Global Scientific JOURNALS

GSJ: Volume 11, Issue 2, February 2023, Online: ISSN 2320-9186
www.globalscientificjournal.com

EFFECTS OF CADMIUM CONTAMINATION ON YIELD AND CADMIUM CONCENTRATION IN DIFFERENT VARIETIES OF BORO RICE

ABSTRACT

A pot experiment was conducted in the net- house of the Department of Agriculture of Bangabandhu Sheikh Mujibur Rahman Science and Technology University, Gopalgonj to evaluate the effects of cadmium contamination on the growth, yield and nutrient concentrations of six varieties of rice. Cadmium(Cd) was added at three rates viz. 0, 10 and 20 ppm (on soil basis) from cadmium chloride ($CdCl_2.H_2O$). The varieties tested were BINA dhan8, BINA dhan10, BINA dhan14, BRRI dhan50, BRRI dhan58 and Kheyali boro. The experiment was carried out in a Completely Randomized Design (CRD), with three replicaions. Nine kg soil was taken into each pot measuring 40 cm in diameter and 35 cm in height. Every pot received 100 ppm N, 25 ppm P, 40 ppm K and 25 ppm S from urea, triple superphosphate, muriate of potash and gypsum, respectively. Soils were treated with Cd as per treatments before transplanting. Cadmium contamination significantly decreased plant height, tillering, panicle length, grains pot^{-1}, 100-seed weight, grain yield and straw yield. However, the effect was quite varied with the rice varieties. The Cd concentration in both grain and straw of all rice varieties increased with increasing rate of Cd addition. BINA dhan8 had the lowest grain Cd concentration and Kheyali boro showed the highest Cd concentration in rice grown with 20 ppm Cd. Application of Cd had reduced the concentrations of N, P, K and S in grain, showing negative interaction between them. The yield of BRRI dhan58 demonstrated the highest yield of grains pot^{-1} followed by BRRI dhan50 and BINA dhan8 under 20 ppm Cd applied to soil.

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CHAPTER 1

INTRODUCTION

Cadmium (Cd) is one of the most toxic pollutants in the surface soil layer (Sanita di Toppi & Gabrielli, 1999). Cadmium is a class one carcinogenic element in nature and is non-degradable contaminant which can be transfered 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 *et al*., 1999). 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).

Abiotic stress is the main factor negatively affecting crop growth and efficiency worldwide. Plants are continuously confronted with the harsh environmental conditions (such as soil salinity, drought, heat, cold, flooding and heavy metal contamination). The heavy metal, Cd is commonly released into the arable soil from industrial processes and farming practices (Wagner, 1993) and has been ranked No. 7 among the top 20 toxins (Yang *et al*., 2004). Even at low concentrations, Cd is toxic for most of the plants at concentrations greater than 5–10 µg Cd g^{-1} leaf dry weight (White *et al*., 2010). Cd is easily taken up by plant roots and transported to above-ground tissues (Liu et al. 2010) and enters into the food chain, where it may pose serious threats to human health (Hall 2002; Gill *et al*., 2011). The International Agency for Research on Cancer in 1993 classified Cd as a human carcinogen. (IARC 1993; Gianazza *et al.,* 2007)

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; Shimbo *et al*., 2001), 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.,* 1997; Jin *et al.,* 2002; Honda *et al.,* 2010).

Increase in international concern about the risks connected with long-term consumption of Cd contaminated crops has led the international food standards organization, Codex Alimentarius Commission, to propose a 0.1 mg Cd kg^{-1} limit for cereals, pulses and legumes (Harris and Taylor, 2001). Plant internal transport of Cd may be influenced by different factors, such as transpiration rate and plant internal chelators (Salt and Rauser, 1995). Earlier it has been reported that the uptake and accumulation rate of Cd changes among plant species (Ozturk *et al*., 2003) 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).

The Cd content in rice must not be more than 0.4 mg kg^{-1} in order to avoid occurrence of renal dysfunction due to Cd toxicity (Nakashima *et al*., 1997). In

Bangladesh, there are very few reports regarding Cd contamination in soil. Haque *et al.* (2006) reported Cd concentration in Chapainawabganj soil <1 mg kg^{-1}. Cadmium concentration in groundwater is also very low. But use of P fertilizers containing Cd and using sewage sludge could increase the Cd concentration in soil. 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.* (2005). The differences in acceptance these cultivars against Cd toxicity provide a base to study the mechanisms of Cd tolerance in crops. The present research was undertaken with the following objectives:

1. To assess the effect of cadmium on growth, yield and nutrient composition of rice genotypes.
2. To select Boro rice variety for lower grain cadmium concentration.

CHAPTER 2

REVIEW OF LITERATURE

Cadmium is among 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. 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.

Sources of cadmium in the environment

McGrath et al. (1987) stated that 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.

OECD (1991) reported 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 fertiliser 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) reported 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) highlighted 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) reported that, thus producing cadmium oxide in the air, reacting with water vapour, 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 CdSO4 in soil demonstrating that lettuce leaves have Cd levels amounting to 800 $mgkg^{-1}$. Furthermore, Cd contamination is also recognized as stemming from fertilizers.

Wagner (1993) reported that 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.

Cook and Morrow (1995) reported 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 0.1

to 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) reported 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.

McLaughlin *et al.* (1999) stated that 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.

Unwin (1999) reported 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.

Sultana (2000) conducted an experiment on the effect of intensive fertilization heavy metal concentration in soils and plants. She found that Cd, Pb and Zn concentrations 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 *et al*. (2000) reported from a recent soil survey from 11 provinces in China, at least 13,330 ha farmland has been contaminated by Cd.

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.

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.

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.

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.

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.

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 (Bandara *et al*. 2008), from base mining contamination (Sriprachote *et al*. 2012, Honda *et al.* 2010, Williams *et al.* 2009), industrial discharge (Horiguchi, 2012), or from phosphate fertilizers (Morwedt & Osborn, 1982).

Haynes et al. (2009) 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.

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.

Cadmium availability to plants

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 than 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 hydroxy 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 mean while, 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.

Matusik *et al.* (2008) reported 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.

2.3. Effects of Cd on plants

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.

Ivano (2001) 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 mg $Pbkg^{-1}$ 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) 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.

Cheng *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 *J.Y 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.

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.

Zeng *et al.* (2008) reported that in a slightly contaminated soil (1.09 mg Cdkg^{-1} soil), the absolute difference in grain Cd concentrations among 138 rice cultivars was 9.1 fold.

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.

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 are mucilaginous, 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 0_2 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 day). Cadmium treatment at all levels tested decreased the various growth and yield 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.

CHAPTER 3

MATERIALS AND METHODS

In this chapter a brief description of location, climate, soil, crop, experimental design, treatments, cultural operations, collection of soil and plant sample and the methods followed for chemical analysis are statistical analysis and presented in this chapter.

Pot Experiment

The pot experiment was carried out during the boro season of 2019 to evaluate the effect of cadmium on boro rice genotypes.

Description of the Experimental Site

Location

The growth and performance was carried out in the net house of the Department of Agriculture, Bangabandhu Sheikh Mujibur Rahman Science and Technology University, Gopalgonj. The net house belongs to the same environment of BSMRSTU farm (AEZ 7).

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 24.75ºN latitude and 90.50ºE longitude at the height of 18 m above the mean sea level.

Collection and preparation of soil

A bulk volume of soil was collected at a depth of 0-l5 cm from the of the Department of Agriculture, Bangabandhu Sheikh Mujibur Rahman Science and Technology University, Gopalgonj. 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.

Pot preparation

An amount of 9 kg soil was taken in a series of pots. Each plastic pot was 0.23 $m^{2.}$ There were altogether 54 pots comprising 3 different treatments to six different boro rice varieties with 3 replications. Water was added to the pot to bring the soil up to saturation.

Table 3.1 Physical and chemical properties of the BSMRSTU farm soil under study

Constituents	Value
Physical characteristics	
% Sand (2-0.05mm)	10.15
% Silt (0.05-0.002mm)	73.94
% Clay (<0.002mm)	15.91
Textural class	Silt loam
Chemical characteristics	
pH (Soil:water = 1:2.5)	6.5
Organic matter (%)	1.90
CEC (me/100g soil)	10.10
Total N (%)	0.08
Available P (mg/kg)	12.2
Available S (mg/kg)	13.7
Exchangeable K (me/100g soil)	0.11
Total Cd (ppm)	0.82

Treatments of the experiment

Three rates of cadmium *viz.* 0, 10 and 20 ppm Cd (on soil weight basis) were applied on six boro rice varieties. The source of Cd was $CdCl_2.H_20$. The rice varieties were *viz*, V_1=BINA dhan8, V_2= BINA dhan10, V_3= BINA dhan14, V_4=BRRI dhan50, V_5=BRRI dhan58 and V_6=Kheyali boro. Treatment consisted of three concentrations of cadmium. The experiment was carried out in a completely randomized block design. Each pot contained one hill of 3 seedlings.

There were altogether 18 treatment combinations which are as follows:

Treatment code		Treatment code		Treatment code	
T_1	V_1Cd_0	T_7	V_3Cd_0	T_{13}	V_5Cd_0
T_2	V_1Cd_{10}	T_8	V_3Cd_{10}	T_{14}	V_5Cd_{10}
T_3	V_1Cd_{20}	T_9	V_3Cd_{20}	T_{15}	V_5Cd_{20}
T_4	V_2Cd_0	T_{10}	V_4Cd_0	T_{16}	V_6Cd_0
T_5	V_2Cd_{10}	T_{11}	V_4Cd_{10}	T_{17}	V_6Cd_{10}
T_6	V_2Cd_{20}	T_{12}	V_4Cd_{20}	T_{18}	V_6Cd_{20}

Description of rice cultivars under study

BINA dhan8

BINA dhan8 was developed by the scientists of BINA (Bangladesh Institute of Nuclear Agriculture) and was officially released by National Seed Board of Bangladesh in 2010. It is a salt tolerant variety which can survive up to 10 dSm^{-1} salinity. Its crop duration is 135-145 days and average yield is 3-6 t ha^{-1} depending on the levels of salinity.

BINA dhan10

BINA dhan10 was developed by the scientists of BINA (Bangladesh Institute of Nuclear Agriculture) and was officially released by National Seed Board of Bangladesh in 2013. It is a salt tolerant variety. Its crop duration is 115-125 days and average yield is 4.50-5.50 t ha^{-1}.

BINA dhan14

BINA dhan14 was developed by the scientists of BINA (Bangladesh Institute of Nuclear Agriculture) and was officially released by National Seed Board of Bangladesh in 2013. It is a high yielding variety. Its crop duration is 120-130 days and average yield is 7 - 7.66 t ha^{-1}.

BRRI dhan50

BRRI dhan50 was developed by the scientists of BRRI (Bangladesh Rice Research Institute). It is a boro rice and aromatic fine rice better than Basmoty in quality. It is resistant to water logging condition. BRRI dhan50 requires 155 days to mature and average yield is 6 t ha^{-1}.

BRRI dhan58

BRRI dhan58 was developed by the scientist of BRRI (Bangladesh Rice Research Institute) and it was officially released by National Seed Board of Bangladesh in 2012. It is a boro rice variety. BRRI dhan50 requires 150-155 days to mature and average yield is 7-7.5 t ha^{-1}.

Kheyali boro

It is a local variety grown in low lying areas of Islampur upazila.

Fertilizer application

All the pot received 100 ppm N, 25 ppm P, 40 ppm K and 25 ppm S from urea, triple super phosphate, muriate of potash and gypsum, respectively. 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.

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 30 January 2014.

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.

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.

Harvesting

The crop was harvested at full maturity on 19 May 2019. 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.

Sampling threshing and processing

The plant samples were dried in an oven at 60 ^{0}C for 48 hours and then cut into small pieces using clean scissors. The plant materials were stored in desiccators to analyze total N, P, K, S and Cd concentrations.

Data Collection

The following data were collected from all the plants grown in each pot.

I) Plant height (cm)

ii) Effective tillers pot $^{-1}$

iii) Panicle length (cm)

iv) Filled grains pot $^{-1}$

v) 100-grain weight (g)

vi) Grain yield (g pot $^{-1}$)

vii) Straw yield (g pot $^{-1}$)

Plant height

The height of the plant (cm) was measured from the ground level to the top of the flag leaf at 30, 45, 60 days after transplanting (DAT) and harvest with help of scale.

Effective tillers pot^{-1}

Number of effective tillers per hill^{-1} was counted at 30, 45, 60 days after transplantation (DAT) and at harvest.

Panicle length

Panicle length was measured in cm from basal node of the rachis to apex.

Filled grains pot^{-1}

The number of filled grains was counted for each panicle.

100-grain weight

Hundred grains were taken from each pot and the sun dry weight was measured using an electrical balance.

Grain yield

Grain obtained from each pot was dried and weighed carefully. The yields were expressed as g pot^{-1} on 14% moisture basis.

Straw yield

Straw obtained from each pot was dried and weighed carefully. The yields were expressed as g pot^{-1}.

Chemical Analysis of Plant Samples

Preparation of plant sample for N, P, K and S

N, P, K and S content in grain and straw was measured. Grain and straw sample were dried in an oven at about 60^0 C for 48 hours and then ground in a grinding machine to pass through a 20 mesh sieve after removing husk from grain. The ground grain and straw were stored in small paper bag and placed in desiccators.

Digestion of plant samples for N determination

A sub sample weighing 0.1 g for grain was transferred into a dry clean digestion vessel. 1.1 g catalyst mixture and 5 ml sulphuric acid were added to the sample and the sample was allowed to digest at 185 ^{0}C for half an hour. Again sample was digested at 300 ^{0}C for an hour and volume up to 100 ml with distilled water.

Digestion of plant sample with nitric-perchloric acid for determination of P, K, S and Cd

A sub-sample weighing 0.5 g was transferred into a dry clean digestion vessel. Eight ml of nitric-perchloric acid was added and the sample was allowed to stand over night under fume hood. The following day, the digestion vessels were placed on a heating block and were heated at a temperature slowly raised to 125 ºC for two hours. After heating, the vessels were allowed to cool and 3 ml of 36% H_2O_2 was added. Again the vessel was heated 180^0C for an hour. Heating was momentarily stopped when the dense white fumes of H_2O_2 was occurred.

Determination of Nitrogen

Nitrogen in the digest was determined by distillation with 40% NaOH followed by titration of the distillate trapped in H_3BO_3 with 0.01N H_2SO_4. (Page *et al.* 1982).

Determination of Phosphorus

One ml digest (grain) from 5 ml extract was taken in a 50 ml volumetric flask. Then the samples were shaken with 0.5 M $NaHCO_3$ solution at pH 8.5 following Olsen method (Olsen *el al*., 1954). The extracted phosphorus was determined by developing blue color by $SnCl_2$ reduction of phosphomolybdate complex and measuring the intensity of color spectrophotometrically at 660 nm wavelength.

Determination of Potassium

Two ml of digest each of grain and straw was taken and diluted into 50 ml. The K was determined from the extract by using flame photometer.

Determination of Sulphur

Sulphur was determined by using 5ml digest (both in grain and straw). Sulfur was determined by developing turbidity by adding 1 ml acid seed solution (20 ppm S as K_2SO_4 in 6N HCl) and 0.5 g $BaCl_2$ crystal. The intensity of turbidity was measured by spectrophotometer at 420 nm wave length. The extraction method was described by Page *et al.* (1989).

Determination of Cadmium

Total cadmium concentration was determined from the digest by SHIMADJU AA 7000 atomic absorption spectrophotometer.

Statistical Analysis

The analysis of variance for various characters of rice and for nutrient concentration and nutrient uptake was done following the F-statistics using statistical package Minitab 16. The mean relationship of the treatments was made by the Duncan's Multiple Range Test (DMRT).

CHAPTER 4

RESULTS

Results obtained from the pot experiment conducted in the net house of the Department of Agriculture, Bangabandhu Sheikh Mujibur Rahman Science and Technology University, Gopalgonj.have been presented in tables and graphs and narrated in this chapter under following headings:

Yield parameters

Plant height

Plant height of rice varieties adversely affected due to application of different rates of cadmium to soil (Table 4.1). Plant height of 88.9 cm was found in the pot without any Cd treatment and the treatment 10 and 20 ppm Cd recorded the plant height of 85.2 cm and 82.2 cm, respectively. A significant variation in plant height was also observed among different varieties of rice (Table 4.1). The Kheyali boro was the tallest one (99.2 cm) and the shortest variety was BINA dhan14 (74.7cm). The plant height of Kheyali boro was statistically significant over all other varieties. The second tallest plant (93.4cm) variety was BINA dhan10. The shortest plant of 84.5 cm was statistically similar to BINA dhan8. The varieties BINA dhan4 and BRRI dhan 50 were also statistically similar in plant height.

The interaction effect of different rates of Cd and different varieties of rice was statistically significant (Table 4.2). Generally, Cd contamination resulted a significant decrease in plant height of all rice varieties. The plant height of six rice varieties over the three rates ranged from 68.3 cm in BINA dhan14 with 20 ppm Cd to 103.6 cm in Kheyali boro without any Cd treatment. At all Cd levels, the variety Kheyali boro showed the tallest plant and BINA dhan14 showed the shortest plant. The application of 10 ppm Cd significantly decreased the plant height of BINAdhan10, BINA dhan14 and Kheyali boro. The varieties BINAdhan8, BRRI dhan50 and BRRI dhan58 were less affected by 10 ppm Cd application. The application of 20 ppm Cd drastically reduced the plant height compared to those without any Cd application.

Effective tillers pot^{-1}

Cadmium contamination significantly reduced the number of effective tillers pot^{-1} of rice varieties (Table 4.1). The application of 10 and 20 ppm Cd reduced the number of effective tillers pot^{-1}. The highest number of effective tillers pot^{-1} (6.7) was found in the pot without any Cd addition and the application of 10 and 20 ppm Cd decreased the number of effective tillers pot^{-1} compared to that obtain without any Cd application. The different varieties of boro rice varied significantly in terms of number of effective tillers pot^{-1}, which ranged from 3.7 to 9.8 (Table 4.1). The highest number of effective tillers pot^{-1} (9.8) was obtained in Kheyali boro which was statistically superior to all other varieties. The lowest number of effective tillers pot^{-1} (3.7) was found in BINA dhan14 which was statistically similar to BINA dhan8 and BINA dhan10. The varieties BRRI dhan50 and BRRI dhan58 were also statistically similar in producing number of effective tillers pot^{-1}.

The interaction effect of different rates of Cd application and different varieties on the production number of effective tillers pot^{-1} was statistically significant (Table 4.2). The formation of effective tillers pot^{-1} due to application of 10 ppm of Cd in all varieties decreased. But such decrease in effective tillering was significant in BINA dhan8, BINA dhan 14 and BRRI dhan50. There was further decrese on the number of effective tillers pot^{-1} due to application of 20 ppm Cd in all rice genotypes. In the Cd control treatment, the number of effective tillers pot^{-1} varied from 4.6 in BINA dhan14 to 11.6 in Kheyali boro. When the varieties were exposed to 10 ppm Cd, the number of effective tillers pot^{-1} ranged from 3.6 in BINA dhan14 to 10.6 in Kheyali boro. The application of 10 and 20 ppm Cd reduced the number of effective tillers pot^{-1} of all six varieties of boro rice.

Panicle length

Cadmium contaminaiton of soil significantly decreased the panicle length of rice varieties (Table 4.1). The panicle length of rice varieties significantly decreased due to 10 ppm Cd application and further significantly decreased with the addition of 20 ppm Cd. There was significant variation among the different varieties of boro rice (Table 4.1). The panicle length was in the range of 19.5 cm in Kheyali boro to 25.4 cm in BINA dhan10.

The interaction effect of different treatments with varieties showed remarkable variations in panicle length of rice though the variation was not statistically significant (Table 4.2).

Table 4.1 Main effects of Cd and varieties on the plant height, effective tillers pot^{-1} and panicle length of different rice varieties

Factors	Plant height (cm)	Effective tillers pot^{-1} (no.)	Panicle length (cm)
Cd levels (ppm)			
Cd$_0$	88.9a	6.7a	24.0a
Cd$_{10}$	85.2b	5.2b	22.9b
Cd$_{20}$	82.2c	4.1c	22.1c
Lsd	1.7	0.7	1.0
Level of significance	**	**	**
Varieties			
BINA dhan8	84.2c	4.1c	23.4b
BINA dhan10	93.4b	4.0c	25.4a
BINA dhan14	74.7d	3.7c	21.6c
BRRI dhan50	76.5d	5.1b	23.5b
BRRI dhan58	84.5c	5.3b	24.5ab
Kheyali boro	99.2a	9.8a	19.5d
Lsd	2.4	1.0	1.5
Level of significance	**	**	**

In a column, the figures having common letter(s) do not differ significantly at 5% level of probability.

Lsd=Least significant difference, ** = $P<0.01$

Table 4.2 Interaction effects of added Cd and varieties on the plant height, effective tillers pot^{-1} and panicle length

Variety	Treatments	Plant height (cm)	Effective tillers pot^{-1} (no.)	Panicle length (cm)
BINA dhan8	Cd_0	87.3fg	5.3cd	24.4
	Cd_{10}	83.8h	4.0d-g	23.1
	Cd_{20}	81.6hi	3.0g	22.6
BINA dhan10	Cd_0	96.6b	5.0de	26.0
	Cd_{10}	92.6cd	3.6efg	25.6
	Cd_{20}	91.0de	3.3fg	24.5
BINA dhan14	Cd_0	80.3ij	4.6def	22.6
	Cd_{10}	75.5k	3.6efg	21.2
	Cd_{20}	68.3l	3.0g	21.1
BRRI dhan50	Cd_0	78.0jk	7.0b	25.4
	Cd_{10}	76.4k	4.6def	23.4
	Cd_{20}	75.0k	3.6efg	21.8
BRRI dhan58	Cd_0	87.9ef	6.6bc	25.5
	Cd_{10}	84.2gh	5.0de	24.5
	Cd_{20}	81.4hi	4.3d-g	23.5
Kheyali boro	Cd_0	103.6a	11.6a	20.0
	Cd_{10}	98.5b	10.6a	19.4
	Cd_{20}	95.6bc	7.3b	19.1
Lsd	4.29	1.81	2.65	2.65
Level of significance		*	*	NS

In a column, the figures having common letter(s) do not differ significantly at 5% level of probability.

Lsd=Least significant difference

* = $P<0.05$ NS = Non-significant

Yield

Filled grains pot^{-1}

The number of filled grains pot^{-1} in boro rice was found to be significantly affected by the soil added Cd (Table 4.3). Each successive levels of Cd application significantly decrease the number of filled grains pot^{-1}. The number of filled grains pot^{-1} in Cd control treatment was 744 while in 10 and 20 ppm Cd treatments were 677 and 574, respectively (Table 4.3). The highest number of filled grains (1046) was obtained in BRRI dhan58. The lowest number of filled grains 404 was found in Kheyali boro which was statistically similar to BINA dhan14.

The interaction of three treatments with different varieties selected for the experiment showed significant variation in terms of filled grains pot^{-1} (Table 4.4). The highest number of filled grains pot^{-1} (1077) in BRRI dhan58 was recorded in pot treated without any Cd addition while the lowest number of filled grain pot^{-1} (341) in BINA dhan14. Among the rice varieties, BINA dhan8 and BINA dhan14 were more sensitive to Cd contamination.

100-seed weight

Hundred grain weight of boro rice varied significantly due to cadmium contamination (Table 4.3). The application of 10 and 20 ppm of Cd recorded the 100 seed weight of 1.92 g and 1.85 g, respectively compared to that of 2.00 at without any Cd application. The different varieties of boro rice showed significant variation on 100-seed weight (Table 4.3). The highest 100-grain weight (2.38g) was obtained in BINA dhan8. The lowest 100-grain weight (1.42g) was obtained in Kheyali boro. The varieties like BINA dhan14 and BRRI dhan58 were statistically identical in 100-seed weight of rice.

The interaction of three cadmium levels with six varieties on 100 seed-weight was not statistically significant. The application of 10 and 20 ppm Cd reduced the 100-seed weight of all varieties.

Grain yield

Grain yield is the most important parameter when judging any variety in terms of Cd tolerance or sensitivity. The grain yield of boro rice was markedly affected by the application of different rates of Cd added to soil. The grain yield significantly decreased due to the addition of 10 and 20 ppm Cd. The treatment 10ppm Cd and 20 ppm Cd produced 12.95 and 10.99 g pot^{-1}, respectively where as in control the grain yield was 15.00 g pot^{-1}. The grain yield of different rice varied significantly in different varieties of boro rice (Table 4.3). The grain yield ranged from 4.93 g pot^{-1} in Kheyali boro to 19.46 g pot^{-1} in BRRI dhan58.

The interaction effect showed some marked variations in grain yield production of rice (Figure 4.4). In Cd control treatment, the highest grain yield (20.51 g pot^{-1}) obtained in BRRI dhan58 while the lowest grain yield (5.44 g pot^{-1}) was recorded in Kheyali boro. When the relative yield is concerned with 20 ppm Cd treatment, BRRI dhan58 (18.27 g pot^{-1}) produced the highest and Kheyali boro (4.41 g pot^{-1}) produced the lowest grain yields. Therefore, BRRI dhan58 may be cultivated in Cd contaminated soil.

Straw yield

Like grain yield, the straw yield of Boro rice varieties was statistically affected by the Cd contamination (Table 4.3). The straw yield due to Cd contamination varied from 20.39 g pot^{-1} in control and 18.19 g pot^{-1} and 15.98 g pot^{-1} in 10 and 20 ppm Cd treatments, respectively. Different varieties of boro rice showed significant variation in straw yield. The straw yield of boro rice ranged from 11.65g pot^{-1} in Kheyali boro to 22.03 g pot^{-1} in BINA dhan10. The highest straw yield was obtained in BINA dhan10 which was statistically identical to BRRI dhan58. BINA dhan8, BINA dhan14 and BRRI dhan50.

The interaction effect showed some marked variations in straw yield production of rice though the variation was not statistically significant (Table 4.4). Among the varieties, straw yield reduction due to 20 ppm was highest in BRRI dhan50 and lowest in Kheyali boro.

Table 4.3 Main effects of added Cd and varieties on yield of different rice varieties

Factors	**Filled grains pot^{-1}**	**100-seed weight (g)**	**Grain yield gpot^{-1}**	**Straw yield gpot^{-1}**
Cd levels (ppm)				
Cd_0	744a	2.00a	15.00a	20.39a
Cd_{10}	677b	1.92b	12.95b	18.19b
Cd_{20}	574c	1.85b	10.99c	15.98c
Lsd	48.25	0.10	0.70	2.32
Level of significance	**	**	**	**
Variety				
BINA dhan8	666c	2.38a	15.76b	17.97b
BINA dhan10	589d	2.19b	12.77d	22.03a
BINA dhan14	454e	1.98c	10.38e	17.90b
BRRI dhan50	831b	1.65d	14.59c	17.74b
BRRI dhan58	1046a	1.91c	19.46a	21.83a
Kheyali boro	404e	1.42e	4.93f	11.65c
Lsd	68.24	0.13	0.99	3.28
Level of significance	**	**	**	**

In a column, the figures having common letter(s) do not differ significantly at 5% level of probability.

Lsd=Least significant difference

** = P<0.01;

Table 4.4 **Interaction effects of added Cd and varieties on the grain yield of different rice varieties**

Variety	**Treatments**	**Filled grains pot^{-1}**	**100-seed weight (g)**	**Grain yield g pot^{-1}**	**Straw yield g pot^{-1}**
BINA dhan8	Cd_0	809c	2.47	18.94b	21.39
	Cd_{10}	669de	2.36	15.48cd	17.99
	Cd_{20}	522fg	2.32	12.85f	14.53
BINA dhan10	Cd_0	679de	2.23	16.15c	23.35
	Cd_{10}	610ef	2.20	12.81f	22.27
	Cd_{20}	478ghi	2.16	9.34g	20.49
BINA dhan14	Cd_0	521fg	2.04	13.19ef	19.95
	Cd_{10}	500gh	1.99	10.40g	17.54
	Cd_{20}	341j	1.89	7.57h	16.22
BRRI dhan50	Cd_0	964b	1.74	15.77cd	21.62
	Cd_{10}	809c	1.67	14.47de	17.99
	Cd_{20}	720cd	1.53	13.52ef	13.62
BRRI dhan58	Cd_0	1077a	1.95	20.51a	23.70
	Cd_{10}	1070a	1.90	19.59ab	21.63
	Cd_{20}	990ab	1.87	18.27b	20.17
Kheyali boro	Cd_0	416hij	1.55	5.44i	12.32
	Cd_{10}	403ij	1.40	4.95i	11.75
	Cd_{20}	392ij	1.31	4.41i	10.87
Lsd		118.19	0.23	1.71	5.68
Level of significance		**	NS	**	NS

In a column, the figures having common letter(s) do not differ significantly at 5% level of probability.

Lsd=Least significant difference
** = P<0.01; NS = Non-significant

Nutrient concentration in element and cadmium

Nitrogen concentration

The N concentration in grain of boro rice was markedly affected by the application of different rates of Cd added to soil (Table 4.5). The N concentration in grain ranged from 1.067% in 20 ppm Cd to 1.172% in control treatment. The highest N concentration was found in BINA dhan8 and lowest in kheyali boro which was statistically similar to BRRI dhan58.

The interaction effect of treatment and varieties in grain was not statistically significant (Table 4.6). The highest N concentration in grain (1.220%) found in BINA dhan8 in control treatment whereas the lowest (1.025%) was obtained in BRRI dhan50 in case of application of 20 ppm cadmium. There was a very poor correlation between grain-Cd and grain- N contents of boro rice (Fig. 4.1 a)

Phosphorus concentration

The P concentration in grain of boro rice decreased with increase in Cd addition. The P concentration in grain was 0.286% in control treatment while that in 10 and 20 ppm Cd treatments were 0.269% and 0.248%, respectively. There was significant variation among different boro rice varieties (Table 4.5). P concentration in grain ranged between 0.228% in BINA dhan10 to 0.289% in BINA dhan14 which was statistically similar to BRRI dhan50 and kheyali boro.

The interaction effect of different levels of Cd application and different boro rice varieties on grain-P concentration was not significant (Table 4.6). Cd_0×kheyali boro gave the highest P concentration in grain with the value of 0.333% and the lowest P concentration in grain was obtained in Cd_0×BINA dhan10 with the value of 0.225%. There was a very poor correlation between grain-Cd and grain- P contents of boro rice (Fig. 4.1b).

Potassium concentration

There was significant effect of Cd contamination as well as different rice varieties on grian-K concentration (Table 4.5). The K concentration in grain ranged from 0.248%

in BRRI dhan50 to 0.313% in BINA dhan14. The highest grain K-concentration found in BINA dhan14. On the other hand, the lowest grain K-concentration (0.248%) was found in BRRI dhan50 which was statistically similar to BINAdhan10 (0.257%).

The interaction effect of added Cd and different boro rice varieties on grain-K concentration was statistically not significant (Table 4.6). The highest K-concentration in grain (0.340%) was found in BINA dhan14 at Cd_0 and lowest grain-K concentration (0.220%) was found in BINA dhan10 and BRRI dhan50 at Cd_{20}.. There was a very weak correlation between grain-Cd and grain-K (Fig.4.1c)

Sulphur concentration

The sulphur concentration in grain of boro rice was statistically significant due to application of different levels of Cd to the crops (Table 4.5). The S concentration in grain was 0.105% in 0 ppm Cd and 0.081 and 0.064% in 10 and 20 ppm Cd treatments, respectively. Different varieties of boro rice significantly varied for grain-S concentration, ranging from 0.075 to 0.093% (Table 4.5). The highest S concentration in grain was obtained in BRRI dhan50 which was statistically similar to BINA dhan14 and Kheyali boro. The lowest S concentration in grain was found in BINA dhan10 which was also statistically similar to BINA dhan8, BRRI dhan58 and kheyali boro.

The interaction effect of cadmium and variety was statistically non-significant in terms of S concentration in rice grain (Table 4.6). The highest S concentration in grain (0.115%) was in BINA dhan8 with Cd_0 and the lowest S concentration in grain (0.057%) was found in BINA dhan8 grown with 20 ppm Cd. The correlation between grain-Cd and grain-S was positively correlated (Fig.4.1 d).

Cadmium concentration

Cadmium concentration in grains of boro rice was significantly increased due to application of different levels of Cd in soil (Table 4.5). Cadmium concentration in grain of control pot (0 ppm Cd) was 0.058 ppm and that in pot receiving 10 and 20 ppm Cd was 0.253 and 0.403 ppm, respectively. The different varieties of boro rice selected for the experiment showed non significant variation in Cd concentration in grain (Table 4.5). The highest grain-Cd concentration (0.287 ppm) was observed in BRRI dhan58 and the lowest (0.168 ppm) was found in BINA dhan8. There was significant interaction effect of different rates of Cd and varieties of Boro rice on Cd concentration of rice grains (Table 4.6). The application of 10 and 20 ppm Cd increased the grain Cd concentration of all varieties boro rice. All the varieties selected for the experiment showed higher Cd concentration in the pots receiving 10 and 20 ppm Cd in soil compared to Cd control pot. Among the treatment combinations, Cd_{20} ×Kheyali boro had the highest Cd concentration (0.480 ppm) in grain and followed by Cd_{20} ×BRRI dhan58 and Cd_{20}×BRRI dhan50. The lowest Cd concentration (0.010 ppm) was found in Cd_0 ×BINA dhan10 which was statistically similar to Cd_0 ×BINA dhan8, Cd_0 ×BINA dhan14, Cd_0 ×BRRI dhan58 and Cd_0 ×Kheyali boro.

Table 4.5 Main effects of added Cd and varieties on nutrient concentration in grain of different rice varieties

Factors	N (%)	P (%)	K (%)	S (%)	Cd (ppm)
Cd levels (ppm)					
Cd_0	1.172a	0.286a	0.304a	0.105a	0.058c
Cd_{10}	1.097b	0.269b	0.272b	0.081b	0.253b
Cd_{20}	1.067b	0.248c	0.250b	0.064c	0.403a
Lsd	0.009	0.009	0.009	0.009	
Level of significance	**	**	**	**	**
Varieties					
BINA dhan8	1.145a	0.250c	0.265c	0.083bc	0.168
BINA dhan10	1.127b	0.228d	0.257cd	0.075c	0.221
BINA dhan14	1.120b	0.289a	0.313a	0.087ab	0.224
BRRI dhan50	1.072d	0.283a	0.248d	0.093a	0.248
BRRI dhan58	1.100c	0.268b	0.267c	0.077bc	0.287
Kheyali boro	1.107c	0.287a	0.302b	0.085abc	0.284
Lsd	0.013	0.013	0.013	0.013	
Level of significance	**	**	**	**	NS

In a column, the figures having common letter(s) do not differ significantly at 5% level of probability.

Lsd=Least significant difference

** = P<0.01; NS = Non-significant

Table 4.6 Interaction effects of added Cd and varieties on nutrients concentration in grain of different varieties of rice

Variety	Treatments	N (%)	P (%)	K (%)	S (%)	Cd(ppm)
BINA dhan8	Cd_0	1.220	0.280	0.285	0.115	0.070gh
	Cd_{10}	1.120	0.245	0.260	0.077	0.166f
	Cd_{20}	1.095	0.225	0.250	0.057	0.270e
BINA dhan10	Cd_0	1.190	0.225	0.290	0.100	0.010cd
	Cd_{10}	1.105	0.235	0.260	0.068	0.260e
	Cd_{20}	1.085	0.225	0.220	0.058	0.393bc
BINA dhan14	Cd_0	1.180	0.306	0.340	0.110	0.050gh
	Cd_{10}	1.100	0.295	0.305	0.086	0.240e
	Cd_{20}	1.080	0.266	0.295	0.065	0.383bc
BRRI dhan50	Cd_0	1.130	0.305	0.285	0.110	0.083g
	Cd_{10}	1.060	0.270	0.240	0.095	0.236ef
	Cd_{20}	1.025	0.275	0.220	0.075	0.426ab
BRRI dhan 58	Cd_0	1.140	0.265	0.295	0.100	0.050gh
	Cd_{10}	1.095	0.280	0.260	0.070	0.346cd
	Cd_{20}	1.065	0.260	0.245	0.060	0.466a
Kheyali boro	Cd_0	1.170	0.333	0.330	0.095	0.080gh
	Cd_{10}	1.100	0.291	0.305	0.090	0.293de
	Cd_{20}	1.050	0.237	0.270	0.070	0.480a
Lsd		0.022	0.022	0.022	0.022	
Level of significance		NS	NS	NS	NS	**

In a column, the figures having common letter(s) do not differ significantly at 5% level of probability.

Lsd=Least significant difference

** = P<0.01; NS = Non-significant

Nutrient concentration in straw

Nitrogen concentration

The N concentration in straw of boro rice was markedly affected by the application of different rates of Cd added to soil. The N concentration in straw ranged from 0.578% in 20 ppm Cd to 0.636% in control treatment. The highest N concentration was found in BINA dhan8 and lowest in BRRI dhan50 which was statistically similar to BRRI dhan58.

The interaction effect of treatment and varieties in straw was not statistically significant (Table 4.8). The highest N concentration in straw (0.667%) found in BINA dhan8 in control treatment (Cd_0 ppm) whereas lowest (0.555%) was obtained in BRRI dhan50 in case of application of 20 ppm cadmium.

Phosphorus concentration

The P concentration in straw of boro rice decreased with increase in Cd addition. The P concentration in straw was 0.104% in control treatment while that in 10 and 20 ppm Cd treatments were 0.0.092% and 0.083%, respectively. There was no significant variation among different boro rice varieties (Table 4.7).

The interaction effect of different levels of Cd application and different boro rice varieties on straw-P concentration was not significant (Table 4.8). Cd_0×BRRI dhan58 gave the highest P concentration in straw with the value of 0.115% and the lowest P concentration in straw was obtained in Cd_{20}×BRRI dhan50 with the value of 0.080%.

Potassium concentration

There was significant effect 0f Cd contamination as well as different rice varieties on straw-K concentration (Table 4.7). The K concentration in straw ranged from 1.607% in BRRI dhan50 to 2.035% in BINA dhan14. The highest straw K concentration found in BINA dhan14. On the other hand, the lowest straw K concentration was found in

BRRI dhan50 which was statistically similar to all other varieties except BINAdhan14.

The interaction effect of added Cd and different boro rice varieties on straw-K concentration was statistically significant (Table 4.8). The highest K-concentration in straw (2.225%) was found in BINA dhan14 at Cd_0 and lowest straw-K concentration (1.060%) was found in kheyali boro at Cd_{20} which was statistically similar in BRRI dhan50 and BINA dhan10.

Sulphur concentration

The sulphur concentration in straw of boro rice was statistically significant due to application of different levels of Cd to the crops (Table 4.7). The S concentration in straw was 0.091% in 0 ppm Cd and 0.066 and 0.052% in 10 and 20 ppm Cd treatments, respectively. Different varieties of boro rice significantly varied for straw-S concentration, ranging from 0.063 to 0.078% (Table 4.7). The highest S concentration in straw was obtained in BINA dhan14 which was statistically similar to kheyali boro and BRRI dhan50. The lowest S concentration in straw was found in BINA dhan10 which was also statistically similar to BINA dhan8, BRRI dhan50 and BRRI dhan58.

The interaction effect of cadmium and variety was statistically non-significant in terms of S concentration in rice straw (Table 4.8). The highest S concentration in straw (0.10%) was in BRRI dhan50 with Cd_0 and the lowest S concentration in straw (0.045%) was found in BINA dhan8 grown with 20 ppm Cd.

Table 4.7 Main effects of added Cd and varieties on nutrients concentration in straw of different rice varieties

Factors	N (%)	P (%)	K (%)	S (%)
Cd levels (ppm)				
Cd_0	0.636a	0.104a	1.976a	0.091a
Cd_{10}	0.594b	0.092ab	1.761b	0.066b
Cd_{20}	0.578c	0.083b	1.506c	0.052b
Lsd	0.009	0.009	0.19	0.009
Level of significance	**	**	**	**
Varieties				
BINA dhan8	0.626a	0.089	1.745b	0.067bc
BINA dhan10	0.615b	0.090	1.670b	0.063c
BINA dhan14	0.609bc	0.100	2.035a	0.078a
BRRI dhan50	0.579d	0.090	1.607b	0.070abc
BRRI dhan58	0.587d	0.098	1.717b	0.063c
Kheyali boro	0.600c	0.091	1.712b	0.075ab
Lsd	0.013	0.013	0.27	0.013
Level of significance	**	NS	**	**

In a column, the figures having common letter(s) do not differ significantly at 5% level of probability.

Lsd=Least significant difference

** = $P<0.01$; NS = Non-significant

Table 4.8 Interaction effects of added Cd and varieties on nutrients concentration in straw of different varieties of rice

Variety	Treatment	N%	P%	K%	S%
BINA dhan8	Cd_0	0.667	0.099	1.875a-d	0.093
	Cd_{10}	0.612	0.087	1.715b-e	0.063
	Cd_{20}	0.599	0.083	1.645cde	0.045
BINA dhan10	Cd_0	0.648	0.098	1.910a-d	0.083
	Cd_{10}	0.604	0.094	1.690b-e	0.058
	Cd_{20}	0.593	0.078	1.410ef	0.050
BINA dhan14	Cd_0	0.647	0.106	2.225a	0.090
	Cd_{10}	0.601	0.100	1.945a-d	0.080
	Cd_{20}	0.580	0.093	1.935a-d	0.065
BRRI dhan50	Cd_0	0.611	0.105	1.850a-d	0.100
	Cd_{10}	0.570	0.085	1.555de	0.065
	Cd_{20}	0.555	0.080	1.415ef	0.045
BRRI dhan58	Cd_0	0.617	0.115	1.900a-d	0.085
	Cd_{10}	0.575	0.095	1.680cde	0.060
	Cd_{20}	0.570	0.085	1.570cde	0.045
Kheyali boro	Cd_0	0.630	0.100	2.095ab	0.095
	Cd_{10}	0.601	0.090	1.980abc	0.070
	Cd_{20}	0.570	0.082	1.060f	0.060
Lsd		0.022	0.022	0.47	0.022
Level of significance		NS	NS	*	NS

In a column, the figures having common letter(s) do not differ significantly at 5% level of probability.

Lsd=Least significant difference

* = P<0.1 NS = Non-significant

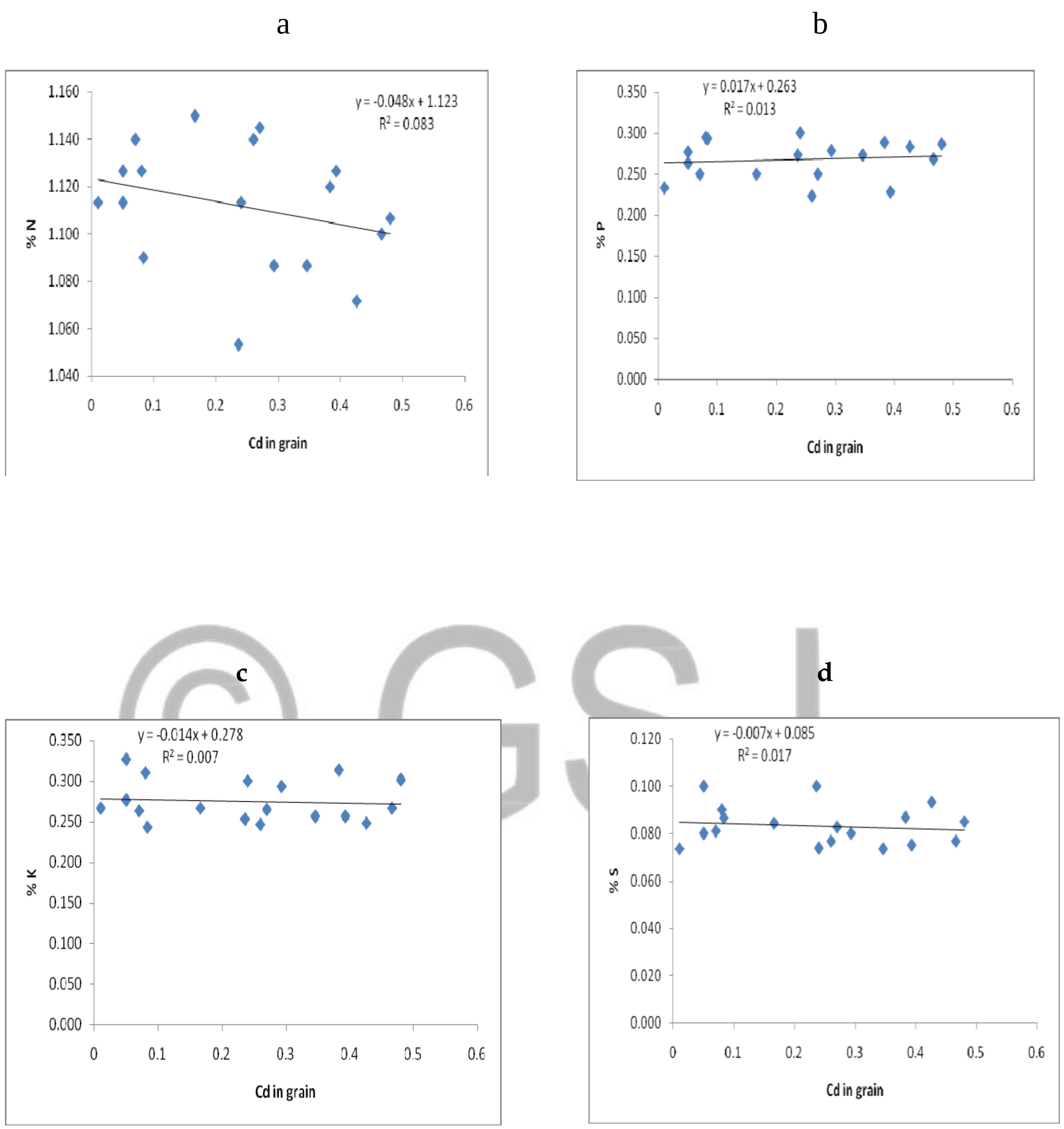

Fig.4.1 Relationship between Cd and N (a), P (b), K (c) and S (d) concentration in rice grain

CHAPTER 5

DISCUSSION

A study was undertaken during the Boro season of 2019 to evaluate the effect of Cd on boro rice genotypes. The experiment was conducted in the net house of the Department of Agriculture, Bangabandhu Sheikh Mujibur Rahman Science and Technology University, Gopalgonj.Soil application of Cd showed distinct negative effect on the growth and yield of Boro rice cv. BINA dhan8, BINA dhan10, BINA dhan14, BRRI dhan50, BRRI dhan58 and Kheyali boro. All the growth parameters tested in the 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 (Holmgren *et al*., 1993; Das *et al*., (1997). The addition of Cd to the crops decreased the growth, yield and yield contributing characters. There are many reports that application of Cd can affect crop growth and yield. According to Sarkunan *et al.,* (1991), rice yield drastically decreased due to the application of 20 ppm Cd. Similar results were reported by Alloway (1988) and Dixit (1992). Cadmium concentration above 20 ppm in soil reduces rice plant biomass by poisoning the roots and restricting the growth (Herawati *et al.,* 2000). 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.

Grain and straw yields of Boro rice were also found to be affected by As and Cd application in soil. Liu-Jian Ghou *et al.* (2007) 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.

This finding also supports the negative effects of Cd on crops. Adverse effects of heavy metals on crops have been reported by Singh and Nayyar (1991) and Sarkunan *et al*., (1991). Cadmium contamination in rice decreased the nutrient element (N, P, K and S)) concentration both in grains and straw.

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.,* 1991). It was found that Cd content in KMD rice grains reached 0.68, 0.68 and 1.45 mg kg^{-1} respectively at the Cd rates of 5, 10 and 20 mg kg^{-1} soil (Haiyan *et al*., 2009).

CHAPTER 6

CONCLUSION

The following conclusions may be drawn from the results of the experiment on “effects of cadmium contamination on yield and cadmium concentration in different varieties of boro rice”.

Cadmium contamination significantly reduced the effective tillers, plant height, seeds panicle^{-1}, 100-seed weight, grain and straw yield of all rice varieties.

BRRI dhan58 had the highest yield of grains pot^{-1} followed by BRRI dhan50 and BINA dhan8 under 20 ppm Cd applied to soil.

Cadmium contamination increased the Cd concentration in grain but reduced the concentration of N, P, K and S. Thus Cd contamination reduced grain yield and nutritional quality (N, P, K and S) of grains.

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