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Human Health Risk Assessment of Toxic Heavy Metals in Commercially Available Rice at Local Markets in Erbil, within the Kurdistan Region of Iraq

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ABSTRACT

For the 15 brands that selected for the present study, a total of 50 rice samples were collected. Including at least 3 samples from each brand were subjected to analysis for the presence of As, Pb, Cd, Ni and Cr using the Inductively Coupled Plasma (ICPE-9820 Shimadzu) technique. Additionally, a survey was conducted to collect information about the rice consumption habits of residents, encompassing the consumed rice types and sources, as well as the rice intake quantity and frequency. The median levels of toxic heavy metals (THMs) in rice were as follows: As (0.607), Pb (0.495), Cd (0.143), Ni (0.346) and Cr (0.162) mg/kg. Factoring in the data on rice consumption, the EDI values (in mg kg/day) were determined for the studied population, resulting in a range of (3.29×10^{-4} – 1.63×10^{-3}) for As, (2.38×10^{-4} – 1.18×10^{-3}) for Pb, (7.59×10^{-5} – 3.75×10^{-4}) for Cd, (1.83×10^{-4} – 9.05×10^{-4}) for Ni, and (7.45×10^{-5} – 3.68×10^{-4}) for Cr. In the context of non-carcinogenic risk assessment (HQ), all THMs were found to be below the acceptable threshold (= 1), except for As, which exceeded the acceptable level for all age groups. Carcinogenic risk assessment (CR) values for individuals of all ages and genders ranged from 2.03×10^{-6} to 9.08×10^{-3}. The average total carcinogenic risk for the population in Erbil was calculated as 5.86×10^{-3}. Additionally, males exhibited higher carcinogenic risk levels than females, and individuals in the age group of 11 – 20 faced the highest carcinogenic risk.

1. Introduction

Rice stands as a significant primary food source consumed on a global scale, with yearly consumption reaching up to 350 million tons, making up half of the total cereal consumption (Elert, 2014). The pollution of paddy fields with toxic heavy metals (THMs) has emerged as a noteworthy environmental issue due to their accumulation in the environment and their non-degradable attributes (Hojsak et al., 2015). THMs are frequently recognized as potential contaminants in rice and are viewed as substantial hazardous materials, posing significant risks to both the ecosystem and human well-being (Hojsak et al., 2015). These toxic elements, when present in elevated concentrations within the body can lead to severe health issues (Sankhla et al., 2016). There is a growing apprehension regarding potential health hazards linked to the consumption of rice tainted with these THMs. Metals can be categorized into 2 groups: essential and nonessential. Essential metals, like Fe, Cu, Zn, Se, and Ni, are vital for regular bodily functions. On the other hand, nonessential metals, including Cr, Cd, Hg, Mn, Pb, and As, don't serve specific physiological roles in the body (Bosch et al., 2016). While essential metals are required for maintaining proper bodily functions, elevated concentrations of these metals can present health risks (Prasad, 2013). Diet is recognized as one of the essential pathways through which humans are exposed to HMs. Rice is a common food product in Iraq. Previous study has shown that rice tends to accumulate higher concentrations of THMs such as As, Pb, Cd, Ni, and Cr (Ali et al., 2023).

As, Cd, and Pb are categorized within the top 10 on the list formulated by the Agency for Toxic Substances and Disease Registry (ATSDR). This ranking is determined by a combination of factors, including their frequency, toxicity, and the potential health consequences of human exposure (ATSDR, 2022). International Agency for Research On Cancer (IARC) has designated As, Cd, Ni and Cr as group 1 carcinogens (IARC, 2012), signifying that prolonged exposure to these substances can elevate the risk of various cancer types such as lung cancer, kidney cancer, lung cancer and nasal cavity cancer, respectively. This can involve disruptions in the expression of tumor suppressor genes, impairments in damage repair mechanisms, and alterations in enzymatic activities linked to oxidative damage within metabolism (Bánfalvi, 2011). HMs come in two primary forms: organic and inorganic. Inorganic varieties, such as pentavalent inorganic arsenic compounds, are more perilous because they can dissolve in water and taint groundwater (Hite, 2013). Organic pollutants may eventually break down into less harmful components over time, either through chemical or biological processes (Ayangbenro and Babalola, 2017).

As toxicity can have a slow onset and can cause skin changes, non-cancerous health problems and potentially organ damage and cancer. Extended exposure to minimal concentrations of iAs in potable water could elevate the likelihood of internal cancer following a latency span of 20 to 30 years (Kozliak and Paca, 2012). Exposure to high concentrations of Pb may have detrimental effects on various systems and organs in the human body, including the hematopoietic system, kidneys, reproductive system, and central nervous system (Assi et al., 2016). Cd is a one of the THMs that has been classified as a group 1 carcinogen for humans, meaning that it has been determined to be a substance that can cause cancer (IARC, 2018). Prolonged exposure to Cd may result in a range of negative health impacts in humans including chronic and acute kidney damage, osteoporosis, and lung cancer (Reyes-Hinojosa et al., 2019). Exposure to high levels of Ni can disrupt normal cellular functioning by altering intracellular Ca levels and causing oxidative stress. Ni has also been shown to cause DNA damage, DNA methylation, and suppression of histone acetylation, which can alter gene expression and potentially contribute to Ni-induced carcinogenesis (Genchi et al., 2020). Brown rice and absorb and contains more Ni compared to other types of rice. Chronic exposure to Cr can have toxic effects on the body and can lead to a range of health problems. Possible consequences encompass allergic responses, hemoglobin deficiency, injuries, and ulcerations in the stomach and small intestine, impairment to the male reproductive system, and adverse effects on sperm and disruption of various biological systems (Hossini et al., 2022).

HMs are recognized for their capacity to accumulate within living organisms. To evaluate the possible health hazards linked to these metals, health risk assessments are carried out, relying on the HM concentrations detected in rice grains. Unfortunately, there have been few studies conducted on the analysis of rice THMs in Iraq (Jarjees and Darwesh, 2023), and there is a lack of data on rice daily consumption and THMs daily intake in the country. Moreover, there have been no attempts to estimate the carcinogenic and non-carcinogenic health effects of THMs in rice in Iraq. Therefore, the primary objective of this study was to evaluate the concentrations of THMs such as As, Pb, Cd, Ni and Cr in commercially available rice found in local markets in Erbil / Kurdistan Region of Iraq. Furthermore, the study had the objective of evaluating the potential health hazards, including both carcinogenic and non-carcinogenic risks, linked to the ingestion of these THMs through the consumption of rice. As far as our awareness extends, this study marks the initial examination of multi-HM levels within diverse varieties of locally sourced rice in Iraq, while concurrently addressing the assessment of potential human health risks concerning the Iraqi population.

2. Methods

2.1. Study area

Erbil, also recognized as Hawler, serves as the capital of the Kurdistan Region, situated in the northern region of Iraq, positioned at coordinates 43 ° 55’15 “N and 44 ° 05 ’31"N longitude, as well as 36 ° 16' 45" E and 36 ° 06' 54"E latitude. Erbil, as an ancient city, holds the distinction of being the 3rd largest province in Iraq and is home to one of the most enduring human settlements on the planet. Erbil province encompasses a total land area of 14,873.68 km^2, with a specific focus on the central district of Erbil, encompassing an area of 168.63 km^2, chosen as the designated study area for this study as seen in Figure 1. In 2015, the population of Erbil province stood at 2,009,637 residents, while the center district recorded a population of 930,389 in the same year (Mustafa et al., 2019).

2.2. Sample collection

To fulfill the purpose of this study, 15 rice brands (50 samples) that most eaten in the city purchased and collected at local markets and sealed in plastic bags. Before to gathering the rice samples, manual surveys were conducted among the Erbil population then rice samples collected accordingly. Therefore, all the brands were chosen based on their popularity among consumers in the area. The samples were collected in a randomized manner. For each selected brand, at 3 − 5 subsequent samples were collected. Each sample, weighing 1 kg, was securely stored in zippered plastic bags and subsequently transported to the laboratory. Samples preparation and digestion was done in the Environmental Advanced Lab at college of Science, Salahaddin University-Erbil. Samples were kept at -4°C until preparation.

2.3. Sample preparation

In this study, high-purity deionized water (DW) was employed exclusively. To prepare the rice samples for analysis, they were finely ground them using a professional commercial grinding machine (specifically, the IKA® machine). The mean concentrations were determined of the 5 THMs (As, Pb, Cd, Ni and Cr) in rice samples. These THMs concentrations were then estimated and presented in mg/kg factoring in the weight of the rice.

2.4. Sample digestion

For the digestion of rice samples, standard acid digestion procedure was followed with the aid of a hot plate, utilizing 2 mixtures: hydrogen peroxide (H_2O_2; 34% by volume) and nitric acid (HNO_3; 65%) (Okada et al., 2007). To ensure the cleanliness of the glassware, all glass items were meticulously cleaned with 8% HNO_3, rinsed with DW, and then dry earlier the digestion process began. Block digestion method was used for the rice powder.

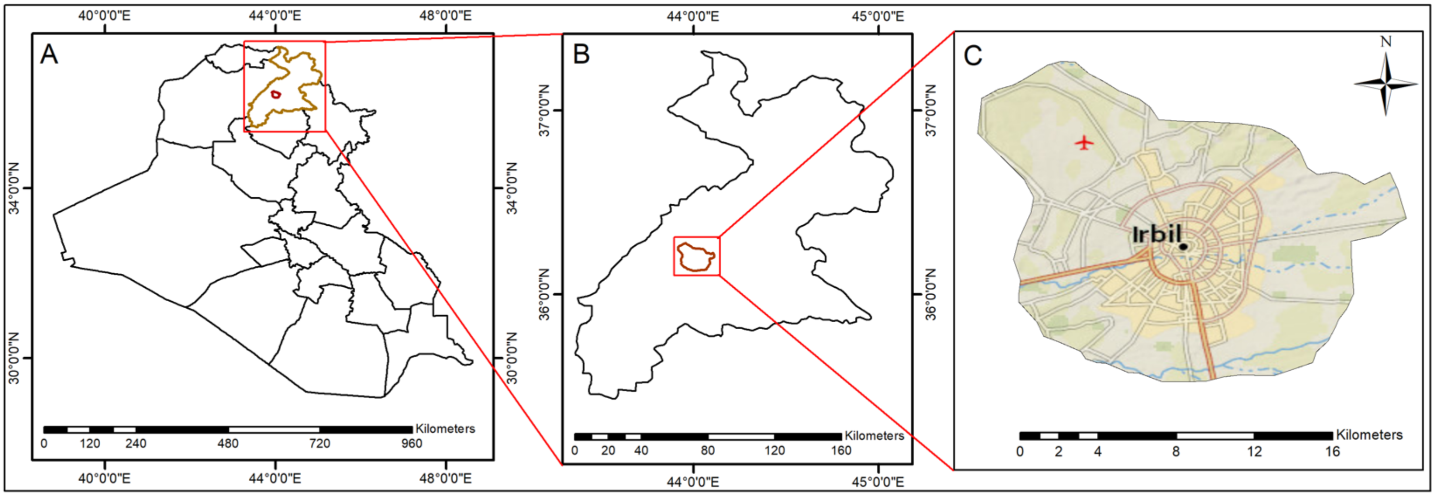

Figure 1. A) Map of Iraq; B) Map of Erbil province; and C) Map of Erbil center district.

For every sample, 0.5 grams of rice powder samples weighed accurately on a high-precision balance (ae adam, model PGW 253i) with a precision of 0.001 gm. Before to full digestion, a preliminary digestion step was carried out, where the samples were treated to treatment with 5 ml of high-purity HNO_3 (65%) in a digestion tube; then allowed to stand for a minimum of 24 h within a chemical hood. Subsequently, the samples underwent digestion in an acid amalgamation with an HNO_3 to H_2O_2 ratio established at 3:2, and the heating was carried out at 130 ^{o}C for 2-3 h, continuing until a colorless filtrate was obtained. Later the digestion process was completed and the samples cooled to room temperature, a colorless filtrate of the digested solution was filtered through Whatman No. 42 filter paper with a pore size of 0.45 μm, ensuring that the filter paper was ash-free. The filtered solutions were then transferred into 25 ml flasks; then it was made up with DW. Blank solutions were also prepared in the same procedure. The five THMs in the rice samples were measured using ICP-AES (9820 Shimadzu) at Razga laboratory for food quality control in Bashmakh.

2.5 Rice consumption patterns in Erbil

To collect data on the rice consumption patterns of Erbil population, the study prepared a survey questionnaire and distributed across the various neighborhoods of the city. Survey collection for data on rice consumption done from April, 2022 to July, 2022. The primary aim of the survey was to document information about rice patterns as well as frequency and quantity of rice consumption. Moreover, it was fundamentally constructed to include investigations about the demographic profile of the participants, such as age, weight, and gender. The Food Frequency Questionnaires (FFQ) survey was distributed randomly but only to the residence of Erbil. Before data collection, participants were asked to accept the consent form. After the cleaning data, 1062 participants were remained that they provided full information and completed the survey questionnaires. These data then used in the risk assessment of THMs to Erbil population that exposed through rice consumption.

2.6. Health risk assessment of THMs from rice

2.6.1. Estimated Daily Intake (EDI)

The EDI refers to the average amount of a chemical or substance that an individual is exposed to on a daily basis over a specific period of time. EDI is typically used to evaluate the plausible health risks linked to the exposure of an individual to a particular chemical or substance (USEPA, 1989).

$$\mathrm{EDI} = \frac{\mathrm{Cm} * \mathrm{IR} * \mathrm{EF} * \mathrm{ED}}{\mathrm{BW} * \mathrm{AT}} \tag{1}$$

where EDI unit is mg/kg/d, Cm is the geometric mean concentration of THMs in rice (mg/kg), IR stands for the rice consumption rate (g/person/d), EF stands for the exposure frequency (365 d/year), ED is the exposure duration (considered as 30 years for non-carcinogens and 70 years for carcinogens) as per (Liu et al., 2009), BW represents the average body weight (kg), and AT is the average time, calculated by multiplying EF by ED. IR and BW data presented in Table 1.

2.6.2. Non-carcinogenic risk assessment

2.6.2.1. Hazard Quotient (HQ)

The HQ is a fundamental tool used to assess the potential health impacts associated with individual's exposure to a specific chemical or substance. It is the risk factor for non-carcinogenic that can be calculate by related the dose at the exposure point (EDI) and a toxicological end-point, the reference dose (Equation 2) (USEPA, 1989). Moreover, HQ is estimated by dividing the EDI of a chemical or substance with its toxicity threshold, which represents the level of exposure at which the chemical or substance is expected to cause adverse effects (Bleam, 2016). It is typically expressed as a ratio, and values surpass one indicated the likelihood of health negative impacts. When the $HQ < 1$, it suggests that negative health impacts are unlikely to occur as an outcome of exposure. However, if the $HQ \geq 1$, it reveals the potential for non-carcinogenic impacts to manifest (Al-Saleh et al., 1999 and Copat et al., 2013).

$$\mathrm{HQ} = \frac{\mathrm{EDI}}{\mathrm{RfD}} \qquad (2)$$

where, EDI is in mg/kg/day and RfD represents the Oral Reference Dose (in mg/kg/day).

2.6.2.2. Hazard Index (HI)

The HI is a useful metric tool used to evaluate and assess the health impacts associated with exposure to a single or multi chemical substances. It can be calculated by totaling the HQs (Equation 3) or so called the Target HQs (THQs) of the total chemical substances or toxic elements in the studied samples. HI is usually expressed as ratio; if the value surpasses the one, it suggesting the likelihood of health risks (USEPA, 1989).

$$\mathrm{HI} = \sum \mathrm{HQ} \qquad (3)$$

2.6.3. Carcinogenic risk assessment

2.6.3.1. Cancer risk (CR) and total cancer risk (CRt)

A cancer risk calculated the additional probability of humans developing cancer during a defined period as an outcome of exposure to a toxic elements or agents that has a carcinogenic risk (Lemke and Bahrou, 2009). The toxicology of a chemical or substance is typically evaluated by its cancer potency, which is a measure of the chemical's or substance's ability to cause cancer (Kroes et al., 2000). The CRt is a measure of the overall cancer risk linked with the introduction of multiple chemicals or substances.

$$\mathrm{CR} = \mathrm{EDI} \times \mathrm{SF} \qquad (4)$$

Here, SF denotes the cancer slope factor for the said carcinogenic element (mg/kg/day).

$$\mathrm{CRt} = \sum \mathrm{CR} \qquad (5)$$

3. Results and discussion

3.1. Patterns of rice consumption habits

Based on the survey results, data on the residents' rice consumption habits, including their rice consumption rate, the frequency of their weekly rice consumption, and their BW, were gathered. The survey then was used this information to calculate the total daily amount of rice consumed by everyone.

The survey investigated the characteristics of the study population with regards to the parameters of IR of rice and BW across distinct age groups and genders and are presented in Table 1. The results indicated that the maximum BW was found among individuals between the age group of 21-70. Additionally, males were found to have a higher BW compared to females. The highest consumption rate of rice per day was found among individuals between the age group of 31-40 years. From a gender perspective, males typically consume more rice per day in comparison to females (P-value < 0.05) based on a Mann–Whitney *U* test. Another study found that individuals aged 45-55 tend to have a more traditional diet, which primarily consists of rice; hence they consumed the highest amount of rice

Table 1. Characteristics of the studied population. Parameters of intake rate (IR) of rice and body weight (BW) among different age groups and gender.

Age group (years)	Gender	n	%	Body weight (kg)			Rice consumption (gm/person-day)		
				Min	Max	Mean ± SD	Min	Max	Mean ± SD
<= 10	Male	41	3.9	9	45	24 ± 9.5	1	176	46 ± 30.4
<= 10	Female	34	3.2	9	49	25 ± 10.5	7	119	52 ± 28.3
11 - 20	Male	117	11	23	115	63 ± 18.8	20	386	144 ± 96.3
11 - 20	Female	103	9.7	20	110	56 ± 12.3	16	223	84 ± 47.1
21 - 30	Male	176	16.6	45	120	75 ± 11.9	18	454	150 ± 87.4
21 - 30	Female	144	13.6	35	95	64 ± 10.9	9	323	105 ± 59.2
31 - 40	Male	54	5.1	37	100	82 ± 11.2	15	394	172 ± 106.2
31 - 40	Female	48	4.5	52	95	73 ± 10.7	35	500	143 ± 102.2
41 - 50	Male	71	6.7	60	108	84 ± 8.9	21	457	147 ± 92.2
41 - 50	Female	88	8.3	55	150	77 ± 12.6	14	269	112 ± 54.6
51 - 60	Male	64	6	60	141	86 ± 14.2	13	326	122 ± 65.8
51 - 60	Female	38	3.6	54	145	74 ± 18.9	12	214	101 ± 63.4
61 - 70	Male	21	2	61	100	82 ± 14.2	29	250	156 ± 68.1
61 - 70	Female	35	3.3	50	95	62 ± 12.3	10	214	82 ± 57.3
> 70	Male	25	2.4	60	98	66 ± 9.9	43	171	93 ± 27.2
> 70	Female	3	0.3	58	82	67 ± 13.3	14	60	31 ± 25.4

n = number of participants; % = percentage of participants; the value shown in average.

(129.28 gm/day) among all the age groups (Cao et al., 2022).

To reveal the rice consumption patterns and BW among different genders and age groups, the subjects were divided into 10-year intervals as demonstrated in Table 1. The studied population also divided into different age groups such as children (1-12 years), adolescents (13-18 years), adults (19-44 years), middle adults (45-65 years), and seniors (>=65 years). The mean daily intake rate of rice by the female citizens was 99.42 g/day (range of 7-500 g/day) while for the male residents it was 137.2 g/day (range of 1-457 g/day). The average BW for females was 63.42 kg (range of 9-150 kg) while the average BW for males was 71.71 kg (range of 9-141 kg). The average body weight was also calculated for the studied population and it find that mean BW was 68 kg as presented in figure 2. The mean rice consumption was 120 g/day and for different age groups were presented in figure 3. A significant contrast was observed in rice consumption patterns between both genders, with males exhibiting elevated metabolic rates and dietary habits than females. Therefore, the results of this study shows that males have higher rates of rice consumption compared to females. The same results were found in other studies (Cao et al., 2022; Liao et al., 2018 and Duan, 2013).

The findings indicated that males exhibit a higher rice consumption compared to females similar to previous studies. However, the overall rice intake observed in the present study falls below the recommended threshold established in 2002.

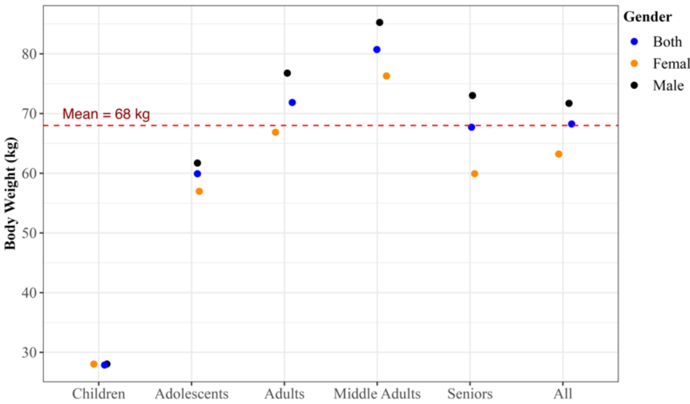

Figure 2. The average body weight for the studied population.

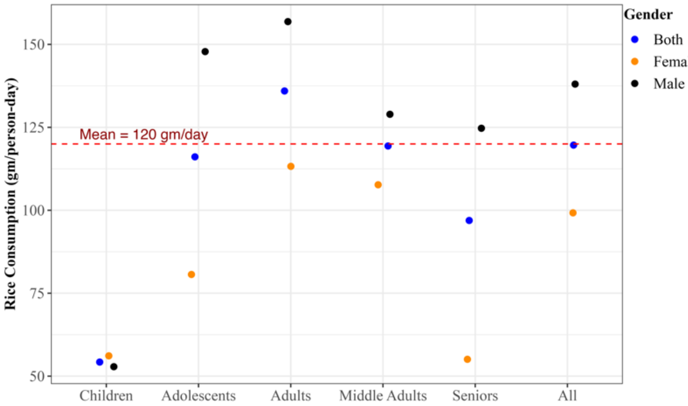

Figure 3. Daily rice consumption for the studied population.

This could be due to changes in dietary patterns and a greater variety of dietary options available because of the fast-paced development of the economy.

3.2. Toxic heavy metals contents

The contents of THMs are presented in Table 2. The results of the analysis of commercial rice samples collected from local markets show that the median concentrations (in mg/kg) of the 5 THMs (As, Pb, Cd, Ni, and Cr) were found to be 0.607, 0.495, 0.143, 0.346, and 0.162, respectively. The range of As concentrations were found to be between 0.107 and 1.885, Pb between 0.094 and 0.985, Cd between 0.062 and 0.619, Ni between 0.016 and 0.884, and Cr between 0.078 and 0.269. According to the results presented in Table 2, the average contents of As and Pb exceeded the maximum allowable limits (0.2 mg/kg) set by the Joint FAO/WHO Expert Committee on Food Additives (JECFA, 2018), while Cd content was found to be within the acceptable limits; approximately 89.1% and 90.91% of rice samples exceed the standard limit, respectively. The levels of Ni and Cr in rice samples did not exceed the standard limits according to Chine’s maximum allowable limits (Clever and Jie, 2014).

Certain THMs, like As, Pb and Cd have been classified as carcinogens by the IARC (2002). These THMs have the potential to cause different types of cancer in humans, both through short-term and long-term exposure (Fakhri et al., 2015 and Farokhi et al., 2017). Therefore, numerous studies have been conducted to examine the levels of metals present in commercially rice across different countries markets. For instance, an investigation by Faraj et al. (2019) focused on assessing the levels of HMs in imported rice varieties purchased from local markets in the city. The results of their study indicated variations in concentrations of As (ranging from 19.27 to 9.51 mg/kg), Pb (ranging from 0.37 to 0.2 mg/kg) and Cr (ranging from 4.02 to 0.15 mg/kg) within the tested rice samples. The contents of As and Cr in the current study were much lower than previous results, while the Pb level was higher. Abu-ALmaaly et al. (2018) reported the HM contents of rice samples of As and Cd, ranging from 0.0226 to 1.8368 mg/kg and 0.0155 to 0.1955 mg/kg, respectively, which exceed the permissible limits set by regulatory authorities. Fakoor et al. (2011) found that As was the most prevalent trace element found in rice, with a mean concentration of 0.05185 mg/kg. The mean contents of Cd and Pb were 0.01 and 0.026 mg/kg, respectively. Nemati et al. (2014) found that total As concentrations ranged from 0.03-0.13 mg/kg among all analyzed samples. Halder et al. (2020) reported lower levels (in mg/kg) of As (0.34), Ni (0.22), and Cd (0.04) in rice, but a higher concentration of Pb (1.70) compared to the current findings. However, several studies found much lower contents of HMs in rice grains available at local markets in different countries. TatahMentan et al. (2020) found that the median levels of toxic substances (mg/kg) in white rice from the USA were 0.131 for As, 0.0028 for Pb, and 0.0065 for Cd. Another study found the concentrations of As, Cd, Pb and Cu were 0.369, 0.0337, 0.123, and 3.095, respectively (Djahed et al., 2018). These results were much lower than the current results.

Table 2. Toxic heavy metals concentrations (mg/kg, DW) in rice grains and comparison with safety guidelines (N = 50).

Statistics	As	Pb	Cd	Ni	Cr
Minimum	0.107	0.094	0.062	0.016	0.078
25th percentile	0.484	0.324	0.116	0.218	0.134
Median	0.607	0.495	0.143	0.346	0.162
Mean	0.607	0.453	0.164	0.352	0.154
75th percentile	0.804	0.65	0.162	0.605	0.182
Maximum	1.885	0.985	0.619	0.884	0.269
SD	0.451	0.251	0.109	0.23	0.041
Coefficient of variance (CV)	63.302	48.755	66.887	58.143	25.723
Max. allowable limit (mg/kg)	0.2[a]	0.2[a]	0.4[a]	1.0[b]	1.0[b]
Over-standard rate (%)	89.1	87.27	5.45	7.27	0.0

[a] JECFA (2018); [b] China’s maximum allowable limits (Clever and Jie, 2014)

These findings demonstrate that the average concentration of THMs such as As, Pb, Cd, Ni, and Cr in rice available at local markets in Erbil is higher than in rice from other countries. The coefficient of variance (CVs) is a great tool works for assessing the variation of toxic elements concentrations as well as for the assessing the extent of differences in toxic elements concentrations across various regions. High CV of THMs (exceeding 25%); suggesting a lack of moderate and low variations. These indicate great differences in the spatial distribution of toxic elements in the rice samples. Consequently, these differences may be influenced by several factors such as the rice variety and their geographical location (Ma et al., 2017 and Li et al., 2012).

3.3. The EDI of THMs in rice

To assess the risk of THMs associated with consumption of rice that the community may encounter, the study estimated and calculated the daily rice consumption. This calculation was derived from the mean of contents of every THMs that measured in rice samples. EDIs were determined by combining the data on rice consumption patterns. Figure 4 presents the statistical synthesis of EDI of various THMs through rice consumption for the study population (N=1062). The average EDI values of THMs from common rice brands consumption were estimated to be; As 1.2E-03, Pb 8.64E-04, Cd 2.75E-04, Ni 6.65E-04 and Cr 2.70E-04 mg/kg/day based upon the assumption that the local population consumes mostly those common rice brands (Figure 4). The average of EDI for Pb, As, Cr, Cd and Ni through rice were estimated to be 1.52E-03, 1.10E-03, 3.50E-04, 8.46E-04 and 3.43E-04 mg/kg day for children (3-9 years old with an average BW of 24 kg); 1.362E-03, 9.85E-04, 3.13E-04, 7.57E-04 and 3.08E-04 mg/kg day for adolescent (9-19 years old with an average BW of 57 kg); 1.24E-03, 9.00E-04, 2.86E-04, 6.92E-04 and 2.81E-04 mg/kg day for adults (19-65 years old with an average BW of 74 kg); and 9.54E-04, 6.90E-04, 2.19E-04, 5.30E-04 and 2.15E-04 mg/kg day for senior (>65 years old with a mean body weight of 67 kg), respectively.

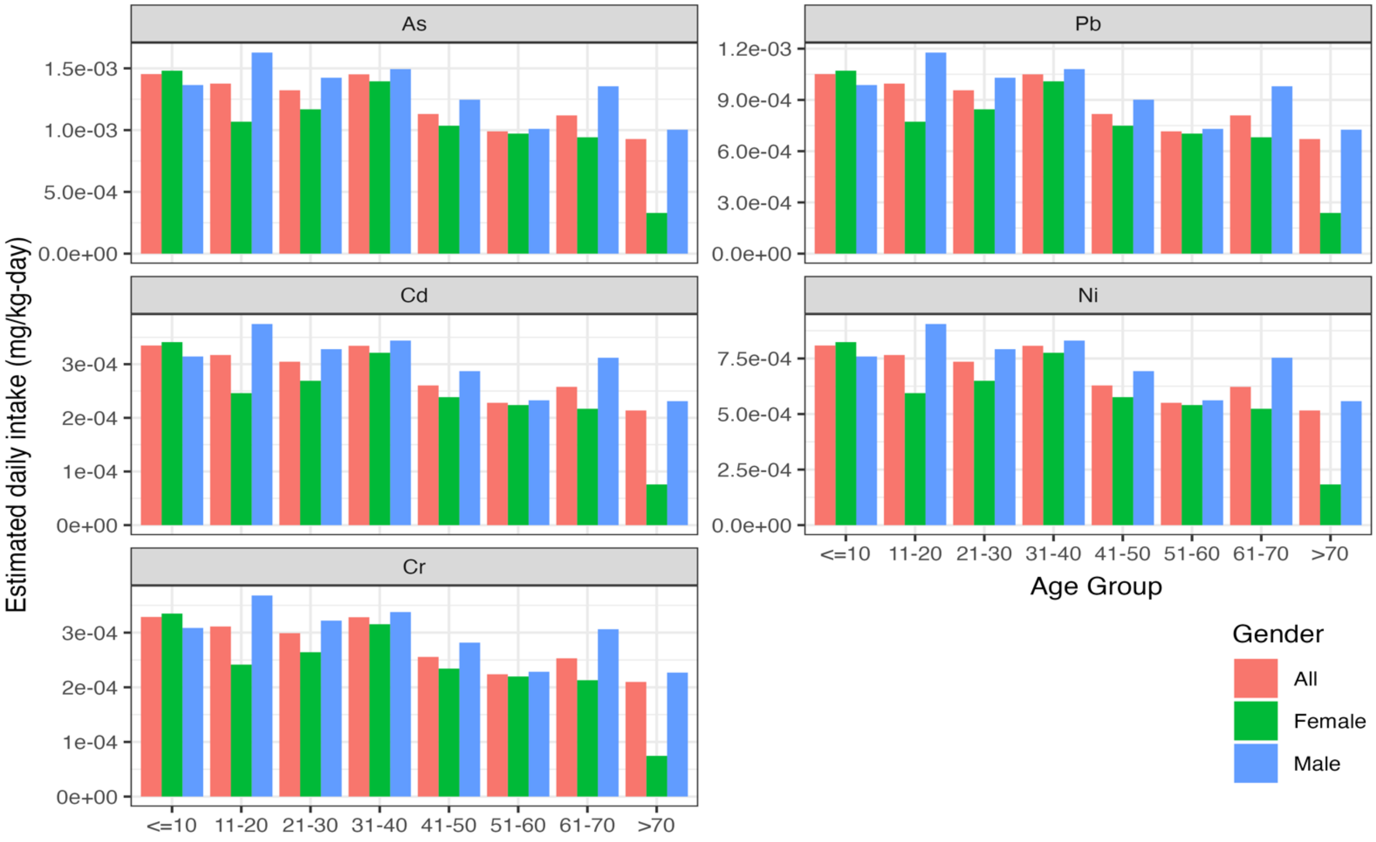

Figure 4. Estimated daily intake (mg/kg-day) of toxic heavy metals in rice for the studied population.

The evaluation of metals potential impact on human health depends on both the levels of these metals in food and the amount of food consumed daily (Song et al., 2015; Neeratanaphan et al., 2017 and Fan et al., 2017). Cao et al. (2010) conducted a study on metal concentrations in rice from Jiangsu, China. They discovered that the daily intake of Pb by adults (weighing 55 kg) through rice consumption was estimated to be 4.30E-4 mg/kg day, which is lower than what our research found (8.07E-4 – 9.59E-4 mg/kg day). Consequently, our study indicates greater exposure levels compared to consumers in Jiangsu, China. Neeratanaphan et al. (2017) also reported exposure to metals through rice consumption compared to a previous study by Huang and Gobran (2005) suggesting potential contamination exposure among residents of Khong Chai district, in the Kalasin province of Thailand.

In a study by Zheng et al. (2007) on adults and children residing near the Huludao Zinc Plant in China, they were found to consume an average daily amount of rice of 389.2 gm of rice and 198.4 gm/person/day, respectively. According to Fan et al. (2017), the ADD value for Cd was found to be much higher than that of other HMs, indicating a significant Cd intake on a daily basis from rice for adults in three main mining regions (Liuyang, Hengyang, Loudi) of Hunan province, China. Consistent consumption of polluted rice yields can lead to harmful health effects resulting from exposure to THMs. A health risk assessment was conducted for the Polish residents, focusing on the levels of As and Cd in rice products. The overall average EDI for As was determined to be 6.2E-4 mg/day. Within the examined rice samples, red rice displayed the highest mean of EDI for As at 1.26E-3 mg/day, while pasta samples exhibited the lowest EDI at 2.7E-4 mg/day. Black rice recorded the lowest minimum EDI at 2.0E-5 mg/day, while red rice showed the highest maximum value at 2.81E-3 mg/day. For individual products, the EDI of Cd ranged from undetectable levels in flakes to 8.6E-4 mg/day in parboiled rice (Bielecka et al., 2020). Consistent consumption of contaminated rice crops can result in negative health effects stemming from exposure to THMs.

3.4. Non-carcinogenic risk assessment

3.4.1. Hazard quotient and hazard index

HQ and HI are models commonly utilized to assess the non-carcinogenic risk to the health of individuals residing in a particular locality. The HQ serves as a specific model that can also be employed to calculate the HI. The HQ equation is a valuable tool for evaluating the health risk linked with non-carcinogenic negative effects resulting from exposure to toxic substances (USEPA, 2011 and WHO, 1993). In this equation, the reference dose (RfD) is utilized to estimate the permissible dose for humans through daily exposure (Di Toppi and Gabbrielli, 1999).

The HQ and HI levels of THMs for the studied population and based on different age groups through rice intake are presented in table 3 and table 4, respectively. Due to rice consumption for both men and women. The average HQs for Pb, Cd, Ni and Cr were < 1. Thus, it is doubtful that they would have a harm impact on local consumers' health. While the average HQ for As was considerably > 1 for all age groups. The minimum HQ for As (1.098) was recorded for females over 70 years of age; while the maximum HQ for As (5.425) was recorded for males aged 11-20 years. This implies that only As potentially present non-carcinogenic hazards to the local population, given that all HQ values surpassed one. The remaining constituents did not exhibit evident individual risk. However, the lowest HI for all 5 THMs was 1.276 for females aged over 70 years, while the highest Hi was 6.304 for males aged 11-20 years. The HI, which is computed to indicate the cumulative risk of HM toxicity, is determined by adding up all the HQ values for a specific rice sample. If the calculated HI exceeds 1, it suggests a high likelihood of adverse health effects associated with exposure to these HMs. Generally, both children and adults, including males had higher the HI values due to rice consumption, which were > 1, while seniors and females had lower HI values. The utilization of HQ and HI calculations has significantly advanced the field of environmental health risk assessment by providing a systematic approach to evaluating the potential health hazards associated with exposure to various pollutants through food and water sources.

Table 3. HQ and HI values of toxic heavy metals for residents via rice consumption.

Age group (year)	Gender	HQ					HI
		As	Pb	Cd	Ni	Cr	
<= 10	Male	4.549	0.282	0.314	0.038	0.103	5.286
<= 10	Female	4.937	0.306	0.341	0.041	0.112	5.737
11 - 20	Male	5.425	0.336	0.375	0.045	0.123	6.304
11 - 20	Female	3.560	0.221	0.246	0.030	0.081	4.137
21 - 30	Male	4.747	0.294	0.328	0.040	0.107	5.516
21 - 30	Female	3.894	0.241	0.269	0.032	0.088	4.525
31 - 40	Male	4.978	0.309	0.344	0.042	0.113	5.785
31 - 40	Female	4.649	0.288	0.321	0.039	0.105	5.403
41 - 50	Male	4.153	0.258	0.287	0.035	0.094	4.826
41 - 50	Female	3.452	0.214	0.239	0.029	0.078	4.012
51 - 60	Male	3.367	0.209	0.233	0.028	0.076	3.912
51 - 60	Female	3.239	0.201	0.224	0.027	0.073	3.764
61 - 70	Male	4.515	0.280	0.312	0.038	0.102	5.247
61 - 70	Female	3.139	0.195	0.217	0.026	0.071	3.648
> 70	Male	3.344	0.207	0.231	0.028	0.076	3.886
> 70	Female	1.098	0.068	0.076	0.009	0.025	1.276

Table 4. HQ and HI for the studied population based on different age groups.

Group	HQ					HI
	As	Pb	Cd	Ni	Cr	
Children	3.741	0.232	0.303	0.032	1.90E-04	4.31
Adolescents	3.751	0.233	0.304	0.032	1.90E-04	4.32
Adults	3.664	0.227	0.297	0.031	1.86E-04	4.22
Middle Adults	2.850	0.177	0.231	0.025	1.45E-04	3.283
Seniors	2.767	0.172	0.224	0.024	1.40E-04	3.188
All	3.423	0.212	0.277	0.029	1.74E-04	3.944

3.5. Carcinogenic risk assessment

3.5.1. Cancer risk and total cancer risk

In the context of evaluating the risk of carcinogens, the CR or CRt is computed to gauge the additional likelihood of a person getting cancer throughout their lifetime. For instance, a CR of 10-4 signifies a probability of one in 10,000 individuals developing cancer (Ma et al., 2017). When multiple carcinogenic factors are present, the cumulative CRt is calculated by assuming their effects are additive. The method for estimating CRt is provided by the USEPA Region III Risk-Based Concentration, as outlined in USEPA (2011). According to research by Ma et al. (2017) and Cao et al. (2015), risk levels within the range of 1.0 x 10^{-6} to 1.0 x 10^{-4} are considered acceptable.

This study estimated the CR and CRt of THMs for the studied population (Erbil) and based on different age groups that may encounter through rice consumption and the results are presented in table 5 and table 6. The results show the CR and total cancer risk (CRt) values of THMs for local population via rice consumption in Erbil. The values are presented for different age groups and genders. The CR values for all HMs were below the acceptable limit, except for Cd and As in both genders and all age groups, which exceeded the limit. Additionally, Pb, Ni and Cr had an acceptable cancer risk levels for all ages and both genders. Overall, the study suggests that the health risks associated with rice consumption in Erbil are generally low. However, As and Cd had cancer risk above the acceptable limit. The CR for Cr and Ni were around 10^{-4}, while for As and Cd were around 10^{-3}. The cancer risk for Pb was considerably lower, hovering around 10-6. In the present study, it is possible that a potential carcinogenic risk is linked to the presence of As and Cd, given that the calculated CR values did not fall within the deemed safe range of 10^{-4} (Table 5). This range supports with the acceptable risk limits set by the

Table 5. CR and CRt values of toxic heavy metals for residents via rice consumption.

Age group (year)	Gender	CR					CRt
		As	Pb	Cd	Ni	Cr	
<= 10	Male	2.05E-03	8.39E-06	4.72E-03	6.91E-04	1.54E-04	7.62E-03
<= 10	Female	2.22E-03	9.11E-06	5.12E-03	7.50E-04	1.67E-04	8.26E-03
11 - 20	Male	2.44E-03	1.00E-05	5.62E-03	8.24E-04	1.84E-04	9.08E-03
11 - 20	Female	1.60E-03	6.57E-06	3.69E-03	5.41E-04	1.21E-04	5.96E-03
21 - 30	Male	2.14E-03	8.76E-06	4.92E-03	7.21E-04	1.61E-04	7.95E-03
21 - 30	Female	1.75E-03	7.18E-06	4.04E-03	5.91E-04	1.32E-04	6.52E-03
31 - 40	Male	2.24E-03	9.18E-06	5.16E-03	7.56E-04	1.69E-04	8.33E-03
31 - 40	Female	2.09E-03	8.58E-06	4.82E-03	7.06E-04	1.58E-04	7.78E-03
41 - 50	Male	1.87E-03	7.66E-06	4.31E-03	6.31E-04	1.41E-04	6.95E-03
41 - 50	Female	1.55E-03	6.37E-06	3.58E-03	5.24E-04	1.17E-04	5.78E-03
51 - 60	Male	1.52E-03	6.21E-06	3.49E-03	5.11E-04	1.14E-04	5.64E-03
51 - 60	Female	1.46E-03	5.97E-06	3.36E-03	4.92E-04	1.10E-04	5.42E-03
61 - 70	Male	2.03E-03	8.33E-06	4.68E-03	6.86E-04	1.53E-04	7.56E-03
61 - 70	Female	1.41E-03	5.79E-06	3.25E-03	4.77E-04	1.06E-04	5.25E-03
> 70	Male	1.50E-03	6.17E-06	3.47E-03	5.08E-04	1.13E-04	5.60E-03
> 70	Female	4.94E-04	2.03E-06	1.14E-03	1.67E-04	3.72E-05	1.84E-03

Table 6. CR and CRt values of toxic heavy metals for residents via rice consumption based on different age groups.

Group	CR					
	As	Pb	Cd	Ni	Cr	CRt
Children	1.68E-03	7.12E-06	1.91E-03	5.92E-04	1.42E-04	4.34E-03
Adolescents	1.69E-03	7.14E-06	1.92E-03	5.94E-04	1.43E-04	4.35E-03
Adults	1.65E-03	6.97E-06	1.87E-03	5.80E-04	1.39E-04	4.25E-03
Middle Adults	1.28E-03	5.42E-06	1.46E-03	4.51E-04	1.08E-04	3.30E-03
Seniors	1.25E-03	5.27E-06	1.41E-03	4.38E-04	1.05E-04	3.21E-03
All	1.54E-03	6.52E-06	1.75E-03	5.42E-04	1.30E-04	3.97E-03

USEPA (2011), which range from 10^{-6} – 10^{-4}. The maximum CRt value (9.08 x 10^{-3}) was found in the age group of 11-20 years for males. The minimum CRt value (1.84 x 10^{-3}) was observed in the age of over 70 years for females. Generally, the CRt values in all THMs studied were around 10^{-3}. This indicates that the local population is at risk of developing cancer due to the consumption of rice contaminated with THMs. For the overall studied population, CR for As, Pb, Cd, Ni and Cr were 1.54E-03, 6.52E-06, 6.52E-06, 5.42E-04 and 1.30E-04, repectively. The CRt for overall studied population was 3.97E-03.

Sharafi et al. (2019) assessed the human health risk related to the consumption of toxic metals in rice brands in Tehran, Iran. They found that Cr for As in all 3 types of rice was higher than the acceptable limit of 10^{-4}. Shahriar et al. (2020) observed that the Incremental Lifetime Cancer Risk (ILCR) for individuals ranged from 1.35 × 10^{-3} to 8.7 × 10^{-3} in commercial rice brands in Bangladesh. Notably and similarly to the present study, the age groups of 2 to 5 years and 6 to 10 years faced elevated risks compared to other age groups. Additionally, both males and females were found to be vulnerable to Cd exposure through rice consumption. A study by Aguilera-Velázquez et al. (2023) aimed to assess the bioaccessibility and health risks associated with the accumulation of metals from rice in Spain, found that Pb made a minimal contribution to the overall carcinogenic risk as found in this study. Cr was found to be approaching the threshold value of 10^{-4}, signifying a higher level of carcinogenic risk associated with its exposure.

The eating of locally grown brown rice by individuals in Hunan province, China carries a significant potential carcinogenic risk, as indicated by multiple carcinogenic assessments. This risk was found to be more than 400x higher than the limit established by the United States Environmental Protection Agency (USEPA, 2011), which corresponds to a one-in-a-million to one-in-a-hundred chance of additional human cancer over a 70-year lifetime (Zeng et al., 2015). Additionally, Fan et al. (2017) discovered that the values for the CR associated with Cd and As were 0.1769 and 0.0003, respectively. Notably, the CR value for Cd exceeded the threshold of

10^{-4}, and the CRt was 0.1773 signifying a significant potential carcinogenic risk associated with the consumption of brown rice in Hunan province, central China. According to a study by Liao et al. (2018), the estimated lifetime cancer risk (LCR) for both males and females in the Kunming, China cohort was found to be 5.28 × 10^{-4}. This LCR value is notably 5 times higher than the upper limit established by the USEPA, which is 1.0 × 10^{-4}. Specifically, for females in this cohort, the calculated maximum LCR was even higher at 8.02 × 10^{-4}, surpassing the LCR upper limit by a factor of 8. Remarkably, these elevated LCR values were primarily driven by the high rates of rice consumption in this cohort, even though the measured inorganic arsenic (iAs) levels in the sampled rice in this study remained below the China's Maximum Contaminant Level (MCL). This discrepancy suggests that rice consumption in this population contributes significantly to cancer risk, even when iAs levels in the rice are within regulatory limits.

4. Conclusion

The non-carcinogenic risk linked with THMs in all the studied rice falls within the range of 0.009 – 5.425. As for the carcinogenic risk, Pb had the least contribution to the overall carcinogenic risk, unlike As and Cd, which exceeded the threshold value of 10^{-4}. These findings underscore the urgency of taking prompt measures to mitigate the health risks linked with rice ingestion in Erbil. Therefore, the population of Erbil may encounter several types of cancer according to IARC (2012). For instance, As may cause skin, lung, urinary bladder cancers. Moreover, Cd may cause lung cancer. This can be achieved by implementing measures to reduce the concentrations of HMs, such monitoring quality of rice sold in local markets. Moreover, public awareness campaigns can be launched to educate the local population about the potential health risks linked with eating polluted rice and to encourage them to adopt healthier dietary habits. In this study, the results achieved did not reflect a closer approximation to real-life scenarios of THMs exposure resulting from the consumption of rice. This is because the research did not consider the effects of cooking and digestion processes, enhancing the accuracy of risk assessments. Like most studies that rely on measurements from unprocessed raw materials, this approach underscores the importance of investigating the digestion and bioavailability of these substances in their raw form. This is crucial for a more comprehensive evaluation of the potential risks associated with these contaminants.

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