentration (100 µM) induced changes in 41 polypeptides.

Rodda (2011) suggested the timing of Cd accumulation in rice plants and determined the major period for accumulation of Cd which can be translocated to the grain. Cadmium was supplied to the roots of rice plants grown under static hydroponic conditions at a non-toxic, environmentally relevant concentration (50 nM), according to three different timing regimes: (1) pre-flowering Cd, (2) post-flowering Cd, or (3) continuous Cd. The rate of accumulation of Cd in the developing grain was monitored by harvesting immature rice panicles at four time points prior to a final harvest. It was estimated that 60% of the final grain Cd content was remobilized from that accumulated by the plant prior to flowering and the other 40% came from uptake during grain maturation. This study showed that Cd uptake from the root to the grain in rice is indeed possible in post-flowering and it is an important source of grain Cd.

Yadav (2010) and Rascio & Navari-Izzo (2011) reported that effect of Cd on growth and development Cd toxicity causes inhibition and abnormalities of general growth in many plant species. After long-term exposure to Cd, roots aremucilaginous, browning, and decomposing; reduction of shoots and root elongation, rolling of leaves, and chlorosis can occur. Cadmium was found to inhibit lateral root formation while the main root became brown, rigid, and twisted.

Gill and Tuteja (2010) and Kranner and Colville (2011) reported that Cd involved destruction of nucleic acids, cell membrane, lipids, and proteins; reduction of protein synthesis; and damage of photosynthetic proteins, which affects growth and development of the whole organism. DNA damage has also been defined via determination of frequency of abnormalities such as fragments, precocious separation, laggards, single and double bridges & stickiness.

Wang *et al.* (2011) investigated that Cd uptake and tolerance were investigated among 20 rice cultivars based on a field experiment (1.2mg kg^{-1} in soil) and a soil pot trial (control, 100 mg $Cdkg^{-1}$), and rates of radial oxygen loss (ROL) were measured under a deoxygenated solution. Significant differences were found among the cultivars in: (1) brown rice Cd concentrations (0.11-0.292 $mgkg^{-1}$) in a field soil, (2) grain Cd tolerance (34-113%) and concentrations (2.1-6.5 $mgkg^{-1}$) in a pot trial, and (3) rates of ROL (15-31 mmol 02 kg^{-1} root d.w h^{-1}). These researchers also found significant negative relationship between retes of ROL and concentrations of Cd in brown rice or straw under field and greenhouse conditions indicating that rice cultivars with higher rates of ROL had higher capacities for limiting the transfer of Cd to rice and straw.

Vijayarengan (2012) reported that rice cultivar ADT 43 plants raised in pots containing the soil amended with various levels of Cd (0, 10, 20, 30, 40 and 50 $mgkg^{-1}$ soil).Morphological parameters like root and shoot length, total leaf area and dry weight of root and shoot of rice plants were recorded at an interval of 15 days (15, 30 and 45 days) cadmium treatment at all levels tested decreased the various yield and growth parameters such as length of the root and shoot, area of leaves and dry weight of root and shoot ; biochemical constituents(chlorophyll, carotene, sugars, starch, amino acids and protein contents of leaves) of rice plants. But the proline content of rice plants increased with an increase in Cd level in the soil.

2.4 Effects of variety

The successful production of any crop depends on manipulation of basic ingredients of crop culture. The variety of crop is one of the basic ingredients. Variation of yield and other crop growth characters due to different varieties. Variety itself is the genetic factor which contributes a lot in improving yield and yield components. Different scientists reported on the effect of rice varieties on grain yields. Some available information and literature related to the effect of variety on the yield and yield contributing characters of rice are furnished here.

An experiment was conducted by Chamely *et al.* (2010) at the Agronomy Field Laboratory, Bangladesh Agricultural University, Mymensingh during the period from November 2010 to May 2011 to study the effect of variety and rate of nitrogen on the performance of Boro rice. Variety exerted significant effect on all the yield and yield contributing characters of boro rice except plant height. The highest number of total tillers hill^{-1}was recorded in the variety BRRI dhan29 which was statistically similar with the variety BRRI dhan28 and the lowest number of total tillers hill^{-1}was observed in BRRI dhan45. The highest number of effective tillers hill^{-1}was recorded in the variety BRRI dhan29 and the lowest one was observed in BRRI dhan45. The reasons for differences in producing bearing tillers hill^{-1}might be due to the variation in genetic make-up of the variety that might be influenced by heredity.

Main *et al.* (2007) reported that there was no significant variation of effective tillers hill^{-1}, total grains panicle^{-1}, filled grains panicle, straw yield and harvest index observed between the two varieties but hybrid variety showed higher panicle length, grain weight and grain yield compared to inbred variety. The variety Sonarbangla-1 gave the longer panicle (26.40 cm) compared to that of BR11 (25.66 cm). The higher weight of 1000 grains (28.32 g) was obtained from the hybrid variety and the lower (27.08 g) was obtained from the inbred variety. The higher grain yield (4.70 t ha^{-1}) was obtained from the hybrid variety Sonar bangla-1 and from inbred variety BR11 (4.43 t ha^{-1}).

An experiment was conducted by Alam *et al.* (2012) during the kharif season to study the effect of variety, spacing and number of seedlings hill^{-1} on the yield potentials of transplant aman rice. Variety had significant effects on almost all the yield component characters and yield. Among the varieties BRRI dhan33 gave significantly the tallest plant (113.17 cm), which is statistically identical with BR11 (111.25 cm). The highest number of total tillers hill^{-1} (12.23) was produced by BR11 and the lowest number of total tillers hill^{-1} (10.17) was produced by BRRI dhan32. All the yield components characters (tillers hill^{-1}, effective tillers hill^{-1}, panicle length, weight of 1000-grain and grain yield) except number of fertile spikelets panicle^{-1} were highest in case of variety BR11 and hence it produced the highest grain yield (5.92 t ha^{-1}).

A field experiment was undertaken by Nahar *et al.* (2009) during the Aman (monsoon) season of 2008 studied the effect of low temperature stress influenced by date of transplanting on yield attributes and yields of two rice varieties. The experiment consisted of two varieties (BRRI dhan46 and BRRI dhan31) and 4 transplanting dates (01, 10, 20 and 30 September, 2008). BRRI dhan46 had significantly higher values of yield attributes (effective tillers hill^{-1}, panicles hill^{-1}, panicle length, spikelets panicle^{-1}, filled grains panicle^{-1} and 1000-grain weight) and yields than the BRRI dhan31 in late transplanted conditions. There were significant reductions in yield attributes and yields after delayed transplanting. Spikelet sterility was increased by late transplanting due to low temperature at panicle emergence stage. Yield reduction of BRRI dhan46 due to late transplanting at 10 September, 20 September and 30 September were 4.44, 8.88 and 15.55%, respectively compared to 01 September transplanting. In case of BRRI dhan31 the reduction was more significant which were 6.12, 20.48 and 36.73%, respectively.

Leenakumari *et al.* (1993) found higher grain yield from the hybrid varieties over the modern varieties. They evaluated eleven hybrids of varying duration against controls Jaya, Rasi, 1R20 and Margala, and concluded that hybrid OR 1002 gave the highest yield (7.9 t ha^{-1}) followed by IR 1000 (6.2 t ha^{-1}).

BRRI (1991) reported that the number of effective tillers produced by some transplant *aman* rice ranged from 7 to 14 tillers hill^{-1} and it significantly differed from variety.

A study was undertaken to evaluate the growth performance and grain quality of six aromatic rice varieties BRRI dhan34, BRRI dhan38, Kalizira, Chiniatop, Kataribhog and Basmati grown under rainfed conditions by Ashrafuzzaman*et al.*, (2009). They found that Kalizira was the tallest (107.90 cm) of all the studied varieties. It had shown no significant difference with BRRI dhan38 (107.80 cm) and BRRI dhan34 (106.70 cm). BRRI dhan34 showed the highest number of panicles per hill (11.67) followed by Kalizira (11.33). The rice varieties differed significantly ($P<0.05$) with respect to leaf chlorophyll content, plant height, internode length, thousand grain weight and grain and straw yields. Varieties differed in morphological and yield and yield contributing traits. Thousand grain weight and grain yield both were highest in BRRI dhan38. Basmati required shorter days to maturity and Kalizira longest days to maturity.

Islam *et al.* (2013) was conducted a field experiment during July- December, 2010 with a view to find out the varietal performance of *aman* rice as affected by different methods of urea application. The experimental treatments included four varieties i.e. BR11, BRRI dhan33, BRRI dhan39, BRRI dhan46 and four urea application methods. The results showed that urea fertilizer application method significantly influenced plant height, tillering production, leaf area index, effective tillers hill^{-1}, filled grains panicle^{-1}, unfilled grains panicle^{-1}, total grains panicle^{-1}, 1000-grain weight, grain yield, straw yield, and biological yield. Application of USG N as at 7 DAT gave highest yield (7.82 t ha-1) while application of

15 kg N ha^{-1} as PU 30 DAT+ 15 kg N ha^{-1} as PU at 50 DAT gave lowest yield (4.88 t ha^{-1}). Varietal influence was significant on tillering pattern, leaf area index, effective tillers hill^{-1}, filled grains panicle^{-1},1000-grain weight, grain yield, straw yield and biological yield. BR11 gave the highest yield (8.17 t ha^{-1}) which was statistically similar with BRRI dhan46 (7.3 t ha^{-1}) while the lowest yield obtained from BRRI dhan33 (2.87 t ha^{-1}).

BINA (1993) evaluated the performance of four varieties- IRATOM 24, BR 14, Binadhan-13 and Binadhan-9. It was found that the varieties differed significantly in respect of plant height, number of unproductive tillers hill^{-1}, panicle length and sterile spikelets panicle^{-1}.

A field experiment was carried out by Roy *et al.* (2014) to evaluate the growth, yield and yield attributing characteristics of 12 indigenous *Bor o*rice varieties collected from South-Western regions of Bangladesh namely; Nayonmoni, Tere bale, Bereratna, Ashanboro, Kajollata, Koijore, Kali boro, Bapoy, Lataibalam, Choiteboro, GS one and Sylhetyboro. The plant height and number of tillers hill^{-1} at different days after transplanting varied significantly among the varieties up to harvest. At harvest, the tallest plant (123.80 cm) was recorded in Bapoy and the shortest (81.13 cm) was found in GS one. The maximum number of tillers hill^{-1} (46.00) was observed in Sylhetyboro and the minimum (19.80) in Bereratna. The maximum number of effective tillers hill^{-1} (43.87) was recorded in the variety Sylhetyboro while Bereratna produced the lowest effective tillers hill^{-1} (17.73). The highest (110.57) and the lowest (42.13) number of filled grains panicle^{-1} was observed in the variety Koijore and Sylhetyboro, respectively. Thousand grain weight was the highest (26.35 g) in Kali boro and the lowest (17.83 g) in GS one. Grain did not differ significantly among the varieties but numerically the highest grain yield (5.01 t ha^{-1}) was found in the variety Koijore and the lowest in GS one (3.17 t ha^{-1}).

WenXiong *et al.* (1996) showed that Shnyou 63 (Zhenshan 97A x Minhui 63) and Teyou 63 (Longtepu A x Minhui 63) showed significant grain yield increase over Minhui 63 of 35.2 and 48%, respectively, in China in 1993. The higher number of productive tillers plant^{-1} had the largest direct effect on grain yield, resulting in increased sink capability. The higher tiller number and number of grains panicle^{-1} were attributable to higher leaf areas, higher net photosynthesis in individual leaves (particularly in the later stages) and favorable partitioning of photosynthesis to plant organs. Compared with Minhui 63, hybrids showed slight heterosis in relative growth rate but significant heterosis in crop growth rate, especially at later growth stages, with increases of 160.52 and 97.62% in shanyou 63 and Teyou 63, respectively.

Number of panicles was the result of the number of tillers produced and the proportion of effective tillers, which survived to produce panicle (Hossain *et al.*, 2008).

Zohra *et al.* (2013) was carried a field experiment during July- December, 2011 with a view to find out the yield performance of three transplant *aman* rice namely, Binadhan-7, BRRI dhan46 and Kalizira were evaluated under five levels of urea super granules (USG) viz. control (no USG), one, two, three and four pellet(s) of USG/4 hills providing 0, 30, 60, 90 and 120 kg N ha^{-1}, respectively, and recommended dose of prilled urea were evaluated. Variety exerted significant influence on yield of transplant *aman* rice. Grain yield was highest (5.46 t ha^{-1}) in BRRI dhan46 and straw yield was highest (6.58 t ha^{-1}) in Kalizira. It was observed that in most of the cases, all the varieties performed better for their yield contributing characters with 2 pellets of USG/4 hills compared to any other levels. The findings suggest that BRRI dhan46 can be cultivated to obtain high rice yield in transplant *aman* season.

Obaidullah (2007) stated that variety significantly influenced panicle length, number of total grains panicle', filled grains panicle1, 1000 grains weight, grain yield and straw yield but not for effective tillers hill' and harvest index. The varietal effects on yield and other yield attributes where hybrid variety gave numerically maximum tillers hill^{-1} (10.08), and significantly highest panicle length (27.36 cm), grains panicle^{-1} (196.75), filled grains panicle^{-1} (156.84), 1000 grain weight (27.40 g) which eventually elevated the grain yield (5.58 t ha^{-1}). These parameters were 9.8, 25.17 cm, 112.83, 86.77, 20.09 g and 3.88 t ha^{-1}, respectively as lowest measurements from inbred varieties.

Debnath *et al.* (2012) observed that variety had significant effect on all the agronomic parameters except number of effective tillers, ineffective tillers, total tillers, grain straw ratio and biological yield. BRRI hybrid dhan2 produced the highest dry grain yield (5.92 t ha^{-1}) and the lowest straw yield (4.97 t ha^{-1}), whereas, BRRI dhan29 produced the lowest grain yield (4.16 t ha^{-1}) and the highest straw yield (6.70 t ha^{-1}).

Jesy (2007) observed that weight of 1000-grains was not significantly affected by variety. Apparently BRRI dhan4l produced the higher weight of 1000-grains (23.42 g) than BRRI dhan40 (23.39 g).

Hasanuzzaman *et al.* (2009) in a study found that the length of panicle in late transplanted Aman rice ranged from 23.59 to 21.30 cm.

Bhuiya (2000) reported that plant height varied variety to variety *viz.*Binasail, Binadhan 4 and Binadhan 19 with different plant spacing *viz.* 20 cm x 10 cm, 20 cm x 15 cm and 20 cm x 20 cm.

BRRI (1985) concluded that BR4 and BR10 were higher yielders than Rajasail and Kajalsail.

Kamal *et al.* (1988) observed that among three rice varieties BR3 produced the highest the grain yield and pajam yielded the lowest. The superiority of promising line over the high yielding varieties in respect of grain yield was recorded.

Miller (1978) from a study of 14 rice cultivars observed that grain yields ranged from 5.6 to 7.7 t ha^{-1}. He also reported that grain yield was significantly influenced by rice cultivars.

Sultana (2008) observed that number total of tillers hill^{-1} was not significantly affected by variety. Apparently, more number (11.07) of total tillers was produced by the variety BR14 than BR26 (10.90).

Akbar (2004) stated that variety, seedling age and their interaction exerted significant influence on almost all the studied crop characters of rice. Among the varieties, BRRI dhan4l performed the best in respect of number of bearing tillers hill^{-1}, panicle length, total spikelets panicle^{-1}, and number of grains panicle^{-1}. BRRI dhan41 also produced the maximum grain and straw yields, Sonarbangla-1 ranked first in respect of total tillers hill^{-1} and 1000 grain weight but produced the highest number of non-bearing tillers hill and sterile spikelets panicle^{-1}. Grain, straw and biological yields were found highest in the combination of BRRI dhan41 x 15 day-old seedlings. Therefore, BRRI dhan4l may be cultivated using 15 day-old seedlings in *aman* season following the SRI technique to better grain and straw yields.

Idris and Matin (1990) reported that number of total tillers hill^{-1} was identical among the varieties studied.

BRRI (2006) studied the performance of BR14, Pajam, BR5 and Tulsimala and reported that Tulsimala produced the highest number of filled grains panicle^{-1} and BR14 produced the lowest number of filled grains panicle^{-1}.

Kabir*et al.*(2009) was carried an experiment in transplant *Aman* season 2008 to find out the effect of urea super granules (USG), prilled urea (PU) and poultry manure (PM) on the yield and yield attributes of transplant *Aman* rice varieties. Two transplant *Aman* rice varieties viz. BRRI dhan41 and BRRI dhan46 and ten levels of integrated nutrient management encompassing USG, PU and PM were tested. In case of varietal effect plant height, total tillers hill^{-1}, effective tillers hill^{-1}, length of panicle, grains panicle^{-1}, unfilled spikelets panicle^{-1}, grain yield, straw yield and harvest index were significantly influenced at different levels of significance. Variety BRRI dhan41 produced higher grain and straw yield and harvest index than that of BRRI dhan46. Higher grain yield in BRRI dhan41was due mainly to higher of effective tillers hill^{-1}and grains panicle^{-1}.

BRRI (2004) reported that the filled grains panicle^{-1} of different modern varieties were 95-100 in BR3, 125 in BR4, 120-130 in BR22 and 110-120 in BR23 when they were cultivated in transplant *Aus* season. They reported that three modern upland rice varieties namely, BR20, BR21 and BR24 were suitable for high rainfall belts of Bangladesh. Under proper management, the grain yield was 3.5 ton for BR 20, 3.0 ton for BR21 and 3.5 ton for BR24 ha^{-1}. They also reported that grain yields of the modern rice varieties in *Aus* season under transplant condition ranged from 4.0-4.5 t ha^{-1} for BR3, 5.5 - 6.5 t ha^{-1} for BR4, 2.5-5.5 t ha^{-1} for BR23 and 4.0-4.5 t ha^{-1} for IR20.

Takita (2009) reported that Nerica rice has erect panicles even after maturity which can favor high canopy photosynthesis with less light interception by these panicles than droopy panicles.

Refey*et al.* (1989) reported that weight of 1000-grains differed among the cultivars studied.

Hossan (2005) observed that grain yield was significantly differed due to variety. It was evident from the result that BRRI dhan4l produced the higher grain yield (5.02 t ha^{-1}) than BRRI dhan31.

In a trial, varietal differences in harvest index and yield were examined using 60 Japanese varieties bred in Asian countries. It was reported that harvest index varied from 36.8% to 53.4%. Mean values of harvest index were 43.5% in the Japanese group and 48.8% in high yielding group. Yield ranged from 22.6 g $plant^{-1}$. The mean value of yield in Japanese group was 22.8 g $plant^{-1}$, and that in high yielding group was 34.1 g $plant^{-1}$. They also reported that a positive correlation was found between harvest index and yield in the yielding group (Cui *et al.*, 2000).

Om *et al.* (1999) conducted a field experiment with four varieties (3 hybrids: ORI 161, PMS 2A, PMS 10A and one inbred variety HKR 126) during rainy season and observed that hybrid ORI 161 exhibited superiority to other varieties in grain yield and straw yield.

Tac *et al.* (1998) conducted an experiment with two varieties, Akitakomachi and Hitombore in tohoku region of Japan. It was found that Hitombore yielded the higher (710 g m^{-2}) and Akitakomachi the lowest (660 g m^{-2})

Miah *et al.* (1993) reported that plant height differed significantly among BR 3, BR 11, BR 22, Nizershail, Pajam, and Badshabhog varieties in Aman season (Jul-Dec). Tiller number varied widely among the varieties and the number of tillers/plant at the maximum tiller number stage ranged between 14.3 and 39.5 in 1995 and 12.2 and 34.6 in 1996.

Mahato*et al.* (2014) carried a field experiment during July-December, 2010 to find out the allelopathic effect on growth and yield of three aman rice varieties. Aman rice varieties were viz. BRRI dhan 46, GutiSwarna and Ranzit. Results showed significantly higher in grain yield of ranzit with ariach (6.5 t ha^{-1}).Araiach and Razit also exhibited the higher number of tillers $hill^{-1}$ (13.6), filled grains $panicle^{-1}$ (256.0) and 1000-grain weight (23.8 g). As a result, BARI- 46 and Ranzit considered as the most important variety and the most effective plant residue was ariach for growth and yield of aman rice.

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Chang and Vergara (1972) stated that the tillering pattern of rice varied with the varieties. In general, tall cultivars showed a tendency to have small number of tillers and shorts on showed a large number. Tiller number and panicle number were positively correlated. *Japonica* cultivars that produced few tillers under tropical conditions were vigorous and produced more tillers when grown under temperate conditions. *Indica* cultivars, which were vigorous under tropical conditions, showed few tillers under temperate conditions.

Chapter III
Materials & Methods

CHAPTER 3
MATERIALS AND METHODS

The experiment was conducted at the Net House of Agricultural Chemistry Department of Sher-e-Bangla Agricultural University, during the period from November (2015) to May (2016). This chapter deals with a detail description of the site, pot preparation, intercultural operations, data recording and procedure of statistical analysis etc.

3.1 Description of experimental site

The pot experiment was carried out during the Boro season of 2015-2016 to evaluate the effect of cadmium on different boro rice cultivars.

3.1.1. Location and site

The growth and performance was carried out in the net house of the Department of Agricultural Chemistry of Sher-e-Bangla Agricultural University (SAU), Dhaka.

3.1.2 Climate

It has sub-tropical humid climate and is characterized by high temperature accompanied by moderately high rainfall during Kharif season (April-September) and low temperature in Rabi season (October-March). Geographically, the net house stands at 23°41' N latitude and 90°22' E longitude at an altitude of 8.6 meter above the sea level.

3.2 Collection and preparation of soil

A bulk volume of soil was collected at a depth of 0-15 cm from the experimental field of Sher-e-Bangla Agricultural University. After collection, the soils were made free from the plant roots and unnecessary materials and dried under sunlight for 2 weeks. Then the soil sieved and mixed up thoroughly and ready for potting.

3.3 Pot preparation

An amount of 8 kg soil was taken in a series of pots. Each plastic pot was 0.23 m^2. There were altogether 45 pots comprising 5 different treatments to three different boro rice varieties with 3 replications. Water was added to the pot to bring the soil up to saturation.

3.4 Treatments of the experiment

Five rates of cadmium *viz.* 0, 20, 40, 60 and 80 ppm Cd (on soil weight basis) were applied on three boro rice varieties. The source of Cd was Cadmium Sulphate ($3CdSO_4.8H_2O$). The rice varieties were *viz*, V_1=BRRI dhan29, V_2= BRRI dhan60, V_3= BRRI dhan61.

Design: CRD with two factorials

Factor A: Variety: 03

V_1 = BRRI dhan29
V_2 = BRRI dhan60
V_3=BRRI dhan61

***Factor* B**: Different doses of cadmium: 05

T_0= (No cadmium applied),
T_1= (20 ppm cadmium on soil weight basis)
T_2= (40 ppm cadmium on soil weight basis)
T_3= (60 ppm cadmium on soil weight basis)
T_4= (80 ppm cadmium on soil weight basis)

Treatment combinations = 3 x 5 = 15
Replications: 3

3.5 Raising of seedlings

Seeds of BRRI dhan29, BRRI dhan60 and BRRI dhan61were collected from BRRI (Bangladesh Rice Research Institute), Gazipur. The seedlings were raised at the wet seed bed in SAU farm. The seeds were sprouted by soaking for 72 hours. The sprouted seeds were sown uniformly in the well-prepared seed bed in 18 November 2015.

3.6 Fertilizer application

All the pot received fertilizers according to BRRI's recommended fertilizer dose (BRRI-Adhunic Dhaner Chash, 2015). The amounts of nitrogen, phosphorus, potassium and sulphur required for each pot were calculated as per their rates of application. Except nitrogen, full dose of P, K were added at the time of final pot preparation. Nitrogen was added in three equal splits at 7, 30 and 45 days after transplanting (DAT). Cadmium was added to soil before transplanting.

3.7 Transplanting of seedlings

The seedlings were uprooted carefully from the seedbed in the morning and transplanted in the same day. Three healthy seedlings of forty days age were transplanted in the pots on 5 January 2016.

3.8 Intercultural operations

Weeding and loosening of soils around the hills were done when felt necessary. Top dressing of urea was done when felt necessary. At the grain filling stage, the pots were covered with net to protect the grains from the attack of birds. Observation was regularly made. All the stages of plants and plants response as per treatments were observed carefully.

3.9 Irrigation

Six cm water was added after transplanting and maintained for 15 days after transplanting. Then water was added following saturation system and allowed to dry until where hair cracking was observed. This process was continued up to panicle initiation stage.

3.10 Harvesting

The crop was harvested at three rice varieties' full maturity. Plants of each pot was bundled separately with tag mark indicating the respective treatment combinations and brought to the laboratory for recording data on yield and yield parameters.

3.11Sampling threshing and processing

The plant samples were dried in an oven at 60 ^{0}C for 72 hours and then cut into small pieces using clean scissors. The plant materials were stored in desiccators to analyze total K, Na, Ca and Cd concentrations.

3.12 Sampling and data collection

Data collections from the experiment on different growth stages were done under the following heads as per experimental requirements.

3.13.1 Plant height

The heights (cm) of the pre-selected 3 hills were taken by measuring the distance from base of the plant to the tip of the flag leaf after 45, 75 DAT and at the time of harvesting. The collected data were finally averaged.

3.13.2 Number of tillers

Number of tillers hill^{-1}was counted from every hill at 45, 75 DAT and at the time of harvesting and finally averaged.

3.13.3 Number of leaves

Number of leaves plant^{-1} was counted three times at 45, 75 DAT of rice plants. Mean value of data were calculated and recorded.

3.13.4 Number of effective and non-effective tillers

Number of effective and ineffective tillers hill^{-1}was counted from the hills of the pots after harvesting and finally averaged.

3.13.5 Panicle length

The panicle length (cm)was measured with a meter scale from the hills of the pots and the average value was recorded as per plant.

3.13.6 Number of filled and unfilled grains

Number of filled and unfilled grains panicle^{-1}were counted from 10 panicles from each pot. Lack of any food materials inside the spikelets were denoted as unfilled grains.

3.13.7 1000-grainweight

One hundred grains (g) were randomly collected from each pot and were sun dried and weighed by an electronic balance and then multiplied by 10.

3.13.8 Grain yield

Grains from each pot were harvested. The grains were threshed, cleaned, dried and then weighed in kg. Thereafter it was converted as ton per hectare (t ha^{-1}).

3.13.9 Straw yield

Straw obtained from each pot were sun-dried and weighed carefully. The dry weight of straw of the respective pot yield was converted to ton per hectare (t ha^{-1}).

3.13.10 Root yield

Root obtained from each pot were sun-dried and weighed carefully. The dry weight of straw of the respective pot yield was converted to ton per hectare (t ha^{-1}).

3.14 Chemical Analysis

3.14.1 Preparation of plant extract:

0.25 g of dry rice straw/grain were weighed, and then transferred into 250 ml Pyrex conical flasks. Then 10 ml 2:1 nitric-perchloric acid mixture was added into each flask and allowed to stand overnight or until the vigorous reaction phase is over. After the preliminary digestion, the conical flasks were placed on a hot plate in digestion chamber and then temperature was raised to 150°C for 1 hour. The temperature was increased slowly upto 300^0C. After the digestion, the conical flasks were lifted out of the digester and allowed to cool at room temperature. The solution was taken in 100 ml volumetric flask through funnel and volume with distilled water upto the mark (Jackson, 1973).

3.14.2 Determination of Potassium

The amount of potassium (K) was estimated from prepared sample with the help of a flame photometer.

3.14.3 Determination of Calcium

The amount of calcium (Ca) was estimated from prepared sample with the help of a flame photometer.

3.14.4 Determination of Sodium

The amount of sodium (Na) was estimated from prepared sample with the help of a flame photometer.

3.14.5 Determination of Cadmium

Total cadmium concentration was determined from the digest by AnalytikJena novAA 400P Atomic Absorption Spectrotometer (Analytik Jena, 2017)

3.15 Statistical Analysis

The data were compiled and tabulated in proper form and were subjected to statistical analysis. Analysis of variance was done following the computer package MSTAT-C program developed by Russel, (1986). The mean differences among the treatments were adjusted by least significant difference (LSD) test at 5% level of significance (Gomez and Gomez, 1984).

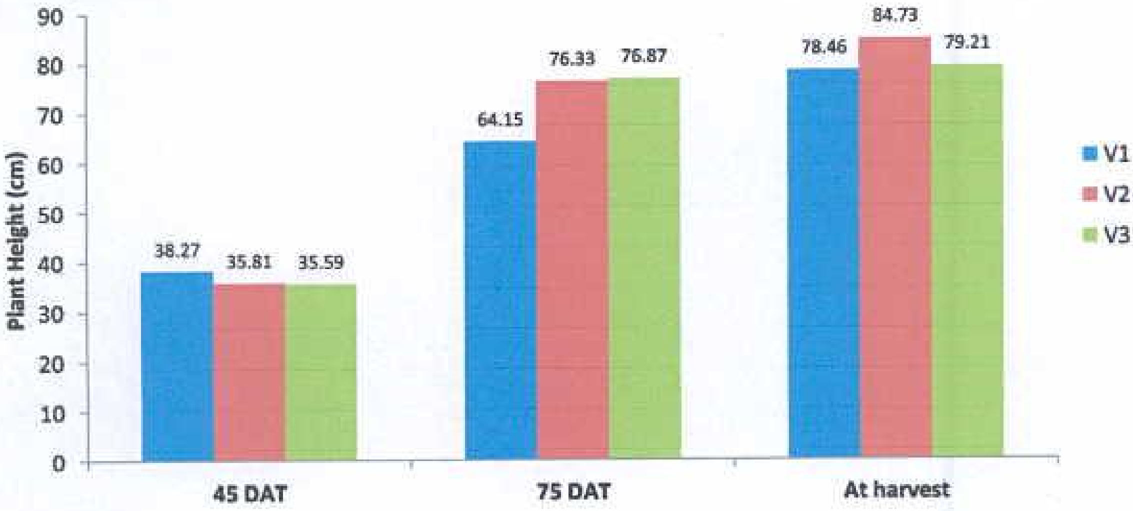
Chapter IV
Results and Discussion

CHAPTER 4

RESULTS AND DISCUSSION

A study was undertaken during the Boro season of 2015-2016 to evaluate the effect of cadmium on different boro rice cultivars. The experiment was conducted in the net house of the Department of Agricultural Chemistry of Sher-e-Bangla Agricultural University (SAU), Dhaka. The results of the study regarding the effect of cadmium on growth, yield and nutrients content of BRRI dhan29, BRRI dhan60 and BRRI dhan61 have been presented with possible interpretations under the following headings:

4.1 Plant Height



V_1 – BRRI dhan29, V_2 – BRRI dhan60, V_3 – BRRI dhan61

Figure 1. Effect of variety on plant height at different days after transplanting

The plant height (cm) of Boro rice was significantly influenced by varieties at 45, 75 days after transplanting (DAT) and at the time of harvesting (Figure 1and Appendix VII). The results revealed that at 45 DAT, the variety BRRI dhan29 produced the tallest plant (38.27 cm) and the variety BRRI dhan61 gave the shortest plant (35.59 cm). At 75 DAT, BRRI dhan61 gave higher plant height (76.87 cm) than BRRI dhan29 and BRRI dhan60 (64.15 cm and 76.33cm respectively). At the time of harvesting BRRI dhan60 produced the tallest plant (84.73 cm) than BRRI dhan61 (79.21 cm) and BRRI dhan29 (78.46 cm) respectively. Probably the genetic makeup of varieties was responsible for the variation in plant height. This confirms the reports of Shamsuddin *et al.* (1988) that plant height differed due to varietal variation.

Table 1. Effect of cadmium on plant height at different days after transplanting

Treatment	Plant Height (cm)		
	45 DAT	75 DAT	At harvest
T_0	45.01 a	83.02 a	92.46 a
T_1	40.69 b	78.68 b	85.26 b
T_2	36.43 c	71.51 c	81.02 c
T_3	33.00 d	66.59 d	75.04d
T_4	27.64 e	62.44 e	70.23 e
$LSD_{(0.05)}$	1.964	2.414	1.760
Significant level	*	*	*
CV (%)	5.56	3.45	2.26

T_0= No cadmium applied, T_1= 20 ppm Cd, T_2= 40 ppm Cd, T_3= 60 ppm Cd, T_4= 80 ppm Cd
*Significant at 5% level

Soil application of Cd showed distinct negative effect on the plant height of BRRI dhan29, BRRI dhan60 and BRRI dhan61. Different doses of cadmium had significant effect on plant height of rice at 45 DAT, 75 DAT and at the time of harvesting (Table 1). At 45 DAT, the highest plant height (45.01 cm) was observed from the T_0 treatment and the lowest (27.64 cm) was observed from T_4 treatment. At 75 DAT, the highest plant height (83.02 cm) was observed from the T_0 treatment whereas, the lowest (62.44 cm) was observed from T_4 treatment. At the time of harvesting, the highest plant height (92.46 cm) was observed from the T_0 treatment whereas, the lowest (70.23 cm) was observed from T_4 treatment. It was observed that lower doses of cadmium gave better plant height than those of higher doses. These results are similar to the findings of Herath *et al.* (2014) who studied the effect of cadmium on growth parameters and plant accumulation in different rice (*Oryza sativa* L.) varieties in Sri Lanka.

Interaction effect of varieties and different cadmium doses showed significant variation on plant height of rice at 45 DAT, 75 DAT and at the time of harvesting (Table 2). At 45 DAT, the highest plant height (46.00 cm) was observed from the V_1T_0 treatment which was statistically similar with V_3T_0 (45.93 cm), V_1T_1 (42.67 cm), V_2T_0 (43.10 cm) whereas, the lowest (26.67 cm) was observed from V_2T_4 treatment which was statistically similar with V_3T_4 (26.93 cm), V_1T_4 (29.33 cm). At 75 DAT, the highest plant height (87.80 cm) was observed from the V_2T_0 treatment which was statistically similar to V_3T_0 (85.67 cm) whereas, the lowest (53.67 cm) was observed from V_1T_4 treatment which was statistically similar with V_1T_3 (57.67 cm). At the time of harvesting, the highest plant height (94.33 cm) was observed from the V_2T_0 treatment which was statistically similar to V_1T_0 (92.60 cm) whereas, the lowest (67.30 cm) was observed from V_1T_4 treatment which was statistically similar to V_3T_4 (68.40 cm). This finding supports Liu *et al.* (2007) who conducted experiment using six rice cultivars with 100 mg/kg soil Cd and concluded that toxicity effect of Cd on plant height is varietal dependent.

Table 2. Interaction effect of varieties and cadmium doses on plant height at different days after transplanting

Treatment		Plant Height (cm)		
		45 DAT	75 DAT	At harvest
V_1	T_0	46.00 a	75.60 ef	92.60 ab
	T_1	42.67 ab	71.87 fg	82.40 cd
	T_2	38.33 cde	61.93 i	78.53 e
	T_3	35.00 ef	57.67 j	71.47 g
	T_4	29.33 hi	53.67 j	67.30 h
V_2	T_0	43.10 ab	87.80 a	94.33 a
	T_1	40.30 bc	83.50 bc	90.67 b
	T_2	36.00 def	75.27 ef	84.67 c
	T_3	33.00 fg	69.77 g	79.00 e
	T_4	26.67 i	65.33 hi	75.00 f
V_3	T_0	45.93 a	85.67 ab	90.43 b
	T_1	39.10 cd	80.67 cd	82.70 cd
	T_2	34.97 ef	77.33 de	79.87 de
	T_3	31.00 gh	72.33 fg	74.67 f
	T_4	26.93 i	68.33 gh	68.40 h
$LSD_{(0.05)}$		3.402	4.182	3.048
Significant level		*	*	*
CV (%)		5.56	3.45	2.26

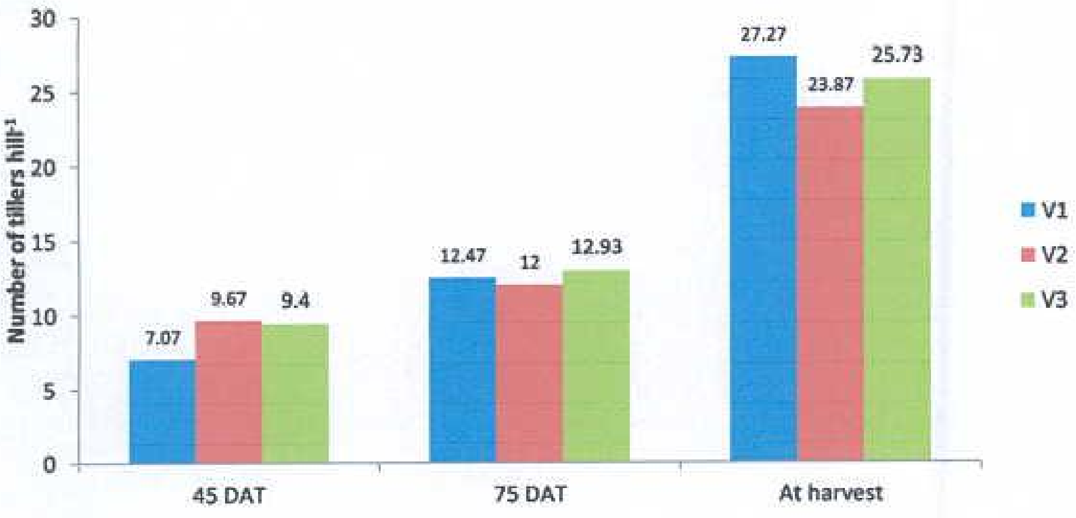
V_1 – BRRI dhan29, V_2 – BRRI dhan60, V_3 – BRRI dhan61

T_0= No cadmium applied, T_1= 20 ppm Cd, T_2= 40 ppm Cd, T_3= 60 ppm Cd, T_4= 80 ppm Cd

*Significant at 5% level

4.2 Number of tillers

The number of tillers hill^{-1} of boro rice was significantly influenced by different varieties at 45, 75 days after transplanting (DAT) and at the time of harvesting (Figure 2 and Appendix VII). The result revealed that at 45 DAT, the variety BRRI dhan60 produced the highest number of tillers hill^{-1} (9.67) which was statistically similar to BRRI dhan61 (9.40) and the variety BRRI dhan29 gave the lowest number of tiller hill^{-1} (7.07). At 75 DAT, the variety BRRI dhan61 produced the highest number of tillers hill^{-1} (12.93) which was statistically similar to BRRI dhan29 (12.47) and the variety BRRI dhan60 gave the lowest number of tillers hill^{-1} (12.00). At the time of harvesting variety BRRI dhan29 produced the highest number of tillers hill^{-1} (27.27) which was statistically similar to BRRI dhan61 (25.73) and the lowest was given by BRRI dhan60 (23.87). Number of tillers hill^{-1} can be different in different varieties due to genetical build-up. Roy *et al.* (2014) found that, number of tillers hill^{-1} at different days after transplanting varied significantly among the varieties up to harvest where maximum number of tillers hill^{-1} was observed in Sylhetyboro and minimum in Bereratna.



V_1 – BRRI dhan29, V_2 – BRRI dhan60, V_3 – BRRI dhan61

Figure 2. Effect of variety on number of tillers hill^{-1}

Different doses of cadmium had significant effect on number of tillers hill^{-1} of rice at 45, 75 and at the time of harvesting (Table3 and Appendix VIII). At 45 DAT, the highest number of tillers hill^{-1} (12.78) was observed from the T_0 treatment and the lowest (4.89) was observed from T_4 treatment. At 75 DAT, the highest number of tillers hill^{-1} (18.00) was observed from the T_0

treatment whereas, the lowest (7.78) was observed from T_4 treatment. At the time of harvesting, the highest number of tillers hill^{-1} (32.33) was observed from the T_0 treatment whereas, the lowest (20.11) was observed from T_4 treatment. Treatment with no cadmium gave higher performances than higher doses of cadmium. This result clearly is keeping pace with the report of Sanita di Toppi and Gabrielli (1999).

Table 3. Effect of cadmium on number of tillers hill^{-1}at different days after transplanting

Treatment	Number of tillers hill^{-1}		
	45 DAT	75 DAT	At harvest
T_0	12.78 a	18.00 a	32.33 a
T_1	10.56 b	14.67 b	28.22 b
T_2	8.667 c	12.22 c	24.78 c
T_3	6.667 d	9.667 d	22.67 d
T_4	4.889 e	7.778 e	20.11 e
LSD $_{(0.05)}$	**1.260**	**1.162**	**2.013**
Significant level	*	*	*
CV (%)	**14.98**	**9.65**	**8.14**

T_0= No cadmium applied, T_1= 20 ppm Cd, T_2= 40 ppm Cd, T_3= 60 ppm Cd, T_4= 80 ppm Cd
*Significant at 5% level

Interaction effect of varieties and different cadmium doses showed significant variation on number of tillers hill^{-1} of rice at 45, 75 DAT and at the time of harvesting (Table 4). At 45 DAT, the highest number of tillers hill^{-1} (13.67) was observed from the V_3T_0 treatment which was statistically similar to V_2T_0 (13.33), V_2T_1 (11.67) and V_3T_1 (11.67) whereas, the lowest (4.00) was observed from V_1T_4 treatment which was statistically similar to V_1T_3 (5.00), V_2T_4 (5.33) and V_3T_4 (5.33). At 75 DAT, the highest number of tillers hill^{-1} (19.67) was observed from the V_3T_0 treatment which was statistically similar to V_1T_0 (18.67) whereas, the lowest (7.00) was observed from V_1T_4 treatment which was statistically similar to V_3T_4 (8.00) and V_2T_4 (8.33). At the time of harvesting, the highest number of tillers hill^{-1} (34.33) was observed from the V_1T_0treatment which was statistically similar with V_3T_0 (32.67) andV_1T_1 (31.33) whereas, the lowest (19.00) was observed from V_2T_4 treatment which was statistically similar with V_3T_4 (19.33), V_2T_3 (21.67) and V_1T_4 (22.00). Herath *et al.* (2014) also found the interaction effect in a pot experiment which was conducted to investigate the variations of plant growth and levels of accumulation of Cd among eight rice genotypes (new improved varieties-NIVs and traditional varieties- TVs) grown under different soil Cd levels.

Table 4. Interaction effect of varieties and cadmium doses on number of tillers hill^{-1} at different days after transplanting

Treatment		Number of tillers hill^{-1}		
		45 DAT	75 DAT	At harvest
V_1	T_0	11.33 bcd	18.67 a	34.33 a
	T_1	8.333 ef	15.00 b	31.33 ab
	T_2	6.667 fg	12.00 cd	26.00 de
	T_3	5.000 gh	9.667 e	22.67 efgh
	T_4	4.000 h	7.000 f	22.00 fghi
V_2	T_0	13.33 ab	15.67 b	30.00 bc
	T_1	11.67 abc	13.67 bc	25.67 de
	T_2	10.00 cde	12.33 c	23.00 efg
	T_3	8.000 ef	10.00 de	21.67 ghi
	T_4	5.333 gh	8.333 ef	19.00 i
V_3	T_0	13.67 a	19.67 a	32.67 ab
	T_1	11.67 abc	15.33 b	27.67 cd
	T_2	9.333 de	12.33 c	25.33 def
	T_3	7.000 fg	9.333 e	23.67 efg
	T_4	5.333 gh	8.000 ef	19.33 hi
LSD $_{(0.05)}$		2.183	2.013	3.487
Significant level		*	*	*
CV (%)		14.98	9.65	8.14

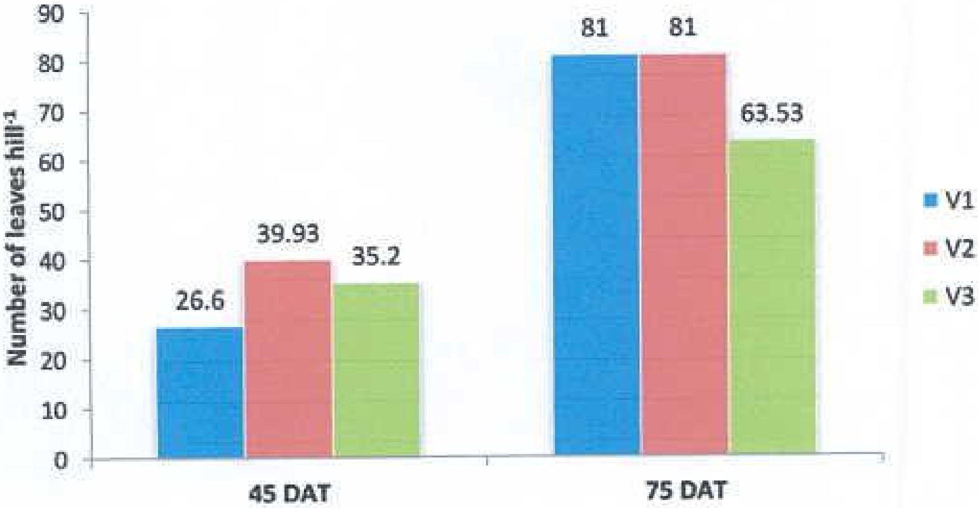
V_1 – BRRI dhan29, V_2 – BRRI dhan60, V_3 – BRRI dhan61

T_0= No cadmium applied, T_1= 20 ppm Cd, T_2= 40 ppm Cd, T_3= 60 ppm Cd, T_4= 80 ppm Cd

*Significant at 5% level

4.3 Number of leaves

The total number of leaves hill^{-1} of boro rice showed variation among the three varieties (Figure 3 and Appendix VIII). Numerically maximum number of leaves hill^{-1} at 45 DAT was observed in V_1 (39.93) and at 75 DAT was observed in the V_1 (81.00) and V_2 (81.00).



V_1 – BRRI dhan29, V_2 – BRRI dhan60, V_3 – BRRI dhan61

Figure 3. Effect of variety on number of leaves hill^{-1}

Different doses of cadmium had significant effect on number of leaves hill^{-1} of rice at 45, 75 DAT (Table 5 and Appendix VII). At 45 and 75 DAT, the highest number of leaves hill^{-1} (44.67 and 91.11) was observed from the T_0treatment and the lowest (24.33 and 61.78) was observed from T_2 treatment. Herath *et al.* (2014) found similar result in the study named effect of cadmium on growth parameters and plant accumulation in different rice (*Oryza sativa* L.) varieties in Sri Lanka.

Interaction effect of varieties and different cadmium doses showed significant variation on number of leaves hill^{-1} of rice at 45 and 75 DAT (Table 6 and Appendix VIII). At 45 DAT, the highest number of leaves hill^{-1} (50.33) was observed from the V_3T_0 treatment whereas, the lowest (16.33) was observed from V_1T_4 treatment, the highest number of leaves hill^{-1} (103.3) was observed from the V_3T_0 treatment whereas, the lowest (53.00) was observed from V_2T_4 treatment at 75 DAT.

Table 5. Effect of cadmium on number of leaves $hill^{-1}$ at different days after transplanting

Treatment	Number of leaves $hill^{-1}$	
	45 DAT	75 DAT
T_0	44.67 a	91.11 a
T_1	39.11 b	81.00 b
T_2	24.33 e	61.78 e
T_3	28.22 d	68.22 d
T_4	33.22 c	73.78 c
LSD $_{(0.05)}$	2.229	3.103
Significant level	*	*
CV (%)	6.81	4.27

T_0= No cadmium applied, T_1= 20 ppm Cd, T_2= 40 ppm Cd, T_3= 60 ppm Cd, T_4= 80 ppm Cd
*Significant at 5% level

Table 6. Interaction effect of varieties and cadmium doses on number of leaves $hill^{-1}$ at different days after transplanting

Treatment		Number of leaves $hill^{-1}$	
		45 DAT	75 DAT
V_1	T_0	40.33 c	97.00 b
	T_1	30.00 ef	87.67 c
	T_2	25.67 g	79.67 d
	T_3	20.67 h	73.67 e
	T_4	16.33 i	67.00 gh
V_2	T_0	43.33 bc	73.00 ef
	T_1	41.00 c	68.00 fgh
	T_2	34.33 d	64.67 h
	T_3	30.33 ef	59.00 i
	T_4	27.00 fg	53.00 j
V_3	T_0	50.33 a	103.3 a
	T_1	46.33 b	87.33 c
	T_2	39.67 c	77.00 de
	T_3	33.67 de	72.00 efg
	T_4	29.67 f	65.33 h
LSD $_{(0.05)}$		3.860	5.375
Significant level		*	*
CV (%)		6.81	4.27

V_1 – BRRI dhan29, V_2 – BRRI dhan60, V_3 – BRRI dhan61
T_0= No cadmium applied, T_1= 20 ppm Cd, T_2= 40 ppm Cd, T_3= 60 ppm Cd, T_4= 80 ppm Cd
*Significant at 5% level

4.4 Number of effective tillers

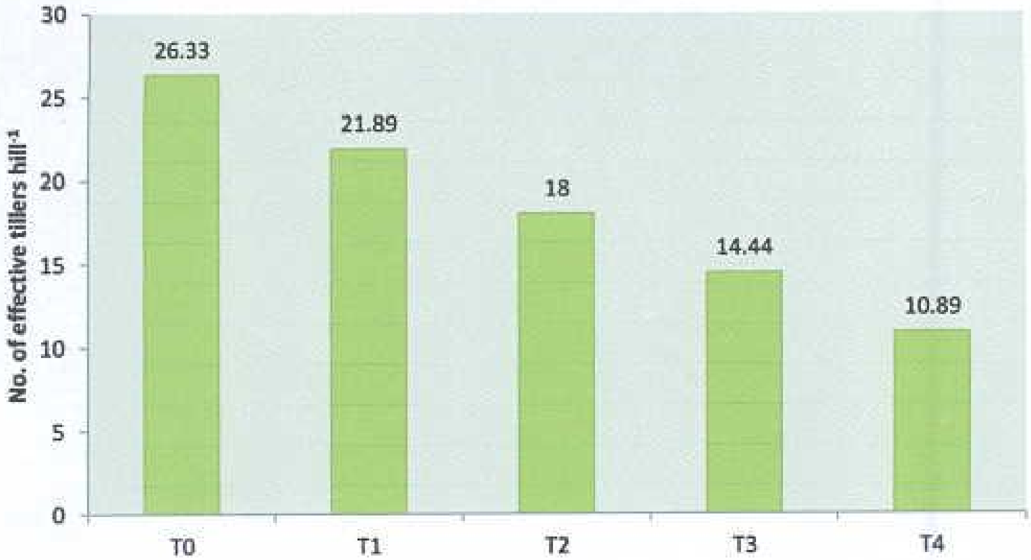
The number of effective tillers $hill^{-1}$ of boro rice was significantly influenced by the three varieties (Table 7 and Appendix VIII). The result revealed that the variety BRRI dhan61 produced the highest number of effective tillers $hill^{-1}$ (20.13) and the variety BRRI dhan60 gave the lowest number of effective tillers $hill^{-1}$ (16.47). The result is similar to that of Nahar *et al.* (2009) who reported that BRRI dhan46 had significantly higher effective tillers $hill^{-1}$ than the BRRI dhan31 in late transplanted conditions. BRRI (1991) and Lockard (1958) also reported similar views that the number of effective tillers differed among different varieties.

Table 7. Effect of variety on number of effective & non-effective tillers $hill^{-1}$ and 1000-grain weight

Treatment	Number of effective tillers $hill^{-1}$	Number of ineffective tillers $hill^{-1}$	1000-Grain weight (g)
V_1	18.33 b	9.200 a	20.72 b
V_2	16.47 c	7.400 b	22.16 a
V_3	20.13 a	5.600 c	19.41 c
LSD $_{(0.05)}$	**1.349**	**0.777**	**0.191**
Significant level	*	*	*
CV (%)	**9.85**	**14.05**	**1.23**

V_1 – BRRI dhan29, V_2 – BRRI dhan60, V_3 – BRRI dhan61
*Significant at 5% level

Different cadmium doses had significant effect on the number of effective tillers $hill^{-1}$ of rice (Figure 4 and Appendix VIII). The highest number of effective tillers $hill^{-1}$ (26.33) was observed from the T_0 treatment and the lowest (10.89) was observed from T_4 treatment. Cadmium is a poisonous and toxic heavy metal which exerts hampering and hindering effect on plant physiology. This result in Figure 4 may be due to that effect.



T_0= No cadmium applied, T_1= 20 ppm Cd, T_2= 40 ppm Cd, T_3= 60 ppm Cd, T_4= 80 ppm Cd

Figure 4. Effect of cadmium on number of effective tillers $hill^{-1}$

Interaction of varieties and different doses of cadmium showed significant variation on the number of effective tillers $hill^{-1}$ of rice (Table 8 and Appendix VIII). The highest number of effective tillers $hill^{-1}$ (29.00) was observed from the V_3T_0 treatment which was statistically similar with V_1T_0 (26.67) whereas, the lowest (10.00) was observed from V_2T_4 treatment which was statistically similar with V_1T_4 (11.00) and V_3T_4 (11.67). Number of effective tillers $hill^{-1}$ can vary from cultivar to cultivar.

Table 8. Interaction effect of varieties and cadmium doses on number of effective & non-effective tillers hill^{-1} and 1000-Grain weight

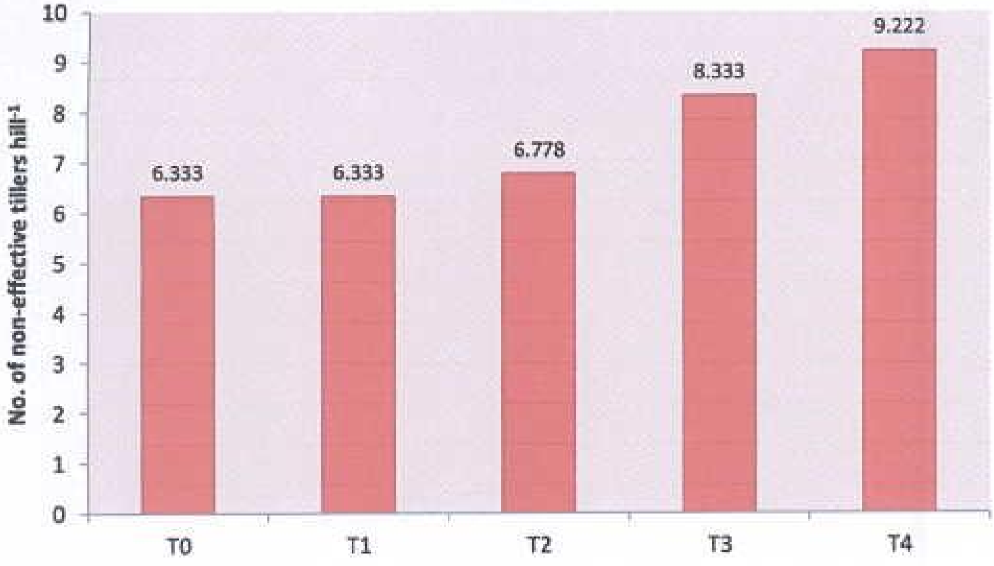
Treatment		Number of effective tillers hill^{-1}	Number of non-effective tillers hill^{-1}	1000-Grain weight (g)
V_1	T_0	26.67 ab	8.667 bc	21.77 d
	T_1	22.33 cd	9.000 b	21.20 e
	T_2	18.00 ef	8.000 bcd	20.73 fg
	T_3	13.67 gh	9.333 ab	20.30 hi
	T_4	11.00 hi	11.00 a	19.60 jk
V_2	T_0	23.33 c	6.667 de	23.23 a
	T_1	19.33 de	6.333 de	22.70 b
	T_2	16.00 fg	7.000 cde	22.27 c
	T_3	13.67 gh	8.000 bcd	21.67 d
	T_4	10.00 i	9.000 b	20.93 ef
V_3	T_0	29.00 a	3.67 f	20.50 gh
	T_1	24.00 bc	3.67 f	19.97 ij
	T_2	20.00 de	5.33 ef	19.53 k
	T_3	16.00 fg	7.667 bcd	18.73 l
	T_4	11.67 hi	7.667 bcd	21.77 d
LSD $_{(0.05)}$		3.016	1.739	0.426
Significant level		*	*	*
CV (%)		9.85	14.05	1.23

V_1 – BRRI dhan29, V_2 – BRRI dhan60, V_3 – BRRI dhan61
T_0= No cadmium applied, T_1= 20 ppm Cd, T_2= 40 ppm Cd, T_3= 60 ppm Cd, T_4= 80 ppm Cd
*Significant at 5% level

4.5 Number of non-effective tillers

The non-effective tillers hill^{-1} of boro rice was statistically significant among the three varieties (Table 7 and Appendix VIII). Numerically maximum number of non-effective tillers hill^{-1} was observed in the V_1 (BRRI dhan29) and the minimum number of non-effective tillers hill^{-1} was obtained from the variety V_3 (BRRI dhan61). Tyeb *et al.* (2013) observed that maximum number of total tillers hill^{-1} (16.02) and effective tillers hill^{-1} (13.19) were obtained from BRRI dhan52 followed by BRRI dhan51 while BRRI dhan41 produced the minimum number of total tillers hill^{-1} (13.08) and effective tillers hill^{-1} (9.29). Debnath (2010) and Ashrafuzzman (2006) observed that varieties differed insignificantly in respect of number of ineffective tillers m^{-2} though Ahmed (2006) found significant effect between inbred and hybrid varieties in respect of number of non-effective tillers m^{-2}.

Number of non-effective tillers hill^{-1} was significantly varied due to cadmium doses at all growth stages (Figure 5 & Appendix VIII). The highest number of non-effective tillers hill^{-1} (9.22) was recorded from T_4 treatment which was statistically similar with T_3 (8.33). In contrast, the lowest number of non-effective tillers hill^{-1} (6.33) was recorded from T_0 treatment which was statistically similar with T_1 (6.33) and T_2 (6.78).



T_0= No cadmium applied, T_1= 20 ppm Cd, T_2= 40 ppm Cd, T_3= 60 ppm Cd, T_4= 80 ppm Cd

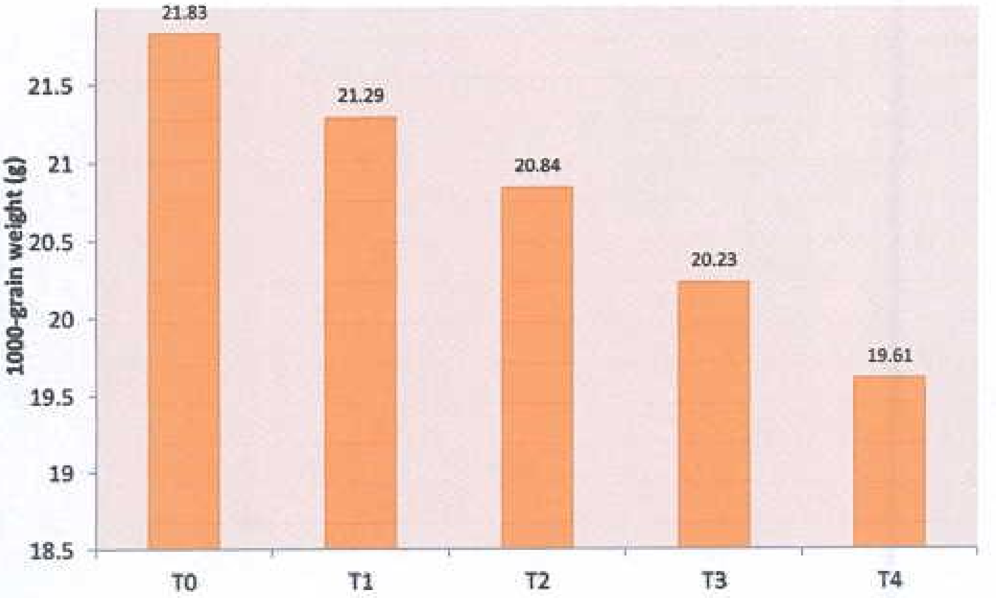
Figure 5. Effect of cadmium on number of non-effective tillers hill^{-1}

Number of non-effective tillers hill^{-1} was significantly varied due to interaction of varieties and different cadmium doses at all growth stages (Table 8 and Appendix VII). The highest number of non-effective tillers hill^{-1} (11.00) was recorded from treatment combination V_1T_4 which was statistically similar with V_1T_3 (9.33). In contrast, the lowest number of non-effective tillers hill^{-1} (3.67) was recorded from the treatment combination V_3T_0 which was statistically similar with V_3T_1 (9.33) and V_3T_2 (5.33).

4.6 1000-Grain weight

The 1000-grain weight of three different boro rice varieties was significantly influenced by different varieties (Table 7 and Appendix VIII). The result revealed that the highest 1000-Grain weight was showed by V_2 (BRRI dhan60) which was 22.16 g and the lowest 1000-grain weight was observed in variety V_3 (BRRI dhan61) which was 19.41 g. Islam *et al.* (2013) observed that the highest 1000 grain weight recorded from BRRI dhan46 (28.17 g) and the lowest from BRRI dhan33 (24.19 g). BR11 and BRRI dhan39 showed statistically similar result.

Different doses of applied cadmium had significant effect on 1000-grain weight of the boro rice varieties (Figure 6 and Appendix VIII). The highest 1000-grain weight was observed in the lowest cadmium dose T_0 (21.83 g) and the lowest 1000-grain weight was observed in the highest dose of cadmium T_4 (19.61 g). According to Holmgren *et al.* (1993) and Das *et al.* (1997), all the growth parameters tested in their experiment viz. plant height, panicle length, grains pot^{-1} and 100-grain weight were affected by the application of Cd. Cadmium has been marked as poisonous heavy metal both for plants and animals.



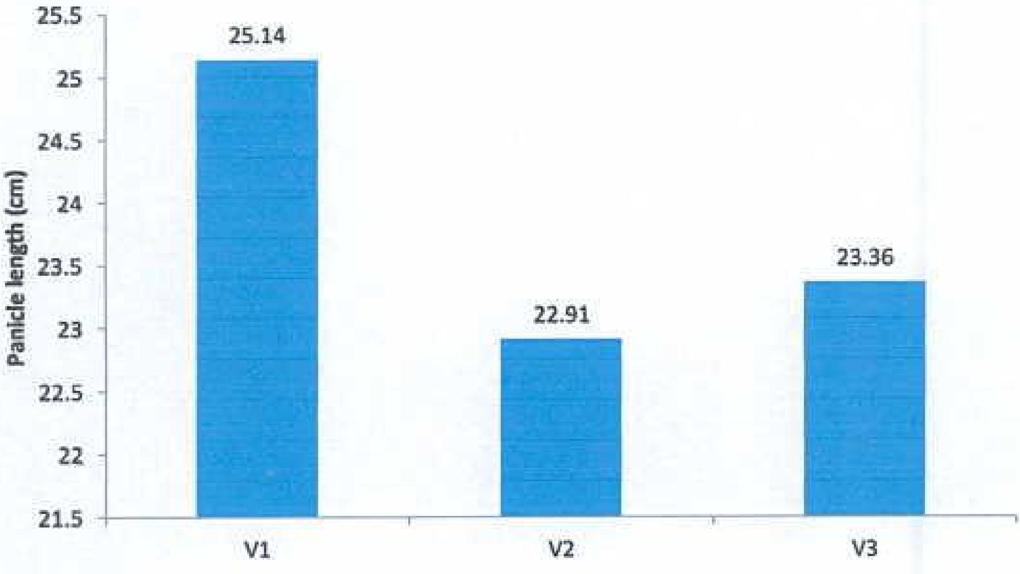
T_0= No cadmium applied, T_1= 20 ppm Cd, T_2= 40 ppm Cd, T_3= 60 ppm Cd, T_4= 80 ppm Cd

Figure 6. Effect of different doses of cadmium on 1000-grain weight

1000-grain weight was significantly varied due to the interaction of varieties and different cadmium doses (Table 8 and Appendix VIII). The highest 1000-grain weight (23.23 g) was recorded from treatment combination V_2T_0. In contrast, the lowest 1000-grain weight (18.73) was recorded from the treatment combination V_3T_3.

4.7 Panicle length

It is obvious that panicle length can vary from variety to variety. The panicle length (cm) of boro rice was statistically significant and hence was influenced by different varieties (Figure 7 and Appendix VII). Numerically longest panicle was observed in the V_1 (BRRI dhan29) and the shortest was obtained from the variety V_2 (BRRI dhan60) which was statistically similar to variety V_3 (BRRI dhan61). This finding is in contradiction with Ashrafuzzaman (2006) and Main (2006) who observed that varieties differed insignificantly in respect of panicle length.



V_1 – BRRI dhan29, V_2 – BRRI dhan60, V_3 – BRRI dhan61

Figure 7. Effect of variety on panicle length

Different doses of cadmium had significantly influenced the panicle length of rice (Table 9 and Appendix VII). The highest length of panicle (27.16 cm) was obtained from T_0 treatment whereas, the lowest (20.28 cm) was observed from T_2 treatment. This also supports the report of Das *et al.*, (1997). He has marked cadmium as poisonous heavy metal both for plants and animals. Like all other parameter, panicle length was affected by the application of Cd in his experiment.

Significant influence was observed on panicle length (cm) due to the different interaction of varieties and different cadmium doses (Table 10). The highest length of panicle (29.80 cm) was obtained from V_1T_0. In contrast, the lowest number of panicle length (19.90 cm) was recorded from the treatment combination V_3T_4 which was statistically similar with V_1T_4 (20.43 cm) and V_2T_4 (20.50 cm).

Table 9. Effect of cadmium on panicle length, number of filled and unfilled grains panicle^{-1}

Treatment	Panicle length (cm)	Number of filled grains panicle^{-1}	Number of unfilled grains panicle^{-1}
T_0	27.16 a	164.0 a	11.89 e
T_1	25.32 b	152.1 b	16.78 d
T_2	20.28 e	102.7 e	29.33 a
T_3	22.33 d	124.7 d	24.67 b
T_4	23.92 c	141.7 c	20.44 c
LSD $_{(0.05)}$	**0.682**	**4.560**	**1.465**
Significant level	*	*	*
CV (%)	**2.97**	**3.45**	**7.36**

T_0= No cadmium applied, T_1= 20 ppm Cd, T_2= 40 ppm Cd, T_3= 60 ppm Cd, T_4= 80 ppm Cd
*Significant at 5% level

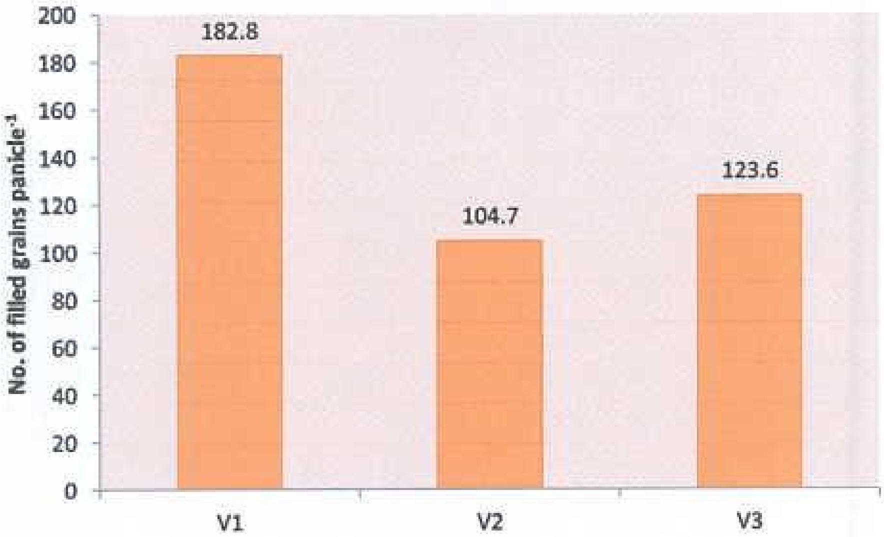
Table 10. Combined effect of variety and cadmium on panicle length, number of filled and unfilled grains panicle^{-1}

Treatment		Panicle length (cm)	Number of filled grains panicle^{-1}	Number of unfilled grains panicle^{-1}
V_1	T_0	29.80 a	220.7 a	17.00 fg
	T_1	27.13 b	203.0 b	25.67 d
	T_2	25.13 cd	193.3 c	31.00 c
	T_3	23.20 fgh	164.0 d	36.00 b
	T_4	20.43 j	133.0 f	41.67 a
V_2	T_0	25.80 c	141.0 e	11.33 i
	T_1	24.60 de	134.0 ef	14.00 h
	T_2	23.87 efg	127.0 fg	15.33 gh
	T_3	22.03 hi	115.0 h	18.67 f
	T_4	20.50 j	101.0 ij	22.33 e
V_3	T_0	25.87 c	130.3 f	7.333 j
	T_1	24.23 def	119.3 gh	10.67 i
	T_2	22.77 ghi	104.7 i	15.00 gh
	T_3	21.77 i	95.00 j	19.33 f
	T_4	19.90 j	74.00 k	24.00 de
LSD $_{(0.05)}$		1.181	7.898	2.538
Significant level		*	*	*
CV (%)		2.97	3.45	7.36

V_1 – BRRI dhan29, V_2 – BRRI dhan60, V_3 – BRRI dhan61
T_0= No cadmium applied, T_1= 20 ppm Cd, T_2= 40 ppm Cd, T_3= 60 ppm Cd, T_4= 80 ppm Cd
*Significant at 5% level

4.8 Number of filled grains

The number of filled grains panicle^{-1} of boro rice was significantly influenced by different varieties (Figure 8 and Appendix VII). The result revealed that the highest number of filled grains panicle^{-1} was observed in variety V_1 (BRRI dhan29) and the lowest number of filled grain panicle^{-1} were observed in variety V_2 (BRRI dhan60). Singh *et al.* (1990) found that number of filled spikelets panicle^{-1} significantly differed among the varieties. BRRI (2006) studied the performance of BR14, Pajam, BR5 and Tulsimala and reported that Tulsimala produced the highest number of filled grains panicle^{-1} and BR14 produced the lowest number of filled grains panicle^{-1}.



V_1 – BRRI dhan29, V_2 – BRRI dhan60, V_3 – BRRI dhan61

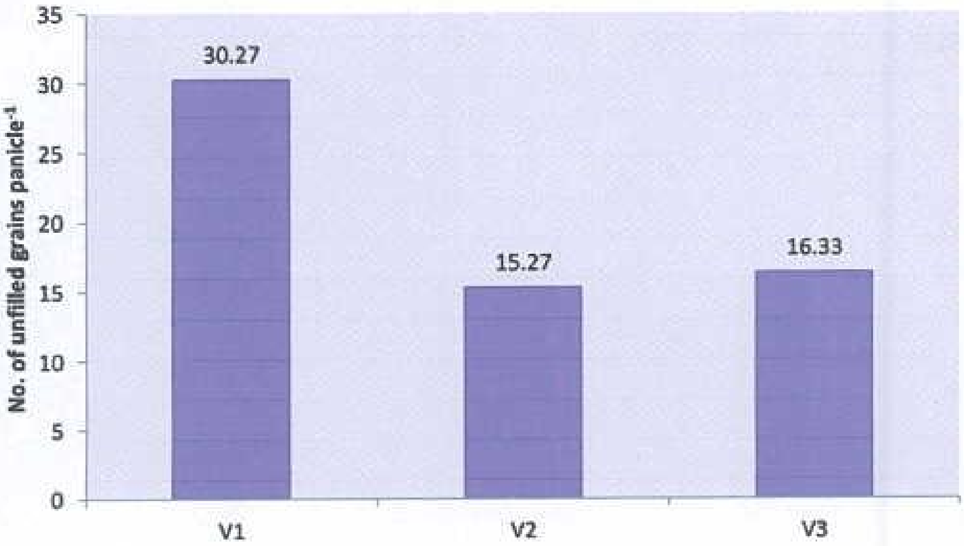
Figure 8. Effect of variety on number of filled grains panicle^{-1}

Different doses of cadmium had significantly influenced the number of filled grains panicle^{-1}. The highest number of filled grains was observed in T_0 treatment and the lowest was observed in T_2 treatment (Table 9). As the number of filled grains panicle^{-1} is a growth contributing character, increase in the number of filled grains panicle^{-1} increase the yield. The yield of rice grain was highly affected by cadmium treatments; the highest values of grain was recorded at without control and sharply decreased with increasing concentration of treatments. These results also are in agreement with Liu *et al.* (2008). They reported that the high values of grain were 0.82 g/plant, obtained at control for Giza 177. While the least value was 0.35 g/plant obtained with 3 mg L^{-1} cadmium concentration of Giza 178.

Interaction of variety and different doses of cadmium had significant influence on number of filled grains panicle^{-1}. In respect of the number of filled grains panicle^{-1}, the highest number of filled grains panicle^{-1} was V_1T_0 (220.7) and the lowest number of filled grains panicle^{-1} was V_3T_4 (74.00) (Table 10). According to Cheng-wang *et al.* (2005) Cd stress significantly reduced grain yield and panicle length, number of spikelets panicle^{-1} and filled grain and grain weight and shoot dry weight at various growth stages. The toxic effect exerted by the Cd in plants was the reasons for getting negative effects of Cd.

4.9 Number of unfilled grains

The highest number of unfilled grains panicle^{-1} were observed in V_1 (BRRI dhan29) and the lowest number of unfilled grains panicle^{-1} was observed in variety V_2 (BRRI dhan60) which was statistically similar to variety V_3 (BRRI dhan61) (Figure 9 and Appendix VII). Tyeb *et al.* (2013) observed that BRRI dhan4l produced the highest number of unfilled grains panicle^{-1} (28.71) followed by BRRI dhan51 (24.88) and BRRI dhan46 (19.50). The lowest number of unfilled grains panicle^{-1} produced by BRRI dhan52 (14.17).



V_1 – BRRI dhan29, V_2 – BRRI dhan60, V_3 – BRRI dhan61

Figure 9. Effect of variety on number of unfilled grains panicle^{-1}

Different doses of cadmium had also significantly influenced the number of unfilled grain panicle^{-1}. The highest number of unfilled grains was observed in T_2 treatment and the lowest was observed in T_0 treatment (Table 9 and Appendix VIII).

The highest number of unfilled grain panicle^{-1} was observed in V_1T_4 (41.67), the lowest number of unfilled grains panicle^{-1} was from the treatment combination V_3T_0 (7.33) (Table 10 and Appendix VIII).

4.10 Grain Yield

Grain yield (t ha^{-1}) of Boro rice was significantly influenced by different varieties (Table 11). The result revealed that the variety BRRI dhan29 produced the highest grain yield (4.627 t ha^{-1}) and the variety BRRI dhan60 gave lowest grain yield (3.83 t ha^{-1}). Zohra *et al.*, (2013) observed that the highest number of effective tillers hill^{-1} (11.42) which eventually contributed to higher grain yield (5.46 t ha^{-1}) of BRRI dhan46 compared to (4.44 t ha^{-1}) Binadhan-7.

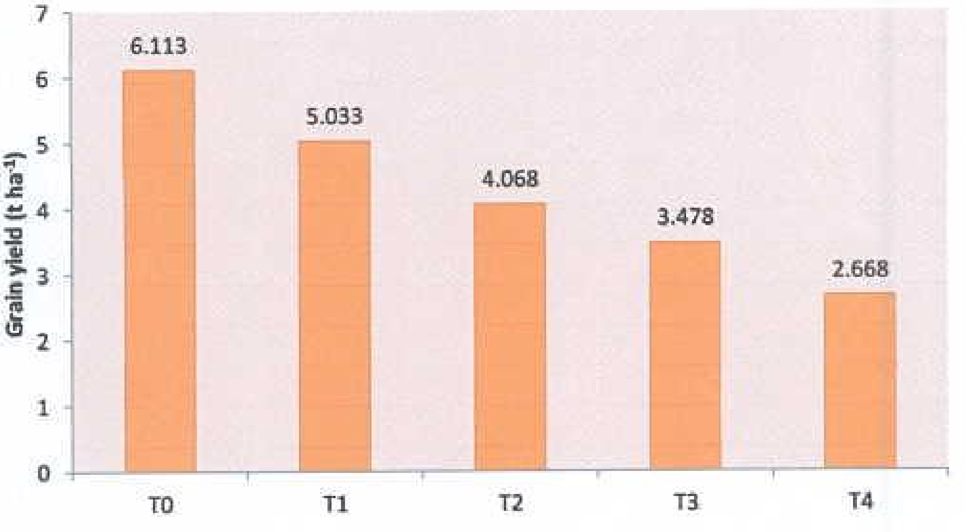
Table 11. Effect of variety on grain, straw and root yield

Treatment	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Root yield (t ha^{-1})
V_1	4.627 a	4.256 c	1.743 a
V_2	3.835 c	5.484 b	1.404 b
V_3	4.354 b	5.815 a	1.745 a
LSD $_{(0.05)}$	**0.074**	**0.040**	**0.023**
Significant level	*	*	*
CV (%)	**2.39**	**1.12**	**1.50**

V_1 – BRRI dhan29, V_2 – BRRI dhan60, V_3 – BRRI dhan61

*Significant at 5% level

Different doses of cadmium had significant influence on grain yield (Figure 10 and Appendix VIII). The highest grain yield (6.113 t ha^{-1}) was obtained from T_0 treatment while the lowest result (2.668 t ha^{-1}) was recorded from T_4. It clearly indicates that the poisonous and detrimental effect of cadmium on plant. Similar result was found by Fathy *et al.* (2011). In his result, he showed that with higher cadmium level led to decrease in final grain yields. The highest grain yield was achieved at 0 cadmium level and the lowest grain yield achieved by the highest cadmium level. According to Cheng-wang *et al.*, (2005) Cd stress significantly reduced grain yield.



T_0= No cadmium applied, T_1= 20 ppm Cd, T_2= 40 ppm Cd, T_3= 60 ppm Cd, T_4= 80 ppm Cd

Figure 10. Effect of cadmium on grain yield

Grain yield of boro rice was significantly influenced by the interaction effect of variety and different cadmium doses (Table 12). The highest grain yield (26.17 t ha^{-1}) was recorded from V_1T_0 treatment. On the other hand, V_3T_4 showed the lowest result (2.77 g) which was statistically similar with V_2T_3 (2.80 t ha^{-1}). According to Sarkunan *et al.*, (1995), rice yield drastically decreased due to the application of 20 ppm Cd. Similar results were reported by Alloway (1988) and Dixit and Gupta (1992).

Table 12. Combined effect of variety and cadmium on grain, straw and root yield

Treatment		Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Root yield (t ha^{-1})
V_1	T_0	6.543 a	4.857 h	2.113 a
	T_1	5.300 d	4.330 i	1.923 c
	T_2	4.363 f	4.137 j	1.773 d
	T_3	3.860 h	4.057 j	1.543 fg
	T_4	3.070 i	3.900 k	1.360 i
V_2	T_0	5.687 c	6.067 b	1.623 e
	T_1	4.830 e	5.917 c	1.527 g
	T_2	3.700 h	5.467 ef	1.387 hi
	T_3	2.800 j	5.163 g	1.307 j
	T_4	2.157 k	4.807 h	1.177 k
V_3	T_0	6.110 b	6.240 a	2.047 b
	T_1	4.970 e	6.093 b	1.893 c
	T_2	4.140 g	5.760 d	1.773 d
	T_3	3.773 h	5.553 e	1.583 ef
	T_4	2.777 j	5.430 f	1.427 h
LSD $_{(0.05)}$		**0.167**	**0.091**	**0.052**
Significant level		*	*	*
CV (%)		**2.39**	**1.12**	**1.50**

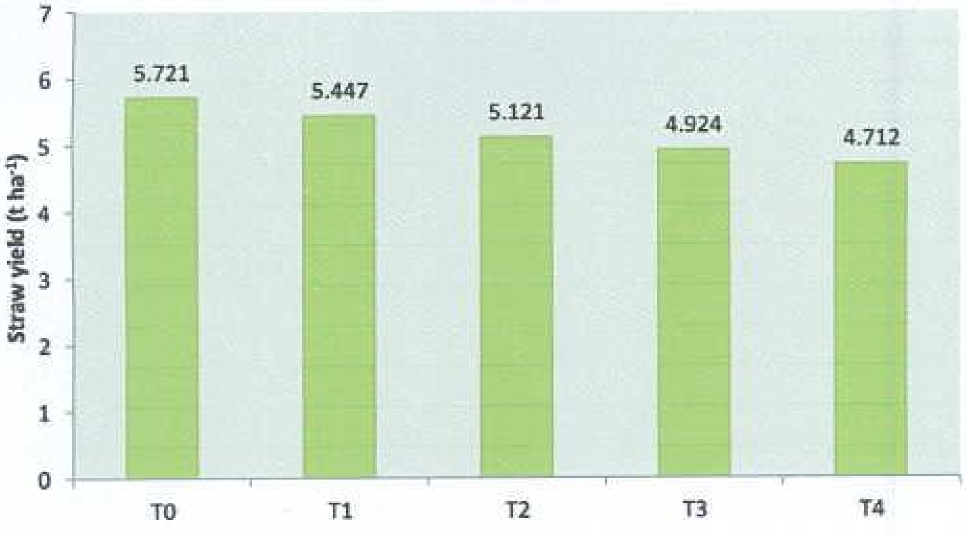
V_1 – BRRI dhan29, V_2 – BRRI dhan60, V_3 – BRRI dhan61
T_0= No cadmium applied, T_1= 20 ppm Cd, T_2= 40 ppm Cd, T_3= 60 ppm Cd, T_4= 80 ppm Cd
*Significant at 5% level

4.11 Straw Yield

Straw yield (t ha^{-1}) was significantly influenced by different varieties (Table 11 and Appendix VIII). The result revealed that the variety BRRI dhan61 produced the highest straw yield (5.815 t ha^{-1}) and the variety BRRI dhan29 gave lowest straw yield (4.256 t ha^{-1}). Islam *et al.* (2013) observed that the highest straw yield was found from BR11 and lowest from BRRI dhan33. BRRI dhan46 showed statistically similar result with BR11 for all cases. This result was in agreement with the finding of Patel (2000) who reported that yield performance varied with variety.

Different cadmium doses had significant influence on straw yield (Figure 11 and Appendix VIII). The highest straw yield (5.721 t ha^{-1}) was obtained from T_0 treatment while the lowest result (4.712 t ha^{-1}) was recorded from T_4 treatment. Results showed that higher doses of cadmium gave lower yield. This may be due to toxic effect of cadmium. Cheng-wang *et al.*,

(2005) mentioned that Cd stress significantly reduced grain yield and panicle length, number of spikelets panicle^{-1} and filled grain and grain weight and shoot dry weight at various growth stages. The toxic effect exerted by the Cd in plants was the reasons for getting negative effects of Cd.



T_0= No cadmium applied, T_1= 20 ppm Cd, T_2= 40 ppm Cd, T_3= 60 ppm Cd, T_4= 80 ppm Cd

Figure 11. Effect of cadmium on straw yield

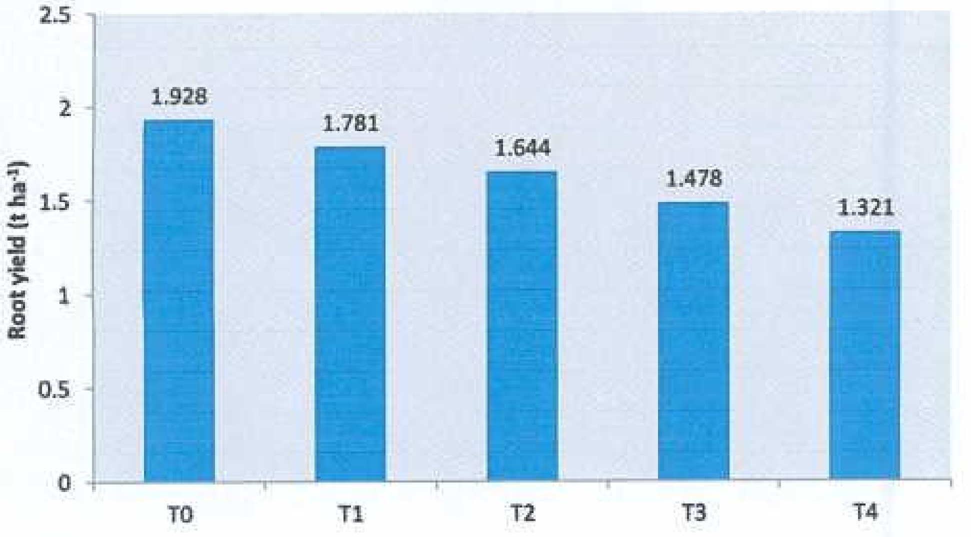
Interaction of variety and different cadmium doses has significant effect on straw yield of rice (Table 12). The highest straw yield (6.240 t ha^{-1}) was obtained from V_3T_0 treatment On the other hand, V_1T_4 showed the lowest result (3.90 t ha^{-1}). Here we can see the lowest dose of cadmium resulted in the maximum yield and the highest dose of cadmium produced the minimum yield. This may be due to the toxic effect of the heavy metal-Cd.

4.12 Root Yield

Root yield (t ha^{-1}) was significantly influenced by different varieties (Table 11 and Appendix VIII). The result revealed that the variety BRRI dhan61and BRRI dhan29 produced the highest root yield (1.745 and 1.743 t ha^{-1}, respectively) and the variety BRRI dhan60 gave the lowest root yield (1.404 t ha^{-1}). This varietal effect on root yield supports the findings of Pal *et. al.* (2008). They stated that the number of roots hill^{-1}, root length, root dry weight and above ground plant weight were significantly influenced by variety at 30, 60 and 90 days after transplanting (DAT).

Different cadmium doses had significant influence on root yield (Figure 12 and Appendix X). The highest root yield (1.928 t ha^{-1}) was obtained from T_0 treatment while the lowest result

($1.321\ t\ ha^{-1}$) was recorded from T_4 treatment. It shows that cadmium hinders the root growth. Cadmium concentration above 20 ppm in soil reduces rice plant biomass by poisoning the roots and restricting the growth (Herawati *et al.*, 2000).



T_0= No cadmium applied, T_1= 20 ppm Cd, T_2= 40 ppm Cd, T_3= 60 ppm Cd, T_4= 80 ppm Cd

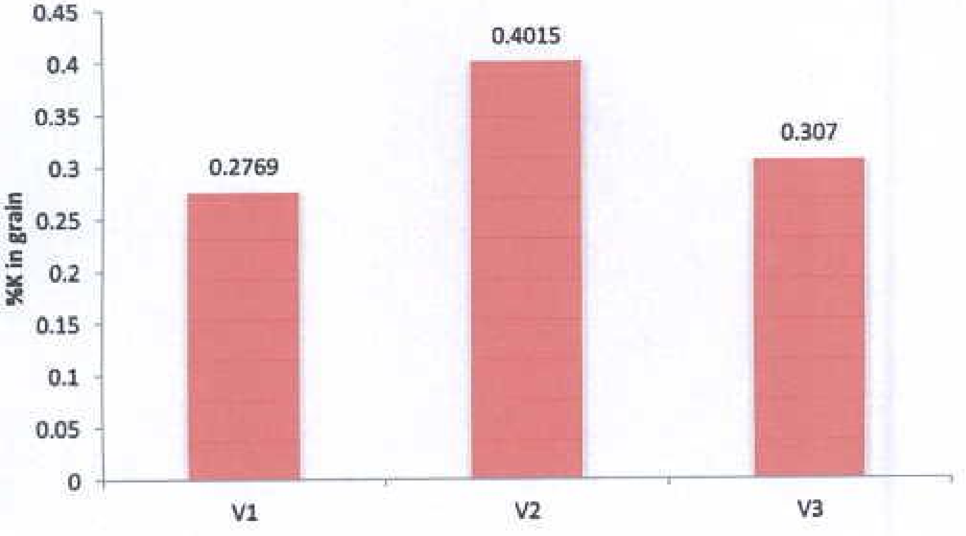
Figure 12. Effect on cadmium on root yield

Interaction of variety and different cadmium doses has significant effect on root yield of rice (Table 12). From the study, the highest root yield ($2.113\ t\ ha^{-1}$) was obtained from V_1T_0 treatment. On the other hand, V_2T_4 treatment showed the lowest result ($1.177\ t\ ha^{-1}$). Low concentrations of Cd retard root growth without toxic effects in leaves, and moderately higher concentrations severely inhibit root growth and lead to Cd accumulation in leaves (Prasad, 1995).

4.13 Chemical Composition

4.13.1 Potassium (K) content in grain

Potassium content in grain showed statistically significant difference due to the varieties (Figure 13 and Appendix IX). Numerically the highest K content (0.4015%) was observed in grain from the variety BRRI dhan60 (V_2) and the lowest amount of K (0.2769%) found in grain for the variety BRRI dhan29 (V_1). Morales *et al.* (2012) found that, K^+ concentration in different rice plant organs was significantly different due to the variety x NaCl concentration interaction. In root, there were differences due to the varietal factor.



V_1 – BRRI dhan29, V_2 – BRRI dhan60, V_3 – BRRI dhan61

Figure 13. Effect of variety on potassium content in grain

It was observed from the results presented in Table 13 and Appendix X that, different doses of cadmium have significant influence on K content in grain. The highest K content (0.4120%) in grain was observed from T_0 treatment while T_4 gave the lowest result (0.2329%). It supports the findings of Veselov *et al*. (2003) who reported that the uptake of potassium and nitrate, transpiration and shoot growth of wheat plant were inhibited by adding cadmium to the nutrient medium.

K content in grain varied significantly due to the interaction effect of variety and different cadmium doses and (Table 14). The highest K content in grain (0.4843%) was observed from V_2T_0 which is statistically similar with V_2T_1 (0.4590%), V_2T_2 (0.4560%) and V_3T_0 (0.4353%) while the lowest result (0.1747%) was recorded from V_3T_4.

Table 13. Effect of cadmium on potassium content in grain, straw and root

Treatment	Potassium content (% K)		
	Grain	Straw	Root
T_0	0.4120 a	3.680 a	0.6044 a
T_1	0.3513 b	3.500 b	0.4989 b
T_2	0.3521 b	2.814 c	0.4911 b
T_3	0.2941 c	2.493 d	0.4500 c
T_4	0.2329 d	2.159 e	0.4289 c
LSD (0.05)	**0.030**	**0.030**	**0.030**
Significant level	*	*	*
CV (%)	**1.51**	**0.45**	**2.29**

T_0= No cadmium applied, T_1= 20 ppm Cd, T_2= 40 ppm Cd, T_3= 60 ppm Cd, T_4= 80 ppm Cd
*Significant at 5% level

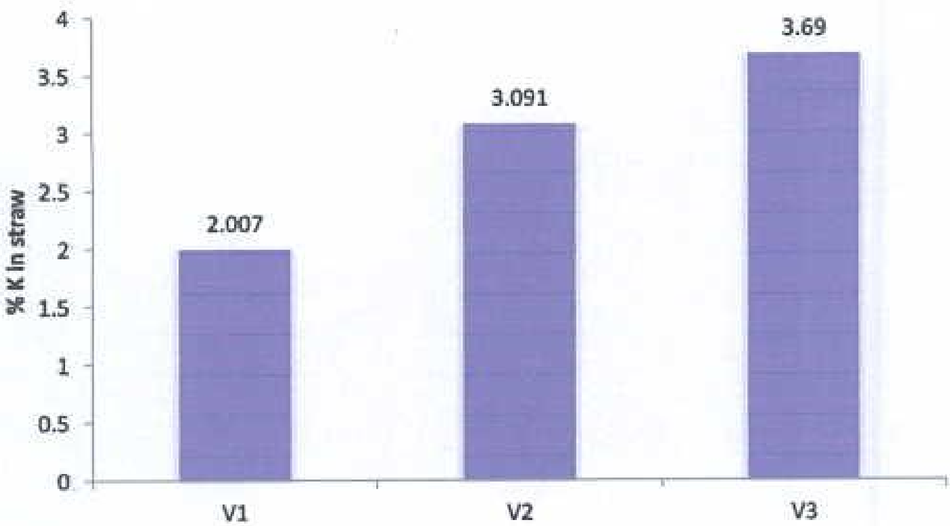
Table 14. Interaction effect of variety and cadmium on potassium content in grain, straw and root

Treatment		Potassium content (% K)		
		Grain	Straw	Root
V_1	T_0	0.3163 bcd	2.333 h	0.4267 fg
	T_1	0.2510 ef	2.147 i	0.3767 gh
	T_2	0.2987 b-f	2.120 i	0.3633 h
	T_3	0.2710 def	1.760 j	0.3400 h
	T_4	0.2477 f	1.673 k	0.3367 h
V_2	T_0	0.4843 a	3.570 c	0.5733 c
	T_1	0.4590 a	3.523 c	0.4767 def
	T_2	0.4560 a	2.903 e	0.4800 de
	T_3	0.3320 bc	2.800 f	0.4467 ef
	T_4	0.2763 def	2.660 g	0.4267 fg
V_3	T_0	0.4353 a	5.137 a	0.8133 a
	T_1	0.3440 b	4.830 b	0.6433 b
	T_2	0.3017 bcde	3.420 d	0.6300 b
	T_3	0.2793 cdef	2.920 e	0.5633 c
	T_4	0.1747 g	2.143 i	0.5233 cd
LSD (0.05)		**0.052**	**0.052**	**0.052**
Significant level		*	*	*
CV (%)		**1.51**	**0.45**	**2.29**

V_1 – BRRI dhan29, V_2 – BRRI dhan60, V_3 – BRRI dhan61
T_0= No cadmium applied, T_1= 20 ppm Cd, T_2= 40 ppm Cd, T_3= 60 ppm Cd, T_4= 80 ppm Cd

4.13.2 Potassium content in straw

K content in straw showed statistically significant difference due to the varieties (Figure 14 and Appendix VII). Numerically the highest K content (3.690%) was observed in straw from the variety BRRI dhan61 (V_3) and the lowest amount of K (0.2007%) found in straw for the variety BRRI dhan29 (V_1).



V_1 – BRRI dhan29, V_2 – BRRI dhan60, V_3 – BRRI dhan61

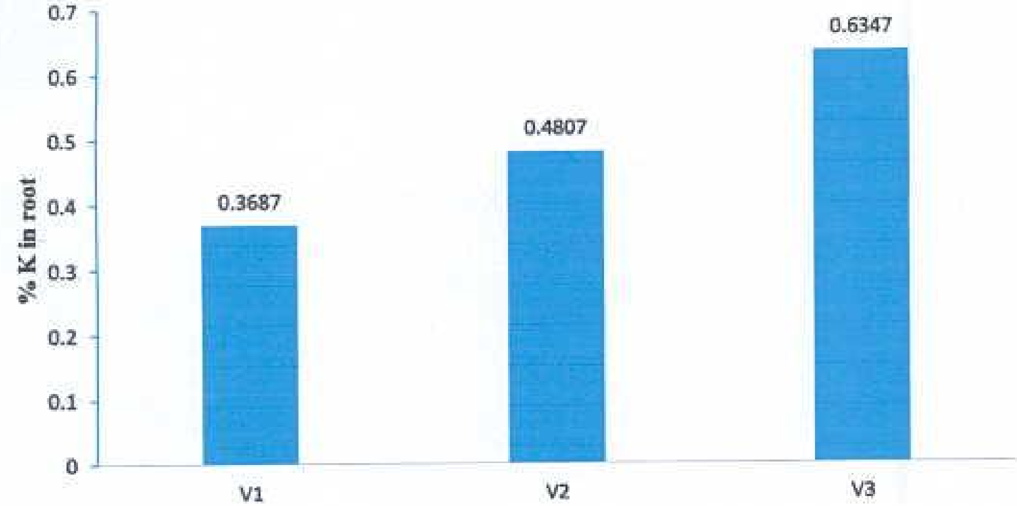
Figure 14. Effect of variety on potassium content in straw

It was observed from the results presented in Table 13 and Appendix X that, different doses of cadmium have significant influence on K content in straw. The highest K content (3.680%) in straw was observed from T_0 treatment while T_4 gave the lowest result (2.159%).

K content in straw varied significantly due to the interaction effect of variety and different cadmium doses and (Table 14). The highest K content in straw (5.137%) was observed from V_3T_0 while the lowest result (1.673%) was recorded from V_1T_4.

4.13.3 Potassium content in root

K content in root showed statistically significant difference due to the varieties (Figure 15 and Appendix VII). Numerically the highest K content (0.6347%) was observed in root from the variety BRRI dhan61 (V_3) and the lowest amount of K (0.3687%) found in root for the variety BRRI dhan29 (V_1).



V_1 – BRRI dhan29, V_2 – BRRI dhan60, V_3 – BRRI dhan61

Figure 15. Effect of variety on potassium content in root

It was observed from the results presented in Table 13 that, different doses of cadmium have significant influence on K content in root. The highest K content (0.6044%) in root was observed from T_0 treatment while T_3 gave the lowest result (0.4500%) which was statistically similar with T_4 (0.4289%).

K content in root varied significantly due to the interaction effect of variety and different cadmium doses and (Table 14). The highest K content in root (0.8133%) was observed from V_3T_0 while the lowest result (0.3367%) was recorded from V_1T_4 which was statistically similar with V_1T_3 (0.34%), V_1T_2 (0.3633%) and V_1T_1 (0.3767%).

4.13.4 Sodium content in grain

Sodium content in grain showed statistically in-significant difference due to the varieties (Table 15 and Appendix IX). Numerically the highest Na content (0.159%) was observed in grain from the variety BRRI dhan29 (V_1) and the lowest amount of Na (0.137%) found in grain for the variety BRRI dhan60 (V_2).

Table 15. Effect of variety on sodium content in grain, straw and root

Treatment	Sodium content (% Na)		
	Grain	Straw	Root
V_1	0.159	0.766 b	0.930 c
V_2	0.137	1.430 a	1.142 b
V_3	0.147	1.443 a	1.271 a
LSD $_{(0.05)}$	**0.023**	**0.023**	**0.110**
Significant level	NS	*	*
CV (%)	**7.24**	**0.77**	**13.39**

V_1 – BRRI dhan29, V_2 – BRRI dhan60, V_3 – BRRI dhan61
NS – Non significant, * Significant at 5% level

It was observed from the results presented in Table 16 and Appendix X that, different doses of cadmium have significant influence on Na content in grain. The highest Na content (0.203%) in grain was observed from T_0 treatment while T_4 gave the lowest result (0.108%).

Table 16. Effect of cadmium on sodium content in grain, straw and root

Treatment	Sodium content (% Na)		
	Grain	Straw	Root
T_0	0.203 a	1.519 a	1.387 a
T_1	0.161 b	1.308 b	1.183 b
T_2	0.140 bc	1.174 c	0.977 c
T_3	0.127 cd	1.053 d	1.038 c
T_4	0.108 d	1.011 e	0.987 c
LSD (0.05)	**0.030**	**0.030**	**0.143**
Significant level	*	*	*
CV (%)	**7.24**	**0.77**	**13.39**

T_0= No cadmium applied, T_1= 20 ppm Cd, T_2= 40 ppm Cd, T_3= 60 ppm Cd, T_4= 80 ppm Cd
* Significant at 5% level

Na content in grain varied significantly due to the interaction effect of variety and different cadmium doses and (Table 17). The highest Na content in grain (0.220%) was observed from

V_3T_0 which was statistically similar with V_1T_0 (0.21%) and V_2T_0 (0.18%), while the lowest result (0.0933%) was recorded from V_3T_4 which was statistically similar with V_2T_4 (0.107%), V_3T_3 (0.117%), V_2T_3 (0.12%), V_1T_4 (0.123%), V_2T_2 (0.127%) and V_1T_3 (0.143%).

Table 17. Effect of combination of variety and cadmium on sodium content in grain, straw and root

Treatment		Sodium content (% Na)		
		Grain	Straw	Root
V_1	T_0	0.210 ab	0.953 i	1.353 abc
	T_1	0.167 bcd	0.860 j	0.907 efg
	T_2	0.153 cde	0.740 k	0.853 fg
	T_3	0.143 cdef	0.657 l	0.810 g
	T_4	0.123 def	0.620 l	0.727 g
V_2	T_0	0.180 abc	1.833 a	1.430 a
	T_1	0.150 cde	1.447 d	1.290 abcd
	T_2	0.127 def	1.330 e	0.813 g
	T_3	0.120def	1.290 ef	1.107 cde
	T_4	0.107 ef	1.250 fg	1.070 def
V_3	T_0	0.220 a	1.770 b	1.377 ab
	T_1	0.167 bcd	1.617 c	1.353 abc
	T_2	0.140cdef	1.453 d	1.263 abcd
	T_3	0.117 def	1.213 gh	1.197 abcd
	T_4	0.0933 f	1.163 h	1.163 bcd
$LSD_{(0.05)}$		**0.052**	**0.052**	**0.248**
Significant level		*	*	*
CV (%)		**7.24**	**0.77**	**13.39**

V_1 – BRRI dhan29, V_2 – BRRI dhan60, V_3 – BRRI dhan61

T_0= No cadmium applied, T_1= 20 ppm Cd, T_2= 40 ppm Cd, T_3= 60 ppm Cd, T_4= 80 ppm Cd

* Significant at 5% level

4.13.5 Sodium content in straw

Na content in straw showed statistically significant difference due to the varieties (Table 15). Numerically the highest Na content (1.443%) was observed in straw from the variety BRRI dhan61 (V_3) which was statistically similar with V_2 (BRRI dhan60) (1.430%) and the lowest amount of Na (0.766%) was found from the variety BRRI dhan29 (V_1) in straw.

It was observed from the results presented in Table 16 that, different doses of cadmium have significant influence on Na content in straw. The highest Na content (1.519%) in straw was observed from T_0 treatment while T_4 gave the lowest result (1.011%).

Na content in straw varied significantly due to the interaction effect of variety and different cadmium doses and (Table 17). The highest Na content in straw (1.833%) was observed from V_2T_0, while the lowest result (0.620%) was recorded from V_1T_4 which was statistically similar with V_1T_3 (0.657%).

4.13.6 Sodium content in root

Na content in root showed statistically significant difference due to the varieties (Table 15). Numerically the highest Na content (1.271%) was observed in root from the variety BRRI dhan61 (V_3) and the lowest amount of Na (0.930%) was found from the variety BRRI dhan29 (V_1) in root.

It was observed from the results presented in Table 16 that, different doses of cadmium have significant influence on Na content in root. The highest Na content (1.387%) in root was observed from T_0 treatment while T_4 gave the lowest result (0.987%).

Na content in straw varied significantly due to the interaction effect of variety and different cadmium doses and (Table 17). The highest Na content in root (1.430%) was observed from V_2T_0which was statistically similar with V_3T_0 (1.377%), V_3T_1 (1.353%), V_1T_0 (1.353%), V_2T_1 (1.290%), V_3T_2 (1.263%) and V_3T_3 (1.197%), while the lowest result (0.727%) was recorded from V_1T_4 which was statistically similar with V_1T_3 (0.810%), V_2T_2 (0.813%), V_1T_2 (0.853%) and V_1T_1 (0.907%).

4.13.7 Calcium content in grain

Calcium content in grain showed statistically in-significant difference due to the varieties (Table 18). Numerically the Ca content was observed numerically same (0.035%) in grain from the three variety BRRI dhan29 (V_1), BRRI dhan60 (V_2) and BRRI dhan61 (V_3).

Table 18. Effect of variety on calcium content in grain, straw and root

Treatment	Calcium content (% Ca)		
	Grain	Straw	Root
V_1	0.035	0.391 a	0.187 b
V_2	0.035	0.372 a	0.268 a
V_3	0.035	0.347 b	0.193 b
LSD $_{(0.05)}$	**0.024**	**0.024**	**0.024**
Significant level	NS	*	*
CV (%)	**0.01**	**2.42**	**3.89**

V_1 – BRRI dhan29, V_2 – BRRI dhan60, V_3 – BRRI dhan61
NS – Non Significant* Significant at 5% level

It was observed from the results presented in Table 19 that, different doses of cadmium have in-significant influence on Ca content in grain. The Ca content was numerically same (0.035%) in five treatments.

Table 19. Effect of cadmium on calcium content in grain, straw and root

Treatment	Calcium content (% Ca)		
	Grain	Straw	Root
T_0	0.035	0.488 a	0.286 a
T_1	0.035	0.392 b	0.253 b
T_2	0.035	0.362 b	0.222 c
T_3	0.035	0.325 c	0.186 d
T_4	0.035	0.283 d	0.132 e
LSD (0.05)	**0.030**	**0.031**	**0.031**
Significant level	NS	*	*
CV (%)	**0.01**	**2.42**	**3.89**

T_0= No cadmium applied, T_1= 20 ppm Cd, T_2= 40 ppm Cd, T_3= 60 ppm Cd, T_4= 80 ppm Cd
NS – Non Significant* Significant at 5% level

Ca content in grain varied insignificantly due to the interaction effect of variety and different cadmium doses and (Table 20). The Ca content in grain (0.035%) was numerically same from all treatment combinations.

Table 20. Effect of combination of variety and cadmium on calcium content in grain, straw and root

Treatment		Calcium content (% Ca)		
		Grain	Straw	Root
V_1	T_0	0.035	0.426 c	0.244 cde
	T_1	0.035	0.423 c	0.228 cde
	T_2	0.035	0.408 c	0.194 ef
	T_3	0.035	0.382 cd	0.142 fg
	T_4	0.035	0.315 ef	0.125 g
V_2	T_0	0.035	0.479 b	0.346 a
	T_1	0.035	0.406 c	0.315 ab
	T_2	0.035	0.346 de	0.280 bc
	T_3	0.035	0.322 ef	0.262 bcd
	T_4	0.035	0.307 ef	0.139 g
V_3	T_0	0.035	0.559 a	0.266 bcd
	T_1	0.035	0.346 de	0.217 de
	T_2	0.035	0.332 de	0.193 ef
	T_3	0.035	0.272 fg	0.154 fg
	T_4	0.035	0.228 g	0.132 g
LSD $_{(0.05)}$		**0.053**	**0.053**	**0.053**
Significant level		NS	*	*
CV (%)		**0.01**	**2.42**	**3.89**

V_1 – BRRI dhan29, V_2 – BRRI dhan60, V_3 – BRRI dhan61

T_0= No cadmium applied, T_1= 20 ppm Cd, T_2= 40 ppm Cd, T_3= 60 ppm Cd, T_4= 80 ppm Cd

NS – Non Significant* Significant at 5% level

4.13.8 Calcium content in straw

Ca content in straw showed statistically significant difference due to the varieties (Table 18). Numerically the highest Ca content (0.391%) was observed in straw from the variety BRRI dhan29 (V_1) which was statistically similar (0.372%) to the variety BRRI dhan60 (V_2) and the lowest amount of Ca (0.347%) was found from the variety BRRI dhan61 (V_3) in straw.

It was observed from the results presented in Table 19 and Appendix X that, different doses of cadmium have significant influence on Ca content in straw. The highest Ca content (0.488%) in straw was observed from T_0 treatment while T_4 gave the lowest result (0.283%).

Ca content in straw varied significantly due to the interaction effect of variety and different cadmium doses and (Table 20). The highest Ca content in straw (0.559%) was observed from

V_3T_0, while the lowest result (0.228%) was recorded from V_3T_4 which was statistically similar with V_3T_3 (0.272%).

4.13.9 Calcium content in root

Ca content in root showed statistically significant difference due to the varieties (Table 18). Numerically the highest Ca content (0.268%) was observed in root from the variety BRRI dhan60 (V_2) and the lowest amount of Ca (0.187%) was found from the variety BRRI dhan29 (V_1) in root which was statistically similar to the result (0.193%) found from the variety BRRI dhan61 (V_3).

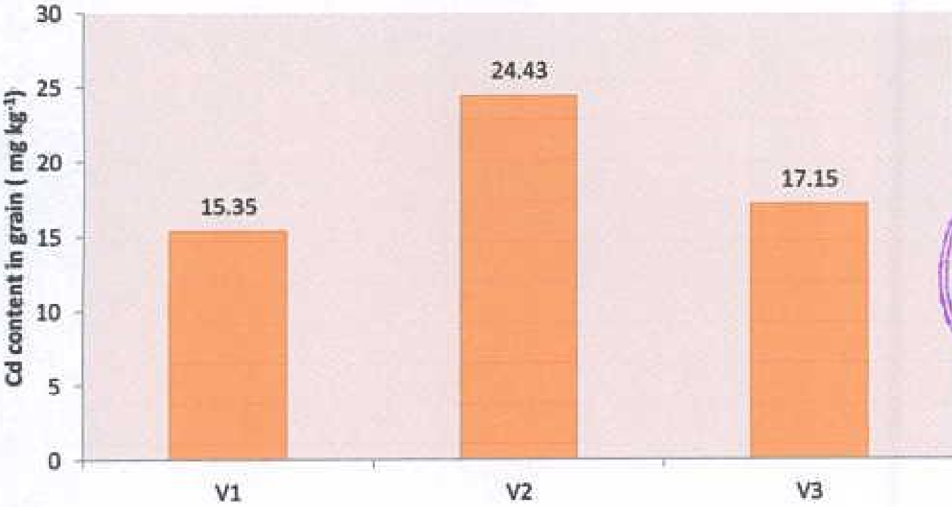
It was observed from the results presented in Table 19 that, different doses of cadmium have significant influence on Ca content in root. The highest Ca content (0.286%) in root was observed from T_0 treatment while T_4 gave the lowest result (0.132%).

Ca content in straw varied significantly due to the interaction effect of variety and different cadmium doses and (Table 20). The highest Ca content in root (0.346%) was observed from V_2T_0 which was statistically similar with V_2T_1 (0.315%), while the lowest result (0.125%) was recorded from V_1T_4 which was statistically similar with V_1T_3 (0.142%) and V_3T_3 (0.154%).

4.13.10 Cadmium content in grain

Cd content (mg kg^{-1}) in grain showed statistically significant difference due to the varieties (Figure 16 and appendix IX). Numerically the highest Cd content was observed from BRRI dhan60 (V_2) (24.43 mg kg^{-1}) in grain and the lowest was observed from the three variety BRRI dhan29 (V_1) (15.35 mg kg^{-1}). This may be due to the different genetic makeup of the varieties.

Grain and straw yields of Boro rice were also found to be affected by Cd application in soil. Liu (2004) found that only a very small portion (0.73%) of Cd absorbed by rice plant was transferred to grain. Cd concentration in rice grain was governed somewhat by plant Cd uptake and the transport of Cd from root to shoot and in a greater extent, by the transport of Cd from shoot to grain. Arao *et al.* (2010) reported grain and straw Cd concentrations 0.4 and 2.0 mg kg^{-1} respectively. Therefore, further experimentation is needed to validate the results reported here.



V_1 – BRRI dhan29, V_2 – BRRI dhan60, V_3 – BRRI dhan61

Figure 16. Effect of variety on cadmium content in grain

It was observed from the results presented in Table 22 that, different doses of cadmium have significant influence on Cd content in grain. The highest Cd content was found from treatment T_4 (26.77 mg kg^{-1}) and the least Cd content was found from the treatment T_0 (2.976 mg kg^{-1}). The concentration of Cd in rice grain was higher in Cd treated pot than the value in Cd untreated pots. The concentration of Cd increased progressively with increasing levels of Cd application. Cadmium is readily available and labile element therefore if present or accumulated in soils, would be taken up by plants and ultimately increased the concentration of Cd in plant parts. Addition of Cd can increase its content in grain and straw of rice (Sarkunan *et al.*, 1995).

Table 21. Effect of cadmium on cadmium content in grain, straw and root

Treatment	Cadmium content (mg kg^{-1})		
	Grain	Straw	Root
T_0	2.976 e	3.808 e	5.332 e
T_1	19.46 d	22.89 d	34.57 d
T_2	20.91 c	27.02 c	41.86 c
T_3	24.78 b	29.52 b	76.58 b
T_4	26.77 a	34.49 a	108.9 a
LSD (0.05)	**0.8944**	**1.528**	**1.568**
Significant level	*	*	*
CV (%)	**4.88**	**6.72**	**3.04**

T_0= No cadmium applied, T_1= 20 ppm Cd, T_2= 40 ppm Cd, T_3= 60 ppm Cd, T_4= 80 ppm Cd
* Significant at 5% level

Cd content in grain varied significantly due to the interaction effect of variety and different cadmium doses (Table 23). The highest Cd content in grain (34.37 mg kg^{-1}) was found from the treatment combination V_2T_4 and the least (1.950 mg kg^{-1}) was found from the treatment combination V_3T_0 which is statistically similar to the treatment combination V_1T_0 (2.993 mg kg^{-1}).

Table 22. Effect of combination of variety and cadmium on cadmium content in grain, straw and root

Treatment		Cadmium content (mg kg^{-1})		
		Grain	Straw	Root
V_1	T_0	2.993 kl	4.360 g	6.927 k
	T_1	15.34 j	23.94 de	44.98 f
	T_2	17.06 i	29.79 c	46.73 f
	T_3	20.12 fg	33.55 b	126.7 b
	T_4	21.22 ef	39.17 a	161.1 a
V_2	T_0	3.983 k	4.083 g	5.020 kl
	T_1	24.90 d	18.67 f	32.88 i
	T_2	26.74 c	22.50 e	42.06 g
	T_3	32.16 b	25.30 d	56.48 e
	T_4	34.37 a	32.99 b	95.92 c
V_3	T_0	1.950 l	2.980 g	4.050 l
	T_1	18.14 hi	26.06 d	25.84 j
	T_2	18.93 gh	28.76 c	36.77 h
	T_3	22.04 e	29.72 c	46.54 f
	T_4	24.71 d	31.30 bc	69.77 d
LSD $_{(0.05)}$		1.549	2.647	2.716
Significant level		*	*	*
CV (%)		4.88	6.72	3.04

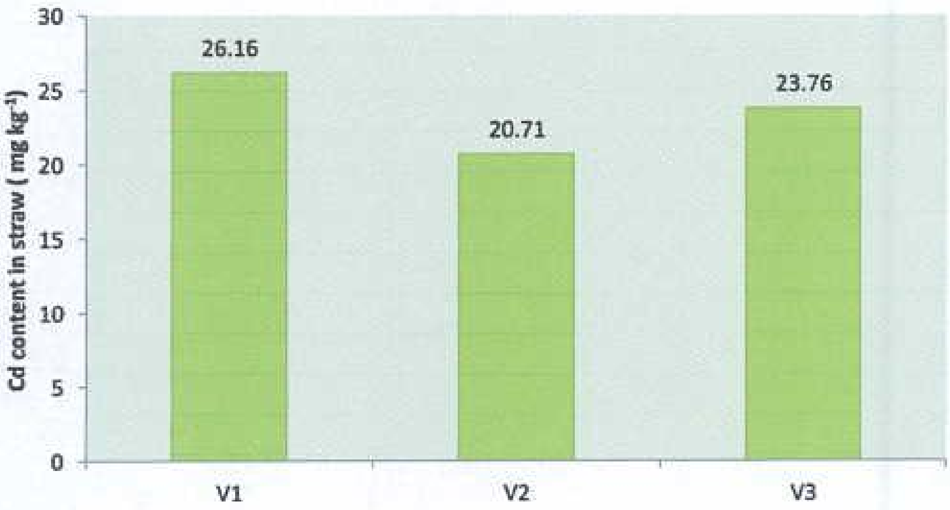
V_1 – BRRI dhan29, V_2 – BRRI dhan60, V_3 – BRRI dhan61

T_0= No cadmium applied, T_1= 20 ppm Cd, T_2= 40 ppm Cd, T_3= 60 ppm Cd, T_4= 80 ppm Cd

* Significant at 5% level

4.13.11 Cadmium content in straw

Cd content in straw showed statistically significant difference due to the varieties (Figure 17 and appendix IX). Numerically the highest Cd content (26.16 mg kg^{-1}) was observed in straw from the variety BRRI dhan29 (V_1) and the lowest amount of Cd (20.71 mg kg^{-1}) was found from the variety BRRI dhan60 (V_2) in straw. It has been shown that Cd is strongly phytotoxic and causes growth inhibition and even plant death (Sanita di Toppi & Gabrielli, 1999). In general, Cd in plants reduces the growth both in roots and stems. This effect is partly due to the suppression of the elongation growth rate of cells, especially in the stem, because of an irreversible inhibition exerted by Cd on the proton pump responsible for the process (Aidid & Okamoto, 1992). Liu *et al.* (2007) conducted the same experiment using six rice cultivars with 100 mg/kg soil Cd and concluded that toxicity effect of Cd on plant height is varietal dependent; the present study also proved this result. Further, Shao Guo-sheng *et al.* (2007) did a hydroponic study to investigate Cd accumulation and its toxicity in rice on the Brittle Culm1 (bc1) gene-a fragile rice mutant and its wild type with 0, 0.1, 1.0 and 5.0 µmol/L Cd levels and they concluded that both rice genotypes substantially inhibited the plant growth under high Cd levels (at 1.0 and 5.0 µmol/L Cd levels).



V_1 – BRRI dhan29, V_2 – BRRI dhan60, V_3 – BRRI dhan61

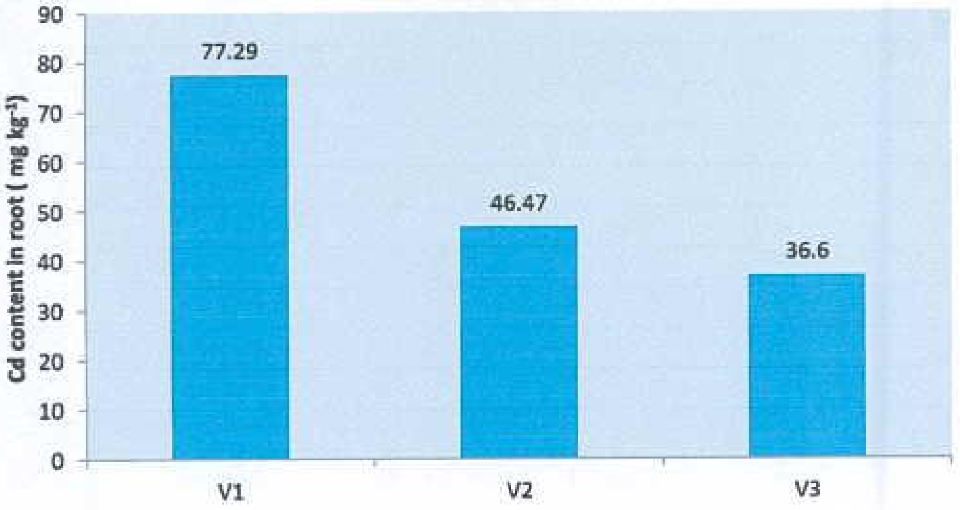
Figure 17. Effect of variety on cadmium content in straw

It was observed from the results presented in Table 22 and Appendix X that, different doses of cadmium had significant influence on Cd content in straw. The highest Cd content (34.49 mg kg^{-1}) in straw was observed from T_4 treatment while T_0 gave the lowest result (3.808 mg kg^{-1}).

Cd content in straw varied significantly due to the interaction effect of variety and different cadmium doses and (Table 23). The highest Cd content in straw (39.17 mg kg^{-1}) was observed from V_1T_4, while the lowest result (2.980 mg kg^{-1}) was recorded from V_3T_0 which was statistically similar with V_2T_0 (4.083 mg kg^{-1}) and V_1T_0 (4.360 mg kg^{-1}). These decreases might be attributed to its effects on cell division and/or cell expansion, and may be through its effect on DNA and RNA synthesis; consequently, any change in the growth which results from increasing Cd supply must be dependent on the change in the rate of net photosynthesis that reduces the supply of carbohydrates or proteins and consequently decreases the growth of plant. These results are in agreement with Liu *et al.* (2008) and Wilson (1992) stated the yield reductions in mustard plants have been attributed to the direct effect of higher Cd concentrations in plant tissue and not through an indirectly induced deficiency of other nutrients. Also, Skorzynska and Baszynski (1995) who worked on bean plant pointed out that, the application of Cd resulted in reduction of photosynthesis efficiency and transpiration.

4.13.12 Cadmium content in root

Cd content in root showed statistically significant difference due to the varieties (Figure 18 and appendix IX). Numerically the highest Cd content (77.29 mg kg^{-1}) was observed in root from the variety BRRI dhan29 (V_1) and the lowest amount of Cd (36.60 mg kg^{-1}) was found from the variety BRRI dhan61 (V_3).



V_1 – BRRI dhan29, V_2 – BRRI dhan60, V_3 – BRRI dhan61

Figure 18. Effect of variety on cadmium content in root

It was observed from the results presented in Table 22 that, different doses of cadmium have significant influence on Cd content in root. The highest Cd content (108.9 mg kg^{-1}) in root was observed from T_4 treatment while T_0 gave the lowest result (5.332 mg kg^{-1}). Results of the study of Herath *et al.* (2014) also revealed significant root dry weight reduction in Cd treated plant.

Cd content in straw varied significantly due to the interaction effect of variety and different cadmium doses and (Table 23). The highest Cd content in root (161.1 mg kg^{-1}) was observed from V_1T_4, while the lowest result (4.050 mg kg^{-1}) was recorded from V_1T_4 which was statistically similar with V_2T_0 (5.020 mg kg^{-1}).

Chapter V

Summary and Conclusion

CHAPTER 5

SUMMARY AND CONCLUSION

The experiment was conducted in the net house of the Department of Agricultural Chemistry of Sher-e-Bangla Agricultural University (SAU), Dhaka-1207 during the period from November, 2015 to May, 2016 to find out the effect of cadmium on growth, yield and nutrients content of three different boro rice varieties (BRRI dhan29, BRRI dhan60 and BRRI dhan61). The two factorial experiment was laid out in a RCBD design with three replications. Factor A: three rice varieties [V_1-BRRI dhan29, V_2-BRRI dhan60, V_3-BRRI dhan61], and factor B: different cadmium doses [T_0 = (No cadmium applied), T_1 = 20 ppm Cd, T_2 = 40 ppm Cd, T_3=60 ppm Cd, T_4=80 ppm Cd]. Different growth and yield parameters varied significantly due to varietal difference. At 45 DAT, the variety BRRI dhan29 produced the tallest plant (38.27 cm) and the variety BRRI dhan61 gave the shortest plant (35.59 cm). At 75 DAT, BRRI Dhan61 gave highest plant height (76.87 cm) and BRRI dhan29 gave the lowest plant height (64.15). At the time of harvesting, BRRI dhan60 gave highest plant height (84.73 cm) and BRRI dhan29 gave the lowest plant height (78.46 cm). At the time of harvesting, the variety BRRI dhan29 produced the highest number of tillers $hill^{-1}$ (27.27) and the variety BRRI dhan60 gave the lowest number of tillers $hill^{-1}$ (23.87) though initially at 45 DAT comparatively BRRI dhan60 gave better results. But in 75 DAT, BRRI dhan61 gave better result (12.93) than BRRI dhan29 (12.47) and BRRI dhan29 (12). Number of leaves $hill^{-1}$ of boro rice showed statistically significant variation among the three varieties. But numerically maximum number of leaves $hill^{-1}$ at 45 and 75 DAT was observed in the V_2 (BRRI dhan60). BRRI dhan29 produced the longest panicle, highest number of filled grains $panicle^{-1}$, highest dry grain yield. The variety BRRI dhan60 gave the highest 1000-grain weight and the variety BRRI dhan61 produced the highest number of effective tiller, highest dry straw yield and highest dry root yield. K, Na and Ca content in grain showed statistically non-significant difference due to the varietal effect. Different doses of cadmium had significant effect on growth and yield of rice. At 45 and 75 DAT and at the time of harvesting, the highest plant height was observed from the T_0 treatment while the lowest was observed from T_4 treatment. At 45 and 75 DAT and at the time of harvesting, the highest number of tillers $hill^{-1}$ was observed from the T_0 treatment and the lowest was observed from T_4 treatment. At 45 and 75 DAT, the highest number of leaves $hill^{-1}$ was observed from the T_0 treatment and the lowest results were obtained from T_4 treatment. The highest number of effective tillers $hill^{-1}$, longest panicle, highest number of filled grains $panicle^{-1}$, highest 1000-grain weight, highest dry grain yield, highest dry straw yield was observed from the T_0 treatment in most of the cases and the lowest was observed from T_4. The highest Na content in grain was observed from T_0 and the lowest from T_4. The highest K content in grain, straw and root was observed from T_0 treatment while T_4 gave the lowest result. At 45 DAT, the highest plant height was observed from the V_1T_0 treatment while at 75 DAT and at the time of harvesting; V_2T_0 showed better results. Whereas, at 45 DAT, the lowest plant height was observed from V_2T_4 treatment and at 75 DAT and at the time of harvesting, the lowest was observed from V_1T_4. At 45 DAT and 75 DAT, the highest number of tillers hill^{-1} was observed from the V_3T_0 treatment while at and at the time of harvesting; V_1T_0 showed significantly better results. At 45 and 75 DAT, the highest number of leaves hill^{-1} were observed from the V_3T_0 treatment, while the lowest were observed from V_1T_4 at 45 DAT and V_2T_4 at 75 DAT. The longest panicle, highest number of filled grains panicle^{-1}, highest dry grain yield and highest dry root yield were observed from V_1T_0, the highest number of effective tillers hill^{-1}, highest dry straw yield were found from V_3T_0, the highest 1000-grain weight was observed from the V_2T_0 treatment whereas, the lowest was observed from V_1T_4, V_2T_4 or V_3T_4 treatment. The highest K content in grain was observed from V_2T_0 which is statistically similar with V_2T_1, V_2T_2 and V_3T_0 while the lowest result was recorded from V_3T_4. The highest K content in straw was observed from V_3T_0 while the lowest result was recorded from V_1T_4. The highest Na content in grain and straw was observed from V_3T_0 but the highest Na content in root was from V_2T_0 while the lowest result was recorded from V_3T_4 and V_1T_4. The Ca content in grain varied insignificantly due to the interaction of variety and cadmium doses. But in straw and root, the highest results were obtained from V_3T_0 and V_2T_0 while the lowest result was found from V_3T_4 treatment. Cadmium concentration in grains of different boro rice varieties was significantly increased due to application of different levels of Cd in soil. The highest Cd content in grain was observed in BRRI dhan60 and the lowest was found in BRRI dhan29. The highest Cd content in straw was observed in BRRI dhan29 and the lowest was found in BRRI dhan60.The highest Cd content in root was observed in BRRI dhan29 and the lowest was found in BRRI dhan61. Cd content in grain, straw and root significantly increased with the increasing application of cadmium. Thus, in most cases the highest cadmium content in grain, straw and root was found from V_1T_0, V_2T_0 or V_3T_0 and the least result was found from V_1T_4, V_2T_4 or V_3T_4 treatment combinations.

From the above results, it can be concluded that,

- BRRI dhan29 has better yield potential than BRRI dhan60 and BRRI dhan61 in Boro season.
- BRRI dhan29 has comparatively lower cadmium accumulation in grain but BRRI dhan60 and BRRI dhan61 has lower cadmium accumulation in straw and root.
- Cadmium contamination increased the Cd concentration in grain but reduced the concentration of K, Na, Ca. Thus, Cd contamination reduced grain yield and nutritional quality of grains.

References

REFERENCES

Adriano, D. C., Bolan, N. S., Vangronsveld, J. and Wenzel, W. W. (2005). Heavy metals. *Encyclopedia of Soils in the Environment.* pp. 175-182.

Afshar, R. M., Ghazaei. S. and Saad, E. (2000). Determination of cadmium in Amol and Thailand rice, 4th international Iranian Congress on poisoning, Tehran, Iran.

Aidid, S. B. and Okamoto, H. (1992). Effect of lead, cadmium and Zinc on the electric membrane potential at the xylem/symplast interface and cell elongation of *Impatiens balsamina*. *Environ. Exp. Bot*. **32**: 439 - 448.

Ahmed, Q. N. (2006). Influence of different cultivation methods on growth and yield of hybrid and inbred rice. M.S. Thesis. Dept. of Agronomy, Sher-e-Bangla Agricultural University, Dhaka.

Akbar, M. K. (2004). Response of hybrid and inbred rice varieties to different seedlings ages under system of rice intensification in transplant aman season. M. S. (Ag.) Thesis. Dept. Agron. BAU, Mymensingh.

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.* (IJAAR). **2**(12): 10-15.

Alloway, B. J. (1995). Cadmium. In Heavy Metals in Soils (2nd edn.). (ed. B.J. Alloway). London: Blackie Academic and Professional. pp. 368.

Alloway, B. J., Thornton, I., Smart, G. A., Sherlock, J. C. and Quinon, M. J.(1988). Metal availability. *Sci. of Total Environ.***75**:41-69.

Analytik Jena AG. (2017). Überlingen, Askaniaweg, 488662, Überlingen/Germany.

Angelova, I. and Atanassov, V. I. (2009). Deposition of Pb, Zn, Cd and Cu in the soil of the smelter's area near Plovdiv. *Sci. Works Higher Inst. Agri*. **38**: 99-102 (BG).

Arao, T.andAe, N. (2003). Genotypic variations in cadmium levels of rice grain. *Soil Sci. and Plant Nutri.* **49**:473-479.

Arao, T., Kawasaki, A., Baba, K., Mori. S. and Matsumoto, S. (2009). Effects of water management on cadmium and arsenic accumulation and dimethylarsenic acid concentrations in Japanese rice. *Environ. Sci. Technol.***43**(24): 9361–9367.

Arao, T. A., Kawasaki, A., Baba, K., Shinsuke, M. A.and Shingo, M. (2010). Effects of water management on Cd and As content in rice grain. 19th World Congress of Soil Science, Soil Solutions for a Changing.

Ashrafuzzaman, M. (2006). Influence of tiller separation days on yield and yield attributes of inbred and hybrid rice. M.S. Thesis. Dept. of Agronomy, Sher-e-Bangla Agricultural University, Dhaka.

Ashrafuzzaman, M., Islam, M. R., Ismail, M. R., Shahidullah, S. M. and Hanafi, M. M. (2009). Evaluation of six aromatic rice varieties for yield and yield contributing characters. *Int. J. Agric. Biol.*11: 616–620.

Bakhtiarian, A., Gholipour, A.and Ghazi-Lhansari, M. (2001). Lead and cadmium content of Korbal rice in Northern Iran. *Iranian J. Public Health.* **30**: 129-132.

Bangladesh Rice Knowledge Bank, Bangladesh Rice Research Institute, Joydevpur, Gazipur. 2017.

BBS (Bangladesh Bureau of Statistics). (2015). The statistical Yearbook of Bangladesh. Bangladesh Bureau of Statistics, Ministry of planning. Dhaka, Bangladesh.

BBS (Bangladesh Bureau of Statistics). (2016). Statistical Year Book of Bangladesh, Statistics Division, Ministry of Planning, Government of the People's Republic of Bangladesh, Dhaka.

Bhattacharya, A., Routh, J., Jacks, G., Bhattacharya, P. and Mörth, M., (2006). Environmental assessment of abandoned mine tailings in Adak, Västerbotten district (northern Sweden). *Appl. Geochem.* **21**: 1760– 1780

Bhuiya, A. K. M. A. (2000). Effect of variety and spacing on the performance of transplant aman rice. M.S. Thesis. Agronomy Dept. Bangladesh Agril. Univ., Mymensingh. pp. 43-45.

Bhuiyan, N. I., Paul, D. N. R. and Jabber, M. A. (2002). Feeding the Extra Millions. In: Proceedings of the BRRI-DAE Workshop on Experiences of HYV Rice Production in Bangladesh, Bangladesh Rice Research Institute, Gazipur-1701.

BINA (Bangladesh Institute of Nuclear Agriculture). (1993). Annual Report for 1992- 1993. Bangladesh Inst. Nuclear Agric. P.O. Box No. 4. Mymensingh. pp. 52-143.

Bolan, N. S., Adriano, D. C.andNaidu, R. (2003). Role of phosphorus in (im) mobilization and bioavailability of heavy metals in the soil-plant system. *Review Environ. Contamination Toxicol.* **177**:1– 44.

Boominathan, R. and Doran, P. M. (2003). Cadmium tolerance and antioxidative defenses in hairy roots of the cadmium hyperaccumulator Thlaspicaerulescens. *Biotechnol. Bioeng.* **83**: 158 –167.

BRKB. (2017). Bangladesh Rice Knowledge Bank (knowledgebank-brri.org), Bangladesh Rice Res. Inst. Joydehpur, Gazipur, Dhaka.

BRRI (Bangladesh Rice Research Institute). (1985). Annual Report for 1982. BRRI Pub. No.79. Bangladesh Rice Res. Inst. Joydehpur, Gazipur, Dhaka. p. 237.

BRRI (Bangladesh Rice Research Institute). (1991). Annual Report for 1988, Joydehpur, Gazipur. pp. 40-42.

BRRI (Bangladesh Rice Research Institute). (2015). Adhunic Dhaner Chash Pub. No. 5. Bangladesh Rice Res. Inst. Joydebpur, Gazipur. pp. 140-158.

BRRI (Bangladesh Rice Research Institute). (2004). Adhunic Dhaner Chash Pub. No. 5. Bangladesh Rice Res. Inst. Joydebpur, Gazipur. pp. 140-158.

BRRI (Bangladesh Rice Research Institute). (2006). Annual Report for 2004 Joydebpur, Gazipur, Bangladesh. pp.8, 320.

Cataldo, D. A., Garl, T. R. and Wildung, R. E. (1983). Cadmium uptake kinetics in intact soybean plants. *Plant physiol*. **73**: 844 - 848.

Chamely, S. G., Islam, N., Hoshain, S., Rabbani, M. G., Kader, M. A. and Salam, M. A. (2010). Effect of variety and nitrogen rate on the yield performance of boro rice. *Progressive Agric*. **26**(1): 6-14, 2015.

Chamon, A. S., Gerxabek, M. H., Mandol, M. N., Ullah, S. M., Rahman, M. and Blum, W. E. H. (2005). Influence of cereal varieties and site conditions on heavy metal accumulations in cereal crops on polluted soils of Bangladesh. *Commun. in Soil Sci. Plant Analysis*. **36**:889-946.

Chang, T. T. and Vergara, B. S. (1972). Rice Breeding, IRRI, Philippines. p.727.

Cheng-wang, Yao, H. G., Zhang, G. P., Tang, M. L. and Dominy (2005). Effect of cadmium on growth and nutrition metabolism in rice. *Scientia Agricultural Sinica*. **38**: 528-537.

Cook, M. E. and Morrow, H. (1995). Anthropogenic sources of cadmium in Canada. In National Workshop of Cadmium Transpot in to Plants (Centres Canadian Network of Toxicology ed.), Ottawa, Ontario, Canada.

Cui, J., Kusutani A., Toyota, M. and Asanuma, K. (2000). Studies on the varietal differences of harvest index in rice. *Japanese J. Crop Sci*. **69**(3): 357-358.

Das, P., Samantaray, S. and Rout, G. R. (1997). Studies on cadmium toxicity in plants: a review. *Environ. Pollut*. **98**:29-36.

Debnath, A. (2010). Influence of planting material and variety on yield of boro rice. M.S. Thesis. Dept. of Agronomy, Sher-e-Bangla Agricultural University, Dhaka.

Debnath, A., Biswas, P. K., Sardar, M. S. A. and Rahman, A. (2012). Influence of mother and clonal tillers on yield and performance of inbred and hybrid boro rice. *Bangladesh Agron. J.* **15**(1): 1-7.

Del Castilho, P., Chandron, W. J. and Salomons, W.(1993). Influence of cattle manure slurry application on the solubility of cadmium, copper, and zinc in a manured acidic loamy sand soil. *J. Environ. Quality.* **22**: 279–689.

Dixit, M. L. and Gupta, V. K. (1992). Influence of soil applied cadmium on growth and nutrient composition of plant species. *J. Indian Society Soil Sci.* **40: 878-880.**

Dudka, S., Piotrowska, M. and Terelak, H. (1996). Transfer of cadmium, lead and zinc from industrially contaminated soil to crop plants: a field study. *Environ. Pollut.* **94**(2):181-188.

Dunbar, K. R., Mc Laughlin, M. J. and Reid, R. J. (2003). The uptake and partitioning of cadmium in two cultivars of potato (*Solanum tuberosum* L.) *J. Exp. Bot.* **54**:349-354.

Ernst, W. H., Verkleji, J. A. and Schat, H. (1992). Metal tolerance in plants. *Acta. Bot. Neerl.* **41**: 229 - 248.

FAO/WHO. (2002). Codex Alimentarius- General standards for contaminants and toxins in food. Schedule 1 Maximum and Guideline levels for contaminants and toxins in food, Joint FAO/WHO Food Standards Programme, Codex Committee, Rotterdam. Reference CX/FAC 02/16.

FAO. (2012). FAOSTAT statistical database (available at faostat.fao.org).

FAO. (2015). FAOSTAT statistical database (available at faostat.fao.org).

FAOSTAT, Archived July 13, 2011, at the Wayback Machine.. Faostat.fao.org (October 23, 2014). Retrieved on September 4, 2015.

Farooqi, Z. R., Iqbal, M. Z., Kabir, M. and Shafiq M (2009). Toxic effects of lead and cadmium on germination and seedling growth of *Albizia lebbeck* (L.) Benth. *Pak. J. Bot.* **41**(1):27-33.

Fathy, A., Khalafall, A., Fatma, H., Ali, FrediSchwagele, Mariam, A. and Abd-El-Wahab, 2011, Heavy metal residues in beef carcasses in Beni-Seuf abattoir, Egypt, *Veterinaria Italiana*; **47**(3): 351-361.

Fergusson, J. E. (1991). The Heavy Elements: Chemistry, Environmental Impact and Health Effects. Pergamon Press, Oxford-New York-Tokyo- Seoul. 329– 406.

Gallego, S. M., Pena, L. B., Barcia, R. A., Azpilicueta, C. E., Iannone, M. F., Rosales, E. P., Zawoznik, S., Gropppa, M. D. and Benavides, M. P. (2012). Unravelling cadmium toxicity and tolerance in plants: insight into regulatory mechanisms. *Environ. Exp. Bot.* **83**:33-46.

Gill, S. S. and Tuteja, N. (2010). Reactive oxygen species and antioxidant machinery in abiotic stress tolerance in crop plants. *Plant Physiol. Biochem.* **48**: 909– 930.

Gomez, K. A. and Gomez, A. A. (1984). Statistical procedure for agricultural research. Second Edn. *Intl. Rice Res. Inst.*, John Wiley and Sons. New York. pp. 1-340.

Guo-sheng, S., Ming-xue, C., Xiu-fu, Z. (2007). Cadmium Accumulation and Its Toxicity in Brittle culm1 (bc1), A Fragile Rice Mutant. *Rice Sci*. **14**(3): 217 - 222.

Hall, J. L. (2002): Cellular mechanisms for heavy metal detoxification and tolerance. *J. Exp. Bot.* **53**:1-11.

Haque, E., Islam, M. R., Jahiruddin, M., Hossain, M. and Islam, S. (2006). Arsenic, lead and cadmium contamination of vegetables growing soils in Chapai Nawabganj, Bangladesh. *Bangladesh J. Crop Sci.* **17**(2): 281–288.

Hasanuzzaman, M., Nahar, K., Alam, M. M., Hossain, M. Z. and Islam, M. R. (2009). Response of transplanted rice to different application methods of urea fertilizer. *Int. J. Sustainable Agric*. **1**(1): 01-05.

Hassan, M. J., Wang, F., Ali, S. and Zhang, G. P. (2005). Toxic effect of cadmium on rice as affected by nitrogen fertilizer form. *Plant and Soil.* **277**: 359–365.

Hassan, M. J., Wang, F., Ali, S. and Zhang, G. P. (2005a). Sulphur alleviates growth inhibition and oxidative stress caused by cadmium toxicity in rice. *J. plant nutri.***28**: 1785-1800.

Hassan, M. J., Wang, F., Ali S. and Zhang, G. P. (2005b). Toxic effect of cadmium on rice as affected by nitrogen fertilizer form. *Plant and Soil.* **277**: 359–365.

Haynes, J. (2007). The biologically relevant targets and binding affinity requirements for the function of the yeast actin-binding protein 1 Src-homology 3 domain vary with genetic context. *Genetics.* **176**(1):193-208.

He, J. Y., Zhu, C., Ren, Y. F., Yan, Y. P. and Jiang, D. (2006). Genotypic variation in grain cadmium concentration of lowland rice. *J. Plant Nutri. Soil Sci.* **169**:711-716.

Herath, H. M. D. A. K., Bandara, D. C., Weerasinghe, P. A., Iqbaland, M. C. M., Wijayawardhana, H. C. D. (2014). Effect of Cadmium on Growth Parameters and Plant Accumulation in Different Rice (*Oryza sativa* L.) Varieties in Sri Lanka. *Tropic. Agric. Res.* **25**(4): 532 – 542.

Hernandez, L. E., Carpena-Ruiza, R. and Gáratea, A. (1996). Alterations in the mineral nutrition of pea seedlings exposed to cadmium. *J. Plant Nutri.* **19**: 1581–1598.

Herawati, N., Suzuki, S., Hayashi, K., Rivai, I. F. and Koyama, H. (2000). Cadmium copper and zinc levels in rice and soils of Japan, Indonesia, and China by soil type. *Bulletin Environ. Cont. Toxicol.* **64**: 33-39.

HIES (Household Income Expenditure Survey). (2009). Bangladesh Bureau of Statistics, Statistics Division, Ministry of Planning, Government of the People's Republic of Bangladesh, Dhaka.

Holmgren, G. G. S., Meyer, M. W., Chaney, R. L. and Daniel, R. B. (1993). Cadmium, lead, zinc, copper, and nickel in agricultural soils of the United States of America. *J. Environ. Quality.* **22**:335–348.

Honda, R., Swaddiwudhipong, W., Nishijo, M., Mahasakpan, P., Teeyakasem, W., Ruangyuttikarn, W., Satarug, S., Padungtod, C. and Nakagawa, H. (2010). Cadmium induced renaldysfunction among residents of rice farming area downstream from a zinc-mineralizedbelt in Thailand. *Toxicol.* **198**: 26-32.

Hossain, M. B., Islam, M. O. and Hasanuzzaman, M. (2008). Influence of different nitrogen levels on the performance of four aromatic rice varieties. *Int. J. Agric. Biol.,* **10**: 693–696.

Hossain, M. A., Piyatida, P., Jaime, A., Silva, T. D., and Fujita, M. (2012). Molecular Mechanism of Heavy Metal Toxicity and Tolerance in Plants: Central Role of Glutathione in Detoxification of Reactive Oxygen Species and Methylglyoxal and in Heavy Metal Chelation. *J. Bot.* **2012:** p. 37, Article ID 872875.

Hossan, M. D. (2005). Effect of variety and spacing on the growth and yield of transplant Aman rice. M. S. Thesis. Agronomy Dept. Bangladesh Agril. Univ., Mymensingh. pp. 54.

Hu, Y. T. and Kao, C. H. (2003). Changes in protein and amino acid contents in two cultivars of rice seedlings with different apparent tolerance to cadmium. *Plant Growth Regulation.* **40**:147- 155.

Idris, M. and Matin, M. A. (1990). Response of four exotic strains of Aman rice to urea. *Bangladesh J. Agril. Sci.* **17**(2): 271-275.

Islam, M. B., Ali, M. H., Masum, S. M., Hasanuzzaman, M., Rahman, A., Hosain, M. T., Islam, M. S., Chowdhury, M. P. and Khalil, M. I. (2013). Performance of Aman varieties as affected by urea application methods. *App. Sci. Report.* **2**(3): 55-62.

Inahara, M., Ogawa, Y. and Azuma, H. (2007). Effect of alkalinity application on cadmium uptake by lowland rice under different water managements. Japan. *J. Soil Sci. Plant Nutr*. **78**: 253–260.

Jackson, M. L. (1973). Soil chemical analysis. Prentice-Hall of India, Pvt. Ltd. pp. 326-338.

Jesy, A. J. (2007). Effect of variety and spacing on the performance of transplant Aman rice. M.S. Thesis. Agronomy Dept. Bangladesh Agril. Univ., Mymensingh. p. 27.

Jiang, W., D. Liu, and P. Xu, (2009). Cd - induced system of defence in the garlic root meristematic cells. *Biologia Plantarum.* **53**: 369– 372.

Jin, T., Nordberg, M., Frech, W., Dumont, X., Bernard, A., Ye, T. T., Kong, Q., Wang, Z., Li, P., Lundstrom, N. G., Li, Y. and Nordberg, G. F. (2002). Cadmium biomonitoring and renal dysfunction among a population environmentally exposed to cadmium from smelting in China. *Bio-Metals.* **15**: 397– 410.

Kabir, M. H., Sarkar, M. A. R. and Chowdhury, A. K. M. S. H. (2009). Effect of urea super granules, prilled urea and poultry manure on the yield of transplant *Aman* rice varieties. *J. Bangladesh Agril. Univ.*7(2): 259–263.

Kahle, H., (1993). Response of roots trees to heavy metals. *Environ. Exp. Bot.*, 33: 99 - 119.

Kamal, A. M. A., Azam, M. A. and Islam, M. A. (1988). Effect of cultivars and NPK combination on the yield contributing characters of rice. *Bangladesh J. Agril. Sci.* **15**(1): 105-110.

Kikuchi, T., Okazaki, M., Kimura, S. D., Motobayashi, T., Baasansuren, J., Hattori, T. and Abe, T. (2008). Suppressive effects of magnesium oxide materials on cadmium uptake and accumulation into rice grains: II: Suppression of cadmium uptake and accumulation into rice grains due to application of magnesium oxide materials. *J. Hazardous Materials.* **154**: 294–299.

Kranner, I. and Colville, L. (2011). Metals and seeds: biochemical and molecular implications and their significance for seed germination. *Environ. Exp. Bot.* **72**(1):93-105.

Kumpiene, J., Lagerkvist, A. and Maurice, C. (2007). Stabilization of Pb- and Cu-contaminated soil using coal fly ash and peat. *Environ. Pollut.* **145**: 365-373.

Kyuma, K. (2004). Soils polluted with hazardous elements. In Paddy Soil Science. Kyoto University Press: Kyoto, Japan. pp. 241-254.

Lee, K., Bae, D. W., Kim, S. H., Han, H. J., Liu, X., Park, H. C., Lim, C. O., Lee, S. Y. and Chung, W. S. (2010). Comparative proteomic analysis of the short-term responses of rice roots and leaves to cadmium. *J. Plant Physiol.* **167**: 161–168.

Leenakumari, S., Mahadevappa, M., Vidyachandra, B. B. and Krishnamurthy, R. A. (1993). Performance of experimental rice hybrids in Bangalore, Karnataka, India. *Intl. Rice Res. Notes.* **18**(1): 16.

Li, R. Y., Stroud, J. L., Ma, J. F., McGrath, S. P. and Zhao, F. J. (2009). Mitigation of arsenic accumulation in rice with water management and silicon fertilization. *Environ. Sci. Technol.* **43**:3778–3783.

Li, S., Liu, R., Wang, H. and Shan, H. (1997). Accumulations of cadmium, zinc, and copper by rice plants grown on soils amended with composted pig manure. *Commun. Soil Sci. and Plant Analysis.* **40**:1889–1905.

Liu, D., I. Kottke, and D. Adam, (2007). Localization of cadmium in the root cells of *Allium cepa* by energy dispersive X-ray analysis. *Biologia Plantarum.* **51**(2): 363 –366.

Liu, D., Zou, J., Wang, M. and Jiang, W. (2008). Hexavalent chromium uptake and its effects on mineral uptake, antioxidant defence system and photosynthesis in Amaranthusviridis L. *Bioresource Technol.* **99**: 2628– 2636.

Liu, D., Xu, P., Meng, Q., ZouGu, J. J. and Jiang, W. (2009). Pb/Cu effects on the organization of microtubule cytoskeleton in interphase and mitotic cells of *Allium sativum* L. *Plant Cell Reports.* **28**: 695 –702.

Liu, J., Zhu, Q., Zhang, Z., Jiakuan, Xu, Yang, J. and Wong, M. H. (2005). Variations in cadmium accumulation among rice cultivars and types and the selection of cultivars for reducing cadmium in the diet. *J. Sci. Food Agric.* **85**:147–153.

Liu, J. G., Qian, M., Cai, G. L., Yang, J. C. and Zhu, Q. S. (2007). Uptake and translocation of Cd in different rice cultivars and the relation with Cd accumulation in rice grain. *J. Hazardous Materials.* **143**:443-447.

Liu, D., Jiang, W. and Gao, X. (2004). Effects of cadmium on root growth, cell division and nucleoli in root tips of garlic, *Physiologia Plantarum*, **47**: 79 -83.

Lockard, R. G. (1958). The effect of depth and movement of water on the growth and yield of rice plants. *Malayan Agric. J.* **41**:266-281.

Lu, R. K., Xiong, L. M. and Shi, Z. Y. (1992). A review about studies on cadmium in soil-crop ecosystem. *Soils.***24**: 129–132.

Mahato, S. K., Poddar, K. K., Roni, M. Z. K., Biswas, P. K. and Jamal Uddin, A. F. M. (2014). Allelopathic effect of different plant residues on growth and yield of three aman rice varieties. *Bangladesh Res. Pub. J.* **10**(3): 270-274.

Main, M. A. (2006). Influence of planting material and planting methods on yield and yield attributes of inbred and hybrid rice. M.S. Thesis. Dept. of Agronomy, Sher-e-Bangla Agricultural University, Dhaka.

Main, M. A., Biswas, P. K. and Ali, M. H. (2007). Influence of planting material and planting methods on yield and yield attributes of inbred and hybrid rice. *J. Sher-e-Bangla Agric. Univ.* **1**(1): 72-79.

Matusik, J., Bajda, T.and Manecki, M. (2008). Immobilization of aqueous cadmium by addition of phosphates. *J. of Hazard. Mat.***152**: 1332–1339.

McGrath, S. P., Meharg, A. A.and Zhao, F. J. (2008). Growing Rice Aerobically Markedly Decreases Arsenic Accumulation. *Environ. Sci. and Technol.* **42** (15): 5574–5579.

McLaughlin, M. J. and Singh, B. R. (1999). Cadmium in soil and plants: a global perspective. In: 'Cadmium in soils and plants'. (Eds MJ McLaughlin, BR Singh). pp. 13-21. (The Netherlands: Kluwer Academic Publishing).

Meharg, A. A., Norton, G., Deacon, C., Williams, P., Adomako, E. E., Price, A., Zhu, Y., Li, G., McGrath, S., Villada, A., Sommella, A., Mangala, P., Silva, C. S. D., Brammer, H., Dasgupta, T. and Islam, M. R. (2013). Variation in rice cadmium related to human exposure. *Environ. Sci. Technol.* **47**: 5613–5618.

Mench, M., Vangronsveld, J., Lepp, N.and Edwards, R. (1998). Physicochemical aspects and efficiency of trace element immobilisation by soil amendments. In: J Vangronsfield & S Cunningham (Editors), *In-situ Inactivation and Phytorestoration Metal Contaminated Soils*. Mortwedt JJ.

Miah, M. A. B., Alam, M. M., Hossain, M. Z. and Islam, M. R. (1993). Morpho-physiological Studies of Some Rice Cultivars. MS in Crop Botany. Department of Crop Botany. Bangladesh Agricultural University. Mymensingh, Bangladesh: p. 111.

Mico, C., Peris, M., Recatala, L. and Sanchez, J. (2007). Baseline values for heavy metal in agricultural soils in a European Mediterranean region. *Sci. Total Environ.* **378**:13-17.

Miller, T. L. (1978). Rice performance trails, sixteen varieties tested at Datta Branch Station. *MAFFS Res. Highlight.* **41**(2): 6.

MoFDM (Ministry of Food and Disaster Management). (2012). Monitoring Report of the National Food Policy Plan of Action and Country Investment Plan, FPMU, Food Division, MoFDM, Khadday Bhaban, Dhaka.

Moradi, A., Abbaspour, K. C.and Afyuni, M. (2005).Modeling field-scale cadmium transport below the root zone of sewage sludge amended soil in an arid region in Central Iran. *J. Cont. Hydrol.***79**: 187–206.

Morales, S. G., Trejo-Téllez, L. I., Merino, F. C. G., Caldana, C., Espinosa-Victoria, D. and Cabrera, B. E. H. (2012). Growth, photosynthetic activity, and potassium and sodium concentration in rice plants under salt stress. *Acta Sci., Agron.* **34**(3).

Nahar, K., Zaman, M. H. and Majumder, R. R. (2009). Effect of low temperature stress transplanted Aman rice varieties mediated by different transplanting dates. *Aca. J. plant Sci.* **2**(3):132-138.

Naidu, R., Bolan, N. S., Kookana, R. S.and Tiller, K. G. (1994). Ionic-strength and pH effects on the adsorption of cadmium and the surface charge of soils. *European J. Soil Sci.* **45**:419-429.

Nakashima, K., Kobayashi, E., Nogawa, K., Kido, T. and Honda, R. (1997). Concentration of cadmium in rice and urinary indicators of renal dysfunction. *Occup. and Environ. Med.* **54**: 750-755.

Naser, S., Mohammad, H., Rebeca, G. and Shamsun, N. (2012). Heavy metal pollution of soil and vegetable grown roadside at Gazipur. *Bangladesh J. Agric. Res.* **37**: 9-17.

Navarro, Silvera, S. A. and Rohan, T. E. (2007). Trace elements and cancer risk: a review of the epidemiologic evidence. *Cancer Causes Control.***18** (1): 7-27.

Nigam, R., Srivastava, S., Prakash, S. and Srivastava, M. M. (2001). Cadmium mobilization and plant availability-the impact of organic acids commonly exuded from roots. *Plant and Soil.* **230**: 107–113.

Nordberg, G. F., Nogawa, K., Nordberg, M.and Friedmann, J. M. Cadmium. In: Nordberg GF, Fowler BA, Nordberg M, Friberg L, editors. Handbook on the Toxicology of Metals. Amsterdam: Elsevier; 2007. pp. 445–486.

Obaidullah, M. (2007). Influence of clonal tiller age on growth and yield of aman rice varieties. M.S. Thesis. Dept. of Agronomy, Sher-e-Bangla Agricultural University, Dhaka

OECD workshop on sources of cadmium in the environment. Summary of Proceedings. Saltsjöbaden, Sweden, 16-20 October 1995.

Om, H., Katal, S. K., Dhiman, S. D. and Sheoran, O. P. (1999). Physiological parameters and grain yield as influence by time of transplanting and rice (*Oryza sativa*) hybrids. *Indian J. Agron.* **44** (4): 696-700.

Osborn, G. (1982). Studies on the chemical form of cadmium contaminants in phosphate fertilizers. *Soil Sci.***13**: 185-192.

Pál, M. E., Horvá, T., Janda, E., Páldi and Szalai, C. (2006). Physiological changes and defense mechanisms induced by cadmium stress in maize. *J. Plant Nutri. Soil Sci.* **169**:239-246.

Pal, N. C., Sarkar, M. A. R., Hossain, M. Z. and Barman, S. C. (2008). Root growth of four transplant Aman rice varieties as influenced by NPKS fertilizer. *J. Bangladesh Agril. Univ.* **6**(2): 235–238.

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

Pearson, C. and Kirkham, K. (1981). Water relation of wheat cultivars grown with cadmium. *J. Pl. Nutr.* **3**: 309 –318.

Pichtel, J. and Bradway, D. J. (2008). Conventional crops and organic amendments for Pb, Cd and Zn treatment at a severely contaminated site. *Bioresource Technol.***99**: 1242–1251.

Popova, L. P., Maslenkova, L. T., Yordanova, R. Y., Ivanova, A. P., Krantev, A. P., Szalai, G. and Janda, T. (2009). Exogenous treatment with salicylic acid attenuates cadmium toxicity in pea seedlings. *Plant Physiol. Biochem.***47**: 224–231.

Prasad, M. N. V. 1995. Cadmium toxicity and tolerance in vascular plants. *Environ. Exp. Bot.* **35**: 525-545.

Refey, A., Khan P. A. and Srivastava, V. C. (1989). Effect of nitrogen on growth, yield and nutrition uptake of upland rice. *Indian J. Agron.* **34**(2): 133-135.

Riffaldi, R., Levi-Minzi, R., Saviozzi, A. and Tropea, M. (1983): Sorption and release of cadmium by some sewage sludges. *J. Environ. Quality.***12**: 253–256.

Rodda, (2011). Time of Cd uptake from the root to the grain in rice. *J. Environ. Biol.***19**:43-47.

Romkens, P. F. A. M., Guo, H. Y., Chu, C. L., Liu, T. S., Chiang, C. F. and Koopmans, G. F.(2009). Prediction of cadmium uptake by brown rice and derivation of soil–plant transfer models to improve soil protection guidelines. *Environ. Pollut.* **157**: 2435–2444.

Roy, S. K., Ali, M. Y., Jahan, M. S., Saha, U. K., Ahmad-Hamdani, M. S., Hasan, M. M. and Alam, M. A. (2014). Evaluation of growth and yield attributing characteristics of indigenous Boro rice varieties. *Life Sci J.* **11**(4):122-126.

Russel, D. F. (1986). MSTAT-C Package Programme. Dept. of Crop and Soil Science, Michigan State University, USA.

Salt, D., Price, R., Pickering I. and Raskin, I. (1995). Mechanisms of cadmium mobility and accumulation in Indian mustard. *Plant Physiol.***109**: 1427 –1433.

Sanita di Toppi L. and Gabbarielli, R. (1999). Response to cadmium in higher plants. *Environ. Exp. Bot.***41**:105-130.

Sarkunan, V., Misra, A. K., Mohapatra, A. R. (1995). Effect of Cadmium on Yield and Uptake of Cadmium by Different Rice Varieties. *J. Indian Soc. Soil Sci.* **43**(2): 298-300.

Satarug, S., Baker, J. R., Urbenjapol, S., Haswell-Elkins, M., Reilly, P. E. B., Williams, D. J. (2003). A global perspective on cadmium pollution and toxicity in non-occupationally exposed population. *Toxicology.***137**: 65-83.

Sauve, S., Norvell, W. A., McBride, M. and Hendershot, W. (2000). Speciation and complexation of cadmium in extracted soil solutions. *Environ. Sci. Technol.* **34**: 291–296.

SCHER (Scientific Committee on Health and Environmental Risks) (2006). Risk to the environment and human health resulting from the use of phosphate fertilizers containing cadmium. Report 285-Czech Republic.

Seth, C. S., Misra, V., Chauhan, L. K. S.and Singh, R. R. (2008). Genotoxicity of cadmium on root meristem cells of *Allium cepa*: cytogenetic and Comet assay approach. *Ecotoxicol. Environ. Safety.***71**:711–716.

Shahjahan, M. (2007). Modern rice in Asia: Role in food security and poverty alleviation. Financial Express.

Shamsuddin, A. M., Islam, M. A. and Hossain, A. (1988). Comparative study on the yield and agronomie characters of nine cultivars of Aus rice. *Bangladesh J. Agril. Sci.***15**(1): 121-124.

Shi-Jing, Li-ZhengWen, Li-LianQing, Pan-GenXing. (2007) Uptake and distribution of Cd and Zn by pakchoi in different growth stages in two paddy soils under Cd treatment. *J. Ecol. Rural Environ.* **23** (4): 57-62.

Simmons, R. W., Pongsakul, P., Saiyasitpanich, D. and Klinphoklap, S. (2005). Elevated levels of cadmium and zinc in paddy soils and elevated levels of cadmium in rice grain downstream of a zinc mineralized area in Thailand: Implications for public health. *Environ. Geochem. and Health.* **27**: 501-511.

Singh, N., Sekhon, K. S. and Kaur, A. (1990). Effect of pre-harvest flooding of paddy on the milling and cooking quality of rice. *J. of the Sci. of Food and Agric.* **52**:23 - 34.

Skorzynska, E. and Baszynski, T. (1995). Some aspects of rammer bean plant response to cadmium at different stages of the primary leaf growth. *Acta. Soc. Bot. Polon.*, **64**: 165 -170.

Streppler, M. (1991). Cadmium, In:Merian, E. (Ed.). Metals and their compounds in the environment, VCH, Weinneim. pp. 803.

Sultana, M. (2008). Effect of variety, method of planting and weeding on the yield and yield components of transplant *Aus* rice. M.S. Thesis. Agronomy Dept. Bangladesh Agril. Univ., Mymensingh. p. 28.

Sultana, T. (2000). Effect of intensive fertilizer on heavy metal concentration in soils and plants. M.S. Thesis, Department of Soil Science. BAU, Mymensingh.

Tac, T. H., Hirano, M., Iwamoto, S., Kuroda, E. and Murata, T. (1998). Effect on topdressing and planting density on the number of spikelets and yield of rice cultivated with nitrogen-free basal dressing. *Plant Prod. Sci.* **1**(3): 191-198.

Takita, T. (2009). Yield and canopy structure of a super high yielding rice variety recently developed. Nogyo Gijutsu. **64**: 136-139.

Thornton. I. (1992). Source and pathways of cadmium in the environment. In: Nordberg, G. F., Herber, R. F. M., and Alessio. L. (Eds). Cadmium in the human environment. Toxicity and Carcinogenicity. International Agency for Research on Cancer, Lyon. IARC, Scientific Publications No. 118, p.149.

Tsukahara, T., Ezeki, T., Moriguchi, J., Furuki, K., Shimbo, S. and Matsuda-Inoguchi, N. (2003). Rice as the most influential source of cadmium intake among general Japanese population. *Sci. Total Environ.* **305**: 41-51.

Tyeb, A., Paul, S. K. and Samad, M. A. (2013). Performance of variety and spacing on the yield and yield contributing characters of transplanted *Aman* rice. *J. Agron. Environ.* 7(1): 57-60.

Unwin, R. J. (1999). Policy aspects of heavy metals in the environment. Pflanzenbelastung-uf-kontaminierten-Standorten:-plant-impact-at-contaminated-sites nternationaler Workshop-am-1-und-2-Dezember-1997-am-Fraunhofer-Institut-fur-weltchemie-und-Okotoxikologie,-Schmallenberg. pp.103-113.

Veselov, D., Kudoyarova, G., Symonyan, M. and Veselov, S. (2003). Effect of Cadmium on Ion Uptake, Transpirationand Cytokinin Content in Wheat Seedlings. Bulg. *J. Plant Physiol.*, Special Issue. pp.353–359.

Vijayarengan, P. (2012). Changes in growth and biochemical constituents in rice (Oryza sativa L.) under cadmium stress. *Intl. J. Res. Bot.* **2**(4): 27-33.

Wagner, G. (1993). Accumulation of cadmium in crop plants and its consequences to human health. In: DL Sparks (Editors). *Advances in Agron.* Newark, USA: Academic Press. pp. 173–212.

Wang, M. Y., Chen, A. K., Wong, M. H., Qiu, R. L.and Cheng, H. (2011). Cadmium accumulation in and tolerance of rice (*Oryza sativa* L.) varieties with different rates of radial oxygen loss. *Environ. Pollut.* **159**: 1730-1736.

Watanabe, R. (2000). Initial enzyme for glycosylphosphatidylinositol biosynthesis requires PIG-P and is regulated by DPM2. *EMBO J.***19** (16):4402-11.

Watanabe, T., Shimbo, S., Moon, C. S., Zhang, Z. W.and Ikeda, M. (1996). Cadmium contents in rice samples from various areas in the world. *Sci. Total Environ.* **184**:191-19.

WenXiong, L., Yiyuan, L. and TingChat, W. (1996). The heterotic effects on dry matter production and grain yield formation in hybrid rice. *J. Fujian Agric. Uni.***25**(23): 260-265.

WHO. (1992a). Cadmium. Environmental Health Criteria 134. World Health Organisation, International Programme on Chemical Safety (IPCS), Geneva, Switzerland.

WHO. (1992b). Cadmium, WHO Geneva. International programme on chemical safety (IPCS). Environmental Health Criteria p.135.

Williams, P. N., Lei, M., Sun, G. X., Huang, Q., Lu, Y., Deacon, C., Meharg, A. A and Zhsu, Y. G. (2009). Occurrence and partitioning of cadmium, arsenic and lead in mine impacted paddy rice in Hunan, China. *Sci. Total Environ.* **43**: 637-642.

Wolnik, K. A., Fricke, F. L., Capar, S. G., Braude, G. L., Meyer, M. W., Satzger, R. D. and Bonnin, E. (1983). Elements in major raw agricultural crops in the United States. 1.

Cadmium and lead in lettuce, peanuts, potatoes, soybeans, sweet corn and wheat. *J Agric. Food Chem.* **31**:1240–1244.

Wilson, N. J. (1992). Accumulation of cadmium in crop plants and its consequences to human health. *Agron.* **51**: 173-212.

Yadav, S. K. (2010). Heavy metals toxicity in plants: An overview on the role of glutathione and phytochelatins in heavy metal stress tolerance of plants. *South African J. Bot.* **76**:167–179.

Yamagata, N. and Shigematsu, I (1970). Cadmium pollution in perspective. *Bull Inst. Pub. Heal*, **19**: 1–27.

Yi-Chu Chang, Yun-Yang Chao, Ching HK 2012: The Role of Iron in stress response to cadmium in rice seedlings. *Crop, Environ. and Bioinfor.* **8**: 175-183.

Zhang, C. H. and Ge, Y. (2008). Response of glutathione and glutathiones-transferase in rice seedlings exposed to cadmium stress. *Rice Sci.***15**: 73–76.

Zhang, J. B. and Huang, W. N. (2000). Advances on physiological and ecological effects of cadmium on plants. Chinese. *Acta Ecologica Sinica.***20**: 514–523.

Zhou, Q., Wang, X., Liang, R. and Wu, Y. (2003). Effects of cadmium and mixed heavy metals on rice growth in Liaoning. *China Soil and Sediment Contamination.***12**:851-864.

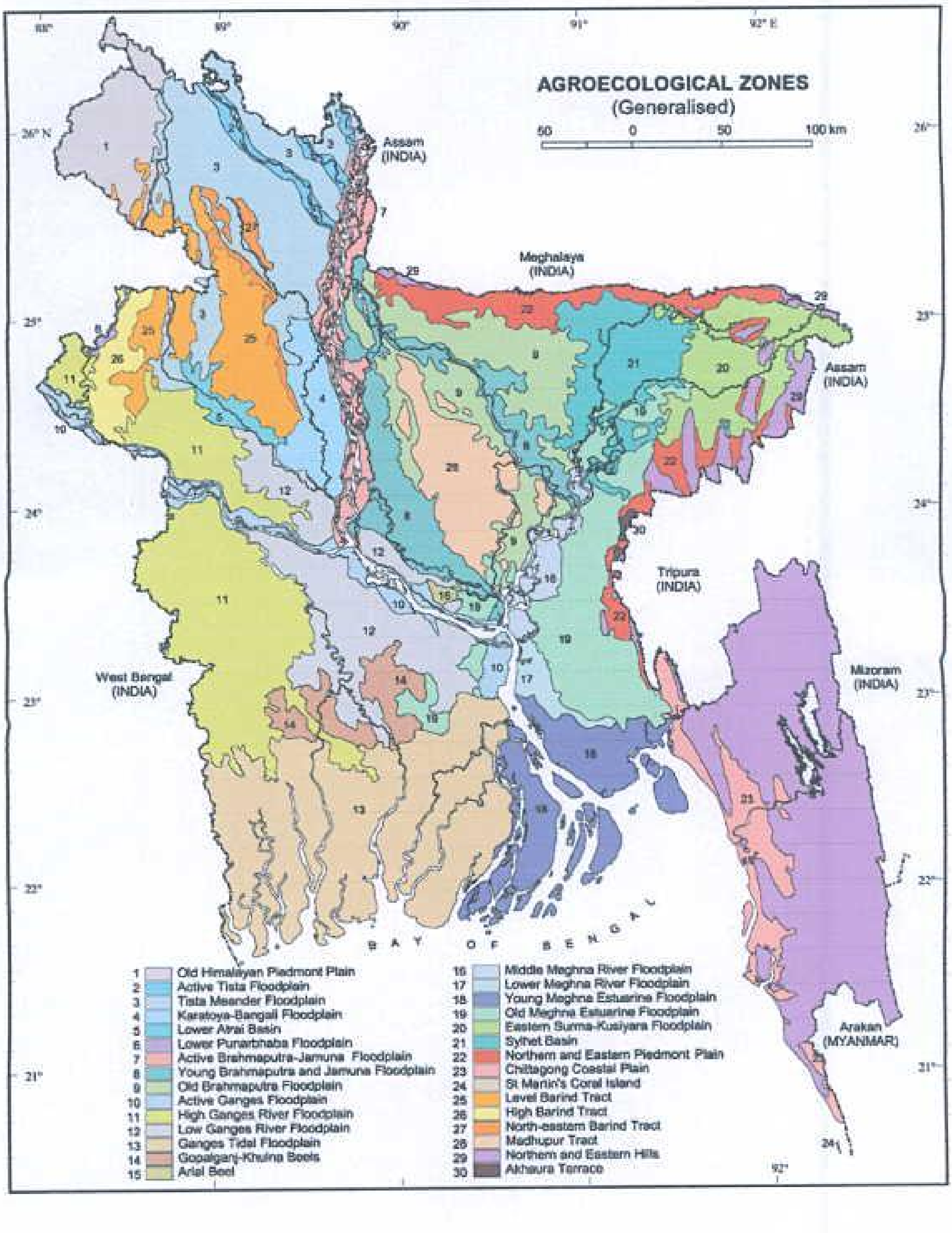
Zhu, B., Pennack, J. A., McQuilton, P., Forero, M. G., Mizuguchi, K., Sutcliffe, B., Gu, C. J., Fenton, J. C., Hidalgo, A. (2008). Drosophila neurotrophins reveal a common mechanism for nervous system formation. *PLoS Biol.* **6**(11): 284.

Zohra, F. T., Ali, M., Salimand, R. and Kader, M. A. (2013). Effect of urea super granules on the performance of transplant aman rice. *J. Agrofor. Environ.* 7(1):49-52.

Appendices

APPENDICES

Appendix I. Experimental location on the map of Agro-ecological Zones of Bangladesh



Appendix II. Morphological characteristics of the experimental field

Morphology	Characteristics
Location	SAU Farm, Dhaka.
Agro-ecological zone	Madhupur Tract (AEZ- 28)
General Soil Type	Deep Red Brown Terrace Soil
Parent material	Madhupur Terrace.
Topography	Fairly level
Drainage	Well drained
Flood level	Above flood level

(SAU Farm, Dhaka)

Appendix III. Initial physical and chemical characteristics of the soil

Characteristics	Value
Mechanical fractions:	
% Sand (2.0-0.02 mm)	22.26
% Silt (0.02-0.002 mm)	56.72
% Clay (<0.002 mm)	20.75
Textural class	Silt Loam
pH (1: 2.5 soil- water)	5.9
Organic Matter (%)	1.09
Total N (%)	0.028
Available K (ppm)	15.625
Available P (ppm)	7.988
Available S (ppm)	2.066

(SAU Farm, Dhaka)

Appendix IV. Analysis of variance of the data on plant height, number of tillers hill^{-1} and number of leaves hill^{-1} of boro rice as influenced by varieties and different doses of cadmium

Sources of variation	Degrees of freedom	Mean square Plant height (cm)			Mean square Number of tillers hill^{-1}			Mean square Number of leaves hill^{-1}	
		45 DAT	75 DAT	At harvest	45 DAT	75 DAT	At harvest	45 DAT	75 DAT
Replication	2	271.720	44.388	0.006	2.489	1.067	31.489	12.422	42.756
Factor A (Variety)	2	33.132*	1618.73*	33.462*	30.689*	3.267*	43.489*	685.356*	1525.422*
Factor B (Cadmium doses)	4	406.453*	576.488*	746.094*	87.144*	147.022*	206.144*	601.411*	1164.756*
A X B	8	3.091*	7.234*	6.865*	0.828*	3.489*	3.544*	9.411*	46.006*
Error	28	4.137	3.107	5.084	1.703	1.448	4.346	5.327	10.327

* Significant at 5% level

Appendix V. Analysis of variance of the data for crop growth characters, yield and other crop characters of BRRI dhan29, BRRI dhan60 and BRRI dhan61 at harvest

Sources of Variation	Degrees of freedom	Mean square values											
		Number of effective tillers hill^{-1}	Number of ineffective tillers hill^{-1}	Panicle length (cm)	Number of filled grains panicle^{-1}	Number of unfilled grains panicle^{-1}	1000-grains weight (g)	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Root yield (t ha^{-1})	K (%) in grain	K (%) in straw	K (%) in root
Replication	2	6.822	13.867	3.658	109.489	29.756	0.001	0.001	0.052	0.044	0.000	0.009	0.004
Factor A (Variety)	2	50.422*	48.600*	20.904*	24919.822 *	1050.689 *	2.432*	2.432*	10.123*	0.577*	0.063*	10.921*	0.268*
Factor B (Cadmium doses)	4	331.411*	15.422*	63.335 *	5197.522*	412.478*	16.236*	16.236*	1.466*	0.518*	0.041*	3.794*	0.041*
A × B	8	2.561*	1.989*	2.148 *	289.239*	22.661*	0.082*	0.082*	0.060*	0.012*	0.007*	0.910*	0.005*
Error	28	3.251	1.081	0.499	22.298	2.303	0.010	0.010	0.003	0.001	0.000	0.000	0.000

* Significant at 5% level

NS – Non Significant

Appendix VI. Analysis of variance of the data for different nutrient contents of BRRI dhan29, BRRI dhan60 and BRRI dhan61 after harvest

Sources of Variation	Degrees of freedom	Mean square values								
		Ca (%) in grain	Ca (%) in straw	Ca (%) in root	Na (%) in grain	Na (%) in straw	Na (%) in root	Cd (%) in grain	Cd (%) in straw	Cd (%) in root
Replication	2	0.000	8.301	12.966	0.000	0.009	0.017	18.339	37.936	43.053
Factor A (Variety)	2	0.000 NS	71.736*	311.822*	0.002 NS	2.250*	0.444*	346.766*	112.089*	6757.430*
Factor B (Cadmium doses)	4	0.000 NS	539.760*	319.795*	0.012 NS	0.383*	0.270*	797.333*	1254.480*	14443.421*
A × B	8	0.000 NS	80.787*	16.909*	0.000 NS	0.023*	0.051*	18.134*	20.562*	1492.128*
Error	28	0.000	0.803	0.706	0.000	0.000	0.022	0.858	2.505	2.638*

* Significant at 5% level

NS – Non Significant

Appendix VII. Effect of variety on various growth and yield parameters of Boro rice cv. BRRI dhan29, BRRI dhan60 and BRRI dhan61

Treat-ments	Plant height (cm)			Number of tillers hill^{-1}			Number of leaves hill^{-1}		Panicle length (cm)	Filled grain panicle^{-1}	Unfilled grain panicle^{-1}	%K in Grain	%K in Straw	%K in Root
	45 DAT	75 DAT	At harvest	45 DAT	75 DAT	At harvest	45 DAT	75 DAT						
V_1	38.27 a	64.15 b	78.46 b	7.067 b	12.47 ab	27.27 a	26.60 c	81.00 a	25.14 a	182.8 a	30.27 a	0.2769 c	2.007 c	0.3687 c
V_2	35.81 b	76.33 a	84.73 a	9.667 a	12.00 b	23.87 b	39.93 a	81.00 a	22.91 b	104.7 c	15.27 b	0.4015 a	3.091 b	0.4807 b
V_3	35.59 b	76.87 a	79.21 b	9.400 a	12.93 a	25.73 a	35.20 b	63.53 b	23.36 b	123.6 b	16.33 b	0.3070 b	3.690 a	0.6347 a
$LSD_{0.05}$	1.521	1.870	1.363	0.976	0.900	1.559	1.726	2.404	0.528	3.532	1.135	0.023	0.023	0.023
CV %	5.56	3.45	2.26	14.98	9.65	8.14	6.81	4.27	2.97	3.45	7.36	1.51	0.45	2.29
Significant level	*	*	*	*	*	*	*	*	*	*	*	*	*	*

V_1 – BRRI dhan29, V_2 – BRRI dhan60, V_3 – BRRI dhan61
* - Significant at 5 % level

Appendix VIII. Effect of different doses cadmium on various growth and yield parameters of Boro rice cv. BRRI dhan29, BRRI dhan60 and BRRI dhan61

Treatments	Number of effective tiller hill^{-1}	Number of ineffective tiller hill^{-1}	1000-grains weight (g)	Grain yield (t h^{-1})	Straw yield (t h^{-1})	Root yield (t h^{-1})
T_0	26.33 a	6.333 b	21.83 a	6.113 a	5.721 a	1.928 a
T_1	21.89 b	6.333 b	21.29 b	5.033 b	5.447 b	1.781 b
T_2	18.00 c	6.778 b	20.84 c	4.068 c	5.121 c	1.644 c
T_3	14.44 d	8.333 a	20.23 d	3.478 d	4.924 d	1.478 d
T_4	10.89 e	9.222 a	19.61 e	2.668 e	4.712 e	1.321 e
$LSD_{0.05}$	**1.741**	**1.004**	**0.246**	**0.096**	**0.052**	**0.030**
CV %	**9.85**	**14.05**	**1.23**	**2.39**	**1.12**	**1.50**
Significant level	*	*	*	*	*	*

T_0= No cadmium applied, T_1= 20 ppm Cd, T_2= 40 ppm Cd, T_3= 60 ppm Cd, T_4= 80 ppm Cd
* - Significant at 5 % level, NS- Non-significant

Appendix IX. Effect of variety on Cadmium content in grain, straw and root

Treatment	Cadmium content (mg kg^{-1})		
	Grain	Straw	Root
V_1	15.35 c	26.16 a	77.29 a
V_2	24.43 a	20.71 c	46.47 b
V_3	17.15 b	23.76 b	36.60 c
LSD (0.05)	**0.6928**	**1.184**	**1.215**
CV (%)	**4.88**	**6.72**	**3.04**
Significant level	*	*	*

V_1 – BRRI dhan29, V_2 – BRRI dhan60, V_3 – BRRI dhan61
* - Significant at 5 % level