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Review article

Cadmium Pollution in the Soil-rice Ecosystem of Bangladesh: A review

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ABSTRACT

The people of Bangladesh are in deliberate health risk threat due to the entrance of excessive amounts of Cd as a result of the unsafe content of the metal in both agricultural soil and rice grain. This review is designed to update the available information regarding the presence of Cd in Bangladesh's soil-rice ecosystem. There is inadequate research so far about Cd in the agricultural system of Bangladesh. None of the studies found suitable to represent the presence of Cd in the soil-rice ecosystem in Bangladesh. This is because most of the investigations involve a particular region of the country with a limited number of samples. A review of the available literature shows that agricultural soils of Bangladesh contain Cd within the range of 0.83–5.23 mg/kg which is higher than the limit value (1 mg/kg). Triple superphosphate (TSP) fertilizer is the major source of Cd in paddy soils. On the other hand, studies identified higher Cd content in the rice grain above the safe limit (0.2 mg/kg). Consumption of rice is the major route to transfer Cd from soil to Bangladeshi citizens. Therefore, the practice of effective measures to minimize Cd content in rice grain is required to reduce the dietary intake of Cd. The maximum allowable concentration (MAC) for Cd in rice may be set to 0.10 mg/kg for Bangladesh for reliable health risk assessment. There should be an national reference MAC value set by Government of Bangladesh (GoB) which also need to be updated in every five to ten years.

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Introduction

Cadmium (Cd) is identified as a dominant environmental pollutant causing risks to the whole ecosystem (Jibril et al., 2017; Zhou et al., 2019). Among 20 most hazardous lethal heavy metals commonly discharge in environment Cd ranks 7th (Saengwilai et al., 2020). Zhao et al. (2015) even claim Cd contamination in agricultural soil as the most serious contamination of its kind. The accelerated release of Cd from both geogenic and anthropogenic activities into the ecosystem puts a deliberate threat to the ecosystem especially human health through contamination of food chain (Purakayastha and Chhonkar, 2009; Dodangeh et al., 2018). Cd research during the last decades has attained widespread attention around the globe because of its toxicity to human, chronic life time build up, biomagnification, pollution in agricultural land etc. (Alengebawy et al., 2021). Bangladesh is one of the countries where significant Cd addition in crop land is observed (Bhattacharyya et al., 2008; Islam et al., 2018). Once incorporated it is difficult to withdraw the metal from the soil and its further degradation is enduring (Jiang et al., 2012). Hence, Cd pollution in cultivated soils and the consequent flow of this toxic metal into food is a high preference environmental research interest globally in connection to food safety (Mamun et al., 2021b).

More than 168.22 million people in Bangladesh take rice twice a day or even more as their staple food (BBS, 2022). General observation shows that about 80% of this population consumes rice even thrice a day (Islam et al., 2015). Bangladesh approximately produces 37.6 million metric tons (MT) of rice annually (BBS, 2021) and ranks third position in terms of global rice production next to

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China and India (BBS, 2022). At present, people of Bangladesh are the highest consumer of rice (181.3 kg/year) worldwide per capita basis (FAO, 2020). Moreover, Cd content of the rice grain produced in agricultural soils of Bangladesh is observed above the safe limit (0.2 mg/kg) in several studies (Al-Rmalli et al., 2012; Meharg et al., 2013; Hezbullah et al., 2016; Uddin et al., 2017; Mamun et al., 2018; Kormoker et al., 2020; Shi et al., 2020). Eating rice is the prime source of Cd in the human body in rice based diet (BfR, 2018; Jean et al., 2018; Su et al., 2021). Higher amount of Cd in rice grain as well as highest consumption of the grain in regular diet put Bangladeshi people under serious health hazard threat (Al-Rmalli et al., 2012; Shi et al., 2020). Therefore, immediate measures are needed to be taken to minimize the flow of Cd from soil to human through rice in order to ensure safe health for the people of Bangladesh (Chen et al., 2020).

The above scenario clearly reveals the fact that there is an excessive flow of Cd in soil-rice agricultural environment of Bangladesh which severely threats human health (Figure 1). The major objective of this review is to bring the Cd status of soil and rice in Bangladesh.

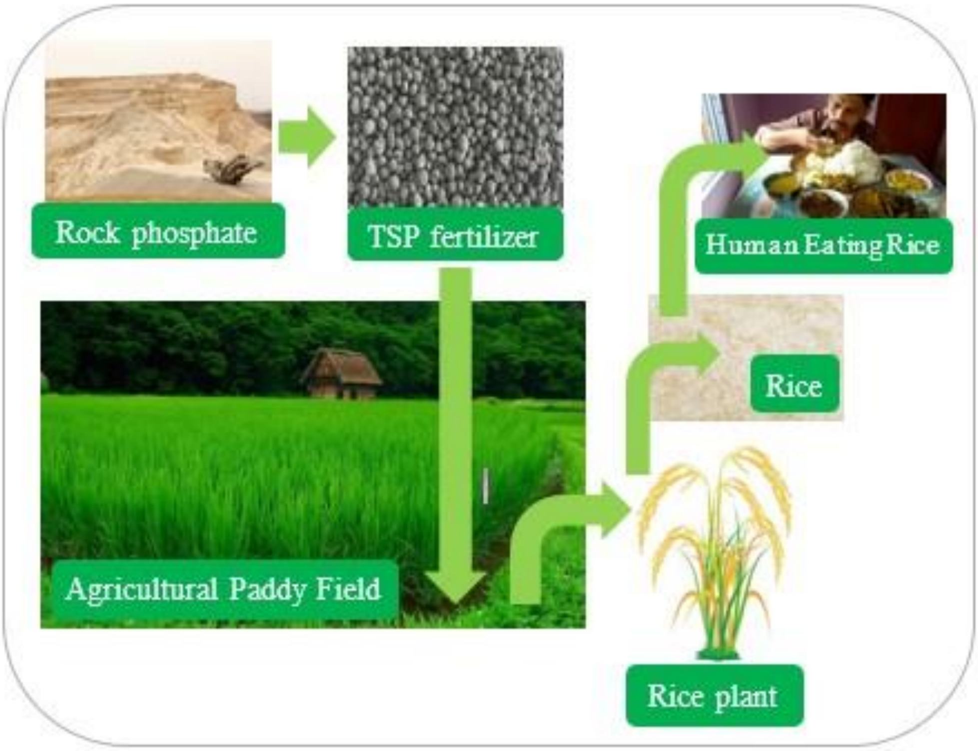

Figure 1. Flow of Cd from its natural reservoir to human through rice

Materials and methods

Online resources were explored from frequently used academic search engines such as Springer Link, Google Scholar, Research-Gate, Science Direct, Scopus and PubMed by December, 2022. About 30 review papers, research articles, GoB and NGO reports were critically analyzed. Selected materials were synthesized into this review that were compatible with the objective.

Phosphatic fertilizers as the major source of Cd in the soil-rice ecosystem

Rice production and increasing fertilizer demand

Rice (*Oryza sativa* L.) is the most popular cereal globally (USA Rice, 2020) which is consumed as a staple food by more than 50% of the people of the globe (FAO, 2021). Rice grain provides energy, amino acids, vitamins, and minerals to human beings (Zeng et al., 2011). Farmers prefer rice cultivation instead of other crops due to its wide adaptability under various ecosystems with lower risk of cultivation (Mamun et al., 2021a). The current rice production of the world is estimated to be 503.17 million MT by USDA (2020). According to the organization, more than 75% of the rice is produced by only six countries including China (29.5%), India (23.8%), Bangladesh (7.0%), Indonesia (6.9%), Vietnam (5.4%) and Thailand (3.7%).

People of Bangladesh get about half of their protein and two-third of their energy supply by eating only rice (Dev et al., 2014). Rice is the backbone of Bangladesh's agriculture (Brolley, 2015) and it alone contributes about 4.5% to the GDP (BBS, 2020). Bangladesh ranks third worldwide in rice production (BBS, 2022) and produced more than 37.6 million MT rice from about 11.7 million hectares of land at an average yield of 3.22 t/ha during 2020–21 (BBS, 2021). The crop is grown in about 78% of the total area under cultivation in the country (Mamun et al., 2021a). Above 96% of the land under cereal cultivation is occupied by rice (Sarwar and Biswas, 2021). Therefore, food security is equivalent to rice security in Bangladesh (Kabir et al., 2020).

It is the major crop that is grown throughout the year in all cropping seasons. Aman, Boro and Aus seasons separately produced 14.4, 19.9 and only 3.3 million MT of rice in 5.6, 4.8 and 1.3 million hectares of land, respectively, during 2020–21 (BBS, 2021). Mamun et al. (2021a) reported that the annual contribution of Boro rice in domestic production is observed to be yearly rising at 0.97%, whereas both Aman and Aus rice is decreasing by 0.49% and 0.48%, respectively. Analyzing the rice yield data of the past 36 years, it is observed that the five top rice growing areas in Bangladesh are Mymensingh (13.9%), Rangpur (9.8%), Bogura (8.6%), Jashore (8.6%) and Rajshahi (8.2%). Annual increment of Boro area under rice cultivation is 3.57% in between 1984–85 to 2019–20. During this period, HYV rice adaptation rate elevated in Boro, Aman and Aus as 98.4%, 73.5% and 72%, respectively. Therefore, the overall production of rice in all cropping seasons has increased in Bangladesh. The country produces 37.6 million MT rice in 2020–21 which is about three times higher than the production of 10.59 million MT in 1971–72 (BBS, 2022). Taking the population growth rate as 1.4% the increasing population will demand more rice to produce in years to come. In addition, rice grain quality is needed to be improve to ensure food safety. Both food security and safety issues need to be seriously addressed to meet the SDG (Kabir et al., 2020).

The agricultural sector in Bangladesh has markedly developed during the last three decades. The agricultural system has significant shift from traditional practices to intensive cultivation and hence, the overall production has remarkably increased (SRDI, 2019). During this tenure cropping intensity has evolved two to three times. Moreover, the introduction of HYV and to achieve higher yield goals the present agriculture depends on the use of chemical fertilizers. Hence, crop cultivation is beyond imagination without using inorganic fertilizers under the current agricultural system. Therefore, the use of inorganic fertilizers in Bangladesh is increasing day by day. According to FRG (2018), fertilizer use in the country has increased about 2.81 times from 1,709 MT in 1988–89 to 4,802 MT in 2016–17. Particularly the use of phosphatic fertilizer in 2016–17 was 1,349 MT while in 1988–89 the amount was only 416 MT. The increment in phosphatic fertilizer usage is about 3.24 fold in 28 years (FRG, 2018). TSP production also increased noticeably during this tenure (Table 1). The global demand for phosphatic fertilizer was 41.7 million ton during 2013 and this raised to 46.6 million ton in 2018. It is expected to increase about 2.2% yearly (Gupta et al., 2019).

Table 1: The trend of TSP fertilizer use in Bangladesh (*FRG, 2018; **BBS, 2021)

Year	***TSP** (in metric tons)*		
	Use*	***Production*****	***Import*****
2010–11	-	63	481
2011–12	641	65	615
2012–13	654	40	566
2013–14	685	86	543
2014–15	722	88	678
2015–16	730	95	632
2016–17	740	107	662
2017–18	-	100	779
2018–19	-	97	779
2019–20	-	104	566
2020–21	-	92	386

Based on the 1.4% of population growth rate, it is calculated that Bangladesh's population may become 290.83 million by the year 2050 (UO, 2019). Hence, an increase in total rice production is required to feed this ever-increasing population. According to the estimation, based on the rice demand as 153.02 kg/person/year, Bangladeshi people will demand 68.09 million MT of rice by 2050, which is about 1.8 times higher than the rice demand in 2007. To grow such amount of rice in 2050, the required fertilizer estimates as 39.17 lakh ton urea, 21.77 lakh ton TSP and 17.13 lakh tons of MP as well as other fertilizers (UO, 2019). At the same time, the total cultivable land is decreasing at a rate of more than 1% per year owing to the construction of industries, factories, houses, roads, and highways (Shelley et al., 2016). On the other hand, due to urbanization, food habits tend to change, demanding the cultivation of new crops that must share land used for rice cultivation. Therefore, attempts should be made to increase the yield of rice per unit area basis.

TSP production and import

Triple Super Phosphate Complex Limited (TSPCL) is the only fertilizer factory in Bangladesh to produce TSP. It is under the administrative control of Bangladesh Chemical Industries Corporation (BC1C) which is located at Patenga in Chittagong. The factory uses rock phosphate as a raw material for TSP which is imported from Jordan, Morocco, Egypt, China, Algeria and Syria (TSPCL, 2022). TSP is manufactured by decomposition of rock phosphate ground to the fineness of 80% pass through 200 Tyler mesh in an air swept ball mill, with phosphoric acid (50% P_2O_5) in a reaction den under standard conditions of temperature and flow. The den product is known as green TSP. Green TSP is fed in a granulator through conveying system, where granules are formed through the principle of agglomeration with steam and processed water. Granular TSP is then dried with hot air generated by the combustion of natural gas and then bagged to get the finished product of granular TSP (TSPCL, 2022). The reaction is as follows

$$Ca_3(PO_4)_2 + 4H_3PO_4 + 3H_2O = 3CaH_4(PO_4)2H_2O$$

During the manufacturing process no step is involved to eliminate Cd which is present as a natural impurity in rock phosphate. Therefore, the amount of Cd initially present in rock phosphate directly become incorporated into TSP fertilizer. TSPCL does not analyze either rock phosphate or TSP for their Cd content (TSPCL, 2022). It is evident from Table 2 that the Cd content of rock phosphate considerably varies in nature.

GoB monitoring of fertilizer quality

GoB follows "Fertilizer management guideline 2007" (SRO no. 92-Law/2007, gazette published on 30 May, 2007) to supervise fertilizer related affairs. This monitoring covers fertilizer manufacture, procurement, import, circulation, storing, retailing etc. of all kind of fertilizers and related materials. The act also includes fines and punishment in case of unauthorized conduct in this regard. GoB has set a maximum allowable concentration (MAC) value for heavy metals in fertilizer by endorsing the fact that they impair fertilizer quality and hazardous to human health. In this act, the MAC value for Cd was set 10 ppm for inorganic fertilizers and 5 ppm for organic fertilizers (FRG, 2018). Fertilizer related affairs in Bangladesh are regulated by the Department of Agriculture Extension (DAE). Each fertilizer activity should take authorization from the DAE through registration. GoB agrees with the fact that regular monitoring of the fertilizer market is vital to assure fertilizer quality. Therefore, DAE monitors fertilizer affairs and has officially the power to take legitimate action against any unauthorized activity. There are "Post Landing Inspection Committee" in all 11 ports (sea, air and land ports) in Bangladesh to ensure fertilizer quality. It is compulsory that, they check the quality of the fertilizer. After analysis if found suitable only then it gets the clearance to enter the country.

Table 2: Cd and P concentrations in some phosphate rocks (Loganathan et al., 2003)

Phosphate rock	*Cd content (mg/kg)*	*P content (%)*
Kola	0.2	17.2
Chatham Rise	2.0	8.9
North Florida	3.0	13.3
Phalaborwa	4.0	17.2
Jordan	5.0	14.0
Egypt (Hamrawein)	5.0	12.3
Egypt (Quseir)	8.0	12.7
Mexico	8.0	14.0
Makatea Island	10.0	13.0
Sechura	11.0	13.1
Morocco (Khouribja)	11.0	14.1
Arad	12.0	14.1
Youssafia	30.0	-
Gafsa	38.0	13.4
Morocco (Boucraa)	38.0	15.7
North Carolina	41.0	13.0
Christmas Island	43.0	15.3
Ocean Island	99.0	-
Nauru	100.0	15.6

Samples are collected randomly and sent mostly to the SRDI and Bangladesh Standards and Testing Institution (BSTI) laboratories for routine analysis. Besides these two organizations, there are four more government notified laboratories namely BRRI, BARI, BINA and Department of Soil Water and Environment (SWE) of Dhaka University. As a service laboratory, SRDI plays a prime role in fertilizer analysis. This laboratory alone analyses on average around 5,000 fertilizer samples each year mainly sent through DAE. They provide annual reports directly to the Agriculture Ministry of GoB about fertilizer quality.

Cd content in phosphatic fertilizers

In 2008–09, a total of 5,053 different types of fertilizer samples were analyzed and on average 52% of fertilizers were found adulterated or substandard. In the case of phosphatic fertilizers, about 31–62% were found adulterated (BARC, 2010). The average Cd concentration in the TSP fertilizer samples collected from all divisions of Bangladesh lies between 0.08–36.60 mg/kg of fertilizer (SRDI, 2014). The Cd was present above the MAC (10 mg Cd/kg of fertilizer) in 61 TSP samples out of 99. The average of all the studied TSP fertilizer sample's Cd concentrations in different divisions was also reported above the MAC (SRDI, 2014). According to the report, "Long term use of cadmium contaminated fertilizers may result in the further increase of cadmium concentration in the agricultural soil and eventually hyper-accumulation in crops including rice plants". The Cd content of TSP fertilizer analyzed by Sarker et al. (2017) was found around 15 mg/kg which is higher than the MAC value. However, in another study Mohiuddin et al. (2017) determined an undetectable amount of Cd in TSP samples. This indicates that the TSP fertilizer may be the major source of Cd contamination in agricultural soils in Bangladesh. Heavy metal content data in fertilizer is no longer mentioned in the recent annual reports of SRDI. According to the annual report of SRDI (2019), only 82 TSP samples were analyzed in their central laboratory and 11% of the samples were found adulterated. A fertilizer is designated as adulterated if it contains enough nutrients specified by GoB. This means if the TSP sample contains

20% P, 1.3% S and 14% Ca, the fertilizer is considered as suitable for use (FRG 2018). The yearly report of SRDI (2019) also endorse that the adulteration is the cause of insufficiency of nutrients and the presence of noxious metals such as Cd, Cr, Ni, Pb etc. in fertilizers. In a global review conducted by Alengebawy et al. (2021) the Cd concentration in phosphatic fertilizers is reported to be within 0.1–170 mg/kg.

Cd in agricultural paddy soils

There are few studies so far regarding Cd enrichment in agricultural land due to the addition of agrochemicals especially phosphatic fertilizers in Bangladesh. In addition, the majority of them studied polluted soils where the metals were added from anthropogenic activities (Kibria, 2012; Aktaruzzaman et al., 2013; Ullah et al., 2017; Islam et al., 2018; Ratul et al., 2018). Agricultural soil Cd concentration in various studies in Bangladesh is presented in Table 3. Aktaruzzaman et al. (2013) investigated Cd concentration along the highway of Dhaka to Aricha in Savar and found higher Cd within the range of 2.14–5.84 mg/kg in the adjoining agricultural fields. SRDI studied the presence of Cd in Bangladesh soil in 2014. The study was undertaken to measure the concentration of toxic metals (Cd, Pb, Ni and Cr) in soils of 49 districts under seven divisions in Bangladesh. Cd content in the agricultural soils of Barisal, Sylhet, Dhaka, Chitagang, Rajshahi, Khulna and Rangpur division was reported as 2.44, 2.33, 2.13, 2.03, 0.66, 0.55 and 0.19 mg/kg, respectively (SRDI, 2014).

Table 3: Agricultural soil Cd concentration in various studies in Bangladesh. (Agricultural soil Cd content of less than 1 mg/kg is considered safe to cultivate crops according to Liu et al., 2017.)

Study area	***Cd concentration in soil (mg/kg)***	***References***
Adjoining agricultural fields along Dhaka-Aricha highway in Savar	2.14–5.84	Aktaruzzaman et al., 2013
Barisal division	2.44	SRDI, 2014
Sylhet division	2.33	
Dhaka division	2.13	
Chitagang division	2.03	
Rajshahi division	0.66	
Khulna division	0.55	
Rangpur division	0.19	
Ishardi	5.23	Mamun et al., 2018
Chorfasio	3.15	
Kaligonj	2.89	
Asasuni	2.43	
Dumuria	2.40	
Lalpur	2.39	
Madhupur	1.64	
Botiaghata	1.51	
Tangail Sadar	1.38	
Agricultural soil in Narayanoanj that was irrigated with Shitalakhaya River water	0.98	Ratul et al., 2018
60 soil samples from ten upazilas of the Tangail district	0.83–4.08	Mamun et al., 2021b

Mamun et al. (2018) found that the highest total Cd was found in Ishardi (5.23 mg/kg) followed by Chorfasion (3.15 mg/kg), Kaligonj (2.89 mg/kg), Asasuni (2.43 mg/kg), Dumuria (2.4 mg/kg), Lalpur (2.39 mg/kg), Madhupur (1.64 mg/kg), Botiaghata (1.51 mg/kg) and Tangail Sadar (1.38 mg/kg). The authors endorsed that the soils of Bangladesh contain Cd exceeding the permissible limit. Ratul et al. (2018) found elevated Cd (0.98 kg/kg) in agricultural soil in Narayanoanj that was irrigated with water from Shitalakhaya River. The study conducted by Mamun et al. (2021b) collected 60 soil samples from ten upazilas of Tangail district. The authors found Cd content as 0.83–4.08 mg/kg (mean value was 2.17 mg/kg) in agricultural surface soil. After calculating the contamination factor (CF) the authors said that all sampling sites are Cd contaminated.

Critical value determination of Cd in agricultural soil is not a simple straightforward matter rather it is quite complicated, and usually depends on numerous soil, crop and climatic factors. The threshold value for Cd contamination in agricultural soil is variable. Many researchers used 1 mg Cd/kg soil as a critical value (Smolders and Mertens, 2013; Zhang et al., 2015; Toth et al., 2016; Liu et al., 2017), whereas 3 mg Cd/kg soil is also in use in this concern (Akbar et al., 2006). Agricultural soils naturally may contain background Cd concentration within 0.02–6.2 mg/kg (Adriano, 2001). However, Kabata-Pendias and Pendias (1992) reported a lower amount of Cd content in the range 0.01–2.7 mg/kg after reviewing the worldwide available data. According to them Cd content lies between 0.06 and 1.1 mg/kg in most instances. Kubier et al. (2019) calculated the average Cd content in global uncontaminated soil as 0.36 mg/kg though the values considerably vary among continents and nation boundaries.

Cd in rice grains

There is an incompetent number of studies on Bangladesh rice in terms of Cd content. Moreover, researchers conducted studies with a limited number of locations which inadequately represent the precise scenario of rice grain quality in Bangladesh. The current Cd content in the global supply chain ranges from less than 0.0049 to as high as 3.712 mg/kg of white rice, with a mean of 0.019 mg/kg (Shi et al., 2020). Watanabe (1996) analyzed rice grains from ten Asian countries (Bangladesh excluded) and reported the presence of Cd in the range of 0.003–0.056 mg/kg. Hence, there is a global increase of rice grain Cd content especially in major rice producing regions probably due to the higher exposure of the metal in agricultural fields.

The rice grain Cd content in different studies in Bangladesh to date is summarized in Table 4. The earliest documentation of rice grain Cd was published by Rivai et al. (1990) which was only 0.017 mg/kg. A study conducted in the Chittagong region by Kibria (2012) observed that rice grain Cd concentration lies between 0.10–0.98 mg/kg. An immense quantity of Cd was found in some puffed rice samples in Bangladesh according to the study of Al-Rmalli et al. (2012). The authors estimated that each people in Bangladesh consume about 12.61 mg Cd each year from dietary sources which is quite higher than that in other regions. This fact is very alarming regarding human health issues. The authors also identified greater intake of rice and vegetable over animal products as the major cause of higher Cd accumulation in human body. Meharg et al. (2013) for the first time analyzed Bangladesh rice grain for Cd in broader coverage comprising 260 samples taken from 12 districts. They found maximum Cd (0.099 mg/kg) in grain from Bangladesh in comparison with other countries. The authors reported that rice cultivars grown in Bangladesh may accumulate relatively higher quantity of Cd from soil.

The study of Meharg et al. (2013) first highlighted the health risk concern of Bangladeshi people due to Cd by eating rice. From the GoB part, SRDI officially studied the presence of Cd in Bangladesh rice in 2014. The study was conducted to measure the content of toxic metals (Cd, Ni, Pb and Cr) in rice grain in 49 districts under seven divisions of Bangladesh. The study identified the highest Cd content (0.04 mg/kg) in rice grains of the Rajshahi division (SRDI, 2014) which was below the safe limit (0.2 mg/kg). A study executed by Bangladesh Rice Research Institute (BRRI) in 2016 reported that about 28% of rice grain samples bear excess Cd than the permissible limit (Hezbullah et al., 2016). Uddin et al. (2017) found the Cd content of four rice verities (BR-28, BR-29, Minicat and Swarna) within the range of 0.19 to 0.93 mg/kg and indicated possible health risks to the consumers. Mamun et al. (2018) also found higher Cd concentration in rice grains than the safe limit. An exclusive study was conducted by Shi et al. (2020) regarding Cd in rice grain in the global food chain. Samples were taken from 32 countries covering six continents. They found higher Cd content in the grains of the Indian sub-continent in comparison to other countries. They reported the presence of excess Cd in rice grain cultivated in particular locations of Bangladesh. The authors apprehend that the people of Bangladesh are in higher Cd risk due to both inflated Cd in rice grains and greater consumption of the cereal regularly.

Table 4: Rice grain Cd concentration in various studies in Bangladesh. The safe limit is usually considered as 0.2 mg Cd/kg rice grain (EFSA, 2009)

Study	***Cd concentration in rice (mg/kg)***	***References***
6 random samples	0.005–0.026 (mean 0.017)	Rivai et al., 1990
Chittagong region	0.10–0.98	Kibria, 2012
260 samples taken from 12 districts	0.099	Meharg et al., 2013
49 districts under seven divisions	0.04 (Highest)	SRDI, 2014
Rice samples collected from market	28% samples contain unsafe amount of Cd	Hezbullah et al., 2016
Industrial field rice	0.17	Hezbullah et al., 2016
BR-28, BR-29, Minicat and Swarna	0.19 to 0.93	Uddin et al., 2017
-	Reported higher Cd content than the safe level	Mamun et al., 2018
32 countries covering six continents including Bangladesh	Reported excess Cd	Shi et al., 2020
-	0.088	Rahman et al., 2014
144 polished rice samples of 16 districts	0.001–0.180	Shahriar et al., 2020
100 rice samples of BR-48 variety from 10 different upazila of Tangail district	0.02–0.37	Kormoker et al., 2020

Shahriar et al. (2020) analysed 144 polished rice samples of 16 districts of Bangladesh and found the Cd content between 0.001–0.180 mg/kg. They observed 9% of rice samples to exceed the tolerable limit (0.10 mg/kg) of Food Standards Australia New Zealand (FSANZ). There was 33% variation in grain Cd among the districts and a 67% difference in grain Cd within the districts. The authors also expressed deep concern about the health hazards of the people of Bangladesh due to high Cd exposure from eating rice. Kormoker et al. (2020) analysed 100 rice samples of BR-48 variety from 10 different upazila of Tangail district in Bangladesh. Cd content of the rice grains was detected in the range of 0.02–0.37 mg/kg. Most grain samples exceed the Cd safe limit in rice according to FAO/WHO standard (7 μg/kg body weight/week). The verage Cd content in this study was found 0.15 mg/kg which was noted to be higher than the previous studies as 0.088 mg/kg (Rahman et al., 2014) and 0.073 mg/kg (Kormoker et al., 2020). Field experiment conducted in Mymensingh in Bangladesh by Norton et al. (2021) in the Boro season for two years upon several cultivars. They observed that rice genotypes remarkably differ in the grain Cd accumulating ability. Chen et al. (2020) suggested to take immediate measures to minimize the flow of Cd in rice of Bangladesh in order to ensure safe health of the people.

Importance of minimizing Cd in Bangladesh rice

Cd accumulation in agricultural soils in terms of food and health safety issue is a worldwide growing concern especially in agrarian countries like Bangladesh (Kormoker et al., 2020). In recent studies (Aktaruzzaman et al., 2013; SRDI, 2014; Mamun et al., 2018; Ratul et al., 2018; Mamun et al., 2021b), it is clearly revealed that Cd content in agricultural soils has elevated significantly due to the application of mostly huge amount of phosphatic fertilizer with other agrochemicals. Contemporary researchers worked on rice grain quality reported the elevated content of Cd in Bangladeshi rice that poses serious threat to the health of Bangladeshi people (Al-Rmalli et al., 2012; Meharg et al., 2013; SRDI, 2014; Hezbullah et al., 2016; Uddin et al., 2017; Mamun et al., 2018; Shi et al., 2020; Shahriar et al., 2020; Kormoker et al., 2020; Norton et al., 2021; Kibria et al., 2022). Health hazards as a result of dietary intake of Cd by eating rice directly increase with the hike in either grain Cd content or ingestion rate (US EPA, 1989). At present, people of Bangladesh consume the highest amount of rice globally which is about 0.497 kg rice/person/day (FAO, 2020).

Cd exerts its toxic effects mainly on the kidney (Ullah et al., 2017). Kidney patient numbers have considerably increased in Bangladesh in recent times. The prevalence of chronic kidney disease among Bangladeshi people is 22.48% (Banik & Ghosh, 2021), which is considerably higher than the global prevalence of only 13.40% (Hill et al., 2016). According to Mamun et al. (2018) around 2017, about 20 million people were suffering from kidney diseases in Bangladesh and among them 0.80 million required dialysis. One in every seven people in the country has been suffering from kidney disease and about 40,000 annually die of longtime kidney failure (Mamun et al., 2018). The authors also reported that the chronic kidney disease rate has become doubled in Bangladesh from 9% to 18% during 1998 to 2008. The presence of excessive quantity of Cd in human body especially from rice diet may be the cause of abnormal number of people suffering from various problems related to kidney (Ullah et al., 2017; Mamun et al., 2018). Therefore, the "safe soil and rice issue" in terms of Cd transfer into the human body is an urgent and essential concern (Meng et al, 2019; Chen et al., 2020). Hence, rice grain Cd content reduction has become an imperative issue considering the human health hazard.

Cd mediation research conducted in Bangladesh

Research regarding Cd reduction in the rice grain is scares in Bangladesh. Only a few articles are available where Cd minimization strategies were addressed. Kibria et al. (2022) investigated eight Aman rice varieties in Bangladesh to assay their Cd affinity. They found significant genetic variation among the studied genotypes in depositing Cd in their grain. There were about 15-fold variations (lowest 0.008 mg/kg for BR-71 and highest 0.0125 mg/kg for BR-87) in their grain Cd content among the rice varieties when grown in agricultural soil. Based on their low Cd affinity (LCA) behaviour, the Aman varieties were arranged as BR-52 > BR-75 > Rani salut > BR-71 > BR-49 > BR-76 > BR-87 > BINA-7. This means that by promoting the extensive cultivation of the varieties following the LCA order grain Cd content may be noticeably minimized.

Researchers used OA to reduce rice grain Cd content in other studies. Mamun et al. (2021b) observed the influence of biochar and vermicompost (VC) application on the Cd reduction in red amaranth (*Amaranthus cruentus*) in pot trial. The authors obtained Cd reduction in the leafy vegetable as high as 72% due to the combined application of the organic amendments (OA). Kibria et al. (2023) studied the effectiveness of six OA in both agricultural and Cd-stressed soil to modify Cd concentration in soil and rice grain. The addition of OA noticeably reduced Cd availability in soil. SL-8 rice variety grown under OA treated soils produced grains with lower Cd (0.15 to 0.30 mg/kg) compared with control (0.38 mg/kg). They reported the highest Cd reduction in grains grown under tea leaf treated soil followed by VC, sawdust, rice husk, mustard oil cake and cow dung. The Author concluded that the addition of OA could be an effective measure to minimize Cd in rice grain.

OA application rate was also recommended from the above two studies. Mamun et al. (2021b) suggested the combined application of biochar and VC at a rate of 0.25% (5 t/ha) in order to reduce Cd hazard in the human diet. Kibria et al. (2023) identified 2% OA application rate as the most effective doze of OA to reduce soil bioavailable Cd as well as rice grain Cd in moderately contaminated agricultural soil (<10 mg Cd/kg soil). Cultivable soil should have at least 2.5% organic matter (OM), however, in Bangladesh most of the soil have less than 1.5%, and some soils has even less than 1% OM (FRG, 2018). OM content is gradually declining with time in agricultural soils. Bangladesh is a subtropical country and the amount of rainfall and temperature are a bit high to perform the higher microbial activity. For this reason, large amount of OA is required to be added in the agricultural soils to maintain a certain level of OM. Moreover, OA from various sources are considerably used as fossil fuel for daily cooking especially in villages in Bangladesh. The recommended dose of organic fertilizer (OF) is 2 to 5 t/ha in Bangladesh. The OF rate of 3 t/ha is being mostly recommended (FRG, 2018). A 1% OA is equivalent to 20 t OA/ha soil. Hence, the highest dose of 5 t/ha is equivalent to only 0.25% OA.

MAC for Cd in rice grain in Bangladesh

Various food safety authorities worldwide set their separate maximum allowable concentration (MAC) standards to monitor the safety level of Cd in rice grain as the human diet. These include 0.10 (EC, 2006), 0.15 (Thailand standard) (Saengwilai et al., 2020), 0.20 (MHPRC, 2014; EFSA, 2009) and 0.40 mg/kg (CODEX, 2019). Studies so far performed in Bangladesh (Jahiruddin et al., 2017; Mamun et al., 2018; Islam et al., 2019; Kormokera et al., 2020; Proshad et al., 2020; Shahriar et al., 2020) used 0.20 mg Cd/kg of rice as MAC according to either EFSA (2009) or MHPRC (2014). However, Kibria et al. (2012) interpreted their findings with a MAC value of 0.10 mg Cd/kg as recommended by WHO (1995). GoB not yet set standard MAC value for rice grain Cd to be used as national reference in order to conduct effective and reliable health risk assessment for the people of the country. Regarding the development of MAC Satarug et al. (2017) put emphasis on the need assessment of the people of the concerned region in order to measure the health risk with adequate precision. In health risk assessment, the estimated daily intake (EDI) of Cd by a person is required to be calculated from parameters like rice ingestion rate (IR), exposure duration (ED), exposure frequency (EF) and average body weight (BW). These four parameters noticeably vary among the regions globally. For example (Table 6), each Bangladeshi people consume about 45% more rice than the Chinese people per day basis (Huang et al., 2013; FAO, 2020) and experience about 14.29% less ED than China (Zhang et al., 2017), and the average BW of Bangladeshi people is about 23.47% lower than that of Chinese population (SGSAC, 2015; WHO, 2010). These information indicate that the people of Bangladesh is in greater risk compared with the Chinese people in terms of Cd consumption through rice diet. Therefore, MAC value would be lower for Bangladesh in comparison to China.

Table 6: MAC of Cd calculation in the rice grain for Bangladesh in comparison to China (Kibria et al., 2022)

Parameters	***Unit***	***China***	***Bangladesh***
Ingestion rate of rice (IR)	kg/day	0.343 (Huang et al., 2013)	0.497 (FAO, 2020)
Exposure frequency (EF)	day/year	365 (Zhang et al., 2017)	365 (Fan et al., 2017)
Exposure duration (ED)	year	70 (Zhang et al., 2017)	60 (assuming)
Average body weight (BW)	kg	68.6 (SGSAC, 2015)	52.5 (WHO, 2010)
Average time (AT)	day	25,550 (Zhang et al., 2017)	21,900 (assuming)
Reference dose (Cd)	mg/kg/d	0.001 (US EPA, 2000)	0.001 (US EPA, 2000)
Maximum allowable concentration (MAC)	mg/kg	$1 = \frac{C \times 0.343 \times 365 \times 70}{68.6 \times 25550 \times 0.001}$ $C = 1/5$ C = 0.20 (MHPRC, 2014)	$1 = \frac{C \times 0.497 \times 365 \times 60}{52.5 \times 21900 \times 0.001}$ $C = 1/9.47$ **C = 0.10 (Proposed)**

Kibria et al., (2022) proposed 0.10 mg/kg as MAC of Cd in rice grain for consumption in Bangladesh. National reference MAC value for rice grain Cd by using the updated data of the concerned parameters would be helpful for reliable health risk assessment. In addition, MAC for Cd in rice grain needs to be updated on a regular basis (may be in every five to ten years) as GoB updates the values of the related parameters to calculate EDI.

Conclusion

There is inadequate research to date about Cd in the soil-rice ecosystem in Bangladesh. Most of the researchers analyzed a limited number of samples which certainly does not represent the overall Bangladesh Cd status in both agricultural soil and rice grain. From the review, it may be concluded that 1) Agricultural paddy soils of Bangladesh are getting more and more Cd with time mostly from the addition of high Cd containing TSP fertilizers, 2) Fertilizer manufacturer should use rock phosphate sources that contain lower amounts of Cd, 3) Bangladesh should import low Cd containing TSP fertilizers from global market, 4) Rice grains produced in Bangladesh contain an unsafe amount of Cd that severally threats human health, 5) GoB could set MAC for Cd in rice grain to be used as a reference by researchers and 6) Measures immediately need to be taken to minimize Cd content in the rice grain.

Future research directions

The following research directions are suggested from the review for better assessment regarding the presence of Cd in soil-rice ecosystem in Bangladesh. 1) Compressive quantitative determination of Cd in both agricultural soils and rice grains in major rice growing regions in Bangladesh, 2) Extensive research is needs to be conducted with Cd remediation strategies to effectively minimize Cd in rice grown in Bangladesh.

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Conflict of Interest
None of the authors present any conflicts of interest.

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