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SELECTION OF CADMIUM NON-ACCUMULATING RICE GENOTYPES TO REDUCE HEALTH RISK

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ABSTRACT

Cadmium (Cd) is regarded as one the most toxic heavy metals. Long term exposure to Cd via air, water, soil or food can be carcinogenic and can also lead to other bone, urinary, reproductive, cardiovascular and nervous disorders. Farmers in order to achieve high quality crops often use excess phosphorus fertilizers and in addition to this leakage of sewage sludge in the agricultural farmlands often leads to Cd contamination in agricultural fields. This holds a long term consequence because the Cd can be easily absorbed by the plants and thus Cd enters the food chain and can get accumulated in human organs. Rice is a major staple crop across the world which holds a vast genotypic variation. Different rice cultivars tends to accumulate different levels of Cd in the rice grains and hence detailed study is required to identify the rice genotypes which do not accumulate Cd in the grains so that they can be regarded as "Cd-safe" cultivars. In the present study, 58 different indica rice cultivars which are popularly grown all over India, have been grown in moderately Cd contaminated soil and results showed differential levels of Cd in the rice grains. Among 58 rice cultivars, 32 cultivars accumulated Cd in the rice grains and rest did not. The rice cultivars namely, Suma, Ranjit, Pratiksha, Kausallya, Ratna, Khitish, Mali-4, Barsha and Annada can be considered to be Cd hyper-accumulators based on the level of Cd accumulation in the rice grains.

***Keywords* :** Cadmium; rice; grain; health risk; cancer risk factor.

Introduction

Rice is consumed as a major carbohydrate source for most of the Asian people and grown since ancient times throughout the World (Pudjihastut *et al.*, 2019). To ensure food security for growing population, rice production and quality both are important aspects. In the recent era, rice production is enormously hampered by heavy metal Cadmium (Cd) contamination. Cd and its inorganic compounds are considered as human carcinogen (Group I) as mentioned by International Agency for Research on Cancer (IARC) (Joseph, 2009).

Cd contamination in agricultural soil mainly arises from excessive use of phosphate fertilizers that are being used in greater quantity in agricultural field. As Cd is highly water soluble it can be easily taken up by root and transported to the aerial parts of plant. When Cd contaminated grain is consumed by human, it poses health risks and subsequent bioaccumulation in body. As Cd is non-essential for body, it shows several toxic symptoms including osteomalacia, kidney dysfunction, respiratory disease and other maladies. Besides human health risk, Cd also causes various toxic symptoms in plants, like root growth inhibition, chlorosis, restricts nutrient enrichment, reduces crop yield and induce many cellular and molecular damages. In recent times Cd input in agricultural field has increased progressively (Jones *et al.*, 1992). To reduce the health risk, selection of Cd Excluder Genotypes (CEGs) that is, genotypes accumulating very low level of Cd in their edible part when grown in contaminated soil, is a novel choice for biosafety purpose (Khan *et al.*, 2008). The concept supporting CEGs is based on prior studies and it has been reported that the uptake and translocation of Cd by plants vary among genotypes, within the same species (Zeng *et al.*, 2008). However, most of the studies on CEGs are focused on Japonica cultivars grown in hydroponic condition but detailed study on indica cultivars grown in field conditions is still scarce.

Since 1970, West Bengal was considered as a rice bio-diversity region but in recent times several agricultural lands are reported to beCd contaminated areas (Kar *et al.*, 2015; Banerjee *et al.*, 2010). Few regions including South 24 Parganas, Birbhum, Bankura, Medinipore are the most important rice growing region in West Bengal, have been contaminated by Cd due to over-application of phosphate fertilizers. Rice grown in these contaminated soils could take up Cd, which cause serious human health risk as it is the major staple food in West Bengal. There are several approaches to minimize the health risk, one of the cost effective method is the selection and breeding of pollution safe cultivars (PSCs) i.e. cultivars grown in contaminated soil accumulate specific heavy metals at a very low concentration (Yu *et al.*, 2006; Chen *et al.*, 2012). Therefore, selection and breeding of non-Cd accumulating grains cultivars is an alternative choice for safe consumption.

In the present study, we have selected 58 widely cultivated rice genotypes of West Bengal and carried out a pot study using these rice cultivars. The rice plants were exposed to 10μM $CdCl_2$ which is equivalent to 1.12 mg kg^{-1}soil. At maturity, difference in grain Cd uptake was measured. Thus, the study intends to identify the rice cultivars, which are Cd non-accumulating (in grains) for safe consumption and also identify the rice cultivars which accumulates higher levels of cadmium in grains.

Materials and Methods

Site Description

Pot experiment was carried out in Baruipur Agricultural Experimental Farm, University of Calcutta, located at Baruipur, West Bengal, India (88°26.164'E and 22°22.526'N).The average rainfall (June-Oct) was recorded to be 109.9 mm, temperature ranged from 27°C-34°C and relative humidity was 68%. The soil used in this study had characteristics as reported by Mukherjee *et al*., 2019.

Plant materials and growth condition

Popularly cultivated 58rice genotypes were collected from different parts of West Bengal, India (**Table-1**). Around 30-35 rice seeds were surface sterilized with 0.2% Dithane for 5 min, washed thoroughly 3-5 times in deionized water followed by overnight soaking in dark condition. The seeds were plated on moist filter paper and allowed to germinate for 3 days. Three seedlings of uniform size (10 days old) were transferred into separate pots containing 5kg soil. 30 days old seedlings were treated by adding aqueous solution of 10 μM $CdCl_2$ (or 1.12 mg $kg^{-1}CdCl_2$) to 5 kg of soil in required amount and again same dose of Cd was applied. Another control set was maintained where Cd was not added to the pot soil. Finally, the plants were grown under natural field condition with regular watering till maturity.

Study of different agronomic traits and yield components

Several agronomic traits were recorded twice during pot culture, once in 45 days and another after maturity. The plant height, leaf length, breadth and tiller numbers were recorded. Among the reproductive characters, the effective tiller numbers, flowering time, panicle length, weight, numbers of hollow seeds and yield were noted.

Estimation of grain Cd content

Harvested rice seeds were de-husked and ground to a fine powered by using mortar and pestle. 100 mg power were allowed to digest in tri acid method containing HNO_3, HCl, $HClO_4$ (4:2:1) at 90°C for 3h and Cd content analyzed by ICP-AES.

Estimation of bio-available Cd

Estimation of bio-available Cd content was done by sequential extraction method according to Yong *et al*. (1993). After each step soil samples were washed with deionized water and subsequently dried at 60°C prior to next step. Dried soil samples were passed through mesh and 1.5g soil samples were dissolved in 15 ml deionized water and allowed to incubate 24 h for extraction of soluble content. For further analysis soil sediment was allowed to dry at 60°C for 24h. Exchangeable fraction and metals (carbonate) were estimated by adding 8 ml of 1M $MgCl_2$ (pH 7) and 8 ml of 1M NaOAc with the dried soil sediments. Oxide and hydroxide content was done by extracting the dried soil with 20 ml of 0.04 M $NH_2OH.HCl$ in 25% (v/v) acetic acid (pH 2.5) at 96 °C for 6 h and 20 ml of 0.04 M $NH_2OH.HCl$ in 25% (v/v) acetic acid (pH 2.5). Reaction mixture containing, 3 ml of 0.02 M HNO_3 and 5 ml of 30% H_2O_2 (pH-2) were again added to the soil sediment and allowed to incubate at 90°C for 2h for collection of organic matter. There after reaction mixture allowed to mixing with 5 ml of 3.2 M NH_4OAc in 20% (v/v) HNO_3 and followed by incubation for 30 min at room temperature. Finally, the residual fraction was collected by digestion at 90°C with 25 ml dilute aquaregia. Cd content was measured by addition of 0.1% APDC and 1% Tween 80 and APDC. The absorbance was read at 324 nm. Standard curve of Cd was calculated by using different concentrations of Cd and Cd content was expressed as mg kg^{-1} soil.

Oral daily intake of Cd through rice

Daily Cd uptake through rice was calculated according to the following formula = Cd grain (mg/ kg) × average daily rice consumption (kg/day) as suggested by Bar *et al*. (2002).

Statistical analysis

Experimental data represented in the graphs were average of five replicates. Hierarchical clustering analysis was done by using SPSS 23 software package. Microsoft Excel software was used to construct matrix plots and graphs.

Results

Effect of Cd toxicity on growth parameters and tillering dynamics

After maturity plant height of most of the rice cultivars declined in response to the Cd treatment. However, only Khandagiri had higher plant height in the Cd treated sets compared to that of control (1.2 fold over control) (**Figure-1**).

The negative impacts of Cd toxicity on plant's vegetative parts were detected, in terms of reduced leaf area with exception to Ratna, Tulsibhog, Radhunipagol, Chaitali, and CSR2 which had higher plant height in the Cd treated sets compared to that of control (1.3, 1.3, 1.15, 1.1, and 1.1 fold over control, respectively) (**Figure-1**).

Formation of effective tillers was significantly hindered under Cd treatment. Additionally, lower percentage of effective tiller number reduction was noticed in rice cultivar Ajit (**Figure-1**).

Cd toxicity drastically reduced yield components and delayed maturation time

Cd exposure significantly increased the hollow grain percentage (**Figure-2**). Maximum increase in the hollow grain percentage was observed in Suma (15.2 fold over control), followed by Annada and Satabdi (10.5 fold over control) and on the other hand, the cultivar Bumpygold had lower hollow grain number.

Cd treatment also delayed the maturation time. The Cd treated plants had longer duration for maturity and highest maturity time was recorded in Khanika (1.16 fold over control) (**Figure-3**).

Panicle length and grain yield of all the rice cultivars decreased when exposed to Cd stress (**Figure-4**). In Bandana and Sabita, maximum decline in the panicle length occurred (0.45 fold with respect to control).Maximum decrease in yield occurred in Ajit, CSR2 and CSR4.

Grain Cd content

Among the 58 cultivars, in the grains of 32 cultivars, significant levels of Cd accumulation were found (**Table-2**). Maximum levels of grain Cd were found in Suma (1.3 µg g^{-1}) which was followed by Kausallya (0.91 µg g^{-1}). Consequently higher levels of oral weekly intake of Cd were found in these cultivars.

On the contrary, lowest Cd accumulation in the grains was found in Rajlaxmi (0.075 µg g^{-1}) and thus consequently lower dietary Cd intake risk was associated with this cultivar. Other cultivars like Khanika, Kariagora, Satabdi, IET4094, IR36, Jaldi13, Triguna, Ajit, Lalat, Pusa Basmati, CSR1, CSR2, CSR4, Radhunipagol, Badshabhog, Gobindobhog, Tulaipanji, Tulsibhog, Purnendu, CN-1039, Bhudeb, Nonabokra, Amolmona, Caning, Pakali and Nilima showed no accumulation of Cd in the grains.

Heat-map and hierarchical clustering

To visualize all the collected data of all the parameters with colour intensity a clustered heat map was generated and hierarchical clustering analysis was performed using Euclidean distance algorithm where it was evident that the cultivar Ajit was an out group since, there was least decline in plant height and effective tiller (**Fig. 5**). However, Cd stress led to decrease of grain yield in Ajit. Thus, Cd stress caused decline in grain yield in all the cultivars, both Cd accumulators and Cd non-accumulators.

Discussion

The study was conducted across 58 rice genotypes popularly cultivated in West Bengal and other parts of India. According to Xie *et al*. 2015 maximum bioaccumulation of Cd in rice occurs when Cd concentration ranges from 1-3 mg/kg. Hence the treatment dose for the study was selected in the reported range. Upon Cd exposure, plant growth and yield associated traits were found to be hindered.

Cd is reported to inhibit plant growth and development which are detectable both morphologically and physiologically (Shanying *et al*., 2017). In our study, the plant height reduced under Cd toxicity with respect to the control set. Cd toxicity lowers root length and biomass, growth inhibition is associated with hindered mitotic activities in the meristematic region (Gratao *et al*. 2009; Seth *et al*. 2008). With respect to control set, the leaf area was found to decrease in Cd accumulating genotypes as leaves are also prone to stunting, necrosis and desiccation when subjected to Cd exposure. The leaf area is reported to significantly decrease under Cd toxicity in previous reports (Solis-Dominguez *et al*., 2007). As Cd toxicity disturbs plant-water relation, nutrient uptake, nitrogen and carbon assimilation, photosynthetic efficiency is declined. Along with that, Cd stress induces ROS mediated oxidative damage, resulting impaired plant growth (Ismael *et al*., 2019).

In addition to reduction in shoot growth in grasses, environmental stress is also associated with reduced tillering production in members of Poaceae family (Zhuang *et al*., 2017). The Cd exposed plants had lower number of tillers than their untreated counterparts in this study. Similarly, reduction in tillering was also observed in perennial rye grass when exposed to Cd, as initiation of tiller bud and outgrowth control the tillering, regulation of several transcriptional factors might play an important role (Niu *et al*., 2021).

Our results indicate that with decrease in number of tillers in treated genotypes, the panicle number and yield subsequently decreased, according to previous reports, the tiller number, panicle number and seed yield are all directly and positively correlated with each other and are important factors in determining total yield (Li *et al*., 2019). Presence of Cd in soil also delayed the maturity of rice which is reported by Guha *et al*., 2020. Cd toxicity mediated decrease in total yield was also observed in several reported studies (Kanu *et al*., 2017; Barman *et al*., 2020; Guha *et al*., 2020; Majumdar *et al*., 2020).

As Cd accumulation potential greatly varies among species, ecotypes and cultivars, many studies have been conducted to explain the variability in grain Cd accumulation of rice, many field studies have been conducted which reported the genotypic variability in Cd accumulation (Uraguchi *et al*., 2009; Duan *et al*., 2017). Our results have exhibited high variability in Cd accumulation, where 32 genotypes accumulated Cd in grain and no Cd accumulation was found in the remaining 26 genotypes. Such variability in Cd uptake can be attributed to several Cd transporters like Os NRAMP (Takahashi *et al*. 2011), OsHMA (Miyadate *et al*., 2011). Studies on quantitative trait loci revealed that a particular QTL on chromosome 7 between 7.23 and 7.61 Mbp is associated with the variability of grain Cd accumulation.

According to CODEX guidelines the permissible level of Cd in rice grain must be below 0.2 mg kg^{-1}. Among the Cd accumulating cultivars, Kabirajsaal, and Rajlaxmi had grain Cd contents below 0.2 mg kg^{-1} hence can be considered to be safe for consumption. The oral weekly intake of Cd upon consumption of the Cd contaminated rice grains have been also calculated considering 300gm of rice consumed by an adult of 50 kg body weight. According to WHO, 2010, the provisional tolerable monthly intake (PTMI) for Cd is around 7 µg kg^{-1} body weight per week. The cultivars like Suma, Ranjit, Pratiksha, Kausallya, Ratna, Khitish, Mali-4, Barsha and Annada can be considered to be Cd hyper-accumulators and the oral weekly intake of Cd upon consumption of these cultivars exceeded 30µg kg^{-1} bodyweight. Cancer risk factor was also calculated according to Zeng *et al*. 2015 considering the slope factor for Cd 15 mg kg^{-1} body weight and the grain Cd content data revealed that Suma had the highest cancer risk factor of 6.18.

Till date, there are no reports about indica rice cultivars which accumulate high Cd and are unsafe for consumption. This report can help to identify the Cd non-accumulator and Cd-accumulating cultivars. In future, the cultivation of Cd hyper-accumulators must be restricted since they can impose potential health risk, or measures may be taken to reduce Cd accumulation in grains by applying Cd remediating agents.

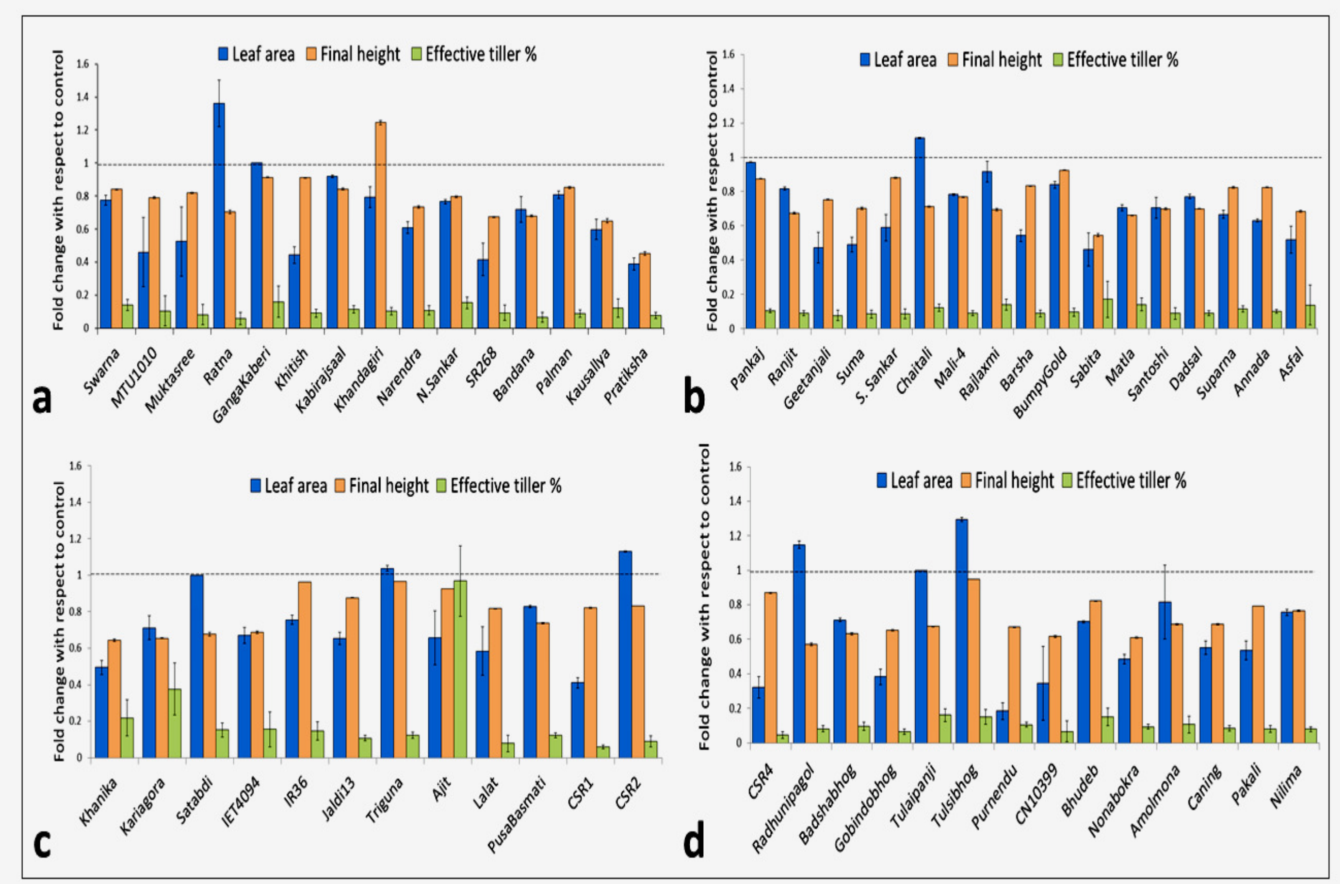

Fig. 1 : Decrease in the leaf area, final height and effective tiller percentage of the Cd treated rice plants after maturity (expressed as fold change with respect to control). Bars represent mean of five independent replica and error bars indicate standard deviation.

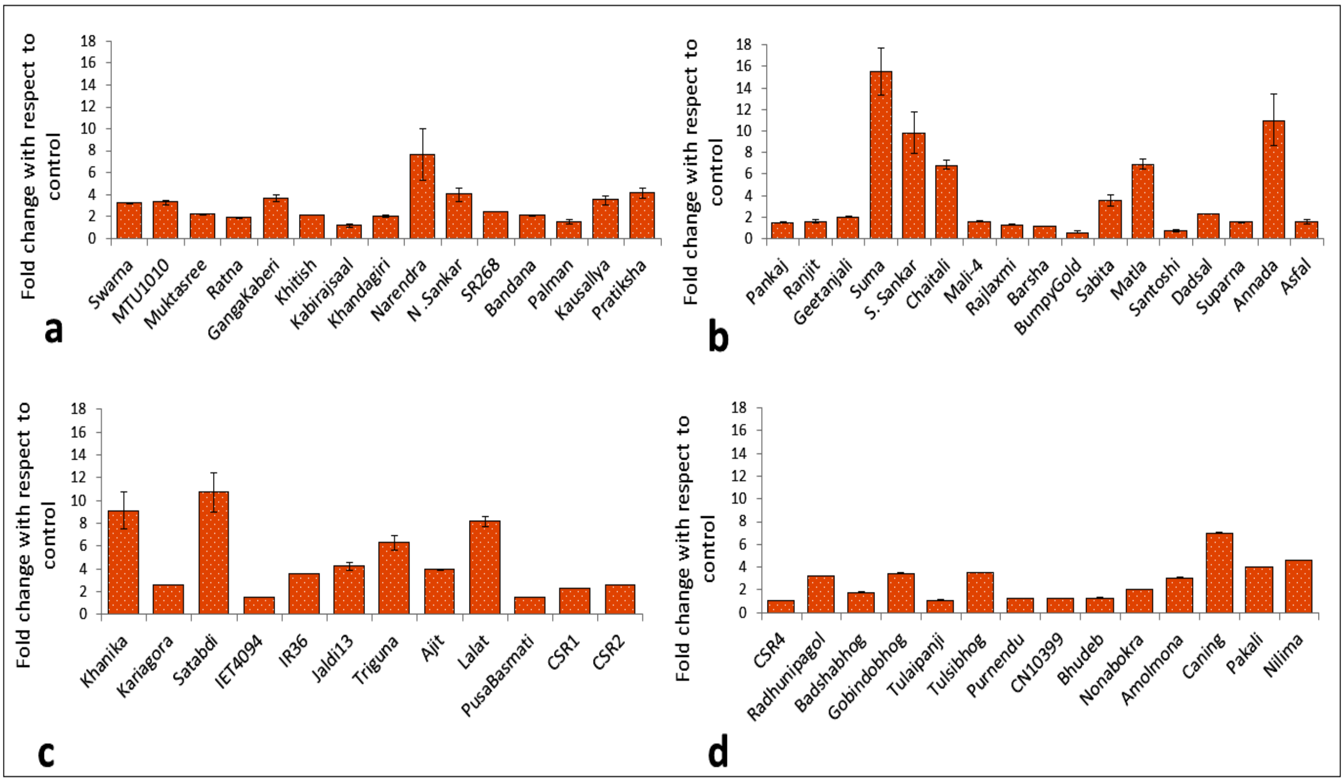

Fig. 2 : Increase in hollow grain percentage of the panicles from the Cd treated rice plants (expressed as fold change with respect to control). Bars represent mean of five independent replica and error bars indicate standard deviation.

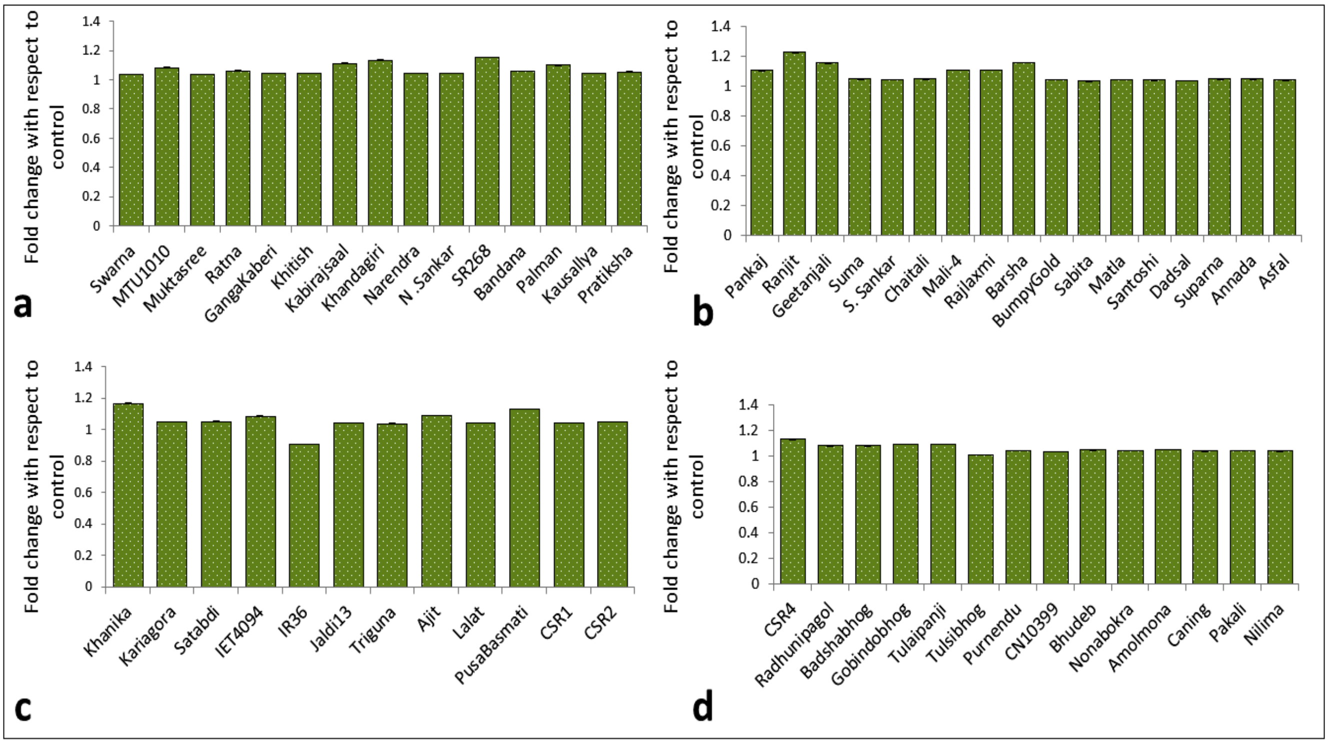

Fig. 3 : Increase in duration of maturity of the Cd treated rice plants (expressed as fold change with respect to control). Bars represent mean of five independent replica and error bars indicate standard deviation.

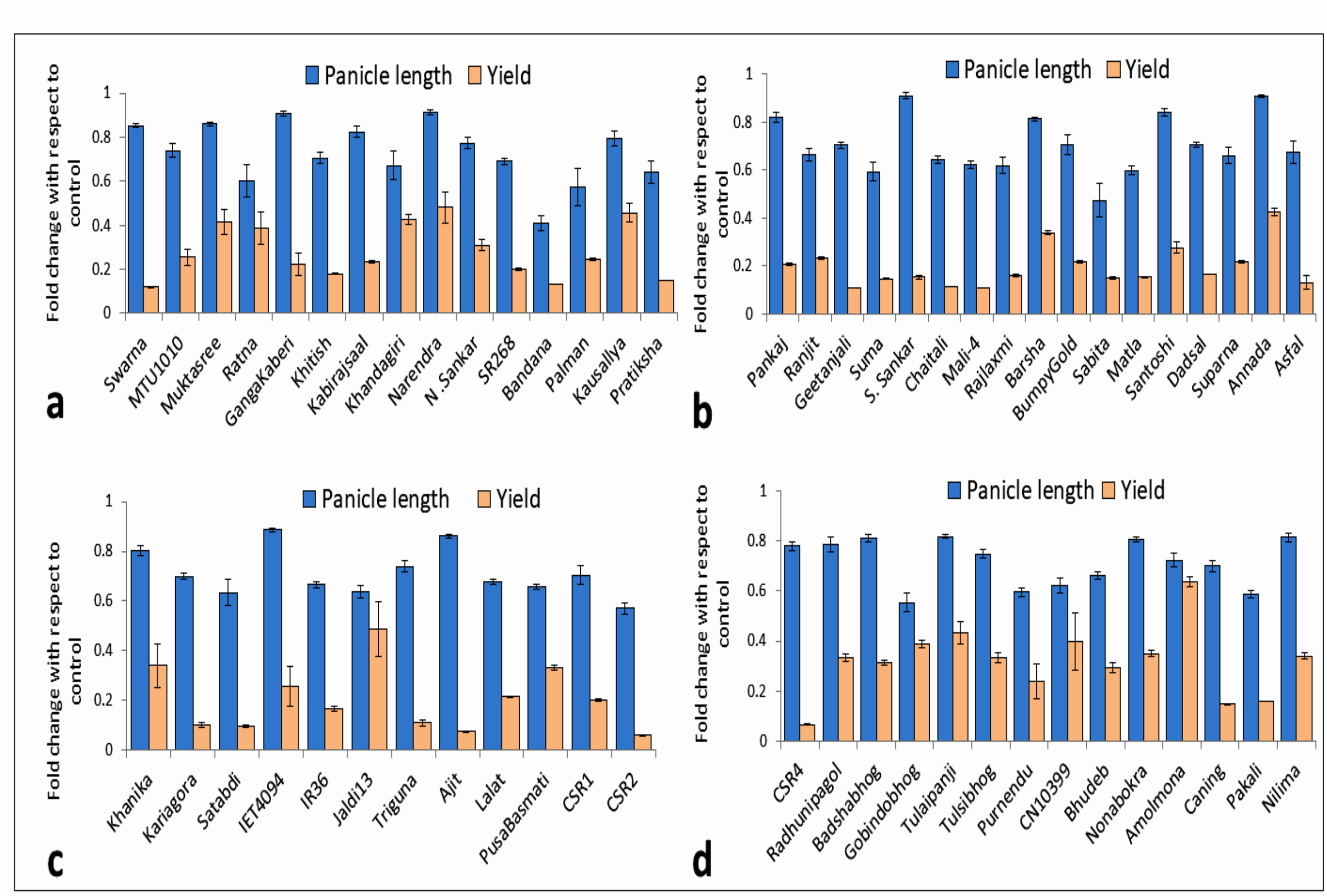

Fig. 4 : Decrease in panicle length and yield of the Cd treated rice plants after maturity (expressed as fold change with respect to control). Bars represent mean of five independent replica and error bars indicate standard deviation.

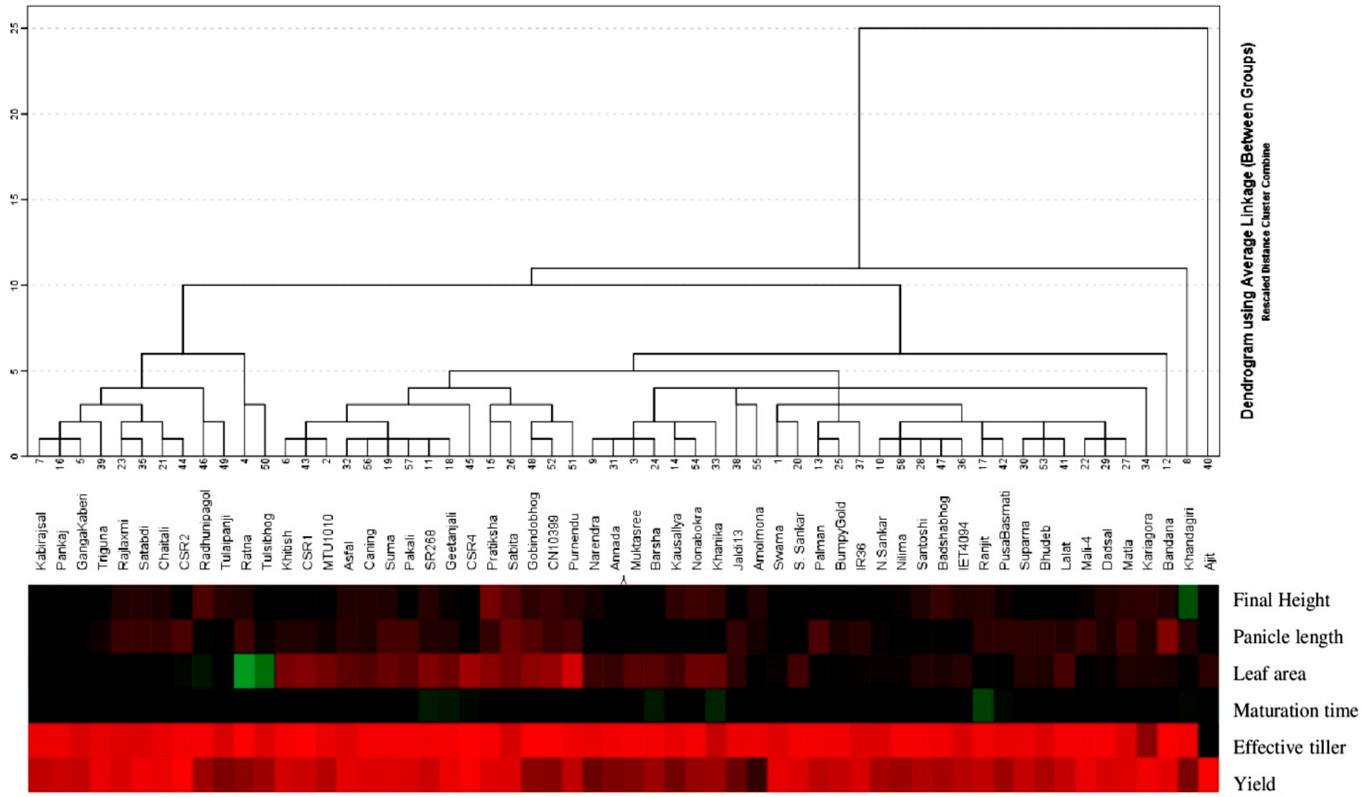

Fig. 5 : Heat map showing fold change in agronomic parameters of rice plants treated with Cd with respect to control. B. Hierarchical clustering of rice cultivars based on the changes in agronomic parameters.

Table 1 : Details of 58 rice cultivars.

SL. No.	Cultivars	Maturation Time(Day)	Ecosystem	Characters	States where the cultivar is produced
1	Swarna	140	Rainfed lowland	Semi-dwarf, tolerant to bacterial leaf blight and many diseases, tolerate salinity, Yield: 58Q/ha	Orissa, West Bengal (WB), Andaman, and Nicobar islands
2	MTU1010	133	Irrigated Medium Lands	(Krishnaveni x IR-64), Irrigated medium lands, semi-dwarf (108 cm), resistant to blast & tolerant to BPH; yield: 74 Q/ha.	Andhra Pradesh
3	Muktasree	125-131	Rain fed Irrigated	Suitable for irrigated, transplanted condition, maturity mid-early, moderately tolerant to sheath blight, brown spot, leaf folder and moderately resistant to leaf blast, black plant hopper, gall midge, resistant to lodging and grain shattering. 42-52 Q/ha.	WB
4	Ratna	130-135	Upland	Dwarf, resistant to blast, sheath blight, Yield: 45-50 Q/ha (quintals per hectare)	WB, Orissa, Punjab, Haryana, Tamil Nadu.
5	Ganga Kaberi	135	Rain fed Irrigated	Fine grained high yielding variety	WB, Uttar Pradesh
6	Khitish	132	Rain fed Irrigated Uplands	(BU-1 x CR-115), irrigated upland or medium, Early, dwarf (82-90 cm), grains: LS, moderately resistant to blast & BS, yield: 45 Q/ha.	WB, Orissa
7	Kabirajsaal	126	Rain fed Irrigated	Local landrace, rich in iron, zinc and vitamin B complex	WB
8	Khandagiri	121	Rain fed Irrigated Uplands	(Parijat x IR-13429-94- 3-2-2), rain fed irrigated uplands, resistant to Sh.R, neck blast, BS, BPH, moderately resistant to RTV, Sh.B, BLB, WBPH, GM, SB & WM; yield: 35 Q/ha.	Orissa.
9	Narendra	140	Irrigated or Rainfed	(IR-36 x Hansraj-A), rain fed upland, dwarf (85 cm), lodging and drought resistant; yield: 30-40 Q/ha.	Uttar Pradesh.

10	N.Sankar	135-140	Irrigated Medium	(IR-58025A x NDR-3026-3-1-R), irrigated medium, yield: 62 Q/ha.	Uttar Pradesh.
11	SR268	121	Lowland, highly rainfed	Salinity tolerant	West Bengal (Sundarban)
12	Bandana	126	Favourable& unfavourable Uplands	C 22 x Kalakeri,Weed competitive; drought tolerant, deep root system: moderately resistant to blast & brown spot.	Bihar, Jharkhand and Orissa
13	Palman	120-125	Low-land	Introduction from IRRI High yielding, Fe rich resistant to sheath blight	Punjab, West Bengal
14	Kausallya	110	Rainfedshall ow	Resistance to gall midge and tolerance to white-backed plant hopper, Yield: 45 Q/ha	Chattisgarh
15	Pratiksha	142	Irrigated/ Rainfed	Semi-dwarf; resistant to whitebacked plant hopper, 40-45 Q/ha	Orissa
16	Pankaj	148	Low-land Areas	Peta x Tongkai Rotan, semi dwarf (110-120 cm), grains: long bold, white, moderately susceptible to BLB, SB and GM, moderately resistant to blast and RTV, Yield: 40-45 Q/ha.	Bihar, Orissa, West Bengal, Andhra Pradesh and Tamil Nadu.
17	Ranjit	155-160	Rain-fed	Semi-dwarf, tolerant to bacterial leaf blight, susceptible to blast, sheath blight; Yield: 40 Q/ha	Assam
18	Geetanjali	130-135	Medium land and irrigated	Basmati 370, Plant height –110-115 cm, semi-dwarf; grains – long slender; resistance to neck blast & mod. resistance to GM; Yield: 50-60 Q/ha	Orissa
19	Suma	121	Rainfed, Irrigated & Upland	Rain fed Irrigated	West Bengal
20	S. Sankar	137	Rain fed	UPRI 95- 17A/UARI 93-287R, Semi dwarf. (115 cm), grains – Long Slender and red ; mod. resist. to BLB, blast, BS, RTV, Sh. B, kernel bunt, SB, BPH, WBPH and LF. Yield: 61- 6.6 Q/ha.	Uttranchal
21	Chaitali	Kharif (110-115 Days) and Boro (140-145 Days)	Rainfed, Irrigated & Upland	Both Rain fed Irrigated Long -Medium Slender, 24-26Q/A	West Bengal
22	Mali-4	140	Rainfed, Irrigated & Upland	Most prevalent HYVs in the district	Odisha and West Bengal
23	Rajlaxmi	125-135	Upland	Tolerate stem borer, brown plant hopper, leaf blast,bacterial leaf blight, white backed plant hopper and gall midge etc. Cold stress tolerant, semi dwarf, Yield: 7- 7.5 t/ha.	Odisha and Assam
24	Barsha	129	Low-land	Most prevalent HYVs in the districtPurba Midnapore	West Bengal(Purba Midnapore)
25	Bumpy Gold	160	Rainfed, Irrigated & Upland	Resistant to BLB, blast, BS, RTV, Sh. B, kernel bunt, SB, BPH, WBPH and LF	West Bengal
26	Sabita	135	Low Lands	Pure line selection from Indica cultivar Boyan .Tall (150-160 cm), grains: LS; Yield: 40 Q/ha.	West Bengal
27	Matla	130	Coastal saline land	Grown in flood-prone areas of West Bengal, tolerate salinity, Yield: 20 Q/ha	South West Bengal
28	Santoshi	130	Rainfed Upland	Resistant to sheath blight, bacterial leaf blight & sheath rot	West Bengal
29	Dadsal	150	Rainfed Upland	Salt tolerant	West Bengal
30	Suparna	115	Ittigated	High yielding	West Bengal
31	Annada	122	Rainfed Upland	MTU-15 x YaikakuNantoku (China). Grains: short bold, moderately resistant to blast & SB, susceptible to BLB, GM & BPH.	Arunachal Pradesh, Madhya Pradesh, Manipur Meghalaya, Nagaland, Orissa

					and Goa.
32	Asfal	119	Lowland, highly rainfed	Salinity tolerant	West Bengal (Sundarban)
33	Khanika	159	Rain fed Uplands	Jaya x CR-237-1 Resistant to sheath blight and brown spot	Jharkhand, Orissa, West Bengal
34	Kariagora	150	Upland	Medicinally important plant, used as tonic	West Bengal, Assam, Orissa
35	Satabdi	150	Upland	CR-10-114 x CR-10115 Semi-dwarf, resistant to sheath blight, bacterial leaf blight & sheath rot	West Benngal, Orissa
36	IET4094	115-120 (Kharif) 145-150(Boro)	Irrigated Early	Dwarf (82-90 cm), grains: LS, moderately resistant to blast & BS, Yield: 45 Q/ha.	West Bengal
37	IR36	110-115	Irrigated, Rainfed Upland /Lowland	Dwarf (80-90 cm), resistant to blast, sheath blight, Rice Tungro Virus, Grasy Stunt Virus and black leaf streak, and bacterial leaf blight, Yield: 40-45 Q/ha	Orissa, West Bengal (WB), Assam, Meghalaya, Manipur, Kerala
38	Jaldi13	125	Rainfed uplands	Kagalikai/JD-8* (*With wide compatibility gene) Semi dwarf; grains –long bold, resist.to neck blast, BS., WBPH, BPH and GM; Yield : 60 – 72 Q/ha.	West Bengal
39	Triguna	120-125	Irrigated	Tolerant to brown plant hopper, bacterial blight. Yield: 50 Q/ha	Andhra Pradesh
40	Ajit	125	Irrigated	Early maturing type, Yield: 50 Q/ha	West Bengal
41	Lalat	125-130	Irrigated medium	Obs.677 x IR-207 x Vikram , Dwarf (85-90 cm), grains: LS, resistant to Sh.R, GM, BPH, GLH, moderately resistant to blast, Sh.B, BS, RTV, BLB & SB; Yield: 40 Q/ha.	All India
42	PusaBasmati	140	Upland	Non-sticky, high cooked kernel elongation ratio, appealing taste, easy digestability	West Bengal, Haryana, Bihar
43	CSR1	155	Lowland, highly rainfed	Salinity tolerant	West Bengal(Sudarban)
44	CSR2	135	Lowland, highly rainfed	Salinity tolerant	West Bengal(Sudarban)
45	CSR4	130	Lowland, highly rainfed	Salinity tolerant, moderately resistant to several pests and diseases.	West Bengal
46	Radhunipagol	135	Lowland	Fe-Zn rich	West Bengal, Odisha, Bihar
47	Badshabhog	134	Shallow lowland	Bacterial leaf blight resistant, soft and digestive	Odisha, West Bengal, Chattisgarh, Bihar, Madhyapradesh
48	Gobindobhog	120	Shallow lowland	Short grained popular aromatic rice, Susceptible to bacterial leaf blight, Yield: 30 Q/ha	West Bengal
49	Tulaipanji	95	Medium land	Non-sticky, high amylose content, disease-pest resistance	West Bengal(DakshinDinajpur district, Uttar dinajpur, Raiganj)
50	Tulsibhog	107	Lowland	Soft and digestive	West Bengal, Odisha, Bihar
51	Purnendu	114	Rainfed semi deep water	Patnai 23 x Jaladhi 2 Tall (140-150 cm), grains -short bold, white resistant to Sh B, Sh.R, LF, SB & moderately resistant to GM; Yield: 53 Q/ha.	West Bengal
52	CN1039-9	129	Rainfed semi deep water	Long duration, Yield: 45-50 Q/ha, Tolerant to sheath blight, sheath rot, stem borer.	West Bengal

53	Bhudeb	118	Rainfed deep water areas	Pankaj/IR 38699-49-3-1-2// IR 41389-20-1-5, Semi tall; grains - long slender, golden colour, mod. resist. toSh.B., Sh. R. and SB, resist. to BLB, BPH, GM; Yield : 31-41 Q/ha.	West Bengal
54	Nonabokra	118	Lowland,sub merged-water logged condition, highly rainfed	Highly salinity tolerant. Genetic background of Koshihikari, a salt-susceptible *japonica* variety	West Bengal (Sundarban)
55	Amolmona	130	Lowland, rainfed	Salt tolerant rice variety	West Bengal
56	Caning	118	Lowland, highly rainfed	Salinity tolerant, moderately resistant to several pests and diseases, high yield	West Bengal (Sundarban)
57	Pakali	140	Lowland, highly rainfed	Salinity tolerant, suitable for rice-prawn co-culture under saline coastal ecology. Got GI Tag.	West Bengal (Sundarban), Kerala.
58	Nilima	135	Irrigated/rain fed	short bold, moderately resistant to blast & SB,	West Bengal, Assam, Orissa

Table 2 : Effects of Cd treatment on the grain Cd levels and estimated oral weekly intake of Cd from the Cd contaminated rice grains.

Sl. No.	Cultivars	Cd Content (μg g^{-1})	Oral weekly intake(μg)	Oral weekly intake per kg body weight (μg kg^{-1})	Cancer risk factor (Zheng *et al*. 2015)
1	Swarna	0.23	525	10.5	1.12
2	MTU1010	0.425	892.5	17.85	1.91
3	Muktasree	0.6875	1443.75	28.875	3.09
4	Ratna	0.8375	1758.75	35.175	3.76
5	GangaKaberi	0.6625	1391.25	27.825	2.98
6	Khitish	0.8	1680	33.6	3.60
7	Kabirajsaal	0.125	262.5	5.25	0.56
8	Khandagiri	0.275	577.5	11.55	1.23
9	Narendra	0.3125	656.25	13.125	1.40
10	N.Sankar	0.35	735	14.7	1.57
11	SR26B	0.7	1470	29.4	3.15
12	Bandana	0.49	1029	20.58	2.20
13	Palman	0.23	483	9.66	1.03
14	Kausallya	0.9125	1916.25	38.325	4.10
15	Pratiksha	0.7875	1653.75	33.075	3.54
16	Pankaj	0.675	1417.5	28.35	3.03
17	Ranjit	0.8875	1863.75	37.275	3.99
18	Geetanjali	0.675	1417.5	28.35	3.03
19	Suma	1.375	2887.5	57.75	6.18
20	S. Sankar	0.3625	761.25	15.225	1.63
21	Chaitali	0.6875	1443.75	28.875	3.09
22	Mali-4	0.8275	1737.75	34.755	3.72
23	Rajlaxmi	0.075	157.5	3.15	0.33
24	Barsha	0.725	1522.5	30.45	3.26
25	BumpyGold	0.4	840	16.8	1.80
26	Sabita	0.7125	1496.25	29.925	3.20
27	Matla	0.65	1365	27.3	2.92
28	Santoshi	0.6625	1391.25	27.825	2.98
29	Dadsal	0.7125	1496.25	29.925	3.20
30	Suparna	0.25	525	10.5	1.12
31	Annada	0.75	1575	31.5	3.37
32	Asfal	0.7	1470	29.4	3.15

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Conflict of interest

None.

Ethical approval

This article does not contain any studies with human participants or animals performed by any of the authors.

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