Chandrasiri *et al. Applied Biological Chemistry* (2022) 65:24
https://doi.org/10.1186/s13765-022-00689-8

KSABC
The Korean Society for Applied Biological Chemistry

ARTICLE **Open Access**

An assessment on toxic and essential elements in rice consumed in Colombo, Sri Lanka

Gayani Udeshika Chandrasiri[1*], Kariyawasam Ranaweerage Ranjith Mahanama[2], Kushani Mahatantila[1], Pavithra Sajeewani Pitumpe Arachchige[3] and Roshan Chathuranga Midigama Liyanage[1]

Abstract

Being the dietary staple in most Asian countries, the concentrations of toxic and essential element content in rice is an important aspect in terms of both toxicological and nutritional standpoints. This study aimed to analyse trace elements (As, Cd, Pb, Hg, Cr, Ni, Zn, Cu, Mn, Fe, and Mo) in improved, traditional, and imported rice varieties consumed in Colombo district**,** Sri Lanka during 2018 and 2019. Further, the potential health risks were assessed in terms of maximum levels and provisional tolerable daily intake. Among the toxic elements analysed, As, Cd, Cr, and Pb were detected in certain rice varieties. Arsenic was detected in all three rice categories and the number of As detected samples were higher compared to other toxic elements in 2018 and 2019. In 2018, 4.2% of traditional rice exceeded As maximum level (0.2 mg/kg) whereas 2.1% of improved and 4.2% of traditional rice exceeded Pb maximum level (0.2 mg/kg). However, none of the toxic elements in rice exceeded the respective maximum levels in 2019. Only mean estimated daily intake of Pb through *Kaluheenati* exceeded the provisional tolerable daily intake value (0.0015 mg/kg bw/d) in 2018. Rice varieties that reported the highest toxic elements were *Basmathi* (imported), *Samba* (improved), and *Kaluheenati, Madathawalu, Pachchaperuman*, and *Suwadel (*traditional*)*. With regard to essential elements, concentrations of Fe, Zn, Cu, Mn, and Mo in rice were positively correlated ($p < 0.05$) to each other, and the highest essential element concentration were found in traditional rice with red pericarp (i.e., *Kaluheenati, Madathawalu,* and *Pachchaperuman*).

Keywords: Essential elements, Provisional tolerable daily intake, Rice varieties, Toxic elements

Introduction

Rice (*Oryza sativa* L.) is the staple food that plays a significant role in stabilizing food security in most Asian countries, including Sri Lanka [1, 2]. Being the dietary staple, rice has become the main nutritional source of essential trace elements (Cu, Mn, Fe, Mo, and Zn) among Asians [2]. In Sri Lanka, paddy cultivation occupies 40 percent of the arable land (approximately 708,000 ha) to meet the demand of annual rice consumption of 2.8 million metric tons [3]. Among paddy cultivated districts in two major climatic zones in Sri Lanka, i.e., dry zone (1000 mm/year rainfall) and wet zone (2280–5000 mm/year rainfall), the highest contribution to the domestic rice production is made by Ampara followed by Pollonnaruwa, Anuradhapura, and Hambanthota in the dry zone [4, 5]. A variety of improved, traditional, and imported rice varieties are available in the Sri Lankan market differing in grain size (long and short), pericarp colour (red and white), method of processing (raw, parboiled, and degree of polishing) [6]. In Sri Lanka, the annual per capita rice consumption is approximately 107 kg [3] and the consumer preference for a rice variety mainly depends on taste, aroma, texture,

*Correspondence: gayaniudeshika123@gmail.com
[1] Industrial Technology Institute, 363, Bauddhaloka Mawatha, Colombo 07, Sri Lanka
Full list of author information is available at the end of the article

ease of cooking, colour, cleanliness, breakability, appearance, shape, and size [7].

There are emerging concerns on the contamination of rice with potentially toxic (i.e., As, Cd, Cr, Hg, Pb, and Ni) and essential elements (i.e., Fe, Cu, Zn, Mn, and Mo) that may lead to trace element imbalances and toxicities in consumers [8]. Heavy metal/metalloid toxicities may interfere with the functions of the brain, lungs, kidneys, liver, blood composition, and other organs, depending on the rate of consumption of contaminated rice and the duration of exposure, i.e., acute or chronic [9]. Further, long-term exposure to heavy metals/metalloids via dietary sources may also cause cancer [9]. In Sri Lanka, several recent research findings indicated elevated levels of heavy metals/metalloids in rice grains [10, 11], whilst others have detected heavy metals/metalloids below the maximum levels (MLs) recommended by FAO/WHO Joint CODEX Alimentarius [1, 12]. Industrial activities and continuous/excessive usage of agrochemicals (containing potentially toxic elements as impurities) have been identified as the main anthropogenic causes of elevated trace element concentrations in rice [1, 8, 13]. In addition, climatic conditions, topography, rice variety, soil physicochemical properties, bioavailability of trace elements, biological processes in soils/plants, and agricultural management practices (i.e., fertilization, irrigation, and micronutrient fortification) may affect the bioaccumulation of trace elements in rice [1, 2, 8, 13]. Diyabalanage et al. [13] found a significant difference in Cd concentration in rice cultivated in dry, intermediate, and wet zones in Sri Lanka while no significant differences in As concentration was observed either between red and white rice varieties or among climatic regions. Moreover, Navarathna et al. [1] reported a relative resistivity for Cd uptake by traditional rice varieties such as *Pachchaperuman* and *Madathawalu* compared to newly improved varieties in both organic and conventional agricultural management systems.

As aforementioned factors (i.e., environmental and management) that affect trace element bioavailability in soil and uptake by paddy may change over time, it is necessary to conduct frequent studies (covering both temporal and spatial variations). The findings of such studies will give a better picture of the quality of rice available in Sri Lanka with respect to trace element concentrations (both toxicological and nutritional standpoints). To the best of our knowledge, there are no recent studies conducted on assessing the temporal variation of potentially toxic and essential elements in commonly consumed rice varieties (including improved, traditional and imported) available in the Colombo district (market available) while addressing the dietary exposure and health risk assessment. Further, we believe determining the variety effect, elemental correlations of essential trace elements in rice grains and the contribution of rice varieties to recommended daily allowances (RDA) of Fe and Zn are vital in implementing efforts to alleviate the hidden hunger issues (i.e., micronutrient deficiencies) in Sri Lanka. In Sri Lanka, a high prevalence of Zn and Fe deficiencies has been identified in humans and more than 50% of children and adults are suffering from the coexistence of micronutrient deficiencies [14]. The assessment of potential health risks in terms of provisional tolerable daily intake (PTDI) is vital as the risk intensifies with the increased rate of rice consumption. In our study, reliable data generated using validated test methods [15] will serve as baseline data for setting national guidelines for trace elements in rice which are yet to be set. Further, this study will be important to regulate the trace element concentrations in rice available in the Sri Lankan market which is proposed as the major dietary source of heavy metal/metalloid exposure to the general public [2]. Therefore, the study aimed to analyse and compare potentially toxic and essential trace elements (As, Cd, Pb, Hg, Cr, Ni, Zn, Cu, Mn, Fe, and Mo) in commonly consumed improved rice varieties, selected traditional and imported rice varieties available in the Colombo district, Sri Lanka (during 2018 and 2019) and also to assess the potential health risks in terms of MLs, PTDIs, and Recommended Daily Allowances (RDAs).

Methodology

Rice sample collection

Highly consumed eight improved rice varieties (based on the Household Income and Expenditure Survey—2016) [16]: *White nadu*, White raw, *White raw samba*, *Red nadu*, Red raw, *Red raw samba*, *Samba*, *Keeri Samba*; commonly available two imported varieties: *Basmathi*, fragrant rice and four traditional rice varieties: *Suwadel*, *Kaluheenati*, *Pachchaperuman*, *Madathawalu* were selected for the study (Table 1). For each rice variety, six samples were collected from leading supermarkets and wholesalers in open economic centers located at Homagama, Nawinna, Borella, Avissawella, Boralasgamuwa, Narahenpita, Meegoda and Pettah in Colombo district, Sri Lanka during 2018 and 2019. Rice grain samples (approximately 250 g) were collected into polyethylene bags and transported to the Industrial Technology Institute (ITI), Colombo, Sri Lanka for further analysis. Improved and traditional rice varieties used in this study were cultivated mainly in dry and wet zones where fields were irrigated and/or rainfed [4]. Improved rice varieties were primarily fertilized with inorganic fertilizers (urea, triple superphosphate and muriate of potash) whereas traditional rice varieties were cultivated using an integrated nutrient management approach (using both

Table 1 Basic characteristics of commonly consumed rice varieties (improved- based on the Household Income and Expenditure Survey—2016, traditional, and imported) selected in the study

Variety	Grain type	Pericarp colour	Method of processing	Appearance	Origin
White raw	Long grain	White	Raw	Polished	Local
Red raw	Long grain	Red	Raw	Polished	Local
White raw samba	Short grain	White	Raw	Polished	Local
Red raw Samba	Short grain	Red	Raw	Polished	Local
White nadu	Long grain	White	Parboiled	Polished	Local
Red nadu	Long grain	Red	Parboiled	Polished	Local
Samba	Short grain	White	Parboiled	Polished	Local
Keeri samba	Short grain	White	Parboiled	Polished	Local
Basmathi[a]	Short grain	White	Parboiled	Polished	Imported
Fragrant rice[b]	Short grain	White	Parboiled	Polished	Imported
Suwadel	Intermediate	White	Raw	Polished	Traditional
Pachchaperuman	Intermediate	Red	Parboiled	Unpolished	Traditional
Kaluheenati	Intermediate	Red	Parboiled	Unpolished	Traditional
Madathawalu	Intermediate	Red	Parboiled	Polished	Traditional

[a] From Pakistan or India

[b] From Thailand

inorganic and organic fertilizers) The imported rice varieties were from Pakistan, India and Thailand.

Sample preparation and analysis

Rice grain samples were oven-dried at 60 °C to a constant weight and were ground (100 g) with a stainless-steel grinder and sieved using a 0.25 mm mesh. Ground rice samples were stored in sealed polyethylene bags (air-tight condition) at room temperature until further analysis. Approximately 0.5 g of each homogenized powdered rice sample was weighed into a pre-cleaned Teflon digestion vessel and 10.0 mL of ultra-pure (>69%) concentrated HNO_3 was added. The digestion of rice samples was carried out by a microwave digester (MAS 5, CEM, USA) for 30 min at 180 °C under 40 bar [15]. Trace element analysis was performed following a validated method using Agilent 7900 Inductively coupled plasma-mass spectrometer (ICP-MS) (Agilent Technologies Inc., Tokyo, Japan) [15]. Reagent blanks, spiked samples, and standard reference material (SRM; NIST 1568B rice flour) were analyzed along with unknown rice samples in triplicates to maintain the precision and accuracy.

Human exposure assessment

The potential human health risk was assessed by comparing mean estimated daily intake (MEDI) with PTDI established by FAO/WHO [17].

The MEDI and the percentage contribution to RDA (for Zn and Fe) were calculated based on Eqs. 1 and 2, respectively:

$$MEDI = \frac{C \times D_{cons}}{B_w}, \tag{1}$$

$$Percentage\ contribution\ to\ RDA = \frac{C \times D_{cons}}{RDA} \times 100, \tag{2}$$

where C is the mean concentrations (mg/kg) of trace elements in rice; D_{cons} stands for daily average consumption of rice (kg/d) and B_w is average body weight (kg). The MEDI values were expressed in mg/kg body weight/d. The calculation was based on 300 g of rice intake by an individual with 60 kg body weight. RDA stands for the recommended dietary allowance.

Statistical analysis

The concentrations of elements in rice varieties were expressed on a dry weight basis. Response variables (Fe, Mn, Mo, Zn and Cu) were analyzed with a two-way factorial (year and variety) treatment structure using the PROC MIXED procedure of SAS (version 9.4, SAS Inst. Inc.) [18]. The Kenward-Rogers denominator degrees of freedom method and Tukey–Kramer adjustment were used for multiple comparisons using PDIFF statement. The least squares means statement (LSMEANS) was used for multiple comparisons. Type III test of fixed effects were employed, and means were considered significantly different at a p-value of <0.05. The correlation analysis was performed using SAS 9.4 to determine the significance ($p \leq 0.05$) of various relationships.

Results and discussion

Variation in potentially toxic element concentrations in rice

Summary of potentially toxic elements present in rice samples collected in 2018 and 2019 is presented in Table 2 (mean concentrations and ranges of potentially toxic element concentrations in improved, traditional, and imported rice varieties during 2018 and 2019 are shown in Additional file 1: Table S1 and S2). The concentrations of total As, Cd, Pb and Cr in rice varieties were reported above the respective limit of quantifications (LOQs). None of the rice varieties (improved, traditional, and imported) detected Hg and Ni. The non-detectable concentrations of Hg in rice grains may be due to low bioavailability of Hg in paddy soils because of its high affinity to soil organic matter/acidic groups of root cell walls, resulting in stable covalent bonding [19]. Therefore, uptake of Hg by plants occurs only in soils with extremely high Hg concentrations [19]. The undetectable concentrations of Ni in rice grains may have been caused due to the low concentrations of Ni in paddy soils. Compared to many potentially toxic elements, exchangeable and bioavailable fractions of Ni were found to be lower in paddy soils in both dry and wet zones of Sri Lanka [4]. Further, the index of geo-accumulation (used to determine trace element contaminations in soils) was reported to be < 1 for Ni in agricultural soils in Sri Lanka, suggesting no effect of agricultural practices on soil contaminations with Ni [20].

Arsenic was detected above the respective LOQ in all three rice categories in both years (Table 2). With regard to the number of samples > LOQ, the number of As detected samples were higher compared to other potentially toxic elements. This agrees with previous studies which showed higher efficiency in uptake and translocation of arsenite (arsenic III) by rice compared to other major cereals, especially barley and wheat [21]. Owing to anaerobic conditions in paddy soils, the concentration of arsenite gets elevated, thus enhancing the bioavailability of arsenic to paddy plants [22]. At the root surface of rice plants, the uptake of As can be mediated by iron plaque and radial oxygen loss [23]. Transporters such as phosphate transporters and aquaglyceroporins have been found to influence the uptake and transport/translocation of different As species in rice [23].

In general, arsenite is efficiently taken up by rice plants through the silicon uptake pathway [21]. In 2018, 4.2% of traditional rice samples exceeded the maximum level (ML) for As (0.2 mg/kg) set by FAO/WHO CODEX Alimentarius [17] (Table 2). With respect to Pb, 2.1% of improved and 4.2% of traditional samples exceeded the

Table 2 Summary of potentially toxic elements (ranges and number of samples > LOQ/ML) present in rice samples collected in 2018 and 2019 from Colombo district, Sri Lanka

Element	ML (mg/kg)	Rice category	Number of samples					Concentration range (mg/kg)	
			Total	> LOQ		> ML			
				2018	2019	2018	2019	2018	2019
As	0.2	Improved	96	20	46	0	0	< 0.05–0.12	< 0.05–0.16
		Traditional	48	18	18	2	0	< 0.05–0.28	< 0.05–0.14
		Imported	24	18	14	0	0	0.11–0.16	< 0.05–0.14
Cd	0.2	Improved	96	10	22	0	0	< 0.06–0.12	< 0.06–0.17
		Traditional	48	8	6	0	0	< 0.06–0.20	< 0.06–0.14
		Imported	24	0	0	0	0	< 0.06	< 0.06
Pb	0.2	Improved	96	2	6	2	0	< 0.07–0.33	< 0.07–0.19
		Traditional	48	2	0	2	0	< 0.07–3.47	< 0.07
		Imported	24	0	0	0	0	< 0.07	< 0.07
Hg	0.1	Improved	96	0	0	0	0	< 0.05	< 0.05
		Traditional	48	0	0	0	0	< 0.05	< 0.05
		Imported	24	0	0	0	0	< 0.05	< 0.05
Cr	N/A	Improved	96	2	12	0	0	< 0.07–0.08	< 0.07–0.27
		Traditional	48	2	0	0	0	< 0.07–0.63	< 0.07
		Imported	24	2	2	0	0	< 0.07–0.14	< 0.07–0.14
Ni	N/A	Improved	96	0	0	0	0	< 0.08	< 0.08
		Traditional	48	0	0	0	0	< 0.08	< 0.08
		Imported	24	0	0	0	0	< 0.08	< 0.08

N/A data not available, *LOQ* limit of quantification, *ML* maximum level (FAO/WHO)

Pb ML in 2018 (Table 2). However, none of the potentially toxic elements (i.e., As, Cd, Pb and Hg) exceeded the respective MLs in 2019. This may be due to differences in paddy cultivated locations where there can be differences in soil physicochemical properties, climatic conditions, and bioavailability of elements over time. Similarly, Liu et al. [24] found that lowering of Cd concentration in rice over time (cultivated in the same contaminated soils) attributed due to the reduction of bioavailable Cd concentration as a result of interactions with microorganisms, metal oxides and soil particles. Lead having low transfer coefficients can be sorbed onto clay/organic matter and precipitated upon interacting sulfates and phosphates [19]. Moreover, differences in post-harvest processes such as the degree of milling and parboiling may have affected the potentially toxic element concentrations in rice collected in 2018 and 2019 [25].

Among the studied rice varieties, the highest mean As concentration was observed in *Kaluheenati* [in both 2018 (0.13 ± 0.03 mg/kg) and 2019 (0.13 ± 0.01 mg/kg)] and *Basmathi* [in 2018 (0.13 ± 0.02)] (Additional file 1: Table S1). *Suwadel* had the highest Cd concentration in 2018 (0.14 ± 0.08 mg/kg) and Cd was detected only in one sample of *Madathawalu* in 2019 (0.14 mg/kg) representing the highest Cd concentration in 2019 (Additional file 1: Table S1). The highest mean Pb concentration was found in *Kaluheenati* in 2018 (3.47 mg/kg) and *Samba* in 2019 (0.19 mg/kg) (Additional file 1: Tables S1 and S2).

Usually, elemental distribution (both potentially toxic and essential) is higher in rice bran than in the corresponding endosperm [25]. Therefore high toxic element levels in traditional rice varieties with red pericarp (i.e., *Kaluheenati, Madathawalu and Pachchaperuman*) may be due to the presence of rice bran, concentrated with potentially toxic elements [26]. Further, as most of the traditional varieties have a relatively long duration (3.5–6 months), there is more time to contact with trace elements in soil resulting in high uptake of both essential and potentially toxic elements. The presence of a significant amount of potentially toxic elements (i.e., Cd, Cr and Pb) in organic amendments used in traditional rice cultivation may have led to increased uptake of potentially toxic elements by rice [27].

Contrastingly, parboiled rice (i.e., *Basmathi* and *Samba*) even with white pericarp contained high amounts of As and Pb. Parboiling is a post-harvesting process that forces nutrients to migrate from bran to the endosperm [26] to preserve the nutrients before milling. Hence, there is a possibility to transfer potentially toxic elements in addition to nutrients. Further, the use of contaminated water for parboiling may also introduce potentially toxic elements to rice. In this study, mean concentrations of total As in most of the rice varieties (< 0.05–0.28 mg/kg) (Table 2) fall within the previously reported ranges in Sri Lanka [8, 28]. The Cd concentrations in rice varieties (< 0.06–0.20 mg/kg) (Table 2) were higher than that of the values reported by Chandrajith et al. [8], while comparable to the values reported by Perera et al. [28].

In general, our study indicated considerably lower concentrations of Pb and Cd (except for Pb in *Kaluheenati* and *Red raw samba* in 2018) compared to the rice varieties (domestic and imported varieties from India and Thailand) available in the Iranian market [29]. In contrast, rice varieties from Brazil [30] and USA [31] have indicated lower Pb and Cd than that of ours. Previous research studies have revealed that some of the phosphorus fertilizers used in Sri Lanka were contaminated with potentially toxic trace elements such as Cd and Pb [10, 27]. Furthermore, it has been found that the paddy farmers tend to apply fertilizers (urea, triple superphosphate, and muriate of potash) to paddy fields at higher levels (a few folds high) than the recommended doses [27]. Therefore, excessive use of poor-quality fertilizers may have promoted the accumulation of potentially toxic trace elements in rice grains.

Variation in essential element concentrations in rice

Significant variety and year effects for Fe and Cu concentrations were observed whereas a significant variety*year interaction effect was observed for Zn concentration (Additional file 1: Table S3). Moreover, a significant variety effect was observed for Mn and Mo (Additional file 1: Table S3). The variety effect suggested the tolerance or ability of rice varieties in uptaking and translocating of trace elements [2]. The results of this study further illustrated that traditional rice varieties (except *Suwadel*) tended to have significantly higher concentrations of Fe and Mn than that of studied rice varieties (Fig. 1a and c). The highest mean Fe and Mn concentrations were observed in *Pachchaperuman* (Fig. 1a and c). The concentration of Cu was significantly higher in *Kaluheenati* compared to all other varieties while there were no significant differences among other rice varieties (Fig. 1b). The highest Zn concentration was obtained in fragrant rice (in 2018) and *Kaluheenati* (in 2019) (Fig. 1d). Our results were found to be consistent with a previous study carried out in Sri Lanka that reported higher concentrations of Zn, Fe and Mn in traditional rice varieties than that of improved rice varieties cultivated in wet zone [13]. Compared to improved rice varieties, the presence of relatively deep and extensively branched root systems in traditional rice varieties may have facilitated nutrient uptake from soils, thus enhancing the essential element concentrations in rice grains [2].

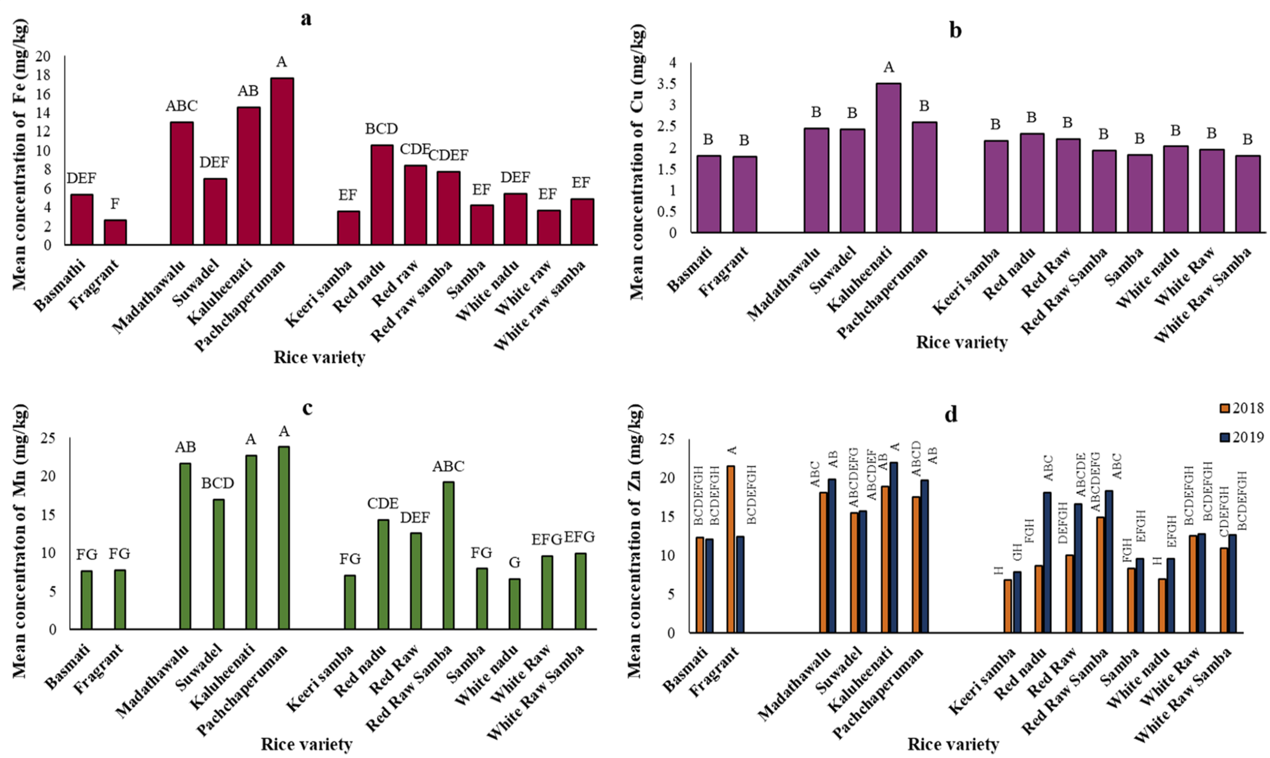

Fig. 1 Comparison of mean Fe (**a**), Cu (**b**), Mn (**c**) and Zn (**d**) concentrations in rice varieties (improved, imported, and traditional) collected in 2018 and 2019 from the Colombo district, Sri Lanka. Fe and Cu had significant variety and year effects whereas Mn and Zn had significant variety and variety*year interaction effects, respectively (at 0.05 probability level). In each figure, bars with different letters are significantly different at $p < 0.05$

Table 3 Pearson's correlation coefficients (r) among essential elements in rice varieties (improved, imported, and traditional) collected in 2018 and 2019 from the Colombo district, Sri Lanka (n = 168)

	Fe	Zn	Cu	Mn
Zn	0.54***			
Cu	0.44***	0.39***		
Mn	0.64***	0.65***	0.52***	
Mo	0.20*	0.38***	0.19*	0.32***

*Significance at p value of < 0.05

**Significance at p value of < 0.01

***Significance at p value of < 0.001

Elemental correlations

According to the correlation analysis, it was found that concentrations of all essential elements were positively correlated ($p < 0.05$) with each other (low or moderate correlations) (Table 3). Agreeing with our study, previous studies have also indicated significant positive correlations between Fe and Zn in brown ($r = 0.5$)/polished ($r = 0.3$) and hybrid rice varieties (r = 0.5) [32, 33]. Even though studied rice varieties were cultivated in different various locations, significant positive correlations among different essential elements suggested the simultaneous effectual selection of micronutrients by rice plants.

Human exposure assessment

The MEDI of potentially toxic and essential elements through the consumption of rice varieties (Table 4) were calculated based on 300 g of rice intake by individuals with 60 kg body weight. In comparison with PTDI established by FAO/WHO [17], MEDI of Pb through *Kaluheenati* (0.017 mg/kg bw/d) exceeded the respective PTDI value (0.0015 mg/kg bw/d) in 2018 (Table 4) and may cause health risks to the average consumer. Similarly, *Kaluheenati* showed the highest MEDI for Cu (0.018 mg/kg bw/d—2018 and 0.017 mg/kg bw/d—2019), Mn (0.121 mg/kg bw/d- 2019), Zn (0.109 mg/kg bw/d—2019) and Mo (0.0041 mg/kg bw/d—2019) (Table 4). Therefore, our study indicated the need to consider the concentrations of potentially toxic elements in rice varieties despite their high concentrations of essential trace elements. Further, MEDI of Pb via consumption of *red raw samba* was 0.0015 mg/kg bw/d which is equal to 100% of PTDI (Table 4), thus may arise alarming health risks. However, none of MEDI of other detected potentially toxic elements (i.e., Cd, As and Cr) exceeded the respective PTDI

Table 4 Mean estimated daily intake (MEDI) of potentially toxic and essential elements in rice varieties collected in 2018 and 2019 from the Colombo district, Sri Lanka

Rice variety	Mean estimated daily intake × 10^{-3} (mg/kg bw/d)									
	Essential elements									
	Fe		Cu		Mn		Zn		Mo	
	2018	2019	2018	2019	2018	2019	2018	2019	2018	2019
Madathawalu[a]	55.7	73.8	11.6	12.9	111.7	104.0	90.2	99.1	2.4	2.7
Suwadel[a]	31.5	38.3	11.4	12.8	81.7	87.0	77.4	78.6	3.5	3.9
Pachchaperuman[a]	**74.4**	**101.7**	12.2	13.7	**120.0**	117.3	87.2	98.4	2.7	3.6
Kaluheenati[a]	54.7	90.9	**18.0**	**17.1**	105.5	**121.3**	94.6	**109.4**	4.1	**4.1**
White nadu[b]	21.5	32.9	8.5	11.7	28.7	37.3	34.7	47.7	2.4	2.7
White raw[b]	20.5	16.2	9.6	9.8	44.9	50.7	62.2	63.3	2.6	2.9
White raw samba[b]	14.0	34.2	8.9	9.8	44.2	55.1	54.3	62.8	2.1	2.3
Red nadu[b]	41.4	64.2	11.4	11.9	66.3	76.2	42.8	90.4	2.8	3.2
Red raw[b]	30.7	53.4	10.1	11.9	51.0	73.9	50.0	82.7	2.4	3.4
Red raw samba[b]	27.7	50.0	8.3	11.0	97.9	93.5	74.4	91.6	< 0.30	3.4
Samba[b]	16.1	25.5	7.7	10.6	32.1	46.8	41.5	47.3	2.5	2.6
Keeri samba[b]	12.6	23.1	10.0	11.6	30.8	40.0	33.9	39.1	2.3	2.7
Basmathi[c]	33.4	20.2	9.2	8.7	37.3	38.4	61.1	60.3	**4.3**	3.4
Fragrant[c]	16.3	10.1	9.5	8.3	42.0	35.7	**107.5**	61.7	3.2	2.5
[#]Provisional tolerable daily intake × 10^{-3} (mg/kg bw/d)	800		500		360		1000		33[d]	

Rice variety	Mean estimated daily intake × 10^{-3} (mg/kg bw/d)							
	Potentially toxic elements							
	As		Cd		Pb		Cr	
	2018	2019	2018	2019	2018	2019	2018	2019
Madathawalu[a]	0.3	0.5	< 0.30	0.7	< 0.35	< 0.35	1.9	< 0.35
Suwadel[a]	0.4	0.4	0.7	0.5	< 0.35	< 0.35	< 0.35	< 0.35
Pachchaperuman[a]	0.6	0.4	< 0.30	< 0.30	< 0.35	< 0.35	< 0.35	< 0.35
Kaluheenati[a]	0.7	0.7	0.4	< 0.30	17.4*	< 0.35	< 0.35	0.6
White nadu[b]	0.4	0.4	< 0.30	< 0.30	< 0.35	0.4	< 0.35	< 0.35
White raw[b]	< 0.25	0.3	< 0.30	0.6	< 0.35	< 0.35	< 0.35	< 0.35
White raw samba[b]	< 0.25	0.3	< 0.30	< 0.30	< 0.35	< 0.35	< 0.35	< 0.35
Red nadu[b]	0.4	0.4	0.4	0.6	< 0.35	0.5	< 0.35	< 0.35
Red raw[b]	0.3	0.5	0.5	0.5	< 0.35	< 0.35	< 0.35	< 0.35
Red raw samba[b]	0.5	0.4	0.5	0.4	1.5**	< 0.35	0.4	1.4
Samba[b]	< 0.25	0.4	< 0.30	< 0.30	< 0.35	1.0	< 0.35	1.7
Keeri samba[b]	0.4	0.4	< 0.30	< 0.30	< 0.35	< 0.35	< 0.35	0.6
Basmathi[c]	0.6	0.5	< 0.30	< 0.30	< 0.35	< 0.35	0.6	0.6
Fragrant[c]	0.6	0.6	< 0.30	< 0.30	< 0.35	< 0.35	< 0.35	< 0.35
[#]Provisional tolerable daily intake × 10^{-3} (mg/kg bw/d)	3		1		1.5		50	

Values in Bold: Health Beneficial

< : mean concentration was less than the LOQ value

*Health Risk

**Alarming Health Risk

[#] Toxilogical guidance values of FAO/WHO (CodexAlimentarious)[17]

[a] Traditional rice

[b] Improved rice

[c] Imported rice

[d] Calculated from Tolerable upper intake level (Institute of Medicine (US) Panel on Micronutrients)[34]

in both 2018 and 2019 (Table 4). We determined the contribution to the RDA for Fe and Zn (for all rice varieties) which have been identified as deficient elements among Sri Lankans [14]. The contribution of the studied rice varieties to the RDA of Fe [34] was in the ranges of 8–76% for males and 3–34% for females in 2018 and 2019 where *Pachchaperuman* contributed the highest in both years (data not shown). With regard to Zn, contributions to RDA [34] were in the range of 25–82% for males and 18–60% for females where *Pachchaperuman* and fragrant rice contributed the highest in 2018 and 2019, respectively (data not shown). Percentage ranges of contribution to RDAs of Zn and Fe were higher for males than females as RDA values for males are lower than females. With the high prevalence of Fe and Zn deficiency in Sri Lanka [14], results of MEDI and RDAs for different rice varieties can be utilized for selecting suitable rice varieties or a mixture of rice varieties for the diet. The rate of consumption of different rice varieties may vary based on demographic areas (i.e., rural, urban and estate) [16] and household income status. However, data on the rice consumption pattern of some of the traditional and imported rice varieties are not available. Therefore, the assessment of dietary exposure based on an average rate of daily rice consumption (300 g/ day) could be considered as a limitation of this study. Further, this study can be expanded spatially (i.e., sample collection from multiple districts) and temporally (i.e., sample collection in multiple years) within Sri Lanka to obtain a clear picture of the trace element concentrations in rice varieties available in the Sri Lankan market.

Abbreviations
ML: Maximum level; PTDI: Provisional tolerable daily intake; RDA: Recommended daily allowance; ICP-MS: Inductively coupled plasma-mass spectrometer; SRM: Standard reference material; MEDI: Mean estimated daily intake; LSMEANS: Least squares means statement; LOQ: Limit of quantification.

Supplementary Information
The online version contains supplementary material available at https://doi.org/10.1186/s13765-022-00689-8.

Additional file 1: Table S1. Mean concentrations and ranges of potentially toxic element concentrations in traditional and imported rice varieties collected during 2018 and 2019. **Table S2.** Mean concentrations and ranges of potentially toxic element concentrations in improved rice varieties collected during 2018 and 2019. **Table S3.** Probability values for the effects of variety, year, and variety x year (two-way interaction effect) for essential elements in the rice varieties collected during 2018 and 2019.

Acknowledgements
Not applicable.

Authors' contributions
KRRM, KM: supervision, reviewed and edited, PSPA: Analysis of data, reviewed and edited, GUC: wrote the first draft and performed the analysis, RCML: performed the analysis. All authors read and approved the final manuscript.

Funding
This work was supported by the Sri Lankan Treasury to Industrial Technology Institute (TG 18/163).

Availability of data and materials
All data generated or analysed during this study are included in this published article and its additional files.

Declarations

Competing interests
The authors declare no competing interests.

Author details
[1]Industrial Technology Institute, 363, Bauddhaloka Mawatha, Colombo 07, Sri Lanka. [2]Department of Chemistry, Faculty of Science, University of Colombo, Colombo 03, Sri Lanka. [3]Frostburg, Maryland, USA.

Received: 9 January 2022 Accepted: 12 March 2022
Published online: 05 April 2022

References
1. Navarathna NMCM, Parthipan R, Pathiratne KAS, De Silva DSM, Wickramasinghe WMDAB (2016) Content of heavy metals; cadmium, chromium and lead in selected rice varieties (*Oryza sativa* L.) grown under different agricultural management systems. In: paper presented at chemistry in Sri Lanka, Institute of Chemistry Ceylon, Sri Lanka. 33(2) May 2016
2. Sebastian A, Prasad MNV (2015) Trace elements management in rice. Agron 5:374–404
3. Galappattige A (2020) Grain and feed annual. Research report no. CE2020-0005. United States Department of Agriculture, Foreign Agricultural Service. https://apps.fas.usda.gov. Accessed 22 Dec 2021
4. Rubasinghe RT, Gunatilake SK, Chandrajith R (2021) Climatic control of major and trace elements in paddy soils from wet and dry regions of Sri Lanka. Environ Chall 5:100361
5. Department of census and statistics (2021) Paddy statistics. Department of census and statistics. http://www.statistics.gov.lk/Agriculture/StaticalInformation/PaddyStatistics/ImperialUnits/IncludingMahaweli/2020-2021Maha. Accessed 22 Dec 2021
6. Liyanaarachchi GVV, Mahanama KRR, Somasiri HPPS, Punyasiri PAN, Kottawa-Arachchiotal JD (2020) Total and free amino acid contents of popular rice varieties (*Oryza sativa* L.) consumed in the capital city of Sri Lanka. J Natl Sci Found 48(2):199–211
7. Rambukwella R, Priyadarshana D, Wijesooriya N (2017) Consumption pattern and consumer preference for different rice varieties in selected districts in Sri Lanka. Research report no: 204. Hector Kobbekaduwa Agrarian Research and Training Institute, Sri Lanka
8. Chandrajith R, Dissanayake N, Dissanayake CB (2012) Arsenic and other heavy metals in rice from Sri Lanka—preliminary results with ICP-MS. In: international symposium on water quality and human health: challenges ahead, PGIS, Peradeniya, Sri Lanka. 22–23 March 2012
9. Jaishankar M, Tseten T, Anbalagan N, Mathew BB, Beeregowda KN (2014) Toxicity, mechanism and health effects of some heavy metals. Interdiscip Toxicol 7(2):60–72
10. Jayasumana C, Paranagama P, Fonseka S, Amarasinghe M, Gunatilake S, Siribaddana S (2015) Presence of arsenic in Sri Lankan rice. Int J Food Contam 2:1
11. Fernando TD, Jayawardena BM, Mathota Arachchige YLN (2020) Variation of different metabolites and heavy metals in *Oryza sativa* L., related to

chronic kidney disease of unknown etiology in Sri Lanka. Chemosphere 247:125836
12. Magamage C, Waidyaratna WHMCU, Dhanapala WPAP, Panampitiya DM (2017) Determination of heavy metals in rice available in Kandy district, Sri Lanka. Ann Sri Lanka Dep Agric 19:351–368
13. Diyabalanage S, Navarathna T, Abeysundara HTK, Rajapakse S, Chandrajith R (2016) Trace elements in native and improved paddy rice from different climatic regions of Sri Lanka: implications for public health. SpringerPlus 5:1864
14. Abeywickrama HM, Koyama Y, Uchiyama M, Shimizu U, Iwasa Y, Yamada E, Ohashi K, Mitobe Y (2018) Micronutrient status in Sri Lanka: a review. Nutrients 10(11):1583
15. Chandrasiri GU, Mubarak MNA, Mahatantila K, Mahanama KRR (2019) Single laboratory validation of determination of 13 trace elements in rice by ICP-MS with an overview of challenges encountered. Am J Analyt Chem 10:367–376
16. Household Income and Expenditure Survey (2016) (ISBN 978-955-702-054-9), Department of Census and statistics, Battaramulla, Sri Lanka. http://www.statistics.gov.lk. HIES2016_FinalReport.pdf. Accessed 23 Dec 2021
17. JECFA. Joint Food and Agriculture Organization/World Health Organization expert committee on food additives. JECFA/61/Sc; Rome, Italy: 2003. Summary and conclusions of the 61st meeting of the joint FAO/WHO expert committee on food additives. 10–19.06.03, pp 1–22
18. Institute SAS (2013) The SAS system for windows (Release 9.3) [software]. SAS Institute, Cary
19. Hajeb P, Sloth JJ, Shakibazadeh S, Mahyudin NA, Hejri LA (2014) Toxic elements in food: occurrence, binding and reduction approaches. Compr Rev Food Sci Food Saf 13:457–472
20. Jayawardana DT, Pitawala HMTGA, Ishiga H (2012) Geochemical assessment of arsenic and selected trace elements in agricultural and non-agricultural soil in Sri Lanka. Trop Agric 160:1–19
21. Su YH, McGrath SP, Zhao FJR (2010) Rice is more efficient in arsenite uptake and translocation than wheat and barley. Plant Soil 328:27–34
22. Xu XY, McGrath SP, Meharg AA, Zhao FJ (2008) Growing rice aerobically markedly decreases arsenic accumulation. Environ Sci Technol 42(15):5574–5579
23. Awasthi S, Chauhan R, Srivastava S, Tripathi RD (2017) The journey of arsenic from soil to grain in rice. Front Plant Sci 8:1007
24. Liu J, Li K, Xu J, Liang J, Lu X, Yang J, Zhu Q (2003) Interaction of Cd and five mineral nutrients for uptake and accumulation in different rice cultivars and genotypes. Field Crops Res 83(3):271–281
25. Yao BM, Chen P, Sun GX (2020) Distribution of elements and their correlation in bran, polished rice, and whole grain. Food Sci Nutr 8:982–992
26. Jo G, Todorov TI (2019) Distribution of nutrient and toxic elements in brown and polished rice. Food Chem 289:299–307
27. Navarathna C, Pathiratne S, De Silva DSM, Rinklebe J, Mohan D, Mlsna T (2021) Intrusion of heavy metals/metalloids into rice (*Oryza sativa* L.) in relation to their status in two different agricultural management systems in Sri Lanka. Groundw Sustain Dev 14:100619
28. Perera MAKKP (2018) Determination of arsenic and cadmium in Sri Lankan rice samples by Inductively coupled plasma mass spectrometry (ICP-MS) following microwave assisted acid digestion. CPQ Nutr 1(6):1–17
29. Naseri M, Vazirzadeh A, Kazemi R, Zaheri F (2015) Concentration of some heavy metals in rice types available in Shiraz market and human risk assessment. Food Chem 175:243–248
30. Mataveli LRV, Buzzo ML, Arauz LJD, Carvalho MD, Arakaki EEK, Matsuzaki R, Tiglea P (2016) Total arsenic, cadmium and lead determination in Brazilian rice samples using ICP-MS. J Anal Methods Chem. https://doi.org/10.1155/2016/3968786
31. TatahMentan M, Nyachoti S, Scott L, Phan N, Okwori FO, Felemban N, Godebo TR (2020) Toxic and essential elements in rice and other grains from the United States and other countries. Int J Environ Res Public Health 17:8128
32. Maganti S, Swaminathan R, Parida A (2020) Variation in iron and zinc content in traditional rice genotypes. Agric Res 9:316–328
33. Anusha G, Rao DS, Jaldhani V, Beulah P, Neeraja CN, Gireesh C, Anantha MS, Suneetha K, Santhosha R, Prasad ASH, Sundaram RM, Madhav MS, Fiyaz A, Brajendra P, Tuti MD, Bhave MHV, Krishna KVR, Ali J, Subrahmanyam D, Senguttuvel P (2021) Grain Fe and Zn content, heterosis, combining ability and its association with grain yield in irrigated and aerobic rice. Sci Rep 11(1):10579
34. Institute of Medicine (US) Panel on Micronutrients (2001) Dietary reference intakes for vitamin A, vitamin K, arsenic, boron, chromium, copper, iodine, iron, manganese, molybdenum, nickel, silicon, vanadium, and zinc. National Academies Press, Washington, DC. https://doi.org/10.17226/10026

Publisher's Note