Acta Sci. Pol. Technol. Aliment. 22(2) 2023, 143–157
www.food.actapol.net pISSN 1644-0730 eISSN 1898-9594 http://dx.doi.org/10.17306/J.AFS.2023.1117

ORIGINAL PAPER

Received: 6.03.2023
Accepted: 16.05.2023

PHYSICAL CHARACTERISTICS AND THE EFFECT OF SOAKING ON MINERAL CONCENTRATION IN RICE VARIETIES ASSOCIATED WITH HUMAN HEALTH RISKS

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ABSTRACT

Background. Rice is the staple food for more than half of the world's population and a major source of essential minerals. The objective of the present study was to determine metal distribution in common rice types before and after soaking and the physical properties of the rice kernel. Rice consumption was used to calculate estimated daily intake (EDI), and target hazard quotient (THQ) for individuals.
Materials and methods. Seven different types of rice from northern Iraq were randomly selected from several markets in the city of Kalar, and their physical and chemical characteristics were studied. The study evaluated possible health concerns associated with rice consumption. Finding out the impact of soaking on the minerals present in the rice was another goal of this investigation. Inductively Coupled Plasma Optical Emission Spectroscopy was used to prepare and examine the samples for possible elements of interest.
Results. Mahmud's rice had the longest grain length, while Kurdish rice had the shortest. All the varieties tested had long and slender grains except for Saman and Kurdish rice. The ash and moisture content of the varieties ranged from 0.29 to 0.39% and 3.09% to 5.9, respectively. The zinc content of the varieties ranged from 23.6 to 15.6 mg/kg, with the highest values found in Gulbahar rice and lowest in Saman rice. The iron content and manganese content of the varieties ranged from 8.1 mg/kg to 14.3 mg/kg and 3.5 to 13.2 mg/kg, respectively. Soaking for one hour reduced the mineral content, with potassium content reduced by 40% in Saman rice and 50% in Gulbahar rice and aluminum content reduced by 40% in Kurdish rice. The water uptake ratios for Russia rice were between 1.39 and 1.6 for 35°C, 1.38 and 1.71 for 50°C, and 1.42 and 1.72 for 60°C, respectively. The EDI values indicate that all minerals in the rice samples were below WHO/FAO limits, and the HI and THQ values did not exceed unity.
Conclusion. It is clear that rice is a primary source of necessary minerals; however, a balanced, varied diet should be adopted to fulfil the human body's nutritional needs. The risk assessment of potentially excessive ingestion of certain elements through rice consumption suggests that the concentrations of Mn, Zn, and Mg in some rice samples exceeded the reference oral dose for adults and children.

Keywords: rice, physical characteristic, soaking, EDI, THQ, HI, Iraq

INTRODUCTION

One cereal grain, rice (*Oryza sativa*), has a significant impact on human nutrition. As well as being an essential part of human nutrition, rice is the third most commonly produced crop in the world after maize and wheat (Yang et al., 2018). Rice contains over 55% of the protein and more than 85% of the calories

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consumed worldwide (Luo et al., 2018). The husk, bran, and germ portions of rice are frequently removed before it is polished and consumed as white rice. 95% of all cereal ingested by Asians comes from rice (Timmer, 2010), which makes up the majority of their diet. However, due to an increased understanding of the properties of the husk, bran, and germ portions of rice nutritional benefits higher amounts of protein, ash, and dietary fiber than white rice (Islam and Mustafa, 2022; Muehe et al., 2019), as well as its recently rise in popularity, brown rice has been much more widely used in some country (Xu et al., 2019) the main human-made source of harmful metal contamination in the environment are industrial discharge, pesticide use, and mining (Zhou et al., 2019). Currently, there is growing concern about hazardous metal contamination of agricultural crops, particularly rice, and their transfer to arable lands (Liu et al., 2009; Zhao and Wang, 2020). Heavy metal contamination affects 20 million hectares or around 20 percent of the total area under cultivation, and this area is growing at a rate of 46,700 ha each year (Ye et al., 2017).

People's general health has been negatively impacted by the consumption of food contaminated with heavy metals, as is widely recognized (Yadav et al., 2016; Zangana, 2022), although vital mineral elements perform a range of functions and are essential in biochemical processes due to their direct or indirect influence on human metabolism (Dhar et al., 2020). It is crucial to estimate the potential health risks that heavy metals pose to people who live in polluted areas (Wang and Qin, 2019). Numerous studies have looked at the quantitative and physical traits of a rice grains from different cultivars, especially those from South-East Asia, the region that produces the most rice worldwide (Islam et al., 2019). The grain rice differ from those of other types of rice due to their reddish-brown hue and longitudinal brown stripes on the body of the grain, which are caused by the soil's unique mineral composition and farming techniques (Djahed et al., 2018). Potentially dangerous compounds put plant yields at risk, are bad for the environment, and jeopardize human health (Chonokhuu et al., 2019; Mustafa, 2021). Zn, Mn, and other potentially toxic elements (PTEs), including micronutrients (Zn, Ba, Cr, and Fe), are necessary for animals and plants in modest amounts, and they are also necessary for the growth and development of rice plants (Tan et al., 2019).

The purpose of these vital metals for biological and physiological uses for example, they help maintain redox balance in both plants and animals (Dipti et al., 2002). To understand their negative effects on those who regularly consume different species of vegetables and rice (Hori, 2016), it is critical to look at the levels of trace elements these species contain. The level of trace elements and how they actively participate in being an integral portion of various enzymes and another way to know more about the safety of nutrients for consumers (Islam et al., 2022). Rice soaking is done before cooking to facilitate faster and more even water absorption while also removing some minerals and carbs. The capacity of rice to absorb water during cooking was less effective as soaking temperature and time increased (Coradi et al., 2021). There are few studies describing the qualities and characteristics of rice grown in different regions (Müller et al., 2022).

According to regional cuisine and culture, customers place varying values on different qualities or characteristics of rice varieties (Islam et al., 2019). In this study, the most widely consumed varieties of rice in several northern Iraqi regions were chosen for analysis. The rice samples were bought in traditional marketplaces according to what was generally consumed in Kalar City sites.

This study focused on detecting the minerals in rice before and after soaking in addition to determining the daily consumption of Fe, K, Mn, Na, Zn, Mg, Sr, Al, Ba and Bi in connection to the nutritional status of children and adults in Kalar city. It stands out because it is the first to conduct a thorough analysis of the physical characteristics of the most popular rice genotypes from diverse district markets. Risk assessment studies were also carried out to identify any potential risks to consumers.

MATERIALS AND METHODS

Plant material

The dried rice kernels were bought in February 2022 at Kalar's local market in southern Iraq. Seven different types of imported rice were purchased in all (Saman rice, Kurdish rice, Gulbahar rice, Thailand rice, Russia rice, Dolfensea rice, and Mahmud rice). In order to maintain the average sample quality of each type, samples were obtained from seven separate vendors (with an average weight of 750 g). Prior to the laboratory tests, cultivar samples were cleared of tiny debris (such as stones and dried weeds) and stored in closed plastic bags at room temperature. To ensure a meaningful result, only high-quality rice grains were utilized in the study, and each measurement was taken several times. Between February 2022 and April 2022, the physical analysis was completed in the University of Garmian's Laboratory of Analytical Chemistry, College of Education.

Digestion and mineral analysis

The samples of dried rice kernels (5 g each) were digested in 20 mL of a 2:1 combination of HNO_3 and H_2O_2 until a clear solution was formed. The samples were placed in a digestion tube and put on the hot plate for digestion. During digestion, the temperature was maintained at 100°C for 1 hour, 180°C for 2 hours and 300°C for 1 hour. After digestion, the digest was cooled, filtered, and transferred to a 50 mL volumetric flask made up to volume with distilled water and kept in clean plastic vials before mineral composition analysis (Muttagi and Ravindra, 2020). The concentration levels of Fe, K, Mn, Na, Zn, Mg, Sr, Al, Ba and Bi were determined using ICP-OES methods (Islam et al., 2022).

Physical qualities

Using Vernier calipers, the grains were measured for the physical characteristics of kernel length, width, and length/width ratio as per Ekwu et al. (Dipti et al., 2003). Using visual inspection, the milled grain appearance was rated as described by Dipti et al. (2002). First, the rice was divided into three groups according to length: long (>6 mm in length), medium (5–6 mm in length), and short (<5 mm in length). Then the grains were divided into three groups based on the length-to-width ratio: slender (ratio more than 2.0), bold (ratio 1–2), and thin (ratio less than 1.0).

Aspect ratio

The aspect ratio R_a (–) was calculated using the formula (Alaka et al., 2011):

$$R_a = \frac{W}{L} \quad (1)$$

Water uptake ratio

A Memmert waterbath was used to evaluate the water uptake ratio. Seven samples (2 g each) of each rice variety were soaked in water at various temperatures and for various soaking times. The test temperatures used were 35, 50, and 70°C for 60 min. Each measurement was carried out three times. The 200 ml beaker with 100 ml of water inside was filled with the 2 g sample and placed in a water bath at a specific temperature for a specified amount of time. The sample was reweighed, and the new weight was recorded after the rice had been decanted through a strainer with a dense mesh and dried with paper towels. The weight of the cooked rice was divided by the weight of the raw rice sample to get the water uptake ratio. Prior to that, the weights of the initial raw rice sample and the final rice sample were recorded on the electronic scale (Kern 572-30 with an accuracy of 0.001 g; Shittu et al., 2012).

Determination of moisture content

The amount of moisture was assessed using the Association of Official Analytical Chemists' recommended procedures (AOAC, 2006). The moisture content was calculated using equation 2.

$$\text{Moisture, \%} = \frac{W_2 - W_3}{W_2 - W_1} \cdot 100 \quad (2)$$

Determination of ash content

The ash percentage of rice was defined by formula 3, mentioned by Mohsenin (1986).

$$\text{Ash, \%} = \frac{W_2 - W_3}{W_2 - W_1} \cdot 100 \quad (3)$$

Soaking procedure for rice samples

To estimate the effect of soaking on mineral content, the traditional method for cooking rice was used. Clean tap water was used to wash the rice three to four times, and after that, samples (500 mg) of each type were placed in a container and soaked in hot water (60°C).

Table 1. General description of health risk assessment parameters and other equations

No.	Symbol	Description	Unit	Value (adult)
1	BW	average of body weight	kg	40 years (approx.)
2	Cm	concentration of metals	mg/kg	–
3	AT	average time	days	40*365
4	ED	exposure duration	years	40
5	RFD	oral reference dose	mg kg^{-1} day^{-1}	(Rybicka, 2018)
6	IR	ingestion rate	kg/day	0.250
7	ATn	average time (non-carcinogenic)	days	40*365
8	EF	exposure frequency	days	250 (excluding holiday and weekend)
9	W	width	mm	–
10	L	length	mm	–
11	W1, W2, W3	weight of dish	g	–
12	EDI	estimation daily intake	mg/day	–
13	THQ	target hazard	mg/day	–

They were given two hours to soak before cooking. For two cups of rice about 15 ounces of water were required. After soaking, the water was removed (Fan and Marks, 1999).

Human health risk assessment

The non-carcinogenic risk of rice consumption was calculated using the hazard quotient (HQ) and total hazard index (THI). The risk to one's health from undesirable, non-carcinogenic effects brought on by toxicant exposure is defined by the hazard quotient.

First, eq. 4 was used to calculate the EDI of each heavy metal separately. The non-carcinogenic health risks (THQ and HI) were then calculated using eq. 5 and eq. 6. Table 1 gives a general explanation of risk assessment factors and defines each symbol with reference values. In scheme 1, the overall research technique has been outlined.

$$EDI = \frac{CM \cdot IR \cdot EF \cdot ED}{BW \cdot AT} \quad (4)$$

$$THQ = \frac{CM \cdot IR \cdot EF \cdot ED}{BW \cdot ATn \cdot RFD} \quad (5)$$

$$HI = \Sigma THQ \quad (6)$$

Statistical analysis

The means and standard deviations of the metal concentrations in the samples were calculated to detect any difference in mean values from triplicate runs of each treatment. Pearson correlation coefficents to evaluate the inter-element relationships in rice samples were calculated using Microsoft Excel 2013.

RESULTS AND DISCUSSION

The longest cultivar among the native varieties was Mahmud rice with a length of 6.2 mm (the longest from research sample), and the shortest was Kurdish rice with a length of 3.7 mm. While Mahmud rice had an average width of 2.8 mm, Gulbahar rice was the thinnest variety with an average width of 2.1 mm.

The results show clear differences between native Kurdish rice and imported varieties (Table 2). From the analysis of measurements of length, width, and length/width, it can be concluded that Gulbahar rice, which is imported into Iraq, has the largest physical dimensions from the research sample while local Kurdish rice has the smallest. The previous authors have confirmed the physical characteristics important when dealing with rice properties (Oli et al., 2016).

Table 2. Dimensions and shape classification of the grain

No.	Full name (trade name)	Length, mm	Average width, mm	Length/width, mm	Shape
1	Saman rice	3.8 ±0.8	2.3 ±0.4	1.65 ±0.2	bold
2	Kurdish rice	3.7 ±0.6	3.1 ±0.3	1.19 ±0.03	bold
3	Gulbahar rice	5.1 ±0.5	2.1 ±0.3	2.43 ±0.04	long slender
4	Thailand rice	4.8 ±0.3	2.2 ±0.4	2.18 ±0.4	long slender
5	Russia rice	5.2 ±0.2	2.5 ±0.5	2.08 ±0.08	long slender
6	Dolfensea rice	6.1 ±0.4	2.25 ±0.6	2.71 ±0.2	long slender
7	Mahmud rice	6.2 ±0.51	2.8 ±0.6	2.21 ±0.11	long slender

The first stage in describing the form of the grain of rice is to measure it; these values are then employed in additional dimensional computations (Tidona et al., 2016). The length-width ratio, which is a measure of the shape and size, ranges between 1.19 and 2.71. Tidona et al. (2016) reported that rice samples whose ratio was greater than 2.0 are classified as slender, ratios between 1 and 2 are bold grains and ratios <2 are round. All the tested varieties fall within the slender category except Saman and Kurdish rice, which are bold.

The grain's shape affects both its volume and weight. Rice cultivars that are round have a smaller volume than slender varieties. A ton of round rice will take up less storage space than a ton of thin rice (Dipti et al., 2002).

The processing of rice such as sifting, de-husting, polishing, storage, and cooking affects the size and rice's physicochemical properties.

The preferred rice size and shape among consumers varies depending on the physical properties (Müller et al., 2022).

A significant factor in determining the rice's quality is how the processed rice looks. All examined types had a good to very good level of aesthetic quality. All the nine rice varieties tested had a translucent kernel except for Saman, Kurdish and Thailand rice. Saman, Kurdish and Thailand rice had an opaque kernel, which is a desirable quality (Table 3). The more chalkiness in the grain, the more it is prone to grain breakage during milling, resulting in lower head rice yield. In addition, glutelin and total protein tend to be lowered by chalkiness (Alaka and Okaka, 2011).

The aspect ratio was found to be highest in Kurdish rice (0.84) and lowest in Dolfensea (0.37), which belonged to the imported varieties group. As was mentioned by Varnamkhasti et al. (2008), the determination of aspect ratio is important due to the classification of

Table 3. Physical characteristics of the samples of rice varieties

No.	Full name (trade name)	Chalkiness	Roundness	Aspect ratio	Moisture, %	Ash, %
1	Saman rice	opaque	0.83 ±0.01	0.61 ±0.02	4.19 ±0.9	0.29 ±0.01
2	Kurdish rice	opaque	0.60 ±0.02	0.84 ±0.04	3.09 ±0.8	0.27 ±0.02
3	Gulbahar rice	translucent	1.21 ±0.04	0.41 ±0.06	5.5 ±0.5	0.38 ±0.23
4	Thailand rice	opaque	1.09 ±0.02	0.46 ±0.07	5.9 ±0.71	0.36 ±0.29
5	Russia rice	translucent	1.04 ±0.05	0.48 ±0.06	4.4 ±0.54	0.39 ±0.21
6	Dolfensea rice	translucent	1.36 ±0.09	0.37 ±0.05	5.48 ±0.9	0.32 ±0.02
7	Mahmud rice	translucent	1.11 ±0.06	0.45 ±0.04	4.02 ±0.44	0.39 ±0.9

grain dimensions and the extent of off-size in market ranking.

Moisture content, which plays a significant role in determining shelf life, varied between 5.9 and 3.09%. Irrespective of grain type, the maximum moisture content was found in Thailand rice (5.9%), however no significant mean difference was observed between Dolfensea (5.48%) and Gulbahar rice (5.5%), and the lowest moisture percentage was recorded in Kurdish rice (3.09%), a local rice type. These values correspond to those reported by Saeed and Mohammad (2013), which ranged from 3.06 to 6.19%.

The amount of ash present in a food sample plays an important role when determining the levels of essential minerals. The ash content was high in the long grain rice variety Mahmud and in Russia rice (0.39%). However, most of the rice varieties did not show a significant difference in mean ash content. This might be because ash content is different in milling fractions due to the degree of severity during milling for the separation of bran (Ahmed and Ayodele, 2023). In this study traditional rice varieties were not polished, hence higher values for ash content were reported. Islam et al. (2022) reported similar values.

The mineral composition of a food is one of the most important indicators of its nutritional value and may be affected by leaching during soaking (Ni et al., 2019). In the current study, a decrease in minerals after soaking was noted. The concentrations of PTEs in the grain before and after soaking are shown in Table 4.

Table 4. Mean concentration of metals in the rice grains of the different varieties before and after soaking, mg kg^{-1}

Samples	Status	Fe	K	Mn	Na	Zn	Mg	Sr	Al	Ba	Bi
Saman rice	before	13.5 ±2.3	685.3 ±4.3	11.5 ±1.47	75.6 ±1.25	15.6 ±1.2	333.4 ±3.01	0.81 ±0.015	5.7 ±0.5	14.8 ±2.09	6.1 ±0.50
	after	6.5 ±1.2	303.2 ±5.34	4.6 ±2.03	74.11 ±2.30	6.5 ±0.98	188 ±3.65	2.1 ±087	2.9 ±0.57	7.3 ±3.05	4.28 ±1.05
Kurdish rice	before	14.3 ±2.32	841.2 ±5.98	13.2 ±2.6	55.9 ±2.87	17.5 ±2.00	351.7 ±4.014	0.78 ±0.06	5.55 ±0.17	10.6 ±3.9	5.44 ±1.9
	after	14.5 ±1.25	496.8 ±4.01	5.03 ±4.3	46.9 ±1.36	15.38 ±2.5	167.2 ±2.06	1.99 ±0.5	3.2 ±0.9	2.3 ±1.05	3.36 ±2.1
Gulbahar rice	before	10.8 ±2.22	850.3 ±3.21	12.3 ±4.1	60.3 ±2.3	23.6 ±2.21	290.45 ±2.3	0.78 ±0.4	5.01 ±1.06	9.3 ±1.03	4.9 ±1.6
	after	5 ±1.9	498.7 ±4.65	0.98 ±0.05	90.5 ±3.20	14.25 ±1.2	103.3 ±1.36	2.13 ±0.35	2.9 ±1.06	10.5 ±2.3	2.43 ±2.3
Thailand rice	before	11.4 ±2.69	643.1 ±6.92	7.9 ±45.3	75.6 ±2.79	21.4 ±1.03	253.2 ±1.47	0.71 ±0.24	4.6 ±0.95	15.4 ±3.0	7.1 ±5.6
	after	2.4 ±1.65	284 ±2.65	2.23 ±0.14	25.3 ±2.63	5.53 ±1.03	98 ±2.8	1.55 ±0.9	3.6 ±0.19	22.3 ±2.8	2.04 ±2.34
Russia rice	before	10.33 ±3.4	700.6 ±4.5	9.5 ±2.35	69.5 ±3.00	18.6 ±2.5	368.5 ±3.015	0.65 ±0.64	3.6 ±1.02	10.4 ±1.4	9.5 ±1.79
	after	10.2 ±3.65	307 ±3.6	2.48 ±2.3	55.3 ±2.42	4.35 ±0.196	106.8 ±2.9	2.45 ±0.97	4.28 ±1.07	29.3 ±2.6	1.45 ±1.22
Dolfensea rice	before	8.17 ±2.45	807 ±4.15	9.07 ±4.1	79.3 ±3.01	23.6 ±2.9	324 ±3.01	0.59 ±0.489	4.3 ±1.6	10 ±0.18	5.14 ±1.24
	after	1.25 ±0.987	375 ±2.78	1.5 ±0.98	44.5 ±1.65	4.55 ±2.01	70.3 ±1.9	0.95 ±1.00	5.33 ±2.01	9.2 ±1.09	0.98 ±0.15
Mahmud rice	before	8.1 ±4.4	1 183 ±5.33	3.5 ±0.89	140 ±3.9	21.3 ±3.30	297.14 ±2.57	0.73 ±0.05	3.8 ±1.03	9.8 ±1.04	8.4 ±25
	after	0.98 ±0.21	534 ±3.8	0.55 ±0.932	60.3 ±32	3.05 ±0.54	34.5 ±2.36	2.35 ±0.65	3.7 ±1.02	25.3 ±2.6	0.87 ±0.02

The following values (mg/kg) were obtained for rice grains before soaking: 8.1–14.3 for Fe, 1183.5–643.1 for K. The lowest Mn content was 3.5 ±0.89 mg/kg in Mahmud rice and the highest was 57.9 ±45.3 mg/kg in Thailand rice. After soaking the rice for one hour, the mineral content decreased. The Na content in Mahmud rice was reduced by nearly 45% after soaking, from 140 ±3.9 mg/kg to 60.3 ±32 mg/ kg. In addition, processing methods, such as cooking and soaking of the rice varieties, may have an effect on their physical characteristics, nutrient composition and sensory attributes of rice (Carcea, 2021).

Data in the present study showed that soaking in water did not significantly affect the Zn content of local Kurdish rice. In all rice genotypes, soaking reduced Mg content. In Saman rice, the original level of 333.4 ±3.01 mg/kg was reduced to 188 ±3.65 mg/kg after soaking. In Mahmud rice, it was reduced from 297.14 ±2.57 mg/kg to 34.5 ±2.36 mg/kg. The soaking of grains leads to extensive quantitative (leachate loss, kernel bursting) and qualitative (color, smell) changes and reduces mineral content (Müller et al., 2022).

Among the analyzed rice genotypes, the highest mean Al content before soaking was recorded in Saman rice (5.7 ±0.5 mg/kg). After soaking, it was reduced to 2.9 ±0.57 mg/kg, while Al content in the Thailand rice after soaking decreased to 3.6 ±1.02 mg/kg. After soaking, the Sr content in some rice samples was increased, which may be due to the water used. Many authors have shown that the hydration kinetics are affected by soaking time, temperature and solute concentration (Kormoker et al., 2022; Muttagi and Ravindra, 2020).

However, differences in soil chemistry, environmental factors, storage, transportation and processing methods may contribute to variations in the physical characteristics, nutrient composition, and sensory attributes of the indigenous and foreign rice varieties.

Soaking temperature affected the mineral composition of soaked rice. The Ba content in Thailand rice was 15.4 ±3.0 mg/kg, whereas in Kurdish rice it was 10.6 ±3.9 mg/kg. Also, like the content of other minerals, the content of Ba was reduced in some rice.

Russia Rice was higher in Bi content, with levels of 9.5 ±1.79 mg/kg. After soaking, this was reduced to 1.45 ±1.22 mg/kg. Soaking causes the leaching of rice constituents into the soaking water (Ibukun, 2008; Otegbayo et al., 2001; Sareepuang et al., 2008).

Minerals in the paddy migrate into the soaking water, thereby changing their distribution in rice grains (Kale et al., 2015). The concentrations of Fe, K, Mn, Na, Zn, Mg, Sr, Al, Ba and Bi in the most commonly consumed rice genotypes in northern Iraq, including Saman, Kurdish, Gulbahar, Thailand, Russia, Dolfensea and Mahmud rice, are presented in Table 4. The results of this investigation were comparable to those of a Pakistani study on the proximate composition and mineral profile of a few different types of rice (*Oryza sativa*), including super basmati, basmati, and others (Alaka et al., 2011).

The FAO/WHO (1985) states that the dietary intake of foods is a trustworthy method for examining the diet of a population in terms of nutrients consumed and pollutants present, giving crucial information on potential nutritional deficiencies or exposure to toxins from meals. According to the mean concentrations of each mineral identified in the rice samples, the EDIs of possible minerals (Fe, Mn, Na, Zn, Mg and Al) were calculated. Table 5 shows the corresponding consumption rates of adults and children. For adult residents, the total daily consumption of Fe, Mn, Na, Zn, Mg and Al was 36.72, 15.51, 354.38, 47.87, 685.80 and 12.96 mg/day, respectively Table 5. For children, the intake of Fe, Mn, Na, Zn, Mg and Al was 47.01, 19.85, 453.61, 61.27, 877.83 and 29.61 mg/day, respectively Table 5. The total EDIs of Zn and Mg from all samples were lower than the Maximum Allowable Concentration Intake (MAC; Table 5).

The daily intakes of Fe and Zn in the studied areas were less than the recommended values of Fe and Zn for adults, which are 50 and 45 mg, respectively. The investigation of the intakes of Zn and Fe showed that the intakes through rice were lower than the safety limit standard in China (Kamarehie et al., 2019). Zinc deficiency causes a variety of health issues in children, many of which can develop into chronic conditions, including weight loss and impaired infection resistance (Yang et al., 2019).

The quantities of Al and Na observed in the grain were not particularly low. Ihedioha et al. (2016) have observed that rice grains had low EDIs for Al and Na. Increased risks of nephrolithiasis (kidney stones) and obesity have been linked to inadequate calcium intake (Tegegne et al., 2020). Thes EDI for Al in both adults and children (12.69 and 29.61 mg/kg, respectively) are

Table 5. Estimated daily intake for a 60 kg adult and for a 15 kg child of metals from rice consumption with the corresponding maximum tolerable daily intake (MTDI), mg kg^{-1} day^{-1}

Samples	Fe		Mn		Na		Zn		Mg		Al	
	adult	children	adult	children	adult	children	adult	children	adult	children	adult	children
Saman rice	40.63 ±3.01	52 ±3.01	28.75 ±2.01	36.81 ±1.59	463.19 ±6.31	592.88 ±2.36	40.63 ±1.98	52 ±1.3	1 175.00 ±10.3	1504 ±1.36	13.13 ±1.5	23.2 ±3.6
Kurdish rice	90.63 ±3.58	116 ±5.1	31.44 ±3.01	40.24 ±1.92	293.13 ±4.21	375.2 ±2.14	96.13 ±2.09	123.04 ±2.4	1 045.00 ±15.3	1337.6 ±2.3	12.44 ±2.01	25.6 ±2.3
Gulbahar rice	31.25 ±4.25	40 ±2.6	6.13 ±1.05	7.84 ±2.05	565.6 ±5.29	724 ±3.14	89.06 ±2.3	114 ±2.01	645.63 ±8.3	826.4 ±3.36	13.31 ±1.9	23.2 ±2.11
Thailand rice	15.00 ±1.05	19.2 ±2.9	13.94 ±2.9	17.84 ±2.5	158.13 ±3.5	202.4 ±2.1	34.56 ±1.65	44.24 ±3.5	612.50 ±7.45	784 ±3.83	9.69 ±0.98	28.8 ±2.35
Russia rice	65.63 ±4.31	84 ±3.64	15.50 ±3.01	19.84 ±3.21	345.63 ±5.36	442.4 ±3.47	27.19 ±1.9	34.8 ±4.3	667.50 ±6.98	854.4 ±3.56	15.31 ±2.6	34.24 ±3.4
Dolfensea rice	7.81 ±2.35	10 ±1.08	9.38 ±1.9	12 ±3.6	278.13 ±2.64	356 ±2.56	28.44 ±2.9	36.4 ±2.6	439.38 ±5.31	562.4 ±3.31	12.19 ±1.7	42.64 ±3.65
Mahmud rice	6.13 ±3.6	7.84 ±1.3	3.44 ±0.51	4.4 ±1.25	376.88 ±2.96	482.4 ±2.93	19.06 ±3.54	24.4 ±1.39	215.63 ±3.69	276 ±2.09	14.69 ±1	29.6 ±2.1
Consumption of rice on a daily basis	36.72	47.01	15.51	19.85	354.38	453.61	47.87	61.27	685.80	877.83	12.96	29.61
MAC	45		11		2300		99.4		412		100	
WHO/FAO 2011	15		1.8		1200		35		210		10	

MAC – maximum allowable concentration, mg/kg dw.

lower than the maximum allowable concentration values, also reported by Bian et al. (2015).

The classification of any chemical or contaminant health concerns as either carcinogenic or non-carcinogenic is often based on assessment of the risk level (Kamarehie et al., 2019).

A quantitative calculation of the likelihood that contaminants would have a negative health effect on an exposed population is not possible using the THQ estimation process, but it does provide an indicator of the risk level owing to contamination exposure. The THQ values of nine potential metals are presented in Table 6.

The non-carcinogenic (THQ) and carcinogenic (HI) risks of the metals (Fe, K, Mn, Na, Zn, Mg, Sr, Al and Bi) in rice contaminated with PTEs were calculated. In decreasing sequence, the target hazard quotients were calculated for Mg > K > Na > Zn > Fe > Sr > Bi > Al. The total THQ values for Mg, K, Na, Zn, Fe, Sr, Bi, and Al were 1.2526, 1.0331, 1.0553, 0.0874, 0.0671, 0.0355, 0.0377 and 0.0042, respectively. The results showed that consumers are at higher risk with respect to As, Cd, and Pb, which can cause non-carcinogenic risks, while Mg, Al, Fe and Bi do not cause non-carcinogenic risks. Similar results have been reported by Islam et al. (2017). The THQ value for Mg exceeds the standard value (>1) for various rice species when individual elements from specific rice species are taken into account, which is a severe worry for the ingestion of these rice varieties.

However, Gulbahar rice presented the maximum THQ for Na (1.684) followed by Mahmud rice (1.122)

Table 6. Target hazard quotient (THQ; non-carcinogenic risk) of minerals from rice for an adult

Soaking	Fe	K	Mn	Na	Zn	Mg	Sr	Al	Bi
Saman rice	0.0742 ±0.002	**1.364 ±0.14**	0.0525 ±0.025	**1.379 ±0.057**	0.074201 ±0.02	**2.1461 ±0.14**	0.036 ±0.35	0.00331 ±0.004	0.0733 ±0.014
Kurdish rice	0.1655 ±0.001	0.987 ±0.97	0.0574 ±0.038	0.873 ±0.009	0.175571 ±0.05	**1.9087 ±0.9**	0.034 ±0.014	0.0030 ±0.002	0.0575 ±0.032
Gulbahar rice	0.0571 ±0.007	**1.143 ±0.08**	0.0112 ±0.031	**1.684 ±0.98**	0.162671 ±0.041	**1.1792 ±0.24**	0.036 ±0.02	0.003311 ±0.005	0.0416 ±0.01
Thailand rice	0.0274 ±0.04	0.624 ±0.05	0.0255 ±0.073	0.471 ±0.014	0.063128 ±0.014	**1.1187 ±0.015**	0.027 ±0.06	0.004011 ±0.0024	0.0349 ±0.0021
Russia rice	0.1199 ±0.14	0.874 ±0.03	0.0283 ±0.063	**1.029 ±0.324**	0.049658 ±0.017	**1.2192 ±0.5**	0.042 ±0.03	0.004886 ±0.003	0.0248 ±0.09
Dolfensea rice	0.0143 ±0.02	0.886 ±0.004	0.0171 ±0.004	0.828 ±0.09	0.051941 ±0.021	0.8025 ±0.31	0.033 ±0.001	0.006084 ±0.004	0.0168 ±0.036
Mahmud rice	0.0112 ±0.031	**1.354 ±0.96**	0.0063 ±0.003	**1.122 ±0.75**	0.034817 ±0.015	0.3938 ±0.35	0.040 ±0.003	0.004224 ±0.007	0.0149 ±0.041
Total	0.0671	1.0331	0.0283	1.0553	0.0874	1.2526	0.0355	0.0042	0.0377

Bold indicates THQ value > 1.

and Russia rice (1.029). The lowermost THQ for Na as a single metal was in Thailand and Dolfensea rice (0.828). The current analysis reveals that the total THQ from different rice species is quite high (except Dolfensea, Thailand rice). The PTEs investigated have the ability to cause non-carcinogenic hazards (THQ > 1; Table 6). The current study unequivocally shows that eating rice poses no cancer risks for the general population (Islam et al., 2022).

Extant research (such as Carcea, 2021; Islam et al., 2017; Proshad et al., 2019) also came to the conclusion that toxic metals will unquestionably present carcinogenic health concerns to Bangladeshi citizens through the intake of tainted food.

Table 7 compares the levels of heavy metals found in this research with those found in studies from other regions of the nation and from other countries. Except in a few instances, the majority of the mineral concentrations found in this study were lower than those reported by other authors for rice grain from other countries (Table 7). Results from the current study was compared with previous literature involving data from different countries such as Turkey, China, Macedonia, India, Nigeria, Iran, Bangladesh, Brazil and China.

The matrix of correlation coefficients shows the strength of the relationship between the logarithms of elemental concentration (Yang et al., 2019). A correlation coefficient is a value between –1 and +1 that expresses how closely two variables are related. A correlation coefficient value of zero indicates no correlation between the variables and a positive correlation (Ni et al., 2019; Oladele et al., 2019).

In this investigation, the correlation coefficients (r) for the samples were used to create Pearson correlation matrices. The correlation matrices for the metals in the rice before and after soaking are presented in Table 8 and Table 9. Significant positive correlations between the pairs of elements Fe–Mg and Zn–Mn were observed in the samples. This positive correlation suggests that the common source of their origin is probably agrochemicals.

After soaking, the direct effect on Mn was positive and high (r = 0.749082) and the indirect effects via soaking on K (r = –0.53026) were negative and high. The correlation coefficients between Fe and Mn before and after soaking were r = 0.217 and r = 0.749, respectively. The correlation coefficients between Mn

Table 7. Comparison of mean mineral concentrations in the current study with those reported in similar studies, mg/kg

Country	Fe	K	Mn	Na	Zn	Mg	Sr	Al	Ba	Bi	Reference
Turkey	5.6 ±2.1	–	3.54 ±1.02	40.66 ±5.8	5.7 ±3.2	70.68 ±3.01	1.36 ±1.3	3.6 ±0.65	12.33 ±1.35	–	(Aydin, 2022)
China	6.3 ±0.98	357.3 ±5.3	2.8 ±1.9	–	6.1 ±3.9	68.47 ±2.6	0.69 ±0.1	2.8 ±0.1	13.7 ±2.09	1.6 ±0.99	(Müller et al., 2022)
Macedonia	–	378.3 ±4.3	2.7 ±1.4	46..9 ±2.54	–	78.69 ±3.1	–	3.04 ±1.03	13.6 ±1.78	1.4 ±0.98	(de Araújo et al., 2021)
India	6.01 ±1.4	354 ±7.1	–	–	3.9 ±2.6	70.3 ±3.02	–	3.055 ±1.05	11.3 ±2.04	–	(Physicochemical et al., 2009; Indian Bureau of Mines, 2020)
Nigeria	5.7 ±0.98	–	2.32 ±0.96	47.3 ±3.20	4.5 ±3.01	73.66 ±2.9	1.5 ±0.64	4.03 ±1.3	10.35 ±3.00	–	(Oko and Ugwu, 2011)
Iran	6.6 ±1.7	278.3 ±3.87	3.5 ±1.09	38.6 ±3.9	4.9 ±3.0	88.9 ±4.01	2.9 ±1.02	2.66 ±1.6	9.6 ±3.6	2.36 ±0.74	(Ziarati and Azizi, 2013)
Bangladesh	–	354.3 ±3.23	2.8 ±1.8	52.3 ±5.14	–	85.3 ±3.8	3.2 ±1.04	3.9 ±0.19	13.88 ±4.02	2.1 ±0.5	(Kormoker et al., 2022)
Current study	5.87 ±1.2	380.0 ±4.6	2.5 ±0.98	59.3 ±2.4	7.8 ±2.01	89.0 ±3.6	2.5 ±1.01	4.1 ±0.9	15.3 ±2.3	2.4 ±0.83	–

and Na in both states were negative, at $r = -0.225$ and $r = -117$, respectively.

Ihedioha et al. (2016), reported a significant correlation between Al, cadmium and Zn in rice.

Higher correlation coefficients between the metals indicated common sources, mutual dependence, and similar or nearly identical metal accumulation properties in rice. This analysis shows that there is no significant link between the minerals in Tables 8 and 9 and that there is no interaction between them.

The quality of rice was evaluated on the basis of the water uptake ratio (ml of water absorbed / g of

Table 8. Pearson's correlation coefficient (r) matrix for the different metals before soaking

	Fe	K	Mn	Na	Zn	Mg	Sr	Al	Ba	Bi
Fe	1									
K	–0.49386	1								
Mn	0.217759	–0.53026	1							
Na	–0.63146	0.764317	–0.22513	1						
Zn	–0.73405	0.299139	0.11431	0.180842	1					
Mg	0.245134	–0.1036	–0.6597	–0.27751	–0.57168	1				
Sr	0.702729	0.075354	0.001124	–0.11678	–0.48338	–0.11303	1			
Al	0.827133	–0.31718	0.101897	–0.53133	–0.4345	0.012628	0.728564	1		
Ba	0.476091	–0.61611	0.710761	–0.13249	–0.44627	–0.33677	0.274616	0.38869	1	
Bi	–0.52961	0.868023	–0.30252	0.954297	0.127834	–0.19792	0.02357	0.50416	–0.2773	1

Table 9. Pearson's correlation coefficient (*r*) matrix for the different metals after soaking

	Fe	K	Mn	Na	Zn	Mg	Sr	Al	Ba	Bi
Fe	1									
K	0.036941	1								
Mn	0.749082	–0.27925	1							
Na	0.059304	0.385681	–0.1178	1						
Zn	0.584246	0.472187	0.380481	0.344958	1					
Mg	0.699844	–0.29631	0.924704	0.173066	0.511351	1				
Sr	0.22639	0.320985	–0.17132	0.578358	–0.14984	–0.14969	1			
Al	–0.3259	–0.23753	–0.37018	–0.4855	–0.57296	–0.54668	0.029197	1		
Ba	–0.29707	–0.23773	–0.54107	–0.23128	–0.6805	–0.60335	0.314931	0.264353	1	
Bi	0.529293	–0.15457	0.824891	0.304002	0.547722	0.947378	–0.19954	–0.73415	0.64366	1

rice), an important factor in rice quality. A higher bulk density means a higher water uptake ratio. This has been ascribed to a rice variety's compact structure. Water uptake ratio shows a positive significant influence on grain elongation. The water uptake ratio of rice varied between 1.34 and 1.72.

Khatoon and Prakash (2006) reported that the maximum water uptake happened in the first 15 min with the samples reaching an equilibrium state after 30 min. The maximum moisture uptake of 29.1% was for basmati rice.

The water uptake ratio was registered for three temperatures: 35, 50, and 70°C, all in one time segment. The results of soaking are shown in Figure 1. In the first part, where rice was soaked for 60 min at different temperatures, significant difference between all the rice samples were observed.

In conditions of rising temperature and stable soaking time, Kurdish and Saman rice had water uptake ratios of 1.39 and 1.40, respectively, at 35°C (Fig. 1).

The rest of the cultivars behaved very differently. They all (with the exception of Mahmud rice) decreased in water uptake ratio at 50°C and rose again (all samples) at 70°C but only to the level of the values obtained at 30°C or slightly above that. For the measurements with a longer soaking time, 60 min, the results were actually similar, with slightly larger water uptake ratios. Water uptake ratio has been measured by several authors (Hori, 2016; Ni et al., 2019; Oladele et al., 2019).

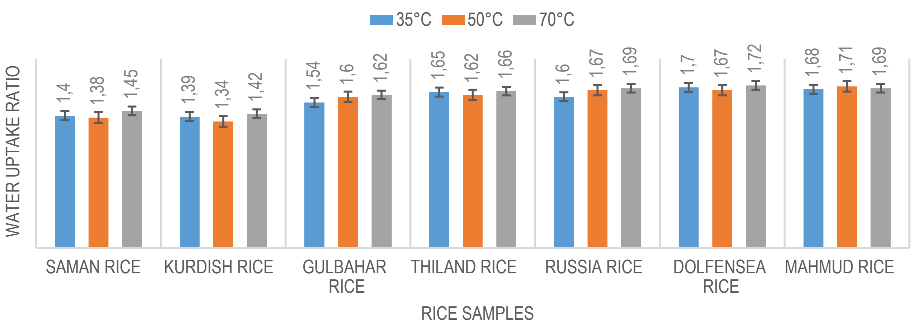

Fig. 1. Water uptake ratio of selected rice varieties

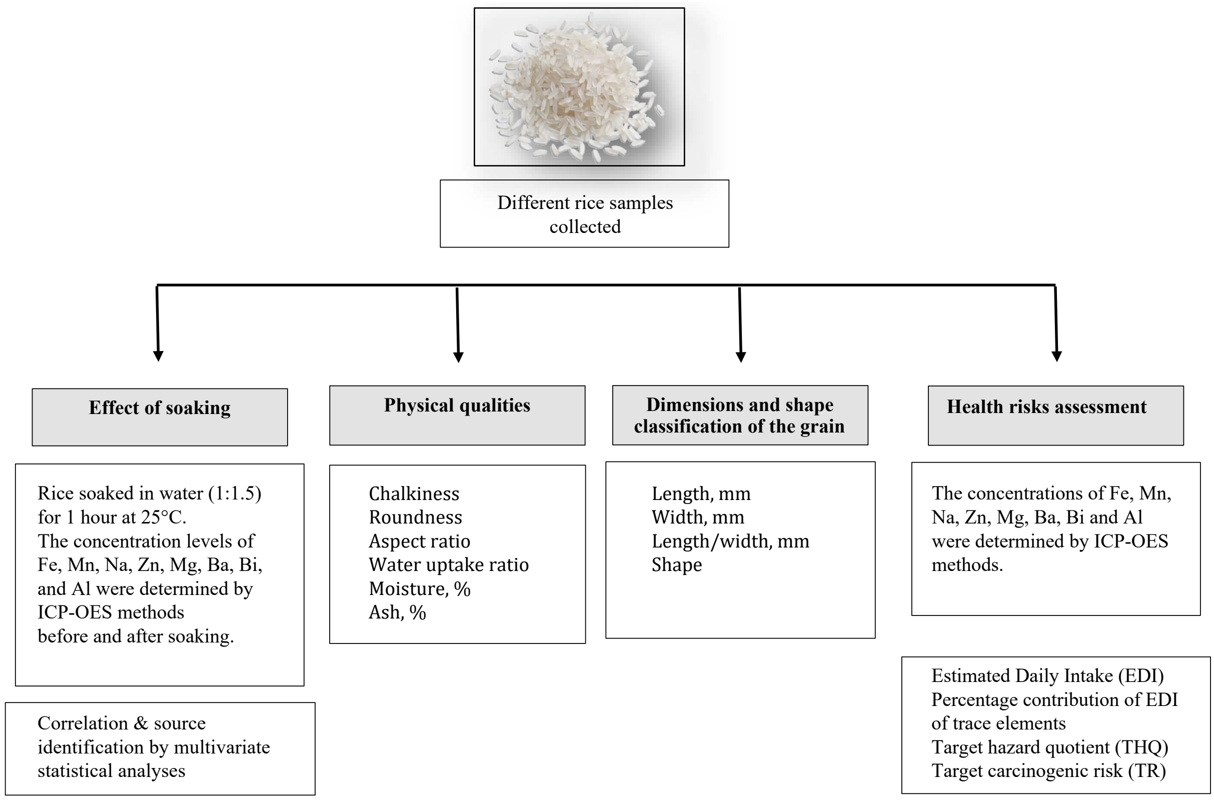

Fig. 2. A flow diagram of the research process

A specific variety's final water uptake was highly associated with its weight and length/breadth (L/B) ratio, negating the effect of volume (Dipti et al., 2002). Khatoon and Prakash (2006) reported that maximum water uptake happened in the first 30 min with the samples reaching an equilibrium state after 45 min. The maximum moisture uptake of 71 was for Mahmud rice.

CONCLUSION

Most of the studied rice samples had levels of minerals that fell within the standard allowable range and were therefore safe to consume. The levels of Fe, Mn, Al, and Zn in these samples did not appear likely to have any significant negative impacts on health, according to the examination of multiple health indices (EDI, THQ, and HI). All minerals (Fe, Mn, Na, Zn, Mg and Al) became less concentrated with increased soaking time. The physical characteristics of the seven rice varieties tested are quite good. Based on grain dimensions and physical characteristics (chalkiness, roundness, aspect ratio, moisture, %, and ash, %), the varieties with a non-native origin differ greatly from the local type (Kurdish rice).

ACKNOWLEDGEMENT

The author would like to express his sincere appreciation to the Chemistry Department, College of Education, Garmian University.

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