Asian Journal of Chemistry; Vol. 36, No. 1 (2024), 247-254

ASIAN JOURNAL OF CHEMISTRY

https://doi.org/10.14233/ajchem.2024.30948

Assessment of Nutrient Minerals and Potentially Toxic Elements in a Bangladesh-Origin Rice Cultivar (*Oryza sativa* cv. BR11) and Associated Health Impacts

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Received: 24 November 2023; *Accepted*: 23 December 2023; *Published online*: 31 December 2023; AJC-21510

Rice contributes significantly to both food security and livelihoods in Bangladesh. Despite challenges such as an immense population growth rate and decreased arable land since gaining independence, Bangladesh has attained self-sufficiency in rice production by adopting modern rice varieties (MRVs). However, not all introduced MRVs have gained widespread acceptance among farmers due to concerns about productivity and profitability. Notably, BR11, an MRV, stands out as a prominently adopted rice cultivar during the Aman rice-growing season. This study aims to assess the levels of essential nutrient minerals (Na, K, Ca and Mg) and potentially toxic elements (PTEs) (Cd, Cu, Pb, Ni, Co, Fe, Mn, Zn, Cr) in the BR11 rice cultivar and also to evaluate associated health risks. The concentrations of Na, K, Ca and Mg (mg 100 g^{-1}) in the sampled BR11 rice cultivar were found to be 4.4 ± 2.4, 108.5 ± 24.9, 3.4 ± 0.4 and 4.5 ± 1.1, respectively. Among the PTEs, Cd, Pb, Ni, Co, or Cr contents were below the detection limit, while Fe, Mn, Zn and Cu contents (mg kg^{-1}) were 12.0 ± 4.0, 9.2 ± 1.5, 18.7 ± 2.7 and 2.9 ± 1.0. Comparisons of PTE contents in BR11 rice cultivars exposed to industrial activities with those cultivated in non-industrial zones did not reveal any statistically significant variations ($p < 0.05$). The estimated daily intake of nutrient minerals through the consumption of BR11 rice was significantly below the daily recommended dietary reference intakes. Likewise, the accumulation of PTEs in the BR11 rice cultivar was well below the maximum allowable concentrations recommended by WHO or FAO. Health risk assessments, involving the computation of non-carcinogenic and carcinogenic risks, did not indicate any concerning risk scenarios associated with the consumption of the BR11 rice cultivar. The data suggests that BR11 is a safe MRV for daily consumption, affirming its suitability for inclusion in the daily diet.

Keywords: Modern rice variety, Nutrient minerals, Potentially toxic elements, Dietary exposure, Health risks.

INTRODUCTION

Bangladesh, with its predominantly agricultural economy, relies significantly on rice as a staple crop [1], which accounts for more than 80% of the total food supply and meets 66% of daily protein requirements [2]. In FY 2021-2022, rice cultivation covered an extensive area of 11.7 million hectares, representing 84% of the total cropped land area and resulting in an annual rice production of 38.14 million metric tons [3]. Numerous modern rice varieties (MRVs) have been introduced to increase agricultural productivity, enhance farmer income and ensure food security and MRVs have become more popular than local varieties due to significantly higher yields [4]. Nevertheless, only a limited number of MRVs have achieved widespread adoption [1,5,6].

The country's three distinct rice-growing seasons, known as Aus, Aman and Boro, correspond to the pre-monsoon, monsoon and dry seasons, contributing to varying rates of total rice production [3,7]. The Aman season, representing the second largest harvest in the annual rice production cycle [7], exhibits a higher adoption ratio of domestic MRVs [1]. Numerous season-specific MRVs have been introduced, with BR11, Paijam, BR10, BR23, BR4, BRRI dhan52 and BRRI dhan49 being popularly adopted during the Aman season [1,8,9]. However, the MRV-type BR11,

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introduced in 1980, has sustained dominance in the Aman season, primarily attributed to its superior yield potential, adaptability to diverse growth conditions and greater acceptance among consumers compared to the subsequently introduced Aman-specific varieties [1,9].

Anthropogenic activities such as chemical and metallurgical industries, smelting processes, agricultural use of chemical fertilizers and pesticides and traffic, as well as lithogenic sources such as element containing rock weathering, all contribute to the accumulation of potentially toxic elements (PTEs) in soil, water and vegetation [10-12]. Because of their persistence and non-degradability, PTEs are significant pollutants [10,13]. The Pb, Hg, As, Cd, Cr, Co and Ni, *etc*. are particularly notable among the PTEs found in environmental samples due to their high toxicity and potential risks to both human health and ecosystems [11,12]. Other PTEs such as Fe, Mn, Zn and Cu are also necessary for human metabolism, while high levels of these elements can be harmful to human health [14]. Given that rice is a fundamental food source in Bangladesh, where it is both produced and consumed abundantly, the accumulation of PTEs in rice grains poses significant health risks to the population. Hence, it is imperative to identify, estimate and consider PTEs to ensure the safety of daily rice consumption for individuals of all ages [15]. While several studies have explored PTEs' presence in rice and vegetables from various parts of Bangladesh [16-20], the current research focuses on the *Oryza sativa* cv. BR11, an Aman-specific MRV cultivar. To the best of our knowledge, no previous studies have investigated the essential nutrient minerals and PTEs in the BR11 rice cultivar or the potential associated health effects. The primary objective is to evaluate how the nutrient minerals and PTEs in the BR11 rice cultivar may impact the consumers, considering factors such as estimated average intake and poten-tial carcinogenic or non-carcinogenic risks.

EXPERIMENTAL

Sampling: A total of 45 BR11 rice cultivar samples were collected from 15 locations of Chattogram district of Bangladesh (Fig. 1): Raozan upazila, S1; Rangunia upazila, S2; Fatikchhari upazila, S3; Hathazari upazila, S4; Anwara upazila, S5; Banshkhali upazila, S6; Chandanaish upazila, S7; Karnaphuli upazila, S8; Lohagara upazila, S9; Mirsharai upazila, S10; Patiya upazila, S11; Satkania upazila, S12; Sitakunda upazila, S13; Boalkhali upazila, S14; Sandwip upazila, S15. Situated in the south-eastern part of Bangladesh, the study area (Chattogram district) spans an area of 5282.92 km^2, positioned between 21°54′ and 22°59′ north latitudes and 91°17′ and 92°13′ east longitudes. Distinguished from other districts of Bangladesh by its diverse features, Chittagong district includes a blend of hills, rivers, sea, forests, valleys and scattered industrial facilities, including the unique open-beach ship-breaking zone [21,22].

The study locations in the current study were further categorized into industrial and non-industrial areas to enhance under-

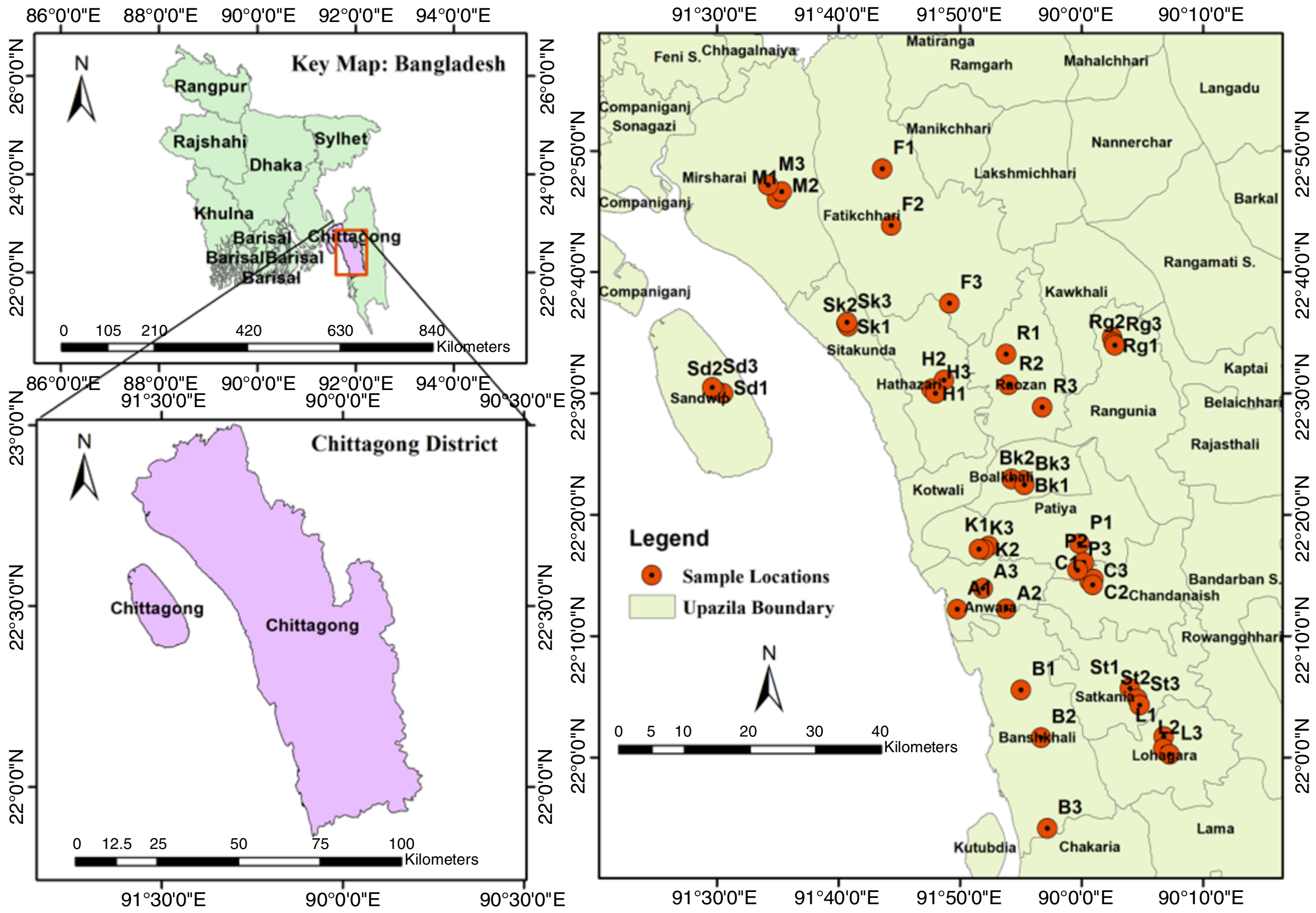

Fig. 1. Sampling locations

standing of metal assimilation in paddy fields and to explore the potential impact on PTE uptake in BR11 rice cultivars. The industrial locations (IL) encompassed S5, S6, S8, S10 and S13, whereas the non-industrial locations (N-IL) comprised S1, S2, S3, S4, S7, S9, S11, S12, S14 and S15.

Three samples were collected from each location and assembled by hand to avoid the cross-contamination. Following collection, the rice samples were stored in plastic bags with proper labeling and markings for chemical analysis.

Sample processing and analysis: The dry ash method was used to prepare samples for analysis, with precautions taken to prevent the elemental volatilization losses. Each 5 g sample was ignited in a muffle furnace after being placed in a pre-weighed porcelain dish. The temperature was increased to 450 ºC at a rate of 50 ºC h^{-1} until complete ash formation occurred. After cooling to room temperature, the ashes were dissolved in dil. HNO_3 and heated on a hot plate until the required amount of acid was added for digestion. Following that, each mixture was filtered, diluted to 100 mL with ultrapure water and stored at 4 ºC for further analysis.

The concentrations of potentially toxic elements (PTEs) (Cd, Cu, Pb, Ni, Co, Fe, Mn, Zn, Cr) and one nutrient mineral (Mg) in the BR11 rice cultivar were determined using an iCE 3300 AAS flame atomic absorption spectrometer (Thermo Scientific, UK). The contents of other nutrient minerals (Na, K, Ca) in BR11 were determined using a PFP7 Flame Photometer (Jenway, Staffordshire, UK).

Assessment of health risks

Estimated average intake (EAI): The estimated average intakes of nutrient minerals and PTEs were calculated by multiplying the mean concentration in BR11 rice cultivar samples by the daily rice intake and dividing by the average body weight. The following equation was used to calculate estimated average intakes [23]:

$$\text{EAI} = \frac{\text{DI} \times \text{C}}{\text{Bw}} \tag{1}$$

In eqn. 1, Bw is the average body weight (kg), C is the nutrient mineral and PTE content in the BR11 rice cultivar (mg kg^{-1}) and DI is the daily rice intake (g $person^{-1}$ day^{-1}). The average adult body weight was assumed to be 60 kg and children's body weight was considered to be 25 kg, with daily consumption set at 445 g for each adult and 200 g for each child.

Non-carcinogenic risk: The assessment of non-carcinogenic risk due to the consumption of BR11 rice cultivar, as indicated by the target hazard quotient (THQ), followed the methodology outlined in Region III risk-based concentration table provided by the US Environmental Protection Agency (USEPA) [24]. The THQ calculation is based on the oral reference dose (RfD), representing the estimated daily exposure to PTEs that poses no adverse effects on human health throughout a lifetime [25]. The formula proposed by Hang *et al.* [26] was utilized to compute the THQ values for the PTEs.

$$\text{THQ} = \frac{\text{EAI}}{\text{RfD}} \tag{2}$$

The RfD (mg kg^{-1} day^{-1}) for Cr, Mn, Zn, Cu, Pb, Cd, Ni and Co were 1.5, 0.033, 0.30, 0.04, 0.0035, 0.001, 0.02 and 3.01, respectively [19,27]. A THQ value below one indicates a negligible risk, signifying harmlessness. Conversely, a THQ value exceeding one suggests an increased non-carcinogenic risk [28].

Hazard index (HI), formulated following USEPA criteria for assessing health-related concerns, was used to estimate the collective non-carcinogenic effects due to the consumption of BR11 rice cultivar, using the sum of individual THQ values for all PTEs involved [29].

$$\text{HI} = \sum \text{THQ} = \text{THQ}_{\text{Cr}} + \text{THQ}_{\text{Mn}} + \text{THQ}_{\text{Zn}} + \text{THQ}_{\text{Cu}} + \text{THQ}_{\text{Pb}} + \text{THQ}_{\text{Cd}} + \text{THQ}_{\text{Ni}} + \text{THQ}_{\text{Co}} \tag{3}$$

Carcinogenic risk: The following equation was used to calculate the carcinogenic risks of PTEs due to the consumption of the BR11 rice cultivar.

$$\text{TR} = \frac{\text{EFr} \times \text{ED} \times \text{FIR} \times \text{C} \times \text{CSFo}}{\text{Bw} \times \text{AT}} \times 10^{-3} \tag{4}$$

In eqn. 4, TR = target risk of cancer over a lifetime; EFr, exposure frequency (365 days yr^{-1}); ED = exposure duration (70 yrs); FIR = food ingestion rate (g $person^{-1}$ day^{-1}); C = metal concentration in food (mg kg^{-1}); AT = averaging time for carcinogens (365 days yr^{-1} × ED); CSFo = oral carcinogenic slope factor from the Integrated Risk Information System USEPA database [30], which was 1.5 and 8.5×10^{-3} mg kg^{-1} day^{-1} for As and Pb.

Statistical analysis: Statistical analyses were conducted using IBM SPSS Statistics 23.0 (International Business Machines Corp., Armonk, USA). The General Linear Model was employed for one-way ANOVA to compare nutrient mineral or PTE content in the BR11 rice cultivar across various sampled locations. The fixed factor was the characteristics of the sampling location or sampling zone and the dependent variable was the nutrient mineral or PTEs content. Mean values were compared using Duncan's multiple range test at a significance level of $p = 0.05$. Additionally, a principal component analysis (PCA) was performed to classify nutrient mineral or PTE content in the BR11 rice cultivar from different locations using Origin Pro 2023b (OriginLab Corporation, Northampton, USA).

RESULTS AND DISCUSSION

Nutrient minerals in BR11 rice cultivar

Nutrient mineral contents: Table-1 shows the concentrations of nutrient minerals (Na, K, Ca and Mg) in the BR11 rice cultivar collected from different locations. In general, the average nutrient mineral content followed the order: K > Mg > Na > Ca, with concentrations (mg 100 g^{-1}) of 108.5, 4.5, 4.44 and 3.43, respectively (Fig. 2a). Variations in mineral content were apparent among samples collected from various locations, displaying disparate patterns (Table-1, $p < 0.05$). Notably, the samples from S2 showed a significantly lower content of K or Ca, while S7 and S15 demonstrated the lowest levels of Na and Mg. On the contrary, significantly higher Na, K, Ca and Mg contents compared to other locations were observed in S13, S10, S12 and S7, respectively ($p < 0.05$). No significant difference

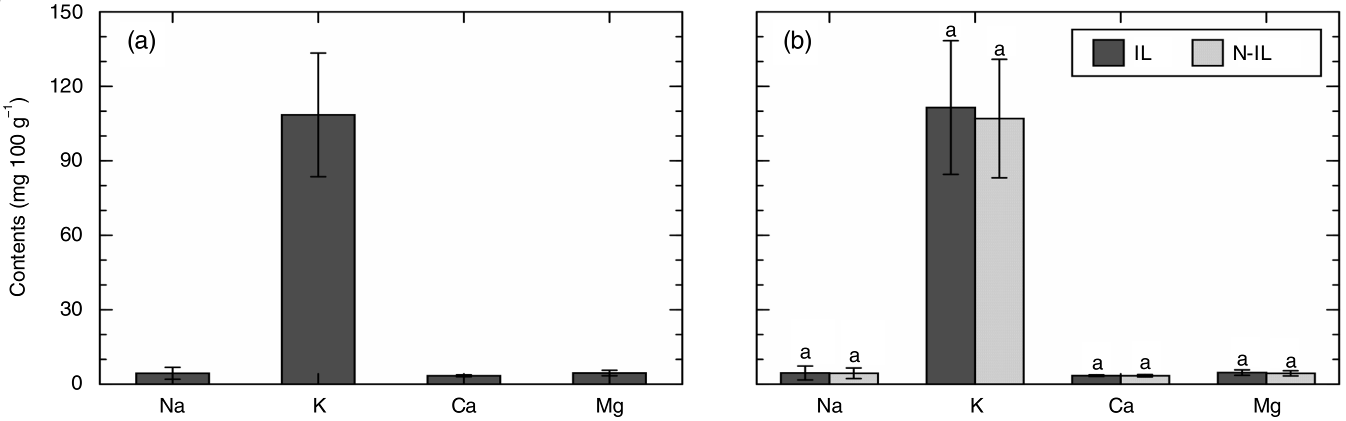

Fig. 2. Nutrient mineral contents (mg 100 g^{-1}) in BR11 rice cultivar: (a) overall mean and (b) comparison between industrial (IL) and non-industrial (N-IL) locations (data-subset of an individual element with identical letters are not significantly different at $p \leq 5\%$)

TABLE-1
CONTENTS (MEAN ± SD) OF NUTRIENT MINERALS IN DIFFERENT SAMPLED LOCATIONS

Sample location	Nutrient minerals (mg 100 g^{-1})[‡]			
	Na	K	Ca	Mg
S1	$3.7 \pm 1.5^{a,b,c,d}$	$101 \pm 18^{a,b,c}$	2.9 ± 0.4^{a}	3.2 ± 1.5^{a}
S2	$7.6 \pm 2.7^{c,d}$	65 ± 26^{a}	2.6 ± 0.5^{a}	3.0 ± 0.4^{a}
S3	$4.8 \pm 2.2^{a,b,c,d}$	$94 \pm 8^{a,b}$	$3.2 \pm 0.2^{a,b}$	$4.4 \pm 1.4^{a,b,c}$
S4	$6.0 \pm 2.5^{a,b,c,d}$	$110 \pm 21^{a,b,c}$	$3.5 \pm 0.2^{a,b}$	$4.6 \pm 1.1^{a,b,c}$
S5	$2.2 \pm 0.9^{a,b}$	$103 \pm 23^{a,b,c}$	$3.5 \pm 0.6^{a,b}$	$4.7 \pm 0.3^{a,b,c}$
S6	$5.7 \pm 2.8^{a,b,c,d}$	$104 \pm 20^{a,b,c}$	$3.7 \pm 0.4^{a,b}$	$4.8 \pm 1.5^{a,b,c}$
S7	1.4 ± 1.8^{a}	$109 \pm 43^{a,b,c}$	$3.3 \pm 0.4^{a,b}$	7.3 ± 1.3^{d}
S8	1.4 ± 1.3^{a}	$101 \pm 15^{a,b,c}$	2.8 ± 0.2^{a}	$3.8 \pm 1.2^{a,b}$
S9	$4.0 \pm 3.0^{a,b,c,d}$	$109 \pm 30^{a,b,c}$	$3.2 \pm 0.6^{a,b,c}$	$5.4 \pm 1.3^{b,c,d}$
S10	$4.9 \pm 4.3^{a,b,c,d}$	160 ± 42^{d}	$4.1 \pm 0.1^{b,c}$	$6.0 \pm 1.1^{c,d}$
S11	$7.0 \pm 4.2^{b,c,d}$	$124 \pm 14^{b,c,d}$	$3.7 \pm 0.4^{a,b}$	$5.1 \pm 0.6^{a,b,c}$
S12	$4.6 \pm 1.4^{a,b,c,d}$	$106 \pm 35^{a,b,c}$	4.8 ± 1.9^{c}	$4.4 \pm 1.4^{a,b,c}$
S13	8.5 ± 4.7^{d}	$90 \pm 34^{a,b}$	$3.2 \pm 0.5^{a,b}$	$4.1 \pm 1.4^{a,b,c}$
S14	$3.0 \pm 1.5^{a,b,c}$	$102 \pm 27^{a,b,c}$	$3.2 \pm 0.2^{a,b}$	$3.4 \pm 0.9^{a,b}$
S15	1.9 ± 0.7^{a}	$150 \pm 16^{c,d}$	$3.7 \pm 0.1^{a,b}$	3.0 ± 0.6^{a}

[‡] Values in the same column (data-subset of an individual element) with identical letters are not significantly different at $p \leq 5\%$.

($p < 0.05$) in nutrient mineral uptake in the BR11 rice cultivar was observed between industrial and non-industrial locations (Fig. 2b).

Estimated average intake (EAI): Table-2 summarizes the EAI values for nutrient minerals in the BR11 rice cultivar. The total EAI values for the cultivar sampled from S10 exhibited higher values for both adults and children, whereas those from S2 were the lowest. The trend in EAI values for nutrient minerals corresponded to the observed pattern in overall contents, *i.e.*, K > Mg > Na > Ca. Nonetheless, the EAI of Na, K, Ca or Mg in the BR11 rice cultivar had a meager contribution ($p < 0.05$) to their overall dietary reference intakes (DRI) in both adult and child consumers.

PTEs in BR11 rice cultivar

PTE contents: The BR11 rice cultivar was analyzed for nine PTEs (Cd, Cu, Pb, Ni, Co, Fe, Mn, Zn, Cr), five of which were found to be below the detection limit (Cd, Pb, Ni, Co or Cr). Thus, the current study exclusively presents data on the Fe, Mn, Zn and Cu levels in the BR11 rice cultivar across diverse

TABLE-2
ESTIMATED AVERAGE INTAKE (mg kg^{-1} bw^{-1} day^{-1}) OF NUTRIENT MINERALS FROM BR11 RICE CULTIVAR IN ADULTS AND CHILDREN, COMPARED TO DIETARY REFERENCE INTAKES

Sample location	Na		K		Ca		Mg	
	Adult	Child	Adult	Child	Adult	Child	Adult	Child
S1	0.28	0.30	7.47	8.05	0.22	0.23	0.24	0.26
S2	0.57	0.61	4.82	5.20	0.20	0.21	0.22	0.24
S3	0.36	0.38	6.97	7.52	0.24	0.25	0.33	0.35
S4	0.44	0.48	8.17	8.82	0.26	0.28	0.34	0.37
S5	0.16	0.17	7.65	8.25	0.26	0.28	0.35	0.37
S6	0.42	0.46	7.73	8.33	0.28	0.30	0.35	0.38
S7	0.10	0.11	8.12	8.76	0.25	0.27	0.54	0.58
S8	0.10	0.11	7.46	8.05	0.21	0.22	0.28	0.31
S9	0.29	0.32	8.07	8.70	0.24	0.25	0.40	0.43
S10	0.37	0.39	11.84	12.77	0.31	0.33	0.45	0.48
S11	0.51	0.56	9.19	9.92	0.28	0.30	0.38	0.40
S12	0.34	0.37	7.88	8.50	0.36	0.38	0.33	0.35
S13	0.63	0.68	6.65	7.18	0.24	0.25	0.31	0.33
S14	0.22	0.24	7.54	8.14	0.24	0.25	0.26	0.28
S15	0.14	0.16	11.13	12.01	0.28	0.30	0.22	0.24
DRI[*,†]	1200-1500	800-1000	2300-3400	2000-2300	1000-1300	700-1000	240-420	80-130

*Dietary reference intakes (DRIs) (mg day^{-1}); [†]Data sources: National Academies [32], Institute of Medicine [33], Institute of Medicine [34], Institute of Medicine [35].

sampled locations Table-3. The respective contents (mg kg^{-1}) ranged from 4.49 to 24.66 for Fe, 3.06 to 13.03 for Mn, 9.42 to 22.72 for Zn and 2.11 to 4.82 for Cu and the averaged variations are shown in Fig. 3a. The variation in the content of PTEs did not exhibit any notable pattern, except for the lowest Mn and Zn contents observed at the same sampled location, S15 (Table-3, $p < 0.05$). Also, there was no statistically significant difference ($p < 0.05$) in the average contents of PTEs in the BR11 rice cultivar between locations classified as industrial and non-industrial (Fig. 3b).

Table-4 compares PTE contents in the BR11 rice cultivar with data reported for unidentified rice varieties from different countries, including previous reports from Bangladesh. The literature reports indicated the detection of PTEs, sometimes surpassing the maximum allowable concentration (MAC), in rice grains cultivated in other countries and those sampled from different locations in Bangladesh. However, the BR11 MRV showed below detectable presence of Pb, Cd, Cr, Co and Ni. Furthermore, none of the observed levels of PTEs that were detected exceeded the corresponding maximum allowable concentrations (mg kg^{-1}; Fe, 45; Mn, 500; Zn, 40; and Cu, 10) [31].

TABLE-3
CONTENTS (MEAN ± SD) OF PTEs IN DIFFERENT SAMPLED LOCATIONS

Sample location	PTEs (mg kg^{-1})[‡,†]			
	Fe	Mn	Zn	Cu
S1	24.7 ± 11.8 ^{c}	8.1 ± 0.1 ^{b}	21.5 ± 1.3 ^{b,c}	2.2 ± 0.8 ^{a}
S2	10.2 ± 5.3 ^{a,b}	8.1 ± 1.6 ^{b}	16.5 ± 1.2 ^{b}	2.8 ± 0.6 ^{a,b}
S3	11.5 ± 3.9 ^{a,b}	10.0 ± 0.4 ^{b,c}	18.0 ± 2.7 ^{b,c}	4.0 ± 0.7 ^{a,b}
S4	9.2 ± 1.1 ^{a,b}	10.4 ± 3.7 ^{b,c}	20.1 ± 4.3 ^{b,c}	4.8 ± 2.7 ^{b}
S5	13.8 ± 5.9 ^{a,b}	8.9 ± 1.4 ^{b}	17.4 ± 2.3 ^{b,c}	3.0 ± 1.1 ^{a,b}
S6	10.9 ± 1.9 ^{a,b}	11.1 ± 0.5 ^{b,c}	19.2 ± 5.5 ^{b,c}	3.2 ± 0.9 ^{a,b}
S7	7.2 ± 1.2 ^{a}	11.0 ± 2.2 ^{b,c}	18.1 ± 1.3 ^{b,c}	2.3 ± 1.2 ^{a}
S8	4.5 ± 2.4 ^{a}	8.3 ± 0.5 ^{b}	17.1 ± 0.6 ^{b,c}	2.2 ± 0.4 ^{a}
S9	10.1 ± 3.6 ^{a,b}	10.1 ± 1.5 ^{b,c}	19.3 ± 0.9 ^{b,c}	3.5 ± 1.7 ^{a,b}
S10	10.5 ± 0.9 ^{a,b}	13.0 ± 3.5 ^{c}	18.3 ± 3.2 ^{b,c}	2.3 ± 0.5 ^{a}
S11	18.1 ± 6.4 ^{b,c}	9.7 ± 2.1 ^{b,c}	20.5 ± 3.5 ^{b,c}	2.1 ± 0.3 ^{a}
S12	22.1 ± 6.8 ^{c}	10.0 ± 2.3 ^{b,c}	22.7 ± 3.4 ^{c}	3.4 ± 1.8 ^{a,b}
S13	10.2 ± 3.3 ^{a,b}	8.1 ± 2.7 ^{b}	20.4 ± 5.5 ^{b,c}	2.3 ± 0.4 ^{a}
S14	11.9 ± 3.7 ^{a,b}	8.7 ± 0.3 ^{b}	22.3 ± 3.1 ^{b,c}	3.1 ± 1.0 ^{a,b}
S15	4.8 ± 1.9 ^{a}	3.1 ± 0.4 ^{a}	9.4 ± 1.8 ^{a}	2.8 ± 1.0 ^{a,b}

[‡] Values in the same column (data-subset of an individual element) with identical letters are not significantly different at $p \leq 5\%$; [†] Five (Cd, Pb, Ni, Co and Cr) of the nine PTEs (Cd, Cu, Pb, Ni, Co, Fe, Mn, Zn, Cr) analyzed in the BR11 rice cultivar were below the detection limit and thus not included in the Table.

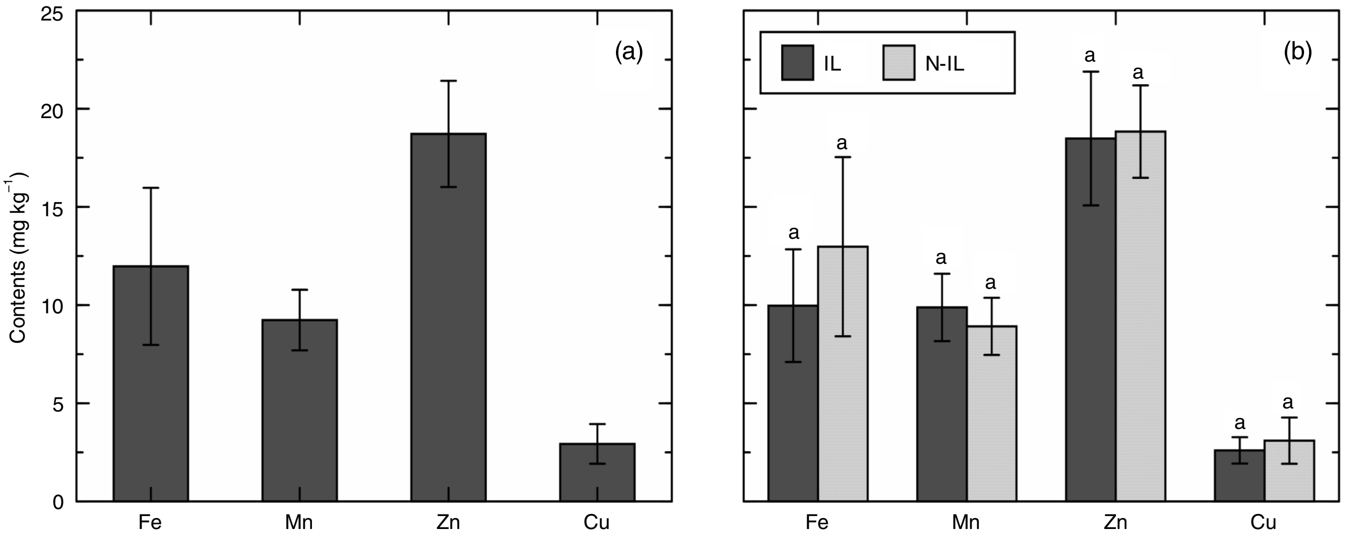

Fig. 3. Contents of PTEs (mg kg^{-1}) in BR11 rice cultivar: (a) overall mean and (b) comparison between industrial (IL) and non-industrial (N-IL) locations (data-subset of an individual element with identical letters are not significantly different at $p \leq 5\%$)

TABLE-4
PTE CONTENTS IN UNSPECIFIED RICE VARIETIES FROM DIFFERENT COUNTRIES COMPARED TO THE BR11 RICE CULTIVAR FROM BANGLADESH[†,#]

	Cd	Cu	Pb	Ni	Co	Fe	Mn	Zn	Cr	Ref.
China	0.01-0.41	0.004-4.04	0.002-0.66	0.22-0.88	0.03	–	–	0.02-27.7	0.11-10.7	[28,29,36-41]
Ethiopia	0.54±0.02	15±1.3	3.3±0.2	69.7±1.5	–	–	–	51.6±0.2	4.82±0.09	[42]
Philippines	< 10	< 25	< 8	< 50	–	–	–	17-68.6	< 36.8	[43]
Australia	0.01	–	0.38	0.17	2.9	–	–	17.1	0.14	[44]
Nigeria	< 0.01	1.59±0.10	< 0.08	0.12±0.02	–	–	–	8.20±0.29	0.18±0.02	[45]
India	0.1-0.21	2.78-4.56	0.17-5.67	0.28-0.83	0.01	1.82-49.8	5.2-7.3	4.2-27.3	0.28-1.12	[46-49]
Bangladesh	0.03-2.89	3.93-38.1	<0.12-4.34	0.18-5.83	<0.22-18.1	9.5-14.9	8.92-32.98	16.8-122	1.2-23.7	[20,24,27, 50-52]
BR11 rice	BDL	2.93±1.23	BDL	BDL	BDL	11.98±6.88	9.24±2.68	18.72±4.03	BDL	Present study
MAC*	0.4	10	0.2	0.5	1	45	500	40	1	

[†] '–'Data not available. 'BDL' Below detectable limit. [#] When multiple reports are available for the same country, data is presented in a range, whereas averaged value and standard deviation are reported for a single data-set. *MAC: Maximum allowable concentrations; [#] Data source: Limit values recommended by FAO or WHO, as extracted from Natasha *et al.* [31].

The PCA was used to explore the origins of PTEs in the sampled BR11 rice cultivar (Fig. 4). Two principal components, PC1 and PC2, accounted for 76.72% of the variance, with eigen values of 1.97309 and 1.09557, respectively. Larger eigen values signify more impactful components. The loading plots illustrate relationship between the original variables (Fe, Mn, Zn or Cu) and the PCs, revealing the contribution of each element. Notably, Fe, Mn and Zn exhibit positive loadings in PC1, suggesting the contribution of anthropogenic activities as the primary source of variation. Conversely, PC2 is predominantly influenced by Cu, with a strong positive loading, indicating that Cu significantly contributes to the variation captured by PC2, likely originating from other human-related activities such as fertilizer application.

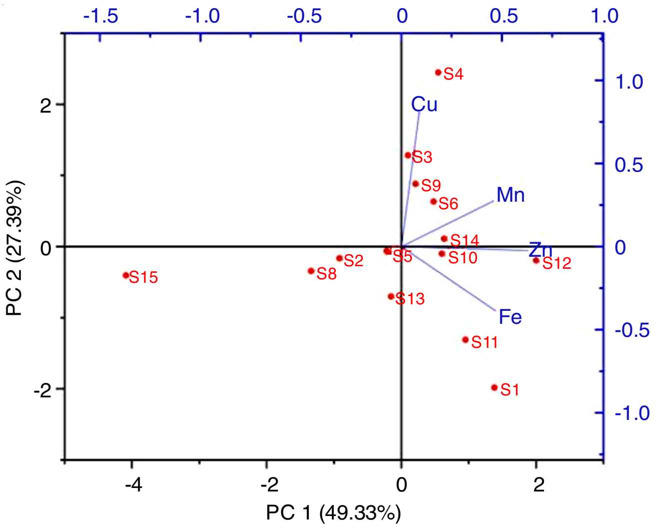

Fig. 4. Principal component analysis of PTEs in BR11 rice cultivar

EAI, THQ and HI: Table-5 listed the EAIs of Fe, Mn, Zn and Cu from the BR11 rice cultivar in both adults and children and all these values are significantly lower than the corresponding DRI values. Non-carcinogenic risks, as indicated by THQ values, due to the consumption of BR11 rice cultivar by adults and children, were assessed (Table-6). THQ values below 1, observed for Mn, Zn or Cu in all sampled locations, suggest an absence of apparent non-carcinogenic health risks associated with these metals. The finding for BR11 contrasts with previous reports on unidentified rice varieties cultivated in various regions of Bangladesh, where THQ values greater than one were reported for Cu, Ni, As, Cd and Pb [24,51]. However, such discrepancies may be attributed to varying geographical and environmental factors. Five PTEs (As, Cr, Ni, Cd and Pb) were not detected in the sampled BR11 rice cultivar, implying no assumed cancer-related risks to human health due to contamination with these elements (Table-5).

Conclusion

The present study assessed the concentrations of nutrient minerals and potentially toxic elements (PTEs) in the BR11 rice cultivar to evaluate potential health impacts associated with its consumption. The analysis revealed that nutrient mineral contents in the sampled BR11 rice contribute minimally to the recommended dietary reference intakes. The mean concentrations of PTEs were well below the maximum allowable concentrations recommended by WHO or FAO, with many remaining below detectable limits. Hazard quotients derived from the PTE concentration data indicated that neither adult nor child consumers are at risk. However, it is recommended to conduct further research on soil contamination in paddy fields and the bioaccumulation factor of PTEs in rice. Furthermore, regular monitoring of PTE contents in rice and other staple foods is advisable to ensure food safety and reduce potential risks to human health.

ACKNOWLEDGEMENTS

The study was supported by grants from (a) Environmental Radioactivity Research Network Center at Fukushima University,

TABLE-5
ESTIMATED AVERAGE INTAKE (mg kg^{-1} bw^{-1} day^{-1}) OF PTEs FROM BR11 RICE CULTIVAR IN ADULTS AND CHILDREN, COMPARED TO THEIR RESPECTIVE DIETARY REFERENCE INTAKES

Sample location	Fe		Mn		Zn		Cu	
	Adult	Child	Adult	Child	Adult	Child	Adult	Child
S1	0.18	0.20	0.06	0.07	0.16	0.17	0.02	0.02
S2	0.08	0.08	0.06	0.06	0.12	0.13	0.02	0.02
S3	0.08	0.09	0.07	0.08	0.13	0.14	0.03	0.03
S4	0.07	0.07	0.08	0.08	0.15	0.16	0.04	0.04
S5	0.10	0.11	0.07	0.07	0.13	0.14	0.02	0.02
S6	0.08	0.09	0.08	0.09	0.14	0.15	0.02	0.03
S7	0.05	0.06	0.08	0.09	0.13	0.14	0.02	0.02
S8	0.03	0.04	0.06	0.07	0.13	0.14	0.02	0.02
S9	0.07	0.08	0.07	0.08	0.14	0.15	0.03	0.03
S10	0.08	0.08	0.10	0.10	0.14	0.15	0.02	0.02
S11	0.13	0.14	0.07	0.08	0.15	0.16	0.02	0.02
S12	0.16	0.18	0.07	0.08	0.17	0.18	0.03	0.03
S13	0.08	0.08	0.06	0.06	0.15	0.16	0.02	0.02
S14	0.09	0.09	0.06	0.07	0.17	0.18	0.02	0.02
S15	0.04	0.04	0.02	0.02	0.07	0.08	0.02	0.02
DRI*,†	8-18	7-10	1.6-2.3	1.2-1.5	8-11	3-5	0.7-0.9	0.3-0.4

*Dietary reference intakes (DRIs) (mg day^{-1}); †Data sources: Institute of Medicine [33].

TABLE-6
TARGET HAZARD QUOTIENT AND HAZARD INDEX FOR BR11 RICE CULTIVAR IN ADULTS AND CHILDREN

Sample location	Adult				Child			
	THQ			HI	THQ			HI
	Mn	Zn	Cu		Mn	Zn	Cu	
S1	0.18	0.05	0.04	0.27	0.20	0.06	0.04	0.30
S2	0.18	0.04	0.05	0.27	0.20	0.04	0.06	0.30
S3	0.23	0.04	0.07	0.34	0.24	0.05	0.08	0.37
S4	0.23	0.05	0.09	0.37	0.25	0.05	0.10	0.40
S5	0.20	0.04	0.06	0.30	0.22	0.05	0.06	0.33
S6	0.25	0.05	0.06	0.36	0.27	0.05	0.06	0.38
S7	0.25	0.04	0.04	0.34	0.27	0.05	0.05	0.37
S8	0.19	0.04	0.04	0.27	0.20	0.05	0.04	0.29
S9	0.23	0.05	0.06	0.34	0.24	0.05	0.07	0.36
S10	0.29	0.05	0.04	0.38	0.32	0.05	0.05	0.42
S11	0.22	0.05	0.04	0.31	0.24	0.05	0.04	0.33
S12	0.22	0.06	0.06	0.34	0.24	0.06	0.07	0.37
S13	0.18	0.05	0.04	0.27	0.20	0.05	0.05	0.30
S14	0.20	0.06	0.06	0.32	0.21	0.06	0.06	0.33
S15	0.07	0.02	0.05	0.14	0.07	0.03	0.06	0.16

Japan (ERAN: I-23-16), (b) Research and Publication Cell at University of Chittagong, Bangladesh (6751/GaBey/Pori/Proka/Doptor/CU/2019 and 241/2023-24/1st call/17/2023) and (c) Grants-in-Aid for Scientific Research (21K12287) from the Japan Society for the Promotion of Science.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interests regarding the publication of this article.

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