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Health risk assessment of heavy metals in *Solanum tuberosum*, *Manihot esculenta,* and *Ipomoea batatas* (orange- and purple-fleshed sweet potatoes) sold at wet markets in Kuala Selangor, Malaysia

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Abstract

The present work examined the health risks of heavy metals from *Solanum tuberosum*, *Manihot esculenta*, and *Ipomoea batatas* (both orange- and purple-fleshed sweet potatoes) sold in Kuala Selangor wet markets, Malaysia. A total of 40 samples were collected using simple random sampling. The concentrations of cadmium (Cd), chromium (Cr), copper (Cu), lead (Pb), and zinc (Zn) were measured using atomic absorption spectrometers (AAS) after the samples were washed, dried, and digested. A non-carcinogenic risk assessment was done without oral slope variables. The Kruskal-Wallis test was used to determine if three or more group medians differed statistically ($p < 0.05$). The present work indicated that cassava and orange-fleshed sweet potatoes posed higher health risks than potatoes and purple-fleshed sweet potatoes. Cd and Pb levels were the highest in cassava (0.90 and 0.39 mg/kg), while Cr and Cu levels were the highest in orange-fleshed sweet potatoes (2.49 and 1.95 mg/kg). Zn levels were also the highest in cassava (1.62 mg/kg). Significant variations between Cu and Zn concentrations were observed in tuber crops ($p < 0.05$). While the consumption of tuber crops did not present health risks based on EDI, THQ, and HRI values established in the present work, it remains vital to assess the factors affecting heavy metal levels in these food crops, and employ suitable agricultural techniques to curb heavy metal contamination in them.

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Introduction

Potato, cassava, orange sweet potato, and purple sweet potato are prominent tuber crops rich in nutrients, and have a complex phytochemical profile. Sweet potatoes come in various colours, including shades of purple, orange, and red, each with health benefits. For example, purple-fleshed sweet potatoes (PFSP) are high in anthocyanins and phenolic acids. In contrast, orange-fleshed sweet potatoes (OFSP) are rich in beta-carotene, a vital antioxidant with anticancer properties. Furthermore, sweet potatoes are known for their role in addressing vitamin A deficiency, with orange-fleshed types especially useful (Neela and Fanta, 2019). Both sweet and regular potatoes are prized for their nutrient density, as they contain essential nutrients such as vitamins, minerals, and antioxidants. Meanwhile, cassava is a starchy tuber crop that is high in calories, and rich in vitamins B and C (Mohidin *et al*., 2023). The variety of phytochemicals in this crop is responsible for their potential health benefits, making them a vital component of a well-balanced diet.

Nonetheless, assessing heavy metals in potato, cassava, orange sweet potato, and purple sweet potato is necessary due to the potential health hazards associated with heavy metal ingestion in these food products. One of the primary pathways through which heavy metals enter the food chain is soil-to-plant transfer. As tuber crops remain in direct contact with the soil for several months before ripening, concerns have arisen regarding their potential to accumulate heavy metals. Crops absorb heavy metals from contaminated soil through passive and active uptake mechanisms, influenced by factors such as root morphology, soil pH, metal concentration, soil

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organic matter content, and the presence of competing elements and metal-binding compounds in plant tissues (Melnikov *et al*., 2016; Huang *et al*., 2020; Vasilachi *et al*., 2023). For instance, some sweet potato cultivars exhibit higher metal uptake efficiency due to their fibrous root systems and increased cation transport activity, whereas tuberous crops like potato and cassava may accumulate heavy metals differently due to variations in metal translocation pathways (Luis *et al*., 2014; Huang *et al*., 2020). Comparative studies have revealed significant differences in cadmium (Cd) and lead (Pb) absorption among sweet potato varieties, highlighting the importance of crop-specific factors in metal accumulation (Huang *et al*., 2020). Furthermore, soil pollutants such as pesticides and industrial waste contribute to variability in heavy metal uptake among these crops (Briffa *et al*., 2020). Given these concerns, a thorough assessment of heavy metal concentrations in tuber crops is essential to safeguard food safety and public health.

In Malaysia, unauthorised disposal and incineration practices represent significant factors rendering soil susceptible to contamination. These activities give rise to hazardous chemical pollution emanating from the deposition of industrial waste, plastic garbage, and heavy metals. The Langat Water Catchment Area, in particular, confronts contamination issues stemming from both landfill topsoil and non-landfill sites, encompassing agricultural, residential, and industrial areas, all of which exhibit the presence of heavy metals, including cadmium (Cd) and copper (Cu) (Lat *et al*., 2023). The accumulation of these heavy metals in agricultural soil raises concerns about their uptake by food crops, including tuber crops, which are widely consumed in Malaysia. Prolonged dietary exposure to heavy metal-contaminated food products has been linked to various health issues, including kidney damage, neurological disorders, and developmental complications. Heavy elements such as iron (Fe), lead (Pb), and copper (Cu) have been documented in polluted soil within the Ampar Tenang non-sanitary dump (Lat *et al*., 2023). Within Selangor's closed and post-closure landfill regions, the by-product of industrial waste deposition, namely hydrogen sulphide (H_2S), has been identified as correlating with heavy metal poisoning in the soil. Prior investigations have identified agricultural and industrial activities as predominant contributors to soil contamination within the Langat Basin area. Given Malaysia's increasing reliance on tuber crops in traditional and modern food products, there is a growing need to assess the potential public health risks associated with their consumption. Pesticides from crop cultivation, and inadequately managed disposal of factory waste near the study area have also been recognised as significant contributors to soil contamination (Lat *et al*., 2023).

Given the potential adverse effects of high levels of heavy metals on human well-being, it is crucial to evaluate the health hazards associated with heavy metal content in food. Over time, heavy metals such as cadmium (Cd), chromium (Cr), copper (Cu), lead (Pb), and zinc (Zn) may accumulate in the human body. These metals have been associated with several health issues, including gastrointestinal and kidney problems, nervous system disorders, and other long-term negative impacts (Balali-Mood *et al.,* 2021). Continuous ingestion of elevated levels of heavy metals from contaminated food can lead to the chronic build-up of these substances in humans' liver, kidneys, and bones, resulting in disorders affecting the kidneys, cardiovascular system, neurological system, and bones (Anwar *et al.,* 2016). Furthermore, heavy metals can cause congenital disabilities and are associated with low birth weight (< 2.5 Kg) and early deliveries (< 37 weeks of full gestation) (Taylor *et al.,* 2015). While certain heavy metals, such as manganese (Mn), cobalt (Co), copper (Cu), nickel (Ni), and zinc (Zn) are essential elements for humans at specified quantities, they become harmful when exposed to greater doses. Cadmium (Cd), lead (Pb), arsenic (As), and hexavalent chromium [Cr(VI)] have the potential to induce carcinogenic consequences, even in small amounts, as demonstrated by several studies (Jaishankar *et al.,* 2014; Wang *et al*., 2017).

The general objective of the present work was to assess the potential health risks associated with exposure to heavy metals (Cd, Cr, Cu, Pb, and Zn) through the consumption of *Solanum tuberosum* (potato), *Manihot esculenta* (cassava), and *Ipomoea batatas* (orange- and purple-fleshed sweet potatoes) sold in wet markets in Kuala Selangor. The specific objectives were to determine and compare the concentrations of selected heavy metals (Cd, Cr, Cu, Pb, and Zn), as well as to calculate the potential health risks associated with exposure to the detected heavy metals in *S. tuberosum*, *M. esculenta*, and *I. batatas* sold in the wet markets in Kuala Selangor, Malaysia.

Materials and methods

Study design

A cross-sectional study was conducted to investigate the concentrations of heavy metals (Cd, Cr, Cu, Pb, and Zn) in potatoes, cassava, orange-fleshed sweet potatoes and purple-fleshed sweet potatoes from several wet markets around the district of Kuala Selangor, Malaysia. The data collection employed a quantitative approach, and laboratory facilities were utilised to analyse the dependent variables.

Sampling and study area

The sampling locations were wet markets in the Kuala Selangor district. Information about the wet markets was obtained from the Kuala Selangor Municipal Council's official portal, which listed approximately 21 wet markets across various areas, including Tanjung Karang, Taman Alam Jaya, Desa Coalfields, Pasir Penambang, Jeram, Bandar Baru, Tiram Buruk, Bukit Rotan, Puncak Alam, Saujana Utama, Kampung Kuantan, Bandar Seri Coalfields, Bestari Jaya, Taman Alam Jaya, Sungai Buloh, and Ijok.

Sample collection

A total of 40 samples (n = 40) were purchased based on the availability of potatoes (n = 10), cassava (n = 10), orange sweet potatoes (n = 10), and purple sweet potatoes (n = 10) from various wet markets around the district of Kuala Selangor. At each location, tuber crops were purchased from different stall vendors. The sampling method employed for vendor selection and sample collection was simple random sampling facilitated by a random number generator.

Reagents and apparatus

All reagents used were of analytical grade. Distilled water was used for all dilutions. Nitric acid (HNO_3), sulphuric acid (H_2SO_4), and hydrochloric acid (HCl) were employed in the experiment. Glassware and equipment for heavy metal analysis were thoroughly washed with distilled water, immersed in a 5% nitric acid solution for 24 h, rinsed with distilled water, and air-dried before use at room temperature. Calibration standard solutions were prepared by diluting a 1,000 ppm stock solution. Heavy metals were identified using PinAAcle 900T Atomic Absorption Spectrometer (AAS) after acid digestion of the samples, following the procedures described by Okereke *et al*. (2020).

Pre-treatment of samples

The pre-treatment procedure for the samples followed the procedures described by Okereke *et al*. (2020). The samples were rinsed with flowing water to eliminate dust and soil particles, and then chopped into smaller pieces using a knife. Afterwards, they were air-dried and transferred to a drying oven set at 80°C for 2 - 3 d. Finally, they were further dried in an oven maintained at 100°C. Once completely dry, the materials were pulverised into a fine powder (80 mesh) using a commercial blender, and stored in polyethene bags until acid digestion.

Acid digestion of samples

The acid digestion process followed the procedures described by Okereke *et al*. (2020). The samples were subjected to triplicate analyses, wherein 5 g of the measured powder was introduced into 250 mL conical flasks. Subsequently, 5 mL of concentrated sulphuric acid, 25 mL of concentrated nitric acid, and 5 mL of concentrated hydrochloric acid were added. The resultant mixture was heated at 200°C for 1 h in a fume hood, then gradually cooled to room temperature. Approximately 20 mL of distilled water was then added, and the solution underwent filtration using Millipore Whatman No. 4 filter paper to ensure complete removal of organic waste. Subsequently, the solution was transferred into a 50 mL volumetric flask, filled to the line, and left undisturbed for at least 15 h to facilitate sedimentation. The resultant supernatant was examined for the presence of Cd, Cr, Cu, Pb, and Zn using AAS.

Non-carcinogenic health risk assessment

Risk assessment involves examining potential adverse health effects within a specified timeframe (Mohammadi *et al*., 2019). In risk assessment, hazards are classified into two primary categories: carcinogenic and non-carcinogenic (Wongsasuluk *et al*., 2014). Carcinogenic risk assessment is a quantitative analysis that ascertains the heightened probability of developing cancer over an individual's lifespan resulting from exposure to a probable cancer-inducing metal (USEPA, 1991). In 2014, a study conducted by the IARC classified Cd as a carcinogenic metal, indicating the potential for cancer manifestation with prolonged exposure exceeding 70 years. Nonetheless, the Integrated Risk Information System (IRIS) programme (USEPA, 2021) refrained from executing a comprehensive quantitative evaluation of the carcinogenic risk of oral exposure to these metals. Consequently, the assessment of cancer-causing risk was omitted due to the absence of an oral slope factor (SFO) for these metals (Gupta *et al*., 2022).

The assessment of the non-carcinogenic risk posed by heavy metals to human health involved evaluating the estimated daily intake (EDI) and the target hazard quotient (THQ), as described by Gupta *et al*. (2022). The overall non-carcinogenic health risk from the combined exposure to all examined heavy metals was calculated using the health risk index (HRI) computation (Eq. 1):

$$EDI = \frac{C \times IR \times EF \times ED}{BW \times AT} \times 10^{-3} \quad \text{(Eq. 1)}$$

where, EDI = anticipated daily intake of heavy metals (mg/person/day); BW = assumed adult body weight, established at 70 kg by the guidelines outlined by the USEPA (1989); AT = average exposure time for non-carcinogenic health risk, computed as the product of ED and 365, resulting in 25,550 days (USEPA, 1989); C = estimated heavy metal content in vegetables measured in mg/kg; IR = ingestion rate of vegetables, specifically tuber crops, presumed to be 65 g per individual; and EF and ED = presumed exposure frequency and exposure duration, set at 365 days per annum and 70 years, respectively (Gupta *et al*., 2022).

The THQ quantifies the combined non-carcinogenic hazards associated with consuming vegetables contaminated with high levels of heavy metals. THQ readings below 1 indicate negligible non-carcinogenic hazards, while values above 1 suggest a significant potential for health problems. The health risk threat is amplified with the elevated THQ (Antoine *et al.,* 2017; Gupta *et al*., 2022). THQ was determined using Eq. 2:

$$THQ = \frac{EDI}{RfD} \quad \text{(Eq. 2)}$$

where, RfD = oral reference dose, of which the values for Cd, Cr, Cu, Pb, and Zn were 0.001, 0.003, 0.4, 0.0035, and 0.3, respectively.

The health risk index (HRI) was calculated using Eq. 3:

$$HRI = \sum THQ \quad \text{(Eq. 3)}$$

where, THQ = target hazard quotient calculated using Eq. 2.

Statistical analysis

The SPSS version 29 software was used to analyse the data. Following the analysis of variance (ANOVA), it was determined that the data did not exhibit a normal distribution since the assumption of normality had been violated. Therefore, the Kruskal-Wallis test was employed as a viable option to ascertain if there were any statistically significant differences among the medians of three or more distinct groups. The significance level (*p*-value) was set at 0.05.

Results

Concentration of heavy metals in potato, cassava, OFSP, and PFSP

The concentrations of five distinct heavy metals (Cd, Cr, Cu, Pb, and Zn) in four varieties of consumed tuber crops were determined, and are presented in Table 1. The overall Cd levels exhibited the following order: cassava > PFSP > potato > OFSP. The mean Cd levels observed in potato, cassava, OFSP, and PFSP were 0.83, 0.90, 0.76, and 0.86 mg/kg, respectively. As previously indicated, OFSP displayed the lowest concentration (0.76 mg/kg), while cassava demonstrated the highest concentration (0.90 mg/kg). All examined tuber crops surpassed the established maximum permissible limit (MPL) for Cd.

OFSP exceeded the MPL of Cr levels among all four types of tuber crops. The notably high Cr value (2.55 mg/kg) is of concern, and the analysis was repeated several times, consistently yielding a similar result. The overall concentration of Cr followed the OFSP > potato > cassava > PFSP order. The mean Cr concentrations in potato, cassava, OFSP, and PFSP were 0.84, 0.81, 2.49, and 0.77 mg/kg, respectively.

The Cu levels did not exceed the MPL in the tuber crops, and remained well below the MPL. The overall levels of Cu followed the order of OFSP > PFSP > cassava > PFSP. The mean Cu levels in potato, cassava, OFSP, and PFSP were 0.13, 0.32, 1.95, and 1.37 mg/kg, respectively. Potato had the lowest concentration (0.13 mg/kg), while OFSP had the highest concentration (1.95 mg/kg), as mentioned earlier.

Table 1. Concentration of heavy metals (Cd, Cr, Cu, Pb, and Zn) in four types of tuber crops ($n = 40$).

Heavy metal	Tuber crop	Mean (mg/kg)	Standard deviation (mg/kg)	Maximum permissible limit (MPL) (mg/kg)	Reference
Cadmium (Cd)	Potato	0.83*	0.23	0.20	FAO/WHO (2001)
	Cassava	0.90*	0.13		
	OFSP	0.76*	0.23		
	PFSP	0.86*	0.23		
Chromium (Cr)	Potato	0.84	1.91	2.30	FAO/WHO (2001)
	Cassava	0.81	1.00		
	OFSP	2.49*	6.07		
	PFSP	0.77	1.74		
Copper (Cu)	Potato	0.13	1.30	10.00	FAO/WHO (2001)
	Cassava	0.32	0.57		
	OFSP	1.95	1.20		
	PFSP	1.37	1.27		
Lead (Pb)	Potato	ND	3.95	0.30	FAO/WHO (2001)
	Cassava	0.39*	2.57		
	OFSP	ND	3.92		
	PFSP	ND	4.13		
Zinc (Zn)	Potato	1.48	0.45	50.00	FAO/WHO (2001)
	Cassava	1.62	0.48		
	OFSP	1.21	0.33		
	PFSP	1.02	0.40		

OFSP: Orange-fleshed sweet potatoes; PFSP: purple-fleshed sweet potatoes; and ND: not detectable. *Values exceeding maximum permissible limit set by FAO/WHO (2001).

As for Pb, the AAS did not detect concentrations inside the potato, OFSP and PFSP. The only detectable reading for Pb was in cassava (0.39 mg/kg).

The assessment of Zn levels revealed a significantly elevated level compared to other analysed heavy metals. Analogous to Cu, the levels of Zn within the tuber crops remained within the established maximum permissible limit. The Zn levels followed the order of potato > cassava > OFSP > PFSP. The mean Zn concentrations in potato, cassava, OFSP, and PFSP were recorded as 1.48, 1.62, 1.21, and 1.02 mg/kg, respectively. Notably, the highest Zn concentration was detected in potatoes (2.48 mg/kg), while the lowest was in PFSP (1.02 mg/kg).

Heavy metal comparison between potato, cassava, OFSP, and PFSP

Table 2 indicates significant differences in the levels of Cu and Zn among different types of tuber crops, as the p-values for these metals were less than 0.05 ($p < 0.05$). However, there were no significant differences in Cd, Cr, and Pb levels among different tuber crops, as the p-values for these metals were more than 0.05 ($p > 0.05$).

Estimated daily intake (EDI)

In potatoes, the order of heavy metals concerning the EDI was as follows: Zn > Cr > Cd > Cu. Conversely, in cassava, the order was Zn > Cd > Cr > Pb > Cu. In OFSP, the EDI of heavy metals followed the order of Cr > Cu > Zn > Cd; while in PFSP, the order was Cu > Zn > Cd > Cr (Table 3). This suggested that the EDI values for Cd, Cr, Cu, Pb, and Zn in potato, cassava, OFSP, and PFSP all fell within the provisional maximum tolerable daily intake (PMTDI) limits outlined by FAO/WHO (2019).

Target hazard quotient (THQ) and health risk index (HRI)

The THQ associated with the intake of heavy metals from potatoes showed a descending order of

Table 2. Comparison of heavy metals between four types of tuber crops (n = 40).

Variable	Tuber crop	Median (IQR)	X^2 statistic (df)[a]	*p*-value[a]
Cadmium (Cd)	Potato	0.925 (0.47)	4.396 (3)	0.222
	Cassava	0.940 (0.15)		
	OFSP	0.890 (0.39)		
	PFSP	0.925 (0.27)		
Chromium (Cr)	Potato	0.975 (2.96)	0.309 (3)	0.958
	Cassava	0.670 (1.84)		
	OFSP	0.700 (3.11)		
	PFSP	0.780 (3.11)		
Copper (Cu)	Potato	0.155 (2.33)	29.021 (3)	< 0.05*
	Cassava	0.350 (0.94)		
	OFSP	1.840 (1.85)		
	PFSP	1.590 (2.50)		
Lead (Pb)	Potato	0.155 (8.52)	4.082 (3)	0.253
	Cassava	1.495 (2.53)		
	OFSP	- 0.200 (8.23)		
	PFSP	1.375 (7.80)		
Zinc (Zn)	potato	1.450 (0.59)	22.255 (3)	< 0.05*
	cassava	1.580 (0.92)		
	OFSP	1.255 (0.48)		
	PFSP	1.050 (0.40)		

[a]Kruskal-Wallis Test; *p-value is significant at 0.05. IQR: Interquartile range; df: degrees of freedom; OFSP: Orange-fleshed sweet potatoes; and PFSP: purple-fleshed sweet potatoes.

Table 3. Estimated daily intake (EDI) due to adult consumption of four types of tuber crops.

Tuber crop	EDI (mg/person/day)				
	Cadmium (Cd)	Chromium (Cr)	Copper (Cu)	Lead (Pb)	Zinc (Zn)
Potato	5.55×10^{-6}	5.67×10^{-6}	9.31×10^{-7}	ND	9.92×10^{-6}
Cassava	6.04×10^{-6}	5.43×10^{-6}	2.14×10^{-6}	2.61×10^{-6}	1.08×10^{-5}
OFSP	5.09×10^{-6}	1.67×10^{-5}	1.31×10^{-5}	ND	8.15×10^{-6}
PFSP	5.81×10^{-6}	5.15×10^{-6}	9.18×10^{-6}	ND	6.87×10^{-6}
PMTDI	2.00×10^{-1}	1.00×10^{-1}	5.00×10^{-1}	3.00×10^{-1}	3.00×10^{-1}

ND: not detectable; OFSP: orange-fleshed sweet potatoes; PFSP: purple-fleshed sweet potatoes; and PMTDI: Provisional Maximum Tolerable Daily Intake (FAO/WHO, 2019).

Cd > Cr > Zn > Cu. Similarly, the THQ in cassava intake showed a comparable trend with Cd > Cr > Pb > Zn > Cu. In the case of OFSP, the THQ of heavy metals showed the order of Cr > Cd > Cu > Zn. Conversely, PFSP showed the order of Cd > Cr > Cu > Zn (Table 4). The highest THQ value was observed for Cd in cassava. However, it remained below the established safe threshold of 1. Even though the THQ for Cd in cassava was higher, it did not surpass the established safe threshold of 1. The THQ values for all investigated heavy metals in potato, cassava, OFSP, and PFSP were consistently below 1. This indicated that consuming vegetables in these regions will unlikely cause significant non-carcinogenic effects on humans. The HRI, which represents the cumulative impact of various heavy metals in consuming potato, cassava, OFSP, and PFSP, was also below the safe limit of 1. This indicated that the intake of these vegetables does not pose significant risks in the specified study area.

Discussion

Heavy metals are poisonous; however, their harmful consequences are only evident with prolonged eating of contaminated foods. Long-term

Table 4. Target hazard quotient (THQ) and health risk index (HRI) of heavy metals in four types of tuber crops.

Type	THQ					HRI
	Cadmium (Cd)	Chromium (Cr)	Copper (Cu)	Lead (Pb)	Zinc (Zn)	
Potato	5.60×10^{-3}	1.90×10^{-3}	2.33×10^{-6}	NA	3.31×10^{-5}	7.50×10^{-3}
Cassava	6.00×10^{-3}	1.80×10^{-3}	5.35×10^{-6}	7.00×10^{-4}	3.61×10^{-5}	8.60×10^{-3}
OFSP	5.10×10^{-3}	5.60×10^{-3}	3.27×10^{-5}	NA	2.72×10^{-5}	1.07×10^{-2}
PFSP	5.80×10^{-3}	1.70×10^{-3}	2.29×10^{-5}	NA	2.29×10^{-5}	7.60×10^{-3}

NA: not available; OFSP: orange-fleshed sweet potatoes; and PFSP: purple-fleshed sweet potatoes.

exposure to hazardous heavy metals from eating vegetables can lead to noticeable effects in humans over time (Ikeda *et al*., 2000). Furthermore, reports indicate that ingesting food contaminated with heavy metals might considerably diminish vital bodily nutrients. The decrease in nutrient levels frequently leads to stunted growth, weakened immune system, impairments, and a significant occurrence of upper gastrointestinal cancer rates (Sultana *et al*., 2022). In the present work, the EDI of heavy metals was computed based on the levels of every heavy metal found in the samples. The average EDI values and the PMTDI of the heavy metals examined through the consumption of the tubers under investigation are reported in Table 3. Fortunately, the EDI values of the heavy metals found in the tuber crops tested were below the PMTDI. Hence, it can be confidently inferred that there is no health hazard for individuals who consume these tuber crops in these areas. The heavy metal concentrations in many tuber crops are crucial trace elements humans require for vital metabolic activities. As long as the intake remains within the allowed limits, these concentrations do not pose a hazard. The highest contribution of different heavy metals to the EDI was reported through the consumption of cassava (Cd), OFSP (Cr), OFSP (Cu), cassava (Pb), and cassava (Zn). This indicated that the transportation of heavy metals *via* cassava and OFSP was more likely than that of potato and PFSP. A study conducted in Bangladesh has documented the daily ingestion of heavy metals resulting from the ingestion of five distinct tuber crops. According to Sultana *et al*. (2022), the study found that the average daily intake of Cd, Cr, Cu, Pb, and Zn from consuming vegetables was estimated to be 0.0032, 0.0672, 0.1275, 0.0047, and 4.1152 mg/person day, respectively. A separate investigation determined that the daily consumption of tuber types resulted in estimated intakes of Cd, Pb, and Zn at levels of 2.65×10^{-5}, 2.46×10^{-4}, and 1.10×10^{-2} mg/kg/day, respectively (Orellana *et al.,* 2020).

Assessing health hazards related to ingesting heavy metals through food consumption commonly employs the THQ and HI. The THQ is a valuable parameter for assessing the risk of consuming food crops contaminated with metals (Zhuang *et al*., 2009). The HRI is calculated by summing the hazard quotients when multiple heavy metals are present (Sultana *et al*., 2022). If the THQ and HRI values are above 1, this suggests a potential health risk for individuals consuming these veggies. The THQ score for every heavy metal detected in all tuber crops in the present work was below 1 (Table 4). Most tuber crops did not surpass the acceptable HI value of all the samples examined. All four tuber crops had HI values less than or equal to 1. The HI values of the vegetable samples exhibited a descending sequence: cassava > orange-fleshed sweet potato > purple-fleshed sweet potato > potato. The HI value for cassava intake was 0.0086, the highest among the tuber crops, while the lowest HI value of 0.0047 was observed for potato intake (Table 4).

The present work revealed that cassava and OFSP had more health hazards than potato and PFSP. The levels of heavy metals in cassava and OFSP, as well as the mean daily intake, THQ, and risk index resulting from eating, were more significant than those of potato and PFSP. PFSP had lower levels of heavy metals than OFSP, owing to their high anthocyanin content. Purple pigments called anthocyanins have antioxidant qualities, and may attach to heavy metals like Cd and Pb. Various cultivars of sweet potatoes exhibit varying abilities to absorb and endure heavy metals. Specific cultivars may exhibit reduced levels of metallic elements in their tuber crops due to their genetic composition and capacity to acclimatise to soils with high heavy metal contents (Luis *et al*., 2014). Certain plant species possess the capacity to amass heavy metals in their tissues, a phenomenon referred to as bioaccumulation (Bedoya-Perales *et al.,* 2023). Potatoes with purple flesh may have a reduced ability to accumulate substances in their bodies, thus resulting in lower levels of toxic chemicals in their edible parts. The potato exhibited low concentrations of all the analysed heavy metals. The low readings could have been due to the soil's characteristics, which resulted in the crop's limited capacity to absorb these heavy metals (Luis *et al.,* 2014). According to reports, potatoes have a lower content of all heavy metals that fall below the permissible levels for human absorption (Setiyo *et al*., 2020). The metal analysis results (Cd, Cr, Cu, Pb, and Zn) in the crop samples indicated that the potato sample from the wet market in Kuala Selangor was unlikely to have accumulated heavy metals or be contaminated with heavy metals to a harmful extent.

Phytoremediation, soil composition, and agricultural practices contribute to the high concentration of heavy metals in cassava and OFSP. Phytoremediation, which involves using plants to extract heavy metals from polluted soil, can increase concentrations in tuber crops. This phenomenon is attributed to the specific plant's ability to absorb and store heavy metals within the soil (Manwani *et al*., 2022; Sharma *et al.,* 2023). Plant growth stage, species variation, elemental absorption, and degree of tolerance to various pollutants are some elements that can affect the bioaccumulation of heavy metals in plants. Although certain plants can accumulate heavy metals for phytoremediation, excessive accumulation can adversely affect the plants and the ecosystem in which they are located (Hasan *et al*., 2019). The levels of heavy metals in sweet potatoes, potatoes, and cassava might fluctuate based on the specific soil attributes in the area. Soil parameters such as pH, nutrient content, and heavy metal presence can impact the absorption of metals by plants (Melnikov *et al*., 2016). Agricultural practices, including using fertilisers, pesticides, and other methods, can also influence the levels of heavy metals in plants. These activities can result in elevated levels of metallic elements in the soil, which plants can absorb and accumulate in their edible portions (Setiyo *et al*., 2020).

The comparison of heavy metal concentrations in tuber crops with international regulatory limits, such as those set by FAO/WHO, highlights the safety of these food products within the studied region. Similarly, a study conducted in Nigeria by Akinyele and Shokunbi (2015) reported that heavy metal levels in tuber crop samples were within the permitted limits, like those observed in the present work. However, variations in heavy metal accumulation among different crop species suggested that global disparities in agricultural practices, industrial pollution, and soil characteristics may lead to differing contamination levels worldwide. Previous studies have reported higher concentrations of Pb and Cd in tuber crops from regions with extensive industrial activities (Briffa *et al*., 2020), underscoring the need for stricter monitoring in such areas. Although tuber crops are not considered staple foods in Malaysia, their increasing use in traditional and modern snacks and desserts, has increased dietary exposure among Malaysian consumers (Tan and Zaharah, 2015). While the heavy metal content of tuber crops varies by region, their consumption may pose significant health risks in areas where they constitute a major diet component. Therefore, in regions with high tuber crop consumption, greater attention should be given to monitoring and mitigating potential health risks associated with heavy metal accumulation in these crops.

Conclusion

Heavy metal levels in tuber crops were affected by soil properties, growing conditions, and farming techniques. Purple-fleshed potatoes often contain fewer heavy metals due to their genetic composition and reduced ability to accumulate them. Potatoes usually exhibit low amounts of heavy metals likely due to soil characteristics and restricted metal uptake. Cassava and orange-fleshed sweet potatoes typically contain elevated levels of heavy metals due to variables such as phytoremediation and farming techniques. Environmental factors such as temperature and soil quality can alter metal concentrations in plants, impacting their toxicity and accumulation. Tuber crop samples contained cadmium, chromium, lead, copper, and zinc; some even surpassed the guideline thresholds. Although certain metals are necessary in small amounts, it is essential to monitor their levels to prevent potential health hazards. The risk assessment concluded that eating tuber crops would be mostly safe. Still, to avoid possible health issues, continuous monitoring of soil and crops is essential, especially for cassava and orange-fleshed sweet potatoes.

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References

Akinyele, I. O. and Shokunbi, O. S. 2015. Concentrations of Mn, Fe, Cu, Zn, Cr, Cd, Pb, Ni in selected Nigerian tubers, legumes and cereals and estimates of the adult daily intakes. Food Chemistry 173: 702-708.

Antoine, J. M. R., Fung, L. A. H. and Grant, C. N. 2017. Assessment of the potential health risks associated with the aluminium, arsenic, cadmium and lead content in selected fruits and vegetables grown in Jamaica. Toxicology Reports 4: 181-187.

Anwar, S., Nawaz, M. F., Gul, S., Rizwan, M., Ali, S. and Kareem, A. 2016. Uptake and distribution of minerals and heavy metals in commonly grown leafy vegetable species irrigated with sewage water. Environmental Monitoring and Assessment 188(9): 541.

Balali-Mood, M., Naseri, K., Tahergorabi, Z., Khazdair, M. R. and Sadeghi, M. 2021. Toxic mechanisms of five heavy metals: Mercury, lead, chromium, cadmium, and arsenic. Frontiers In Pharmacology 12: 643972.

Bedoya-Perales, N. S., Maus, D., Neimaier, A., Escobedo-Pacheco, E. and Pumi, G. 2023. Assessment of the variation of heavy metals and pesticide residues in native and modern potato (*Solanum tuberosum* L.) cultivars grown at different altitudes in a typical mining region in Peru. Toxicology Reports 11 23-34.

Briffa, J., Sinagra, E. and Blundell, R. 2020. Heavy metal pollution in the environment and their toxicological effects on humans. Heliyon 6(9): e04691.

Food and Agriculture Organization / World Health Organization (FAO/WHO). 2019. General standard for contaminants and toxins in food and feed. Italy: FAO/WHO.

Food and Agriculture Organization / World Health Organization (FAO/WHO). 2001. Food additives and contaminants. Italy: FAO/WHO.

Gupta, N., Yadav, K. K., Kumar, V., Prasad, S., Cabral-Pinto, M., Jeon, B. H., ... and Alsukaibia, A. K. D. 2022. Investigation of heavy metal accumulation in vegetables and health risk to humans from their consumption. Frontiers in Environmental Science 10: 791052.

Hasan, M. M., Uddin, M. N., Ara-Sharmeen, I. F., Alharby, H., Alzahrani, Y., Hakeem, K. R. and Zhang, L. 2019. Assisting phytoremediation of heavy metals using chemical amendments. Plants 8(9): 295.

Huang, F., Zhou, H., Gu, J., Liu, C., Yang, W., Liao, B. and Zhou, H. 2020. Differences in absorption of cadmium and lead among fourteen sweet potato cultivars and health risk assessment. Ecotoxicology and Environmental Safety 203: 111012.

Ikeda, M., Zhang, Z. W., Shimbo, S., Watanabe, T., Nakatsuka, H., Moon, C. S., ... and Higashikawa, K. 2000. Urban population exposure to lead and cadmium in east and south-east Asia. Science of the Total Environment 249(1): 373-384.

Jaishankar, M., Tseten, T., Anbalagan, N., Mathew, B. B. and Beeregowda, K. N. 2014. Toxicity, mechanism, and health effects of some heavy metals. Interdisciplinary Toxicology 7(2): 60-72.

Lat, D. C., Yusof, D. A. M., Yasin, M. H., Noor, S. N. A. M., Rahman, N. S. A. and Razali, R. 2023. Effect of soil contamination on human health and environment with preventive measures: A review. Construction 3(1): 142-151.

Luis, G., Rubio, C., Gutiérrez, A. J., González-Weller, D., Revert, C. and Hardisson, A. 2014. Evaluation of metals in several varieties of sweet potatoes (*Ipomoea batatas* L.): Comparative study. Environmental Monitoring and Assessment 186(1): 433-440.

Manwani, S., Vanisree, C. R., Jaiman, V., Awasthi, K. K., Yadav, C. S., Sankhla, M. S., … and Awasthi, G. 2022. Heavy metal contamination in vegetables and their toxic effects on human health. In Singh Meena, V., Choudhary, M., Prakash Yadav, R. and Kumari Meena, S. (eds). Sustainable Crop Production - Recent Advances, p. 181. United Kingdom: IntechOpen.

Melnikov, P., Cônsolo, F. Z., Zanoni, L. Z., da Silva, A. F., Rimoli, J. and do Nascimento, V. A. 2016. Trace elements in common potatoes, sweet potatoes, cassava, yam and taro.

International Journal of Medicinal Plants and Natural Products 2(2): 8-12.

Mohammadi, A. A., Zarei, A., Majidi, S., Ghaderpoury, A., Hashempour, Y., Saghi, M. H., ... and Ghaderpoori, M. 2019. Carcinogenic and non-carcinogenic health risk assessment of heavy metals in drinking water of Khorramabad, Iran. MethodsX 6: 1642-1651.

Mohidin, S. R. N. S. P., Moshawih, S., Hermansyah, A., Asmuni, M. I., Shafqat, N. and Ming, L. C. 2023. Cassava (*Manihot esculenta* Crantz): A systematic review for pharmacological activities, traditional uses, nutritional values, and phytochemistry. Journal of Evidence-Based Integrative Medicine 28: 2515690X231206227.

Neela, S. and Fanta, S. W. 2019. Review on nutritional composition of orange-fleshed sweet potato and its role in the management of vitamin A deficiency. Food Science and Nutrition 7(6): 1920-1945.

Okereke, J. N., Nduka, J. N., Adanma, U. A. and Ogidi, O. I. 2020. Heavy metals in cassava (*Manihot esculenta* Crantz) harvested from farmlands along highways in Owerri, Nigeria. Turkish Journal of Agriculture - Food Science and Technology 8(4): 800-806.

Orellana, E., Bastos, M. C., Cuadrado, W., Zárate, R., Sarapura, V., Yallico, L., ... and Bao, D. 2020. Heavy metals in native potato and health risk assessment in highland Andean zones of Junin, Peru. Journal of Environmental Protection 11(11): 921.

Setiyo, Y., Harsojuwono, B. A. and Gunam, I. B. W. 2020. The concentration of heavy metals in the potato tubers of the basic seed groups examined by the variation of fertilizers, pesticides and the cultivation period. AIMS Agriculture and Food 5(4): 882-895.

Sharma, J. K., Kumar, N., Singh, N. P. and Santal, A. R. 2023. Phytoremediation technologies and their mechanism for removal of heavy metal from contaminated soil: An approach for a sustainable environment. Frontiers In Plant Science 14: 1076876.

Sultana, R., Tanvir, R. U., Hussain, K. A., Chamon, A. S. and Mondol, M. N. 2022. Heavy metals in commonly consumed root and leafy vegetables in Dhaka City, Bangladesh, and assessment of associated public health risks. Environmental Systems Research, 11(1): 15.

Tan, S. L. and Zaharah, A. 2015. Tuber crops. UTAR Agriculture Science Journal 1(1): 41-48.

Taylor, C. M., Golding, J. and Emond, A. M. 2015. Adverse effects of maternal lead levels on birth outcomes in the ALSPAC study: A prospective birth cohort study. BJOG - An International Journal of Obstetrics and Gynaecology 122(3): 322-328.

United State Environmental Protection Agency (USEPA). 1989. Risk assessment guidance for superfund. Volume I: Human health evaluation manual (Part A). Retrieved on January 15, 2024 from USEPA website: https://www.epa.gov/sites/default/files/2015-09/documents/rags_a.pdf

United State Environmental Protection Agency (USEPA). 1991. Risk assessment guidance for superfund. volume I: Human health evaluation manual (Part B - Development of risk-based preliminary remediation goals). Retrieved on February 20, 2024 from USEPA website: https://www.epa.gov/risk/risk-assessment-guidance-superfund-rags-part-b

United State Environmental Protection Agency (USEPA). 2021. Regional screening levels (RSLs) - Generic tables. Retrieved on February 20, 2024 from USEPA website: https://www.epa.gov/risk/regional-screening-levels-rsls-generic-tables

Vasilachi, I. C., Stoleru, V. and Gavrilescu, M. 2023. Analysis of heavy metal impacts on cereal crop growth and development in contaminated soils. Agriculture 13(10): 1983.

Wang, Y., Su, H., Gu, Y., Song, X. and Zhao, J. 2017. Carcinogenicity of chromium and chemoprevention: A brief update. OncoTargets and Therapy 10: 4065-4079.

Wongsasuluk, P., Chotpantarat, S., Siriwong, W. and Robson, M. 2014. Heavy metal contamination and human health risk assessment in drinking water from shallow groundwater wells in an agricultural area in Ubon Ratchathani Province, Thailand. Environmental Geochemical Health 36(1): 169-182.

Zhuang, P., McBride, M. B., Xia, H., Li, N. and Li, Z. 2009. Health risk from heavy metals *via* consumption of food crops in the vicinity of Dabaoshan mine, South China. Science of Total Environment 407(5): 1551-1561.