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Heavy Metals Contamination of Local and Imported Rice in Semarang, Central Java, Indonesia

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ABSTRACT

This study defined the heavy metal concentration in rice, a commonly consumed staple food in Indonesia that is domestically produced and also imported from other countries due to its high demand. A total of six rice samples, comprising of four domestic and two foreign were randomly taken from Semarang stores and analyzed using the Atomic Absorbance Spectrometer (AAS). The laboratory results revealed that three varieties of rice, two from Indonesia (MW and PW; 0.561 and 0.456 mg/kg, each), and one from the United States (B; 0.307 mg/kg), exceeded the Indonesian dietary standard for lead (Pb) (SNI). Furthermore, the concentration of chromium (Cr) in two rice that are imported (B, 0.241 mg/kg and J, 0.723 mg/kg) were greater than the 0.2 mg/kg threshold established by the Chinese government. However, all samples had acceptable levels of As and Hg, and none had detectable levels of Cd. In terms of pH levels, domestically produced rice had a wider range (3.88–5.78) compared to imported rice (4.96–5.68). Although locally grown and imported rice had acceptable levels of LCR, only one local rice sample and two imported rice samples exceeded the Target Hazard Quotient (THQ) as well as Hazard Index (HI) values. In conclusion, consuming heavy metals contamination rice on a regular basis poses carcinogenic as well as non-carcinogenic health risks.

Keywords: pH, heavy metals, rice, local, imported.

INTRODUCTION

Chemical pesticides are commonly used in rice farming in many countries to protect plants from pests (Ali M.P. et al., 2017). However, the excessive usage of agricultural chemicals, including pesticides as well as fertilizers, can lead to soil contamination. This contamination can result in the presence of heavy metals residues, for instance Cadmium (Cd), Chromium (Cr), Lead (Pb), Mercury (Hg), as well as Arsenic (As), in the soil arising from both natural and human-made sources. Alengebawy et al. (2021) and Ali et al. (2019) stated that contamination causes food safety concerns, environmental pollution, as well as health risks for animals and humans (Alengebawy et al., 2021; Ali H. et al., 2019).

The nutrient content of rice produced through paddy cultivation differs based on local climate and soil conditions. Studies by Zhao and Wang (2020), Ishikawa et al. (2016), and Islam et al. (2016) have shown that rice can absorb cadmium and arsenic from the soil, especially in reducing soils (Ishikawa et al., 2016; Islam et al., 2016; Zhao & Wang, 2020). In Asian countries, rice is a significant source of lead and cadmium, as well as consumption of contaminated vegetation and soil has been linked to kidney dysfunction (Budaraga & Salihat, 2021; Zakaria et al., 2021). In order to prevent contamination, it is essential to monitor both soil and agricultural chemicals (Satpathy et al., 2014).

Rice provides 61% of protein and contains essential nutrients such as carbohydrates, thiamin, vitamin B6, magnesium, zinc, and copper (D'odorico et al., 2014). *Oryza sativa* L., commonly referred to as Asian rice, is the most extensively grown species of rice in the world, followed by *Oryza glaberrima* S. (African grain), which differs in appearance in only a few ways (Roma-Burgos et al., 2021). In 2022, rice was cultivated in approximately 120 countries worldwide, with China and India being the largest contributors, accounting for more than half of the global production (214 and 173 million tons, respectively). Nine out of the top ten rice-producing nations and thirteen out of the top twenty are located in Southeast Asia (World Population Review, 2022). However, many countries that produce or transport rice have arsenic-contaminated agricultural land or groundwater (Khosravi-Darani et al., 2022; Upadhyay et al., 2020).

Rice becomes a significant dietary essential in Indonesia (Saliem et al., 2019). As the population grows, annual rice consumption in the country continues to increase (Hafizah et al., 2020). According to data from the Indonesian Central Statistics Agency (BPS), between 2014 and 2018, the consumption of rice-based industrial foods has increased significantly. The consumption of white rice, fried rice and lontong or rice cake increased by 51.85%, 115.6%, and 91.34%, respectively. Traditional cakes, baby porridge, and sticky rice made from rice flour have also seen an increase in consumption (BPS, 2022).

Indonesia's high rice consumption has led to the implementation of a rice import policy. The Indonesian market offers rice from both domestic agriculture and various other countries, including the United States, Vietnam, China, Thailand, India, Pakistan, Taiwan, Singapore, and Myanmar. Importing rice has been a consistent practice in Indonesia for the past 15 years (2000-2015), with Vietnam being the largest supplier, accounting for almost 50% of the total imports during this period, with a total volume of 7.44 million tons.

According to a preliminary study, Indonesian rice samples contain amounts of Cd, Pb, Zn, Fe, Mn, and Cu that exceeded established safety standards in 58%, 78%, 39%, 42%, 6%, and 28% of the total tested samples, respectively (Barinda & Ayuningtyas, 2022; Rozaki, 2021). Despite this, studies are rarely conducted that compare the heavy metals concentration in imported and domestic rice in Indonesia, resulting in insufficient data on the safety of rice from the contamination. Referring to the explanations above, this study assesses as well as understands the potential risks linked to heavy metals levels (As, Hg, Pb, Cr and Cd,) as well as pH in both imported and domestic rice samples available in the market.

MATERIALS & METHODS

Sample

The study utilized six rice samples acquired from diverse sources, with four samples procured from three major markets in Semarang, Central Java, Indonesia. The samples selected for the study were from rice brands that are most in demand and traded in the city, consisting of three different types of local rice as well as one premium local rice, namely local rice 1 (MW), 2 (PW), and 3 (RL), as well as premium local rice 4 (SM). Additionally, two samples of imported rice, namely Imported Rice 5 (J) from Thailand as well as Imported Rice 6 (B) from India, were obtained online from different vendors in the marketplace. All samples were collected in duplicate, with each sample being obtained from the same rice variety purchased from three major markets in the city. The selection of each brand was randomized to ensure an unbiased collection process.

The Preparation of samples

Prior to performing the tests, both types of samples underwent preparation procedures, which involved washing with running water (three times) and subsequently with aquadest (two washes). Overnight air-drying was then performed on the samples, followed by oven drying at 65 °C for two to three hours. Afterward, the samples were homogenized employing a glass mortar. The rice flour per sample was evaluated by shaking it in a plastic bag, passing it through a sieve measuring 428 μm, and ultimately heating the resulting solution.

Brought to a gentle boil

Rice samples digestion

The rice samples, which ranged in weight from 5 to 10 grams, were weighed accurately with the help of an analytical balance before being transported to a chemical beaker for further examination. The rice flour was then left to marinate in thirty milliliters of nitric acid for four days. The resulting solution was then heated on a hot griddle until brown vapor ceased and it became transparent. After being cooled, the processing solution was filtered at room temperature using filter paper with a pore size of 0.45 micrometers (Whatman 41). The filtrate and the sample cleansing were then reduced to a 25.0 mL volume employing deionized water.

Spectrophotometer instrumentation

The Flame Atomic Absorption mode of the Perkin Elmer 2380 atomic absorption spectrophotometer was utilized to measure the levels of Cu, Co, Cd, Pb, Cr, Zn, Ni, and Mn. For the experiment, the fuel used was compressed air that was oxidized by acetylene, and a luminaire with a 0.7 nm rib width was employed. Each component of the spectrophotometry was calibrated using a series of dilutions to ensure precision. In addition, the lamp was properly aligned by adjusting wavelength, flame height settings, as well as the instrument's fuel-oxidant ratio. The maximum sensitivity of the AAS instrument for detecting arsenic (As) metals is 0.02 mg/kg. Any results below this value were recorded as 0.020 mg/kg, while a value of 0.019 mg/kg was used for calculations in this study.

pH instrumentation

A rice sample of 5–10 grams was milled into a smooth powder employing a pestle as well as transferred to a 10 cc glass beaker. In order to prepare a standardized solution, 10 grams of rice was mixed with 10 cc of double-distilled water and agitated for 5 minutes. Calibration fluid and double-distilled water were used to calibrate the pH meter at 26 °C to 7.00 (neutral). After putting the digital pH meter in the solution, a steady value was obtained. The pH meter was carefully washed two times with distilled as well as double-distilled water after use.

Limit of heavy metals content in rice

The Indonesian National Standard (SNI) does not currently establish a maximum permissible level for all types of heavy metals in rice. Several references were used to determine the highest acceptable concentrations of heavy metals in plants and soil, as illustrated in Table 3. The European Union (EU 2002) has established the highest heavy metal threshold in soil at 300 mg/kg for Pb, 150 mg/kg for Cr, and 3.0 mg/kg for Cd. In contrast, the Chinese standard (GB 2762-2017) has set the highest allowable levels of heavy metal content in rice plants at 0.02 mg/kg for Hg, 0.2 mg/kg for Cr, 0.5 mg/kg for As, 0.2 mg/kg for Pb, and 0.2 mg/kg for Cd. Furthermore, based on the European Union Std standard (EC: No. 692/2008), it is 0.2 mg/kg for Pb, 0.2 mg/kg for Cd, 0.02 mg/kg for Hg, and 0.5 mg/kg for As. The World Health Organization/Food and Agriculture Organization (WHO/FAO) has determined the highest heavy metals threshold in plants at 0.02 mg/kg for Hg, 0.2 mg/kg for Pb, 0.2 mg/kg for Cd, and 0.15 mg/kg for As. The Indonesian Food Standard (SNI) of 2009 stipulates that the highest acceptable levels of heavy metal content in rice are as follows: 0.3 mg/kg for Pb, 0.4 mg/kg for Cd, 0.03 mg/kg for Hg, and 0.25 mg/kg for As. However, certain heavy metals have yet to be assigned a maximum permissible limit.

Assessment of health risks arising from exposure to heavy metals in rice grains

Heavy metals are classified as either carcinogenic or non-carcinogenic based on their conceivable health risks to human beings. The average daily intake was employed to evaluate the danger caused by heavy metals. The oral exposure dose for harmful chemicals was calculated employing the USEPA equation, 2011 and expressed as the Average Daily Intake (ADI) in milligrams per kilogram per day (mg/kg/day) units (Onyele, 2018).

$$CDI = \frac{CW \times IR \times ED \times EF}{BW \times AT} \quad (1)$$

Heavy metals concentrations (mg/kg), Rice Intake (IR), Exposure Duration (ED), Exposure Frequency (EF), Reference Body Weight (BW), as well as Average Time (AT) are denoted by CW, IR, ED, EF, BW, and AT, each.

In 2019, the Provincial Government revealed that the annual consumption of rice in Central Java was 3.2 million tons or equivalent to 94 kg per. Based on the Food Consumption Bulletin from 2021, this study estimated the IR to be 0.24 grams per individual daily. Mulyati (2016) estimated that the mean body weight

Table 1. Input parameters of CDI values

Parameter / Factor	Symbol	Units	Adult
Exposure duration	ED	Years	74.515
Exposure frequency	EF	Days/year	365
Averaging time	AT (ED × 365)	Days	27198
Body weight	BW	Kg	52.7
Ingestion rate	IRW	kg/day	0.248

(BW) of the population in Indonesia was 52.7 kg. The mean duration of non-carcinogenic exposure was determined according to the life expectancy of the population at Central Java in 2021, of 74.515 years based on the Central Statistics Agency (BPS).

The non-carcinogenic hazards related to rice consumption was assessed using Reference Dose (RfD) stipulated by the Joint FAO/WHO Expert Committee on Food Additives (JECFA) as well as the U.S. Environmental Protection Agency (USEPA), adopting a target hazard quotient. The Target Hazard Quotient (THQ) was described as the comparison between the contamination level of the toxic substance and the RfD, the highest level that does not induce adverse health effects. The THQ assists in identifying potential non-carcinogenic health risks caused by poisonous elements including heavy metals. According to Onyele (2018), the THQ for assessing health risks related to rice consumption in citizens was calculated utilizing the methodology described by USEPA in 1999.

$$THQ = \frac{ADI}{RfD} \tag{2}$$

The RfD represented the highest allowable daily oral dose for humans from the USEPA (2000) [34], expressed in mg/kg/day. As long as the Total Hazard Quotient (THQ) remains under 1, it is not necessary to worry about non-carcinogenic health effects. In contrast, THQ of equal to or above 1 may cause adverse health consequences. The Hazard Index (HI) was used to assess the possible risk of harmful health effects resulting from the presence of heavy metals contamination in rice. HI determination was performed by summing up the HQs, assuming that the impacts of heavy metals were additive, using the following formula.

$$HI = \sum HQ \tag{3}$$

The calculation suggested that when the HI was less than 1, there was no long-term risk but when HI was greater than or equal to 1, there was a possibility of non-carcinogenic risks. To determine Cancer Risk (CR), the calculated mean daily intake of heavy metals (in mg/(kg per day)) was multiplied by the Cancer Slope Factor (CSF), that represents the maximum likelihood of an individual developing cancer after being exposed to a specific chemical matter over their lifetime (assumed to be 70 years). CR represents the additional possibility of a person getting cancer over their lifetime. The following equation was used to calculate CR.

$$CR = ADI \times CSF \tag{4}$$

$$CRt = \sum CR \tag{5}$$

In the case where multiple carcinogenic elements were present, CR was calculated by assuming an additive effect. CR was estimated based on an additive effect assumption, and risks falling between 1.0×10^{-6} to 1.0×10^{-4} were deemed acceptable. Risks exceeding 1.0×10^{-4} were considered unacceptable, while those between 1.1×10^{-4} and 1.0×10^{-6} were within a tolerable scale. Risks below 1.0×10^{-6} were thought to have no significant impact on health. The study's primary objective was evaluating the possible risks to human health resulting from the presence of heavy metals in planted rice.

Table 2. Oral RfD for heavy metals and Slope Factor (SF) for carcinogenic elements

Elements	SF $(mg/kg{\cdot}d)^{-1}$	RfD $mg/(kg{\cdot}d)$
	SF_{ingest}	RfD_{ingest}
Hg	-	3.00×10^{-4}
As	1.50×10^{0}	3.00×10^{-4}
Cr	0.50×10^{0}	3.00×10^{-4}
Pb	-	1.40×10^{-3}
Cd	5.01×10^{-1}	5.00×10^{-4}

Note: USEPA IRIS (2011), Wang N, 2019 and Pan Y, 2019(Pan et al., 2019; USEPA, 2012; N. Wang et al., 2019).

Results

Heavy Metals Concentration in Imported and Local Rice

Table 3 shows the Cadmium (Cd), Chromium (Cr), Lead (Pb), Arsenic (As), and Mercury (Hg) concentrations found in samples of both locally produced and imported rice.

Table 3 lists the arsenic (As), cadmium (Cd), lead (Pb), chromium (Cr), and mercury (Hg) content in imported and local rice samples. The findings of laboratory examinations of four regional and two rice samples Imported rice samples with five heavy metals parameters revealed heavy metals content above the standard, specifically for lead (Pb) in two local rice samples and one imported rice sample against Indonesian food standards for Pb (0.3 mg/kg) and Cr on two imported rice samples against the standard quality standard for rice in China for Cr 0.2 mg/kg.

Samples 1 (MW), 2 (PW), and 6 (M) contain 0.561 mg/kg, 0.456 mg/kg, and 0.303 mg/kg of heavy metals, respectively. Meanwhile, Samples 5 (J) and 6 (M) have a chromium (Cr) content of 0.72 mg/kg and 0.24 mg/kg, each. All samples, including the aforementioned samples, have heavy metals content under the treshold of 0.02 mg/kg for all listed standards, including the Chinese rice standard of 0.5 mg/kg, the European Union rice standard of 0.1 mg/kg, the WHO rice standard of 0.15 mg/kg, and the Indonesian food standard SNI of 0.25 mg/kg. Additionally, the heavy metals content of Mercury (Hg) in all sample's scales from 0.006 to 0.009 mg/kg, which is also below the quality standard of all standards. In all the samples analyzed, cadmium (Cd) was not found. The pH range of local rice is greater than imported rice, which ranges from 3.88 to 5.78. (4.96–5.68).

Potential Health Risks

Table 4 details the calculation of THQ or prospective risks associated with oral contamination to heavy metals.

Based on the non-carcinogenic health risk calculation (B) THQ and HI >1 was obtained in imported rice 5 (J) and 6 (J) as well as local rice 1 (MW) and 2 (PW). Imported rice samples 5 and 6 had the highest and second-highest health index

Table 3. Heavy metals levels in imported and local rice as well as the highest heavy metals quality standard in plants and soil

Samples	Units	Cd	Cr	Pb	As	Hg	pH value
Local Rice 1 (MW)	mg/kg	0	0	0.456	<0.020	0.009	3.95
Local Rice 2 (PW)	mg/kg	0	0	0.561	<0.020	0.009	5.78
Local Rice 3 (RL)	mg/kg	0	0	0	<0.020	0.006	3.88
Local Rice 4 (SM)	mg/kg	0	0	0	<0.020	0.008	5.57
Imported Rice 5 (J)	mg/kg	0	0.723	0	<0.020	0.008	4.96
Imported Rice 6 (M)	mg/kg	0	0.241	0.303	<0.020	0.009	5.68
Standard for rice							
Chinese (GB 2762-2017)	mg/kg	0.2	0.2	0.2	0.5	0.02	
European Union Std (EC: No. 692/2008)	mg/kg	0.2		0.2	0.1	0.02	
WHO/FAO	mg/kg	0.2		5	0.15	0.02	
Food Indonesia SNI, 2009	mg/kg	0.4	-	0.3	0.25	0.03	

Note: Ji et al., 2012; Kong et al., 2018 (Ji et al., 2012; Kong et al., 2018).

Table 4. HI and THQ values of heavy metals in imported and local rice traded in the local market of Semarang, Central Java, Indonesia

Samples	THQ Cd	THQ Cr	THQ Pb	THQ As	THQ Hg	HI of Rice
Local Rice 1 (MW)	0.00	0.00	1.53	0.30	0.14	1.05
Local Rice 2 (PW)	0.00	0.00	1.89	0.30	0.14	1.19
Local Rice 3 (RL)	0.00	0.00	0.00	0.30	0.09	0.39
Local Rice 4 (SM)	0.00	0.00	0.00	0.30	0.13	0.43
Imported Rice 5 (J)	0.00	11.34	0.00	0.30	0.13	11.77
Imported Rice 6 (B)	0.00	3.78	1.02	0.30	0.14	4.63

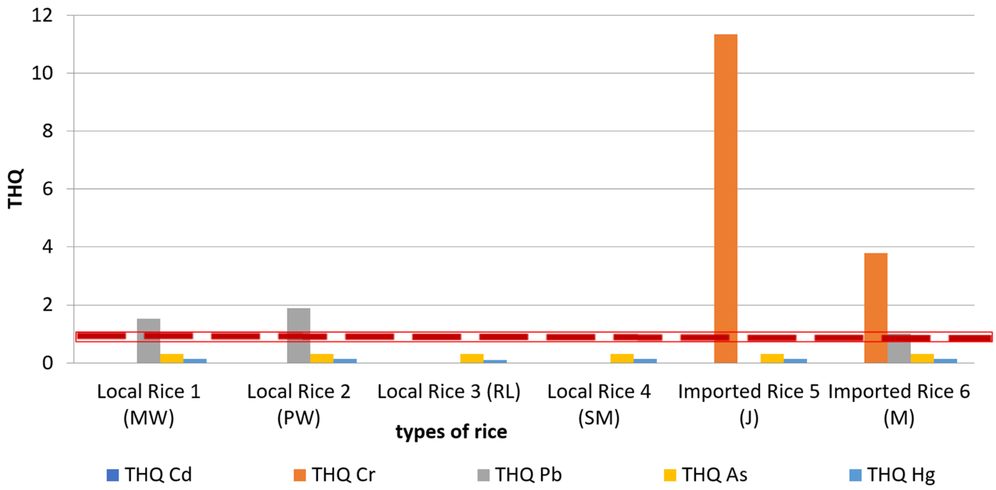

Figure 1. THQ of heavy metals in local and imported rice sold in local markets in Semarang, Central Java Province, Indonesia, in 2020

(HI) scores of 11.77 and 4.63, each. The measurement of these yields was based on the mean BW of the Indonesian population at 52.7 kg for a rice consumption per day of 0.248 kg per individual. The individual THQ greater than 1 indicates that consuming single heavy metals from rice alone poses a relatively high health risk. Two imported rice samples had the highest HI, suggesting that some imported rice is not safe for human consumption. These findings show the potential for risks to one's health from non-carcinogenic daily consumption of imported and domestic rice containing heavy metals levels determined in this study.

The assessment on Lifetime Carcinogenic Risks (LCR) of heavy metals in rice, presented in Table 5, showed that two imported rice (samples 5 and 6)

Table 5. LCR for metals in rice, Semarang, 2020

Sample	CR Ingest Cd	CR Ingest Cr	CR Ingest Pb	CR Ingest As	CR Ingest Hg	LCR Ingest
Local Rice 1 (MW)	0	0	0	1.34×10^{-4}	0	1.34×10^{-4}
Local Rice 2 (PW)	0	0	0	1.34×10^{-4}	0	1.34×10^{-4}
Local Rice 3 (RL)	0	0	0	1.34×10^{-4}	0	1.34×10^{-4}
Local Rice 4 (SM)	0	0	0	1.34×10^{-4}	0	1.34×10^{-4}
Imported Rice 5 (J)	0	17×10^{-4}	0	1.34×10^{-4}	0	18.34×10^{-4}
Imported Rice 6 (B)	0	5.6×10^{-4}	0	1.34×10^{-4}	0	6.94×10^{-4}

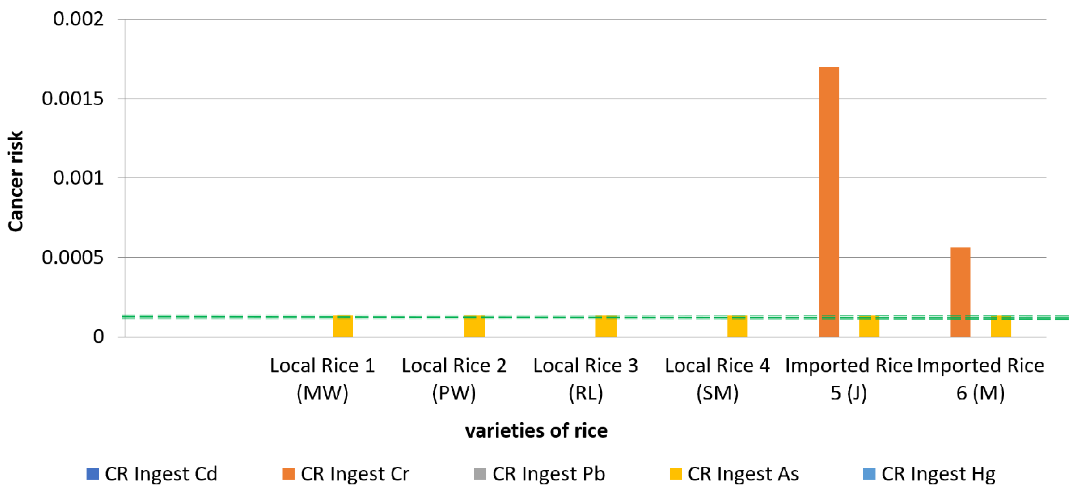

Figure 2. LCR of heavy metals in imported and local rice traded in local market Semarang city, Central Java Province, Indonesia, 2020

had Chromium LCR levels exceeding the allowable limit. The CR ingest values for these samples were 18.34×10^{-4} and 6.94×10^{-4}, respectively, which fall outside the allowable range of $1\times10^{-6} - 1\times10^{-4}$. These findings indicate that consuming these particular types of rice may pose a CR to individuals.

DISCUSSION

Heavy metals level in local and imported rice

Lead (Pb)

This study found that two local rice samples and one imported rice sample, namely (MW, 0.561 mg/kg), (PW, 0.456 mg/kg), and (B, 0.303 mg/kg), had lead (Pb) content exceeding the Indonesian food limit of 0.3 mg/kg. Merismon (2017) examined Pb and Cd levels and soil pH in 20-, 40-, 60-, and 80-year-old farming soil (Merismon et al., 2017). The result showed that the longer the soil was used, the lower its pH, from 5.56 to 6.46, and the higher its Cd and Pb levels in rice grains and soil. Pb in rice grains and soil increased from 2.35 to 3.11 and 17.82 to 20.56, respectively. Meanwhile, Cd increased from 0.15 to 0.29 ppm and 0.26 to 0.72. In 2021, Iresha found that rice crops grown near the landfill site had Pb and Cd levels exceeding the Maximum Residue Limits (MRLs) of 1.20 mg/kg and 0.048 mg/kg, each. According to Sintorini et al. (2021) acidic soil makes these metals more mobile and easier for plants to absorb (Sintorini et al., 2021).

Chromium

According to this study, only B (0.241 mg/kg) and J (0.723 mg/kg) surpassed the Chinese rice quality treshold of 0.2 mg/kg for chromium. According to Faraj (2019) in the Iraqi market, imported rice from the United States contained higher levels of chromium, at 4.02 0.51 mg/kg, than local Iraqi rice, at 0.15 0.02 mg/kg. Ali (2022) reported that 97.4% of rice samples in Pakistan exceeded the chromium limit of 1.0 mg/kg (Faraj et al., 2019). The presence of chromium in the soil can be attributed to various sources, including contamination resulting from human activities like the application of pesticides and fertilizers that contain chromium, improper disposal of industrial waste, and the disposal of fossil fuels (Testa, 2004; Xu et al., 2023). Soil contaminated with chromium can distribute to rice and increase its concentration in food derivatives.

Ph

The pH range of local rice was found to be higher compared to imported rice, ranging from 3.88 to 5.78 and 4.96 to 5.68, respectively. The ideal pH for the growth of rice plants is 6.5–8.5 (Xu et al., 2023). Furthermore, according to Merismon (2017) soil with a pH ranging from 6.4 to 6.8 is considered ideal for plant growth and possesses qualities that can supply sufficient nutrients to plants (Merismon et al., 2017).

The mobility of metals can be increased by low soil pH, resulting in easier discharge of heavy metals and greater mobility. However, the presence of natural humates or synthetic compounds such as EDTA, which can form complexes with heavy metals, can reduce their release and mobility, consequently decreasing soil toxicity. Soil pH variation is predominantly caused by plant and microorganism activity, as well as carbon decomposition, and is crucial for regulating the transformations and chemical properties of heavy metals like lead and cadmium. According to (Abdul Halim et al., 2018; Adamczyk-Szabela & Wolf, 2022), soil pH can also influence other soil processes.

Several previous studies stated that various factors such as pH, soil metals content, organic matter, soil type, species, cation exchange capacity, and genotype can impact the absorption of metals by roots (Adamczyk-Szabela & Wolf, 2022; Cataldo & Wildung, 1978; Jung, 2008; Romdhane et al., 2021) Inadequate time for soil to rest and replenish the necessary nutrients for plant growth is caused by continuous rice cultivation, such as planting rice three times a year. As a result, the soil is depleted and needs fertilization, while plants need pesticides to repel pests, which facilitates heavy metals to be available in the soil. This situation leads to heavy metals entering the food hierarchy and causing human health problems. According to Rai et al. (2019), consuming toxic plants for an extended period of time can disrupt biochemical processes, which can result in the accumulation of these metals in the kidneys and liver as well as toxicity in various body organs (Rai et al., 2019). The toxic metals toxicity is determined by the route and form of disturbances of intracellular homeostasis, exposure, and oxidative harm to biological macromolecules (Figueiredo-Pereira et al., 1998; Jan et al., 2015; Yadav, 2010). It is necessary to improve pH of the soil to make agriculture-related goods less acidic without affecting body metabolism.

Potential health risks

The analysis showed the lead levels of two local samples and Indian imported rice exceeded the SNI. This is in line with (Kasam et al., 2018) study on rice farming regions close to the Gunung Tugel landfill in Banyumas, Central Java, Indonesia, which revealed that the lead (Pb) content was significantly higher compared to other heavy metals at 1.202 mg/kg.

Faraj (2019) reported significantly higher heavy metals concentration in both imported and local rice in the Iraqi market than those in Indonesia (Faraj et al., 2019). Local Iraqi rice had the maximum rate of heavy metals, at 19.27±0.25 mg/kg, while the minimum concentration was detected at 9.51±0.08 mg/kg.

The elevated levels of Pb in rice plants are attributed to passive absorption known as biosorption (Ashraf et al., 2020; Lahiji et al., 2016). Biosorption happens when low-fertility soil absorbs nutrients from phosphorous fertilizers. Fertilization has potential to increase the productivity of soil (J.-Y. Wang et al., 2015). Roots can quickly absorb heavy metals in ion forms, such as Pb^{2+} and Cd^{2+}, including lead and cadmium. Multiple sources can contribute to elevated chromium levels, including soil contaminated by human actions such as the use of chromium-containing pesticides and fertilizers, the disposal of industrial waste, as well as the disposal of fossil fuels (Mustafa & Komatsu, 2016; Sulaiman & Hamzah, 2018; Yan et al., 2020). This contamination may extend to rice plants, thereby raising the amount of chromium in food products.

Other heavy metals (As, Hg and Cd)

Referring to the findings, the arsenic (As) and mercury (Hg) levels in all samples were within the permissible range, while cadmium (Cd) was not found in all samples. The heavy metals rate varied due to several factors, such as the plants' ability to absorb and transport heavy metals as well as the environmental conditions and location of rice cultivation.

There are numerous causes for the presence of heavy metals in the soil, including the utilization of pesticides and also the disposal of industrial and heavy metals waste. When soil or water contains excessive levels of heavy metals, it can adversely affect the growth and well-being of plants, including rice, and ultimately affect the quality and quantity of rice produced'.

Heavy metals exposure can have negative impacts on the musculoskeletal, cardiovascular, and respiratory systems, posing a potential health problem (Bielecka et al., 2020; Guo et al., 2020). Rice plants can absorb heavy metals in the soil, consequently it is essential to routinely supervise their levels in both the irrigation water and soil. Therefore, to reduce health hazards associated with heavy metals exposure, the general public should avoid eating contaminated crops (Jolly et al., 2013; Sharma et al., 2016).

The conventional technique of rice cultivation involves submerging the soil, resulting in the absorption of heavy metals including lead, copper, cadmium, as well as arsenic from the groundwater and sediment. Currently, the heavy metals concentration close to the soil surface is high, indicating that a significant quantity is present in the soluble soil component, making them readily accessible to plants as well as potentially causing long-term toxicity issues. Pb, Cd, Cu, and as are heavy metals particularly susceptible to accumulation in rice (Fan et al., 2017; Hasan et al., 2022; Myat Soe et al., 2023).

Heavy metals concentrations in rice

The content of the rice plant is affected by its surroundings. In rice cultivation areas, it is crucial to avoid industrial waste, hazardous materials, heavy metals, and pesticides. However, many rice fields are located in industrial areas, which poses a significant risk to the quality of rice produced. Studies conducted in Perak, Malaysia, have shown that rice plants cultivated in this region contain cadmium, arsenic, and lead. The heavy metals levels varied across Perak, with the highest concentrations found in areas affected by mining activities (Sibuar et al., 2022). Guizhou Province's rice grown in regions with strong geological histories contains more heavy metals, mainly Pb and Cd, than those grown in low geological backgrounds (Kong et al., 2018; Yang et al., 2022).

The rise in heavy metals pollution in ecosystems can be attributed to anthropogenic sources such as industries, mining, and waste discharge. These sources release Zn, As, and Cu from smelting activities, As from insecticides, Hg from the combustion of fossil fuels, and Pb from car exhaust (Alengebawy et al., 2021). In the agricultural sector, heavy metals can be introduced through four main sources, namely effluent, fertilizers, herbicides, and animal manure. The heavy metals contamination in the earth may be traced back to the utilization of fertilizers, which typically include both organic and artificial components. The overuse of fertilizers over a long period can cause heavy metals accumulation in agricultural soil. This, in turn, can reduce soil productivity, plant development, and output.

Consequences of heavy metals on humans

Long-term contamination to heavy metals found in soil seriously harms several human organs, including the liver, kidneys, cardiovascular system, and central nervous system. This exposure may also raise the risk of getting respiratory diseases and cancer (Steffan et al., 2018). Lead, for example, can harm many biological systems and has a half-life of up to 30 years in bones. Symptoms caused by lead toxicity are often nonspecific, including cognitive function decline in adults, behavioral disorders in children, miscarriage in women, and male infertility. Other common symptoms include anemia, hypertension, kidney dysfunction, and stomach colic (Alengebawy et al., 2021).

Lead is one of the dangerous heavy metals that can have negative effects on the nervous system, bones, and cardiovascular system of humans. The toxic effects of lead can interfere with the metabolism of vitamin D, which can lead to negative impacts on calcium metabolism. Lead is mostly found in bones in both humans and animals, which can impair the normal development of erythroid components in bone marrow, especially in children with blood lead levels of 12–120 g/l. Lead is also a neurotoxin, which can harm the peripheral and central nervous systems, leading to sub-encephalopathic neurological and behavioral effects. The impact of lead exposure includes effects on epidemiology at 30 g/l of blood lead level, Prenatal or postnatal lead exposure at blood lead levels ranging from 11 to 33 g/l can lead to a four-point reduction in children's intellectual intelligence, as well as digestive problems, headaches, weight loss, anxiety, fatigue, fetal death, hypertension, kidney tumors, and stillbirth. Despite this, studies on humans showed that cancer as well as neurotoxic effects can happen even at low lead concentrations, and suggested guideline values can also guard against the impacts of carcinogens. Additionally, a study conducted in Tamar Valley, England, and Ceredigion, Wales, revealed a connection between increased lead levels in soil used for plant growth and the incidence of dental caries in children.

Excessive intake of copper and chromium can lead to toxicity despite their essential nature. Chromium helps maintain normal blood glucose levels, but its poisoning can result in reactive dermatitis, including eczema. Chronic exposure to chromium is related to several harmful health problems, such as anemia, kidney problems, cardiovascular disease, anosmia, which is the loss of scent and taste, as well as hypertension. Rice farming can contribute to heavy metals accumulation when the soil or irrigation water used is contaminated, which causes the rice grains and other plant parts can become contaminated with toxic substances like heavy metals. This accumulation is primarily caused by anaerobic soil conditions, resulting in increased arsenic mobilization and rice bioavailability.

Studies indicate that heavy metals concentrations are generally higher in imported rice than locally grown rice due to the possibility of soil or irrigation water contamination. As the population grows and the demand for farmland increases, it becomes increasingly difficult to locate safe and uncontaminated areas for rice cultivation, free from industrial waste and heavy metals. Additionally, there may be insufficient or no regulations in place to restrict the use of fertilizers and pesticides that contain heavy metals (Faraj et al., 2019). To deter the hazardous impacts on the community, the Indonesian government should regularly monitor and test imported rice. Maintaining clean and uncontaminated land for rice cultivation is crucial since rice plants can absorb heavy metals, especially as the population and demand for rice continue to rise.

Given that for more than half of the world's population, rice is the primary food source, international regulations under the guidance of the United Nations should be established to protect health of all individuals. This requires the agreement of multiple nations to ensure that rice products are free from hazardous or toxic substances. Consumers have the right to eat uncontaminated food and live a healthful lifestyle. To reduce the risk of cancer and other harmful effects, it is vital to work together on pesticide policies aimed at reducing or eliminating the global use of chemical pesticides, which are a significant source of heavy metals. All nations should collaborate to investigate natural and environmentally friendly alternatives to conventional fertilizers and pesticides.

STUDY LIMITATION

This exploratory study examined the heavy metals levels found in both imported and locally produced rice. However, there were several limitations in this study, including the fact that it only analyzed a few rice brands, representatives of the most commonly consumed rice varieties in Indonesia. Additional study should be performed on a wider variety of rice varieties that are frequently consumed by the Indonesian population to improve the precision of the predicted risk outcomes.

CONCLUSIONS

In conclusion, this study discovered that two local rice varieties (MW, PW) and one imported rice variety (B) have higher levels of lead than the Indonesian food quality standard. In addition, two imported rice varieties, namely J and B exceeded the quality requirement for Cr based on the Chinese rice standard (0.2 mg/kg). Two local (MW, PW) and two imported (J, B) rice varieties had THQ values above 1, with the maximum HI seen in two imported rice varieties as well as the highest LCR for Cr also found in two imported rice varieties. Prolonged heavy metals contamination in rice, particularly Pb and Cr, causes carcinogenic and non-carcinogenic health threats. Furthermore, the pH range of locally grown rice was higher compared to imported rice. The government must regulate and closely monitor the importation of rice.

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