



**EFFECTS OF SOIL pH AND ORGANIC MATTER ON THE ACCUMULATION OF CADMIUM IN THE GRAINS OF SALT TOLERANT RICE GENOTYPES GROWN IN Cd CONTAMINATED SOIL**

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**Abstract**

Cadmium (Cd) poses a serious threat to the environment and its concentration in rice grain causes significant dangers to people's health. However, the effects of soil pH and organic matter (OM) on the accumulation of Cd in salt-tolerant rice genotypes under Cd stress remain unknown. In this study, separate pot experiments were conducted under Cd stressed soil (5 mg kg<sup>-1</sup>) with variations in soil pH and OM for the growth of rice plants. The study includes three pH (4, 7 and 9) and OM levels (1%, 2% and 3%). Under these conditions, the bioavailability of Cd in soil and its subsequent entry into the grain of rice genotypes were examined. Cd translocation from soil to the grain was compared among non-salt tolerant varieties (BRRI 28 and Heera) and salt-tolerant varieties (BRRI 67 and BRRI 47). The associated health risk assessment was also undertaken. All rice genotypes absorbed more Cd from soil and accumulated it in their grain when grown under low pH soil conditions. With increasing soil pH, grain Cd deposition declined significantly ( $p \leq 0.05$ ) in the order of Heera, BRRI 28, BRRI 67 and BRRI 47. Among the varieties a marked variation was obtained in the Cd absorption by each plant. OM addition in soil at a rate of 2% greatly reduced Cd accumulation in the grain of rice genotypes. A noticeable reduction was found in non-salt tolerant varieties over salt-tolerant genotypes. The hazard quotient (HQ) of Cd for both adults and children revealed the highest values at low soil pH conditions. Significant reductions in HQ values occurred in grain grown with OM only in non-salt-tolerant varieties. The result means that lower soil pH favors the accumulation of Cd in rice. Furthermore, grain Cd in rice genotypes can be reduced thorough the modification in soil bioavailable Cd and OM application in soil.

**Keywords:** Soil pH, Organic matter, Cd, Rice grain, Transfer factor, Hazard quotient

**Introduction**

Heavy metal load in agricultural soil persistently affects plants, animals and humans. Of the heavy metals, cadmium (Cd) has attained greater attention for its low degradability and high mobility in soil. The metal enters soil through the application of phosphatic fertilizers (Suciu et al., 2022), sewage sludge (Schiptosova et al., 2020) and various industrial activities like mining and waste production (Tang et al., 2023). Plants take up the metal easily when it is introduced to soil system and it has high bioaccumulative potential (Rahman et al., 2021a; Khanna et al., 2022). Cd shows inhibitory effects on different physiological processes inside plant cells. After entering the plant's body, it has an impact on stomatal closure, photosynthesis, and interferes with the intake and build-up of minerals (Sabir et al., 2020). Furthermore, it prevents ferric reductase production in the root and this results in a nutritional imbalance (Naveed et al., 2020).

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Plant cells experience a more pronounced oxidation of biomolecules due to the excessive presence of Cd. For example, Cd toxicity results in an excess of reactive oxygen species (ROS), which significantly diminishes the amount of antioxidants (Rahman et al., 2021b). As a result, plant growth restricts to limit crop yield (Rahman et al., 2021b). Cd finds its way into the human body through the food chain. Excess Cd in humans creates health problems that include cardiac diseases, kidney failure, osteoporosis, or hypertension, etc. Rice is the major kind of food that Bangladeshi people consume. Studies have revealed that rice plant contains excessive amounts of Cd in its grain (Hasan et al., 2022; Kibria et al., 2022). Subsequently, rice consumption will emerge as an important pathway of Cd intake for the people of Bangladesh. Humans may experience serious health-related problems due to Cd toxicity. For this reason, it is essential to understand the Cd reactivity and mobility in soil, in order to judge its probable exposure to the surroundings.

Cd absorption by plant is influenced by the availability of Cd in soil. It should be noted that the bioavailability is regulated by soil characteristics such as the pH level, content of OM, oxidation reduction potential and cation exchange capacity (Bai et al., 2020; Pan et al., 2021). Soil pH is one of the important factors affecting the speciation of Cd and its related bioavailability in soil (Kibria et al., 2022). Ali et al. (2019) stated that the adsorptive capacity of Cd in soil triples with each pH unit increase over the pH range of 4 to 7. Plants may accumulate excessive Cd with soil pH variation. According to estimates, rice grain produced in soil with a pH of 4.6 had around 2.8 times more Cd than rice grown in soil with a pH of 6.6 (Siddique et al., 2022). Identically, wheat and barley grain Cd content was considerably impacted by soil total Cd and pH (Adams et al., 2004). Potato plants grown at pH 6.5 acquired more Cd than those cultivated below this (Larsson and Asp, 2013). Raising soil pH from 4.9 to 6.0 lowered the shoot Cd content in the maize plant (Cunha et al., 2008).

In several investigations the levels of ROS in the plant were shown to be affected by pH. For instance, acidic soil pH has a major impact on the ability to prevent lipid peroxidation and oxidative damage in rice (Zhang et al., 2015) and wheat (Toth et al., 2020). Ultimately it has a detrimental effect on the grain filling stage and yield reduction. Several research studies identified pH as the main determinant of soil Cd availability. In contrast, other analyses emphasized the significance of soil OM (Cruz-Paredes et al., 2017; Chen et al., 2020). Organic residues added to heavy metal contaminated soil reduces the heavy metal phytoavailability (Pei et al., 2021). Additionally, the added materials increase organic fractions that enhance the chemical or biological qualities of soil.

Cd entry into plants depends on the kinetic features of Cd in soil. Organic matter content in the soil affects its movement (Yuan et al., 2021). Smolders and Mertens (2013) pointed out that functional groups contained in OM have a strong preference for Cd adsorption. Moreover, soil pH may be altered by OM addition either directly or indirectly (Yuan et al., 2019). This constitutes the primary variable for segregating Cd into its ionic forms. When compared to mineral soil, high OM content soil has a 30-fold higher affinity for Cd adsorption (Hamid et al., 2018). However, the capacity to bind Cd may be significantly determined by the quality of soil OM (Abbas et al., 2018).

Studies have not done much work on the effect of soil pH and OM on Cd accumulation using salt-tolerant rice varieties grown in coastal saline areas of Bangladesh. Therefore, it is necessary to take steps to examine the effect of soil pH and OM to identify the availability of Cd and their entry into salt-tolerant rice genotypes. Moreover, the techniques of Cd minimization in rice plant using different rates of soil OM should be explored. The present investigation was designed to find out the effects of soil pH and soil OM on: (i) Cd accumulation and uptake in the grain of salt-tolerant rice genotypes; (ii) transfer factor of Cd from soil to rice grain; and (iii) hazard quotient (HQ) of Cd through rice intake grown under Cd stress conditions.

## **Materials and Method**

### **Soil preparation**

Samples of agricultural topsoil (0–15 cm) were taken from a field on the campus of Khulna University. Collected samples were air dried, unwanted materials were removed and sieved through a 2 mm sieve. Moist soil equivalent of 5 kg dry soil was placed inside earthen pots and spiked with CdCl<sub>2</sub>·2H<sub>2</sub>O salt to achieve 5 mg kg<sup>-1</sup> Cd concentration. On this Cd contaminated soil, three desired soil pH levels (pH 4, 7 and 9) were maintained by the addition of either NaOH or HCl. To obtain three levels of soil OM (1%, 2% and 3%) cow dung was used in appropriate quantity. Complete randomized design (CRD) was followed for pot arrangement. Each treatment was replicated in triplicate. The experimental soil was analyzed and it contained 2.60 mg kg<sup>-1</sup> Cd, pH 7.86 and an EC value of 1.90 dS/m. The routine analysis of the soil is presented in Table 1.

Table 1. Routine analysis of experimental soil

Parameters	Soil
Moisture content (%)	14.06 ± 0.38
Sand (%)	14.25 ± 1.42
Silt (%)	50.57 ± 2.58
Clay (%)	35.18 ± 1.14
Textural Class	Silty clay loam
Bulk Density (gcc <sup>-1</sup> )	1.05 ± 0.12
pH <sub>H2O</sub> (1:2.5)	7.86 ± 0.02
pH <sub>H2O</sub> (1:1)	8.11 ± 0.01
pH <sub>KCl</sub> (1:2.5)	7.43 ± 0.12
pH <sub>CaCl2</sub> (1:2.5)	7.73 ± 0.12
EC(dS/m)	1.90 ± 0.18
Organic C (%)	1.28±0.21
Total Cd (mg kg <sup>-1</sup> )	2.60 ± 0.10
Bioavailable Cd (mg kg <sup>-1</sup> )	0.50± 0.03

Mean±sd

### Selection of Rice Varieties and pot experiment

Salt sensitive (BRRI 28 and Heera) as well as salt-tolerant (BRRI 47 and BRRI 67) rice varieties commonly grown in the southwest coastal region were selected for this study. 35 days-old seedlings of these rice varieties were placed into the pots (1 seedling per pot). The pot experiment was conducted from January to April in 2021. Throughout the whole growing period, the pots were kept under flooding conditions. Urea, TSP, Muriate of Potash (MOP) and gypsum were added to pot soil as sources of N, P, K and S at the rate of 100 kg N, 60 kg P<sub>2</sub>O<sub>5</sub>, 75 kg K<sub>2</sub>O and 20 kg S ha<sup>-1</sup>, respectively (BARC, 2018). One third urea and whole amounts of TSP, MOP, gypsum were applied 1 week prior to transplantation of rice plants. The remaining two-thirds of the urea were top dressed in two equal installments at 25 and 50 days after transplanting. At maturity, the plants were sampled and were hand-threshed following the panicle count. Grain samples were collected for the purpose of Cd determination.

### Analytical methods

Soil particle size was detected as described by Gee and Bauder (1986) using the hydrometer method. The pH of the soil was measured as suggested by Li et al. (2005). EC was measured by taking 10 g air dried soil (soil:water, 1:5) by an EC meter (Hanna, HI2315, USA) (Hardie and Doyle, 2012). Soil was digested for Cd determination by taking 0.50 g of air dry soil with 10 ml of acid mixture (HNO<sub>3</sub>:HClO<sub>4</sub> = 2:1) (Hseu, 2004).

Rice grain sample analysis for Cd determination:

For the analysis of the Cd content, the chaffs were separated from the grain and oven dried at 80°C to produce a consistent weight. A roller was used to thoroughly grind the dry sample. About 1 g grain sample was taken to digest with 10 ml of acid mixtures (HNO<sub>3</sub> and HClO<sub>4</sub>) at a ratio of 2:1(v/v). This acid mixture was heated at 180°C until it became colorless. The resultant solutions were filtered using Whatman filter paper no. 42. Finally, the content was marked to 25 ml volumetric flask using distilled water. Cd was determined in the digests utilizing atomic absorption spectrophotometry (Shimadzu AAS System AA-7000, Japan).

### Determination of Cd content, uptake and transfer factor (TF):

Cd content in the digest was determined by appropriate calculation. Cd uptake by rice grain was measured according to the equation (Zhang et al., 2007): Cd uptake = dry weight (DW) x Cd concentration

TF was calculated according to the following formula (Wang et al., 2006):

$$\text{Transfer Factor (TF)} = (\text{Cd concentration in the grain (mgkg}^{-1}\text{)}) / (\text{Cd concentration in soil (mgkg}^{-1}\text{)})$$

### Noncarcinogenic health risk assessment

HQ values were calculated according to the equation formulated from Kibria et al (2022) as follows:

$$\text{HQ} = \text{C} \times 9.47 \text{ (for adult)} \text{ and } \text{HQ} = \text{C} \times 9.38 \text{ (for children)} \text{ where C stands for rice grain Cd concentration in mg kg}^{-1}.$$

### Quality assurance and quality control

The samples were prepared in controlled conditions. Samples were transported as soon as possible in paper bags to the laboratory. Then the plant samples were properly cleansed in distilled water after being rinsed with tap water. The Cd that was added to the chemicals used in the study was removed using a reagent blank. Triplicate samples, reading, and continuing check verifications (CCVs) to reduce analytical error were all employed in the sample analysis of Cd.

### Statistical Analysis

STATISTIX (version 10.0) software was deployed to analyze the data. Analysis of variance (ANOVA) was implemented for calculation. Means were differentiated using the Tukey HSD comparison method at a 5% level of significance.

## Results

### Effects of soil pH on the bioavailable Cd in soil and its subsequent accumulation in grain

#### Cd bioavailability in soil

Cd bioavailability in soil was greater in soil with low pH which decreased gradually when the pH level rose (Figure 1). At pH 4.0, Heera exhibited the highest bioavailable Cd which was 0.68 mg kg<sup>-1</sup>. Bioavailable Cd for BRRI 47, BRRI 67 and BRRI 47 amounted to 0.53 mg kg<sup>-1</sup>, 0.60 mg kg<sup>-1</sup> and 0.53 mg kg<sup>-1</sup>, respectively. At neutral soil pH, bioavailable Cd showed a similar pattern of change among rice genotypes. Results indicated that bioavailability of Cd in soil at low pH was mainly influenced by the rice genotypes. However, at pH 9.0, variation in Cd bioavailability became minimal within the rice genotypes.

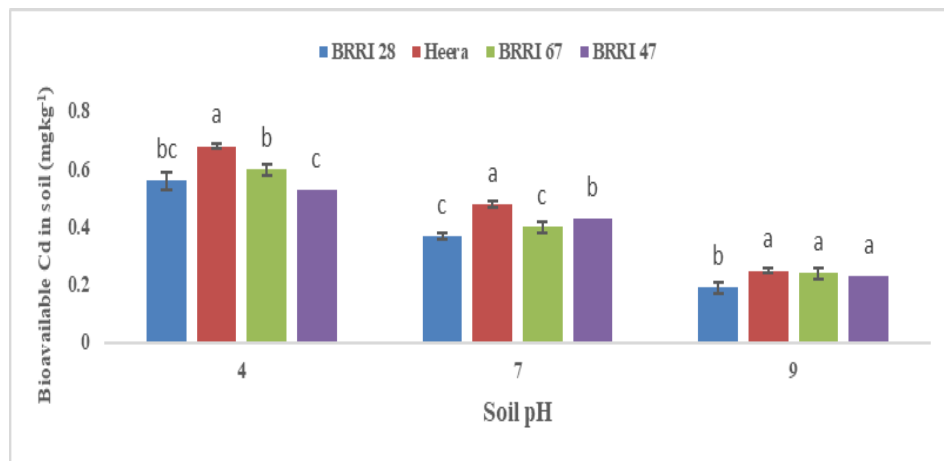


Figure 1. Effects of soil pH on the bioavailability of Cd in soil. Bars with the same letter are not significantly different at  $p < 0.05$  level.

#### Cd accumulation and uptake in rice grain

The accumulation of Cd in the grain of different rice genotypes under the variations in soil pH is shown in Figure 2. In general, Cd concentrations were elevated in rice grain at low pH and it declined when the soil pH increased. The variations in grain Cd content were more prominent within the variety at a specific pH value. The highest Cd was accumulated in the grain of Heera (1.91 mg kg<sup>-1</sup>) followed by BRRI 28 (1.73 mg kg<sup>-1</sup>), BRRI 67 (1.59 mg kg<sup>-1</sup>) and BRRI 47 (1.15 mg kg<sup>-1</sup>), respectively, at pH 4.0. When soil pH rose from 4.0 to 7.0, all rice varieties aside from BRRI 47 experienced a large decrease in grain Cd.

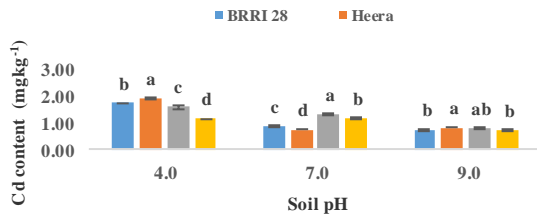


Figure 2. Effects of soil pH on Cd content in the grain of different rice varieties. Bars with the same letter are not significantly different at  $p < 0.05$  level.

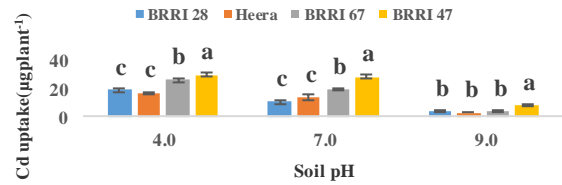


Figure 3. Effects of soil pH on Cd uptake in the grain of different rice varieties. Bars with the same letter are not significantly different at  $p < 0.05$  level.

When the pH was elevated from 4.0 to 7.0, Cd accumulation in the grain of BRRI 28 and Heera reduced to 49.13% and 60.73%, respectively. Only 18.24% of the reduction was evident in BRRI 67, and apparently no reduction was observed in BRRI 47. Due to these variations, it is alarming to grow salt-tolerant rice in soil with low pH. When soil pH increased, the Cd concentration continued to decline from its maximal level. For all rice grains except Heera, a noticeable drop in Cd concentration was observed when the soil pH was adjusted to 9.0. The grain Cd uptakes with varying soil pH of rice genotypes are shown in Figure 3. Cd uptake showed a decreasing order as follows - BRRI 47 > BRRI 67 > BRRI 28 = Heera. However, the change in the grain Cd uptake within the rice genotypes significantly varied for salt-tolerant rice.

### Transfer Factor (TF)

TF is used to measure the ability of Cd transport to different parts of the plant. Cd can be transferred easily from soil to plant with a high TF value. Results showed that low Cd was transported from soil to the grain ( $TF < 1$ ) of rice genotypes irrespective of soil pH (Figure 4). At pH 4.0, there were significant differences in the TF of different rice genotypes. The maximum TF was found in the grain of Heera (0.13) and the lowest in BRRI 47 (0.06). BRRI 28 and BRRI 67 had TF values of 0.10 and 0.11, respectively, in this scenario. The result also indicated that the TF value reduced with the increase in soil pH although the changes were insignificant.

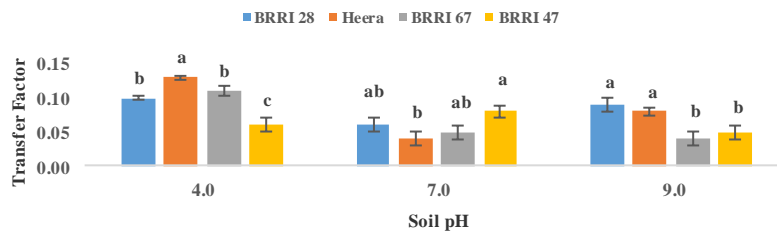


Figure 4. Effects of soil pH on transfer factor of Cd to grain in different rice varieties. Bars with the same letter are not significantly different at  $p < 0.05$  level.

### Hazard Quotient (HQ)

Consumption of contaminated food crops is one major route for Cd to enter the human body. The hazard quotient (HQ) values of Cd through rice grain in various soil pH levels are given in Figure 5. Depending on the soil pH, both salt-tolerant and non-salt-tolerant rice genotypes had HQ values of greater than 1 for both adults and children. The outcome indicated that HQ of rice plants proved to be significantly high when grown at low to neutral soil pH. Consequently, rice grain consumption may pose health risks to people. Appropriate measures then should be taken to reduce the entry of Cd into the grain of rice plant.

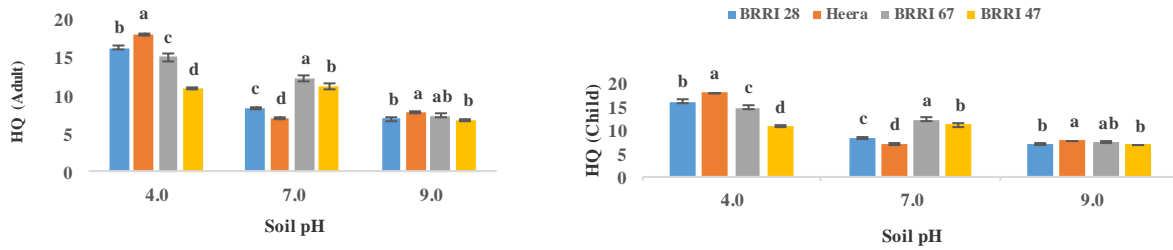


Figure 5. Effects of soil pH on hazard quotient of Cd in different rice varieties for adult and child. Bars with the same letter are not significantly different at  $p < 0.05$  level.

### Correlation between grain Cd with soil bioavailable Cd

The correlation between grain Cd with soil bioavailable Cd is calculated and displayed in Table 2. The strength of the relationship is expressed by correlation coefficient,  $r$ . The measured  $r$  values for grain Cd and soil bioavailable Cd suggested a strong positive relationship regardless of rice varieties. The present study indicated that soil pH was the major determinant in controlling grain Cd content.

Table 2. Correlation between grain Cd with soil bioavailable Cd under different soil pH

Variety	pH	Grain Cd (mg kg <sup>-1</sup> )	Soil Bioavailable Cd (mg kg <sup>-1</sup> )	Pearson correlation coefficient ( $r$ )
BRR1 28	4	1.73	0.56	0.93**
	7	0.88	0.37	
	9	0.74	0.19	
Heera	4	1.91	0.68	0.87**
	7	0.82	0.48	
	9	0.75	0.25	
BRR1 67	4	1.59	0.60	0.96**
	7	1.3	0.40	
	9	0.78	0.24	
BRR1 47	4	1.15	0.53	0.92**
	7	1.18	0.43	
	9	0.72	0.23	

\*\*Significant at  $p < 0.01$

### Effects of soil OM on the bioavailable Cd in soil and its subsequent accumulation in grain Cd bioavailability in soil

The concentration of bioavailable Cd in soil varied according to the application rate of soil OM (Figure 6).

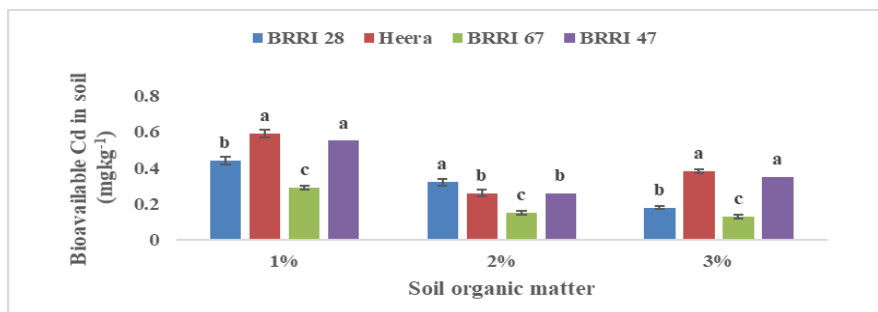


Figure 6. Effects of soil organic matter on the bioavailability of Cd in soil. Bars with the same letter are not significantly different at  $p < 0.05$  level.

At the low rate (1%), bioavailable Cd was found to be the lowest in the BRRI 67 rice, which was 0.29 mg kg<sup>-1</sup> followed by BRRI 28 (0.44 mg kg<sup>-1</sup>). At this OM level Cd bioavailability did not change significantly for Heera and BRRI 47 rice. Soil bioavailable Cd was further diminished when a high rate of application was used. The smallest amount was recorded for BRRI 67 which was 0.15 mg kg<sup>-1</sup> and 0.13 mg kg<sup>-1</sup> obtained at 2% and 3% rates, respectively.

### Cd accumulation and uptake by rice grain

Cd content in the grain of both non-salt-tolerant and salt-tolerant rice genotypes significantly varied with the addition of OM (Figure 7). Cd build-up in the grain of rice genotypes decreased more with 2% OM addition.

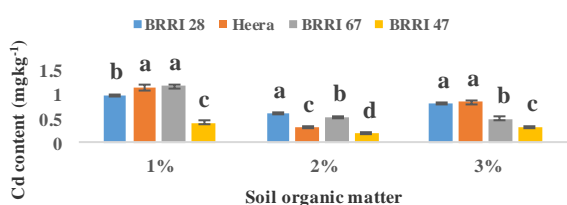


Figure 7. Effects of soil organic matter on Cd content in the grain of different rice varieties. Bars with the same letter are not significantly different at  $p < 0.05$  level.

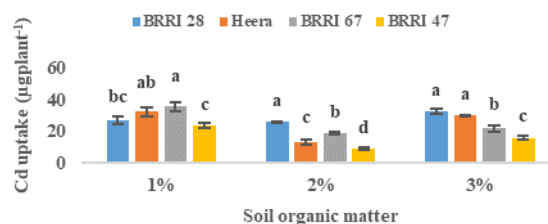


Figure 8. Effects of soil organic matter on Cd uptake in the grain of different rice varieties. Bars with the same letter are not significantly different at  $p < 0.05$  level.

In non-salt-tolerant rice, a greater reduction in grain Cd was found in Heera rice which was 72% compared to BRRI 28 in which only 39% reduction in grain Cd was recorded. In salt-tolerant rice genotypes, these reductions were, respectively, 54.71% and 53.66% found in BRRI 67 and BRRI 47 rice. More Cd was accumulated in the grain with the application of OM beyond 2% for all the rice varieties. Variations in grain Cd uptake were also noticed with the application of various rates of soil OM (Figure 8). During the application of 1% OM, the highest Cd uptake was obtained in the grain of BRRI 67 (35.85 µg plant<sup>-1</sup>) which insignificantly varied with Heera (32.60 µg plant<sup>-1</sup>). Higher variations in Cd uptake within the rice cultivars were found when OM was applied at the 2% rate. At this rate, BRRI 47 showed the lowest Cd uptake which was 9.03 µg plant<sup>-1</sup> followed by Heera (13.37 µg plant<sup>-1</sup>). BRRI 67 and BRRI 28 showed Cd uptake of 19.16 and 25.99 µg plant<sup>-1</sup>, respectively. Organic matter applied at the 3% rate could not minimize grain Cd uptake and instead it was increased in some instances. In this case only salt-tolerant rice showed significant differences.

### Transfer Factor (TF)

The transfer factor (TF) of Cd from soil to the grain of both salt-tolerant and non-salt-tolerant rice genotypes is described in Figure 9. Significant variations in TF were found within the rice genotypes at a low rate (1%) of OM addition. At this rate, the lowest TF was recorded for BRRI 47 rice (0.04) and it did not differ with TF of BRRI 67 (0.09). However, the TF of BRRI 28 and Heera were similar. The outcome showed that salt-tolerant rice genotypes bear relatively lower TF value than that of non-salt-tolerant rice (Figure 9). The TF in the rice was mostly unchanged with the addition of a high OM rate. This means that a low rate of OM application regulates the Cd translocation from soil to the grain of rice plant.

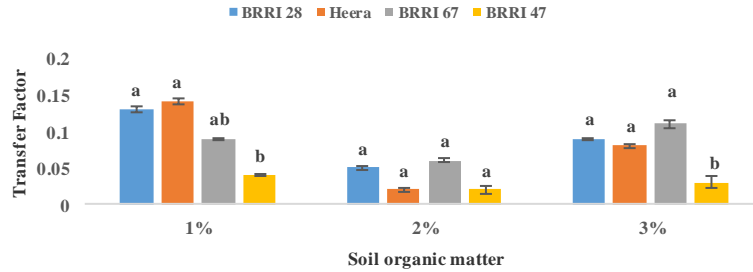


Figure 9. Effects of soil organic matter on transfer factor of Cd to grain in different rice varieties. Bars with the same letter are not significantly different at  $p < 0.05$  level.

### Hazard Quotient (HQ)

Figure 10 showed the effects of soil OM on the HQ values of Cd for different rice genotypes. BRRi 28 rice genotype revealed the lowest value of HQ following the addition of 3% OM for both adult (0.92) and child (0.91). The result demonstrated the potential of OM addition to lower the HQ of Cd in rice grain.

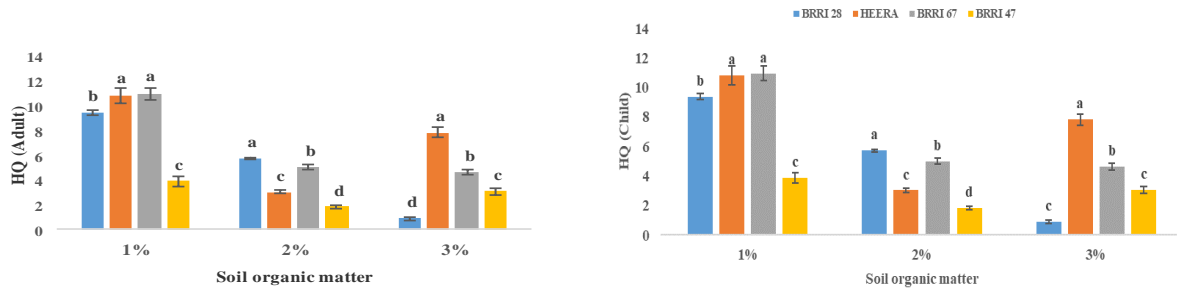


Figure 10. Effects of soil organic matter on hazard quotient of Cd in different rice varieties for adult and child. Bars with the same letter are not significantly different at  $p < 0.05$  level.

### Correlation between grain Cd and soil bioavailable Cd

The correlation between grain Cd and soil bioavailable Cd after adding OM in soil is shown in Table 3. The strength of the relationship ( $r$ ) was a strong positive one. The study specifies that Cd bioavailability in soil is noticeably controlled by the amount of OM in soil rather than by the rice genotypes itself.

Table 3. Correlation between grain Cd with soil bioavailable Cd under different soil organic matter

Variety	OM	Grain Cd (mg kg <sup>-1</sup> )	Soil Bioavailable Cd (mg kg <sup>-1</sup> )	Pearson Correlation coefficient ( $r$ )
BRRi 28	1%	1.00	0.44	0.99**
	2%	0.61	0.32	
	3%	0.10	0.18	
Heera	1%	1.15	0.59	0.95**
	2%	0.32	0.26	
	3%	0.84	0.38	
BRRi 67	1%	1.17	0.29	0.99**
	2%	0.53	0.15	
	3%	0.49	0.13	
BRRi 47	1%	0.41	0.55	0.92**
	2%	0.19	0.26	
	3%	0.33	0.35	

\*\*Significant at  $p < 0.01$

## Discussion

Soil pH plays an important role in influencing Cd bioavailability. The increase in bioavailable Cd was attributed to the increased positive charges on soil colloid under low soil pH conditions (Wang et al., 2021). Here,  $\text{Cd}^{2+}$  competes with other cations for the exchange sites present in soil solution. Hence, it limits the opportunities of  $\text{Cd}^{2+}$  for adsorption. Conversely, Cd bioavailability was reduced at higher soil pH due to the increased negative charges on soil colloids. These charges may arise from the dissociation of various functional groups such as  $-\text{OH}$ ,  $-\text{COOH}$ , and  $\text{CO}_3^{2-}$ . These anions immobilize  $\text{Cd}^{2+}$  in soil by precipitation, adsorption, ion exchange, or electrostatic methods (Liu et al., 2020). The findings of the current study revealed that at low pH, rice genotypes may play an important role for the increased Cd bioavailability in soil. At high soil pH, bioavailability was mainly controlled by soil properties.

Regardless of the rice genotypes, Cd accumulation and uptake were elevated in low soil pH but gradually decreased in high soil pH conditions. The enhanced bioavailability of Cd in soil may be the result of the escalated Cd build-up and its uptake in the grain at low soil pH. In non-salt-tolerant rice, more Cd moves to the grain as the pH of the soil rises from 4.0 to 7.0. Conversely, a reverse trend was found with salt-tolerant rice.

Many researchers have suggested that increased bioavailability of Cd in low soil pH raises the Cd level in rice grain (Meng et al., 2018; Ali et al., 2019; Kicinska et al., 2021). Alterations in the TF at low soil pH were not controlled by soil chemical properties. Yet, as pH rises gradually, the changes in TF within the rice genotypes become less evident, meaning that changes in TF were influenced by soil pH under this condition. The TF of Cd in the grain of rice genotypes ranges from 0.06 to 0.13 at low soil pH, 0.04 to 0.08 at neutral soil pH and 0.04 to 0.09 at high soil pH. Song et al. (2015) reported soil to grain bio-concentration factors of 20 rice cultivars ranging from 0.30 to 1.11. All rice genotypes exhibited high HQ ( $>1$ ) regardless of the soil pH. As a result, rice grown under this soil condition may create risks for people in terms of HQ. Therefore, appropriate measures are needed to grow rice plant in soil with varying levels of pH.

The variations in bioavailable Cd were influenced by the rates of OM applied and rice genotypes grown. Higher application rate dramatically lowered the available Cd in soil. The differences in Cd content and its uptake by rice grain were also influenced by the added OM in soil. However, higher bioavailability and grain Cd accumulation were noticed with low rates of OM. This indicates low OM had little capacity to reduce the uptake of Cd in rice grain. According to reports, organic manure like cow dung contains a significant amount of humified OM. This could release free radical ions such as  $\text{OH}^-$ ,  $\text{HPO}_4^{2-}$ , and  $\text{CO}_3^{2-}$  upon decomposition.  $\text{Cd}^{2+}$  ion reacts and precipitates as insoluble compounds and in this way reduces the bioavailability of Cd (Lei et al., 2019; Budianta et al., 2022).

In addition, the oxygen-containing functional groups (such as  $-\text{OH}$ ,  $-\text{COOH}$ , and  $\text{C}=\text{O}$ ) on the surface of OM could complex with Cd in soil. This has the effect of immobilizing Cd in soil (Rocco et al., 2018; Hamid et al., 2019; Li et al., 2022). A larger dose of OM application increases Cd accumulation and uptake in some instances. This may be the fact result of the released Cd from the binding site of OM. The reduction in the transfer of Cd in the rice plant may be attributed to the formation of an organic metal complex. This metal complex formed from the increased CEC and functional groups after adding OM. The outcome agrees with what was observed by Li et al. (2022). In BRRI 28 rice, HQ was found  $<1$  for both adult and child at 3% OM. Indicated here is the low potential risk for health of BRRI 28 rice consumption.

## Conclusion

Impacts of pH and OM in soil at constant soil Cd concentrations were examined in order to predict grain Cd accumulation in non-salt-tolerant and salt-tolerant rice genotypes. Cd bioavailability increased in soil with low soil pH and OM. The rate of Cd build-up in rice grain was reduced by raising the soil's pH. Non-salt-tolerant rice had greater ability for this reduction compared to salt-tolerant rice. BRRI 47 has a strong ability to accumulate Cd over a wider pH range than the other rice genotypes. This makes it more vulnerable to grain Cd deposition to variations in soil pH. Rice grain from both salt-tolerant and non-salt-tolerant strains of rice absorbs more Cd from the soil when the pH is low due to increased Cd bioavailability. The quantity of OM supplied, and rice genotypes employed determine how much Cd is transferred and accumulated in the grain. According to the transfer factor values, it can be inferred that 2% OM had a superior capacity to reduce Cd deposition in the grain of various rice genotypes. The HQ values of Cd for rice grain grown in a variety of soil pH ranges were over the safe limit, making this rice susceptible to causing health issues for both adults and children. Conversely, BRRI 28 rice cultivated on soil with an addition of 3% OM had HQ of Cd values that were determined to be safe for both adults and children. On this

basis, it was assumed that consuming BRRI 28 rice posed no health risks. According to the study, controlling soil Cd phytoavailability may be accomplished by modifying pH and OM of soil even if this needs to be assessed in a field environment. Correlation study confirmed that grain Cd can be controlled by manipulating soil bioavailable Cd. Therefore, soil pH and soil OM modification emerge as a promising option to regulate Cd bioavailability in soil.

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### Conflict of Interest

None of the authors present any conflicts of interest.

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