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Assessing heavy metal contamination in leafy vegetables and associated health risks in Dhaka, Bangladesh

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Abstract

Leafy vegetables, widely consumed for their nutritional benefits, can pose significant health risks when contaminated with toxic metals, emphasizing the need to monitor and assess their safety. An atomic absorption spectrophotometer (AAS) was used to analyze the metal accumulation in leafy vegetables. The specific minerals analyzed included calcium (Ca), magnesium (Mg), zinc (Zn), manganese (Mn), and iron (Fe). Additionally, heavy metals such as copper (Cu), cadmium (Cd), lead (Pb), chromium (Cr), cobalt (Co), and nickel (Ni) were also examined. Risk factors for the human population were examined, focusing on the transfer of metals from different sources to vegetable samples. These metals were then consumed by humans through the ingestion of leafy vegetables that had accumulated them. The results of this study showed that the average concentrations detected ranged from 68.0 to 1507 mg/kg of Ca, 126.0 to 829.0 mg/kg of Mg, 4.03 to 44.0 mg/kg of Zn, 2.7 to 74.5 mg/kg of Mn, 25.0 to 154.5 mg/kg of Fe, 0.74 to 4.51 mg/kg of Cu, 0.005 to 0.22 mg/kg of Cd, 0.19 to 1.75 mg/kg of Pb, 0.43 to 4.69 mg/kg of Cr, 0.005 to 0.39 mg/kg and 0.25 to 2.21 mg/kg of Ni. The highest mean levels of minerals like Ca, Mg, Zn, Mn and Fe were detected in red amaranth, Garden purslane, Stem amaranth. The study used, estimated daily intakes (EDIs), target hazard quotient (THQ), and cancer risk (CR) assessments to assess the potential health risks of consuming contaminated vegetables. The results showed that the value of THQ was found to be larger than 1 in the cases of Pb and Mn in Stem Amaranth, indicating a significant non-carcinogenic health risk, especially due to high lead exposure exceeding the standard limit by two-fold in all fields. Furthermore, the CR values for Cd, Cr, and Ni indicated a notable carcinogenic risk in multiple cases.

Keywords Environmental contamination, Metal accumulation, Estimated daily intake, Health risks, Food systems

Introduction

The desire for a luxurious life with the new benefits of industrialization may make our daily lives more comfortable, but it has caused the environment to get worse over time. Heavy metals released by different industries are very important in this situation and pose a serious health risk to the public (Ahmed et al. 2022). The heavy metal contamination of food is one of the most crucial parts of food quality assurance since eating leafy greens that have been polluted with heavy metals may be harmful to human health (Shayne et al. 1989; Costa and Klein 2008; Monisha et al. 2014). The negative impact of heavy metal contamination on green vegetables cannot be negligible due to their importance in the human diet. In addition to being a great source of vitamins, minerals, and fiber, leafy greens also offer healthy antioxidant properties. Heavy metals, in general, are not biodegradable, have long biological half-lives, and have the potential for accumulation in different body organs,

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leading to unwanted side effects (Martin and Griswold 2009). Plants take up heavy metals by absorbing them from contaminated soils through root systems as well as from airborne deposits on the parts of the plants exposed to the air from the polluted environment.

Heavy metals and essential minerals are two distinct categories of elements, each with its own characteristics and roles in biological systems. The term heavy metal refers to a category of metallic elements with high density that can be hazardous or detrimental to living organisms at specific levels of concentration. Heavy metals such as lead, mercury, cadmium, arsenic, and chromium are examples of toxic elements (Goncalves et al. 2014). On the other hand, essential minerals are necessary nutrients for living organisms to carry out certain physiological activities. These minerals are crucial for sustaining health and facilitating vital functions in the body. Key minerals comprise calcium, magnesium, potassium, sodium, iron, zinc, and other others. Iron can be classified as both a metal and a mineral, depending on the context. In agricultural and environmental studies, iron is considered both as a nutrient essential for plant growth and as a metal that can be present in excess. Although zinc and copper are necessary minerals that play crucial roles in biological processes when consumed in moderate amounts, overexposure to these minerals can result in toxicity and negative health consequences. It is essential to maintain a balance to avoid toxicity while ensuring adequate intake of essential minerals through a well-rounded diet.

Vegetables can come into contact with heavy metals as a result of natural or human activities. Naturally occurring metals originate from crustal materials, gases, and particulate matter emitted by volcanoes and continental dust. The concentration of metals induced by the environment is generally lower compared to human activities (Ahmad and Goni 2010). Metals in vegetables mainly come from human activities such as excessive use of pesticides and fertilizers, as well as metal emissions from industrial activities. Bangladesh is a swiftly developing nation characterized by rapid industrialization and disorganized urbanization. The vegetables grown in fields near heavy metal pollution sources, such as industrial areas, may contain high concentrations of metals (Shaheen et al. 2016). Moreover, irrigation of vegetables with contaminated water may result in the contamination of vegetables with heavy metals (Das et al 2019). The uptake of heavy metals in vegetables has effect on climate, air deposition, and the concentration of heavy metals in soil, the nature of the soil used to produce the vegetables, and the maturity of the plants during harvesting (Lake et al. 1984; Scott et al. 1996).

These metals will eventually accumulate in soil and water, may be absorbed by various parts of plants, and can enter the human food chain if the plants are consumed (Laura et al. 2017). Prior research has indicated that industrial wastewaters containing heavy metals cause toxic effects on natural elements such as soil, water, and living species. Shaheen et al. (2016) found toxic heavy metals in nationally representative samples of highly consumed fruits and vegetables in Bangladesh. The study showed that metal pollution consistently exposes individuals who consume contaminated fish and vegetables, leading to both carcinogenic and non-carcinogenic effects. The study by Islam et al. (2014) estimated the concentrations of heavy metals in fish and vegetables to assess contamination levels and associated health risks. The study demonstrated that individuals who consume contaminated fish and vegetables are consistently exposed to metal pollution, resulting in both carcinogenic and non-carcinogenic effects. Researchers studied the levels of various heavy metals in fruits and leafy vegetables from particular markets in Lagos, Nigeria (Sobukola et al. 2010 and Tasrina et al. 2015). Selected fruits and vegetables from local Egyptian marketplaces were tested for lead, cadmium, copper, and zinc concentrations (Shayne et al. 1989). Demirezen and Aksoy conducted research on the levels of several heavy metals in various vegetables grown in various regions of Turkey (FAO 2006). The presence of heavy metals in vegetables grown in an industrial area in northern Greece has been examined by Fytianos et al. (HIES 2011). Findings showed that Cd and Pb were found as cancer-causing elements. The prevalence of upper gastrointestinal cancer was linked to high levels of heavy metals (Cu, Cd, and Pb) in fruits and vegetables. (Turkdogan et al. 2002). Therefore, in several nations and in various industrial settings, regulations have been established to restrict the emission of heavy metals (Mohammad et al. 2015). Due to the persistence and cumulative behavior of trace heavy metals as well as the likelihood of potential toxic effects, it is necessary to analyze food items to ensure that the levels of trace heavy metals meet the accepted international standards. This is because the consumption of leafy vegetables leads to the absorption of heavy metals in human diets. Thus, research on heavy metal concentration is crucial for agricultural goods from various parts of the world where little information is available (Zhuang et al. 2009).

Dhaka, the capital city of Bangladesh is a living place for about 160 million people. Everyday huge amount of crops and vegetable entered into Dhaka from nearby city. The surrounding area of Dhaka is a significant agricultural area in Bangladesh known for extensive crops and vegetables cultivation (Huda et al. 2024). The rapid urbanization and industrial growth in these regions may impact the quality of irrigation water, thereby affecting the safety of crops and vegetable. Consequently, a thorough assessment of heavy metal contamination in vegetable samples vicinity of Dhaka is vital. There is also limited data available regarding the heavy metal concentrations in commonly consumed fruits and vegetables in Bangladesh (Shahrukh et al. 2023). Some 90 different varieties of vegetables are grown in Bangladesh and this is one of the main dishes in the majority of people's meals (Haque et. al 2021). Therefore, there is a high risk of exposure to heavy metals from vegetable consumption. Therefore, the current study was carried out with the aim to compare and evalute the concentration of some specific minerals (Ca, Mg, Zn, Mn and Fe) and heavy metals, (Cu, Cd, Pb, Cr, Co and Ni) found in some selected leafy vegetables from this region and an assessment of the potential health hazards associated with the absorption of metals by consuming vegetables, focusing on risk indicators such as daily metal intake and non-carcinogenic risk.

Material and methods

Sample collection

A total of 16 different types leafy vegetables were purchased from several locations throughout Bangladesh, in between October, 2021 to January, 2022. The locations were selected near or close to industrial areas to study the source of contamination. The samples were collected, 1 kg for each commodity, from different districts randomly throughout the country. Only the edible portions of each leafy vegetable were included and the injured or rotten parts were removed. The English name, local name, scientific name of the collected leafy vegetables are given in Table 1.

Sample preparation and treatment

Accurately weighted 10 g of each sample with three replicates were taken and processed by the microwave digestion method for analysis for their heavy metal content. The samples were first taken in a Teflon tube then 10 ml of concentrated HNO_3 acid were added and kept it overnight for pre-digestion. Following that, a specific order was followed when inserting all of the Teflon tubes containing samples into the digesting rotor. It was then placed to a microwave for digestion. The microwave digester was operating at 800 W and 180 °C. (Thompson et al 1989). The digestion process took 30 min in total, as well as 30 min for cooling. After completing the digestion, all the sample was filtered into a 50 mL volumetric flask through Whatman No. 1 filter paper, and the volume was made up to the mark with deionized water. Then all of them were kept at room temperature, and then different elements were analyzed using a zeeman atomic absorption spectrometer (model: GTA 120-AA240Z with PSD 120 auto sampler, Varian, Australia). To analyze their moisture and ash content, samples (10 g of each) were oven-dried at 105°c for 24 h with a three replicate. The ashing process in a muffle furnace was carried out, step-by-step increasing the temperature up to 600 °C, and left the samples to ash at this temperature for 6 h (Neriman et al. 2010).

Standards

Standard solutions of the heavy metals, namely, Ca, Mg, Zn, Mn, Fe, Cu, Cd, Pb, Cr, Co and Ni, were provided by Fluka Analytical, Sigma-Aldrich (Germany). A calibration curve was created for each element by comparing the amounts of heavy metals in the samples to standard solutions obtained from CRM, Sigma-Aldrich and Fluka Analytical. The separate 1000 mg/L standards (Merck) supplied in 0.1N HNO3 were used to prepare the standards. These standard stock solutions were used to create several working standards.

Quality assurance

To ensure the reliability of the results, appropriate quality assurance procedures and precautions were taken in each analysis and handled carefully to avoid cross contamination. Analytical grade reagents were used, and glassware was properly cleaned. Deionized water was used throughout the study. For the correction of instrument reading reagent blank determination was used. Repeated analyses of the samples were conducted using the National Institute of Standard and Technology's (NIST) plant standard reference material (SRM), which was utilized to validate the analytical process. The results were found to be within 1% of the certified values.

Flame atomic absorption analysis

Heavy metals were analyzed by AAS. The Ca, Mg, Zn, Mn, Fe, Cu, Cd, Pb, Cr, Co and Ni concentrations of leafy vegetable samples were analyzed using Zeeman Atomic Absorption Spectrometer (Model: GTA 120-AA240Z with PSD 120 auto sampler, Varian, Australia). Measurements were made using standard hollow cathode lamps for Ca, Mg, Zn, Mn, Fe, Cu, Cd, Pb, Cr, Co and Ni. Table 2 provides the standard operating conditions used in our experiments for the analysis of heavy metals using atomic absorption spectrometry.

The daily intake of heavy metals through vegetables

The Estimated Daily Intake (EDI) of heavy metals were determined using their respective average concentrations in food samples by the weight of food items consumed by an individual (body weight of an adult in Bangladesh is 60 kg; FAO 2006), which was obtained from the household income and expenditure survey (HIES 2011).

Table 1 The collected leafy vegetable samples with English name, local and scientific names

English name	Local name	Scientific name	Family	Photo
Indian spinach (green)	Puishak (sabuj)	*Basella alba*	Basellacease	
Stem amaranth	Danta	*Amaranthus lividus*	Amaranthaceae	
Spinach	Palonggshak	*Spinacia oleracea*	Chenopodiaceae	
Water spinach	Kolmishak	*Ipomoea aquatica*	Convolvualceae	
Spearmint	Pudina pata	*Mentha spicata*	Lamiaceae	
Taro/Tania	Dudkachu	*Xanthosoma violaceum*	Araceae	
Fern	Dhekishak	*Dryopteris filix-mas*	Polypodiaceae	

Table 1 (continued)

English name	Local name	Scientific name	Family	Photo
Bottle gourd	Laushak	*Lagenaria siceraria*	Cucurbitaceae	
Cabbage	Bandhakopi	*Brassica oleracea* var *capitata*	Cruciferae	
Radish	Mulashak	*Raphanus sativus*	Cruciferae	
Coriander leave	Dhana pata	Coriandrum sativum	Apiaceae	
Marsh herb	Helencha	*Enhydra fluctuans*	Compositeae	
Jute leaf	Patpata	*Corchorus capsularies*	Tiliaceae	
Garden purslane	Nunia	*Portulaca oleracea*	Portulaceae	

Table 1 (continued)

English name	Local name	Scientific name	Family	Photo
Lettuce	Lettuce	*Lactuca sativa* var. *capitata*	Compositeae	
Red amaranth	Lalshak	*Amaranthus gangeticus*	Amaranthaceae	

Table 2 Standard operating conditions for elemental analysis using atomic absorption spectrometry

Heavy metals	Lamp current (mA)	Wave length (nm)	Flame	Slit width (nm)
Ca	10.00	422.70	Air-acetylene	0.50
Mg	4.00	285.20		0.50
Mn	5.00	279.50		0.20
Fe	5.00	248.30		0.20
Pb	10.00	217.00		1.00
Cu	4.00	324.80		0.50
Zn	5.00	213.90		1.00
Co	15.00	240.70		0.20
Ni	10.00	232.00		0.20
Cd	4.00	228.80		0.50
Cr	7.00	357.90		0.20

$$\mathrm{EDI} = (\mathrm{FIR} \times \mathrm{C}) / \mathrm{BW}$$

where FIR is the food ingestion rate (g/person/day), C is the metal concentration in food samples (mg/kg), and BW is the body weight.

The research region conducted a thorough survey to determine the daily consumption of leafy vegetables. In order to determine the daily intake rate of the tested veggies, a market site interview was done with 60 people between the ages of 20 and 40 who ranged in weight from 55 to 78 kg. Every participant represented a household of at least four people, hence, a minimum of 240 people were properly sampled. Using these statistics, a daily average consumption rate of each vegetable per person was computed and presented in Table 3.

Noncarcinogenic risk

THQ and total target hazard quotient (TTHQ) can be calculated as (FAO/WHO 2011)

$$\mathrm{THQ} = (\mathrm{Efr} \times \mathrm{ED} \times \mathrm{FIR} \times \mathrm{C}) / (\mathrm{RfD} \times \mathrm{BW} \times \mathrm{AT}) 10^{-3}$$

$$\mathrm{TTHQ\ (individual\ food)} = \mathrm{THQ\ metal\ 1} + \mathrm{THQ\ metal\ 2} + \cdots \mathrm{THQ\ metal\ n}$$

A hazard index (HI) has been developed based on the USEPA's Guidelines for Health Risk Assessment of Chemical Mixtures in order to evaluate the total potential for noncarcinogenic impacts from multiple heavy metals (USEPA 1989):

$$\mathrm{HI} = \sum \mathrm{TTHQ} = \mathrm{TTHQ\ food1} + \mathrm{TTHQ\ food\ 2} + \cdots + \mathrm{TTHQ\ food\ n}$$

where THQ is the target hazard quotient, Efr is the exposure frequency (365 days/year), ED is the exposure

Table 3 Daily Average consumption rate of each vegetable per person

No of people purchase	Purchase amount (g)	Total family member (No)	Average consumption (g/day/person)
9	5867	40	146.67
6	2295	17	135.00
3	1448	11	131.67
2	1050	9	116.67
1	190	5	38.05
2	712	7	101.67
2	361	5	72.28
3	1142	9	126.94
4	8500	36	236.11
4	1884	19	99.17
12	1050	42	25.00
3	660	6	110.00
2	787	6	131.11
1	378	4	94.44
1	157	3	52.22
5	3500	21	166.67

duration (70 years), FIR is the food ingestion rate (g/person/day), C is the metal concentration in foods (mg/kg), RfD is the oral reference dose (mg/kg/day), and AT is the averaging time for noncarcinogens (365 days/year × number of exposure years). The oral reference dose of Zn, Mn, Cu, Cd, Pb, Cr and Ni are 0.3, 0.14, 0.04, 0.0003, 0.0035, 1.5 and 0.02 mg/kg/day respectively (USEPA 2015). In order to determine the appropriate RfD for THQ, it is assumed that all chromium ions in the fruits and vegetables are trivalent (noncarcinogenic) and all arsenic ions are inorganic. If THQ less than one (i.e. $THQ < 1$), the exposed population is unlikely to experience obvious adverse effects. If THQ is equal or higher than one (i.e.$THQ \geq 1$), there is a potential health risk (Wang et al. 2005), and related interventions and protective measurements are needed to be taken.

Carcinogenic risk

The target CR factor (lifetime cancer risk, USEPA 1989) can be calculated as

$$CR = (Efr \times ED \times FIR \times C \times Csfo) / (BW \times AT) \times 10^{-3}$$

where CR represents the target cancer risk or the risk of cancer over a lifetime, AT is the averaging time for carcinogens (365 days/year_ED), and Csfo is the oral carcinogenic slope factor obtained from the integrated risk information system (USEPA 2015) database, which was 8.5×10^{-3} $(mg/kg/day)^{-1}$ for Pb, 13 for Cd, 0.5 for Cr (Oni et al. 2022) and 0.84 for Ni (Mohammadi et al. 2019) respectively. The slope factor of Co and Cu were not found in literature.

Results and discussion

Heavy metal content in vegetable samples

The results of the current study demonstrated that the metal content of specific green vegetables purchased from market locations in the Bangladeshi city of Dhaka contained Ca, Mg, Mn, Zn, Fe, Cu, Cd, Pb, Cr, Co, and Ni. To determine the level of food contamination, the detected quantities of Ca, Mg, Mn, Zn, Fe, Cu, Cd, Pb, Cr, Co, and Ni in leafy vegetables were compared to the safety limit established by the FAO/WHO and other reference standards. The determinations of all elemental concentrations were based on fresh sample weight. The average concentrations of metals (Ca, Mg, Mn, Zn, Fe, Cu, Cd, Pb, Cr, Co and Ni) and respective skweness values found in fresh leafy vegetables sampled from the local markets in Dhaka City, Bangladesh, are summarized in Table 4.

The heavy metal contamination in selected leafy vegetables indicate that the concentration level of Ca, Mg, Mn, Zn, Fe, Cu, Cd were obtained below the permissible limit recommended by WHO (Rahman et al 2013; Sharma et al. 2007) which were shown in the Table 4. Ca, Mg, Mn, Zn and Fe are essential elements for the human body. But the concentrations of Pb, Cr, Co and Ni in leafy vegetables were found in toxic level. The results showed that the concentration of Pb in all leafy vegetables ranged between 0.19 mg/kg in cabbage and 1.75 mg/kg in stem amaranth. The highest concentration of Pb within the selected leafy vegetable was noticed in stem amaranth followed by bottle gourd, mint, water spinach, spinach, radish, Indian spinach, taro, jute leaf, red amaranth and lettuce. The majority of selected green vegetables exceed the permitted level for Pb content in accordance with Chinese food hygiene standards (China Food Hygiene Standard 1994). Table 4 shows that, with the exception of garden purslane and cabbage, all vegetables have lead concentrations that are higher than the allowed limit, making them unfit for human consumption. Human activities such as waste water irrigation, solid waste disposal and sludge applications, solid waste combustion, agrochemicals, and vehicle exhaust are to blame for the lead content that was discovered in the green vegetables. Due to their hyper accumulative nature, leafy plants take in a significant amount of Pb from the soil and water. Vegetables cultivated in lead-contaminated soil or water can absorb the metal through their roots or by direct deposition on their surfaces. Lead, if taken in, can build up in various plant components such as leaves, stems, and fruits. Consuming vegetables tainted with lead can

Table 4 Average measured concentrations of metals (mg/kg) in selected leafy vegetables; *green cells* for values under the reference standard and *red cells* for those exceeding the standard

Sample	Ca	Mg	Zn	Mn	Fe	Cu	Cd	Pb	Cr	Co	Ni
Indian spinach	654	772	9.5	12	36	2.7	0.04	1	0.52	0.03	0.77
Stem amaranth	1420	729	44	74.5	154	2.93	0.22	1.75	0.76	0.1	0.89
Spinach	68	419	9	18.9	144	2.56	0.045	1.23	0.88	0.07	0.51
Water spinach	146	136	4.89	14.7	71.5	3.33	0.005	1.26	0.43	0.05	0.43
Mint	1110	780	11.7	19.9	109	4.51	0.005	1.27	1.75	0.07	1.72
Taro	517	379	11.2	40.5	52	2.69	0.01	0.9	1.39	0.06	0.85
Fern	129	304	9.35	3.6	22.5	3.97	0.03	0.23	0.56	0.05	0.52
Bottle gourd	497	301	9.85	16.4	50	1.55	0.08	1.63	1.12	0.39	0.61
Cabbage	529	126	15	2.75	13.9	0.49	0.005	0.19	0.9	0.005	0.25
Radish	1430	503	9	10.4	148	1.29	0.04	1.13	2.1	0.09	1.06
Coriander leave	638	231	4.03	4.88	191	0.75	0.05	0.25	2.65	0.1	0.93
Marsh herb	408	424	8.4	19.9	69	0.74	0.005	0.3	0.96	0.005	0.47
Jute leaf	1280	369	15.5	43.7	38	1.49	0.045	0.57	1.15	0.01	1.18
Garden purslane	410	829	6.15	15.9	58.5	1.92	0.015	0.2	4.69	0.09	2.21
Lettuce	500	290	192	9.5	25	1.8	0.05	0.35	0.65	0.04	0.61
Red amaranth	1507	181	7.9	8.4	67.5	2.18	0.045	0.48	1.6	0.06	0.98
Skewness	0.55	0.62	2	2.01	0.84	0.42	2.86	0.35	2.2	3.17	1.49
Standard reference			60[a]	500[b]	425[b]	40[c]	0.1[b],0.3[d]	0.3[b],0.2[e]	2.3[b]	0.05-0.1[f]	1.5[g]

[a] WHO (Codex Alimentarius Commission, 1991)

[b] WHO (Codex Alimentarius Commission, Joint FAO/WHO 2001 and Codex Alimentarius Commission 1994)

[c] WHO/FAO (FAO/WHO, codex general standard for contamination and toxin in foods, 1996)

[d] European Union (EU)

[e] China Food Hygiene Standard 1994

[f] Agency for toxic substance disease registry (ATSDR 1994)

[g] WHO/FAO (Codex Alimentarius Commission. Joint FAO/WHO, 2007) and Indian Standard Awashthi

result in lead poisoning, which can cause severe health effects, particularly in children and pregnant women.

Although plants typically have the ability to absorb significant amounts of lead without visible changes in their appearance, lead is a poisonous element that can be damaging to plants. According to Ahmad and Goni (2010), lead accumulation in many plants can reach levels that are hundreds of times higher than what is considered to be safe for humans. Both acute and chronic health effects may result from the introduction of lead into the food chain. Exposure to lead is especially detrimental to the developing brains of fetuses and young children. It may result in developmental delays, learning impairments, reduced IQ, and behavioral issues. Exposure to lead has been associated with hypertension, cardiovascular disease, and an elevated likelihood of stroke. Lead can result in kidney damage and hinder kidney function, ultimately causing kidney disease. Lead exposure can impact the reproductive health of both males and females, leading to issues with fertility and an increased risk of miscarriages (Machate 2023). Appetite loss, headaches, high blood pressure, abdominal pain, kidney malfunction, exhaustion, insomnia, arthritis, hallucinations, and vertigo are among potential effects of acute exposure. Chronic lead exposure may cause death as well as mental retardation, birth defects, psychosis, autism, allergies, dyslexia, weight loss, hyperactivity, paralysis, muscle weakness, and kidney damage for children (WHO 2023, Jaishankar et al. 2014; Jayamurali et al. 2021).

Research on Cr accumulation in vegetables has therefore become more important. The Cr content ranged from 0.43 mg/kg in water spinach to 4.69 mg/kg in Garden purslane in the selected leafy vegetable. The level of Cr concentration in garden purslane and coriander leaves is higher than the WHO permissible limit (Machate 2023). Among the selected leafy vegetables radish, red amaranth, and mint contained alarmingly high levels of Cr. According to recent studies, Cr is also necessary for humans at low concentrations. For some degree of exposure to hexavalent chromium compounds, the human body has effective detoxifying mechanisms in larger concentrationsSixteenth-valent chromium compounds are known to cause cancer, damage metals, make skin more sensitive over time, and their main target organ is the kidney (Calderon et al. 2023). Chromate compounds cause health problems like skin rashes, upset stomachs and ulcers, respiratory problems, weakened immune systems, liver damage, alteration of genetic material, lung cancer and can induce DNA damage (Sadee et al. 2023).

Bottle gourd (0.39 mg/kg, highest), stem amaranth and coriander leaves contain a Co concentration that exceeds the limit of the Agency for Toxic Substance Disease Registry (ATSDR 1994). As a metal component of vitamin B_{12}, cobalt serves a biologically important function, but excessive exposure to it has been linked to a number of harmful health outcomes, including neurological (such as hearing and vision impairment), cardiovascular, and endocrine deficiencies. A newly proposed bio kinetic model indicates that adverse health effects from chronic exposure to Co are unlikely to occur below 300 µg/l in healthy individuals, with hematological and endocrine dysfunctions identified as primary health endpoints. Chronic exposure to acceptable doses is not anticipated to pose considerable health hazards according to the model (Leyssens et al 2017). Ni concentration in Garden purslane (2.21 mg/kg) and mint (1.72 mg/kg) was exceeds the FAO/WHO and Indian standard (Singh et al. 2024). The most common harmful health effect of nickel in humans is an allergic skin reaction in those who are sensitive to nickel. Accumulation of nickel in the environment poses a significant risk to human health, with documented effects including skin allergies, lung fibrosis, varying degrees of kidney and cardiovascular toxicity, and the promotion of neoplastic transformation (Genchi et al 2020). The concentration level of Cd in all selected leafy vegetables were found lower than the safety limit of the WHO and the European Union. Although Ca, Mg, Mn, Zn, Fe, and Cu are also necessary for plants and animals, only a slight increase in their concentration can interfere with physiological functions. The concentration level of Ca, Mg, Mn, Zn, Fe, Cu in this study were found blow the all safety limit. Cu acts as a biocatalyst, and it is necessary the body pigmentation and to maintain a healthy central nervous system. Moreover, it is crucial for the prevention of anemia and interacts with Zn and Fe metabolism in the body (Hassan et al. 2024). Skewness values falling between − 1 and − 0.5 (indicating negative skewness) or between 0.5 and 1 (indicating positive skewness) suggest data distributions that are slightly skewed. Data exhibiting skewness values below − 1 (indicating negative skewness) or above 1 (indicating positive skewness) are classified as highly skewed.

Physico-chemical characteristics vegetable samples

The moisture content of the leafy vegetables in this study ranged between 82 and 94% (Fig. 1). Among the analyzed green leafy vegetables, Garden purslane had the maximum amount of moisture, whereas Mint had the least. When the ash content of the GLV was considered, the maximum amounts were found in Amaranths. In the other leafy vegetables, it was found to be in the range of 0.6–2.8 g/100 g in fresh vegetables (Fig. 1). The effect of dehydration on the retention of iron and calcium was studied. The average calcium content was determined to be 6.32 3.63 mgdm^{-3}, which is less than the WHO reported maximum acceptable limit of 7.5 mgdm^{-3} (1985). Due to its importance for human bone growth and maintenance as well as for lowering blood cholesterol levels, calcium is not known to be harmful. The mean iron concentration was found to be 1.50 0.49 in the

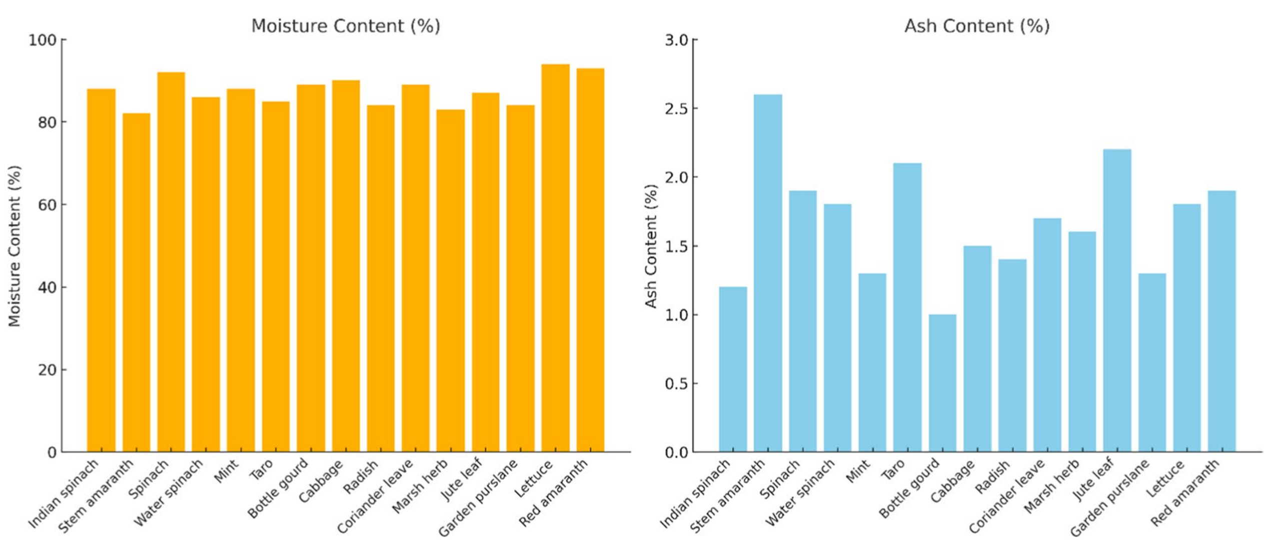

Fig. 1 The Moisture and the ash content of selected leafy vegetables (%)

samples examined, but it was higher than the maximum permissible concentration of 0.30 $mgdm^{-3}$ (WHO 1996), which may be related to a number of factors, including climate, atmospheric deposition, the type of soil the plant is grown in, and irrigation with waste water (Anyawu 2004).

The higher levels of heavy metal contamination detected in some leafy vegetables may be directly related to pesticides, irrigation water pollutants, and farm soil pollutants. Various industries, road traffic, municipal, and industrial sewage are significant contributors to heavy metal pollution in the environment. Moreover, the mineral composition of vegetables is influenced by multiple factors, including the natural presence of trace elements in the environment, the levels of these elements in mineral fertilizers, and the quantities of fertilizers applied (Zwolak et al. 2019).

Table 5 compares the metal concentration of leafy vegetables in some different regions of the world. The concentration of Pb in Stem amaranth was found to be much greater than that found in Turkey, India, and China. In contrast, it was discovered that the Pb concentration in potatoes was lower than that in Bangladesh's industrial area with arsenic contamination (Haque et al. 2021).

Health risk assessment

EDI of heavy metal

The EDI of metals (Ca, Mg, Zn, Mn, Fe, Cu, Cd, Pb, Cr, Co and Ni) was calculated according to the mean concentration of each metal in each food and the respective consumption rates. Table 6 shows the EDI and maximum tolerated daily intake (MTDI) of the examined metals from vegetable consumption. Total daily intake of Ca, Mg, Zn, Mn, Fe, Cu, Cd, Pb, Cr, Co and Ni were 1.49×10^{-1}–4.18×100, 9.62×10^{-2}–1.88×100, 1.7×10^{-3}–9.99×10^{-2}, 2.0×10^{-3}–1.67×10^{-1}, 2.17×10^{-2}–3.47×10^{-1}, 3.12×10^{-5}–6.59×10^{-3}, 3.17×10^{-6}–5.0×10^{-4}, 1.0×10^{-4}–3.9×10^{-3}, 6.0×10^{-4}–7.4×10^{-3}, 9.0×10^{-6}–8.0×10^{-4}, 5.0×10^{-4}–3.5×10^{-3} mg/day, respectively. Daily intakes of all the metals were less than the MTDI.

THQ of heavy metal

The THQ is a way to figure out how dangerous certain contaminants in food might be to your health. It is used in risk assessment. As long as the THQ for a metal is higher than 1, it suggests that the intake of that metal from the food poses a potential health risk to individuals. Notably, none of the foods' individual THQs for the metals Zn, Cu, Cd, Cr, and Ni are greater than 1. (Table 7). This shows that eating the foods tested in and of themselves has no unreasonable risk of having non-carcinogenic health impacts. The value of THQ was found to be greater than 1 in the cases of Pb and Mn in Stem Amaranth. A THQ greater than 1 does not indicate a statistical likelihood that negative non-carcinogenic health effects may materialize (Antoine et al. 2017).

THQ levels for zinc range from 0.031721 in water spinach to 0.330264 in stem amaranth (Table 7). It is noteworthy that stem amaranth has a higher zinc level than other foodstuffs, as evidenced. In fact, stem amaranth contributes more than 26% of the THQ of all foods for Zn (Fig. 2). By comparison, cabbage, bottle gourd, Indian spinach and radish only account for a cumulative 30% of the THQ. Altogether, four crops account for 56% of the THQ (Fig. 2). According to an analysis of the individual contributions made by each food crop, stem amaranth contributes roughly 28% manganese to the THQ with a contribution from jute leaf, taro, spinach and marsh herb of 16%, 11%, 7% and 6%, respectively. These five crops together account for 68% of the THQ for manganese (Fig. 2). Cadmium exhibits a little more even distribution than the preceding elements. Stem amaranth contributes 37% of the total THQ, followed by Indian spinach (7%), bottle gourd

Table 5 Comparison with other reports of metal concentrations (mg/kg fw) in different types of vegetables of the present study in Bangladesh and other country

District (Country)	Sampling site description	Zn mg/kg	Cu mg/kg	Cd mg/kg	Pb mg/kg	Cr mg/kg	Ni mg/kg	References
Dhaka, Bangladesh	City bazar	4.03–19.2	0.49–2.18	0.005–0.22	0.19–1.75	0.43–2.65	0.25–2.21	This study
Dhaka (Bangladesh)	Industrial area	16.3–119	8.30–4.3	0.009–1.05	0.06–3.45	0.61–3.04	1.61–11.7	Haque et al. (2021)
Dhaka (Bangladesh)	Industrial area	NA	3.85	0.62	3.89	1.66	2.97	Ahmad and Goni (2010)
Noakhali (Bangladesh)	Arsenic contaminate area	NA	2.10–86.3	0.006–0.265	0.67–16.5	0.18–1.91	0.32–4.67	Rahman, et al. (2013)
Dabaoshan (China)	Near mine area	2.34–40.2	0.28–3.61	0.001–0.71	0.01–0.39	NA	NA	Zhuang et al. (2009)
Varanasi (India)	Urban area	NA	20.5–71.2	1.1–4.5	0.9–2.2	NA	NA	Sharma et al. (2007)
Manisa, (Turkey)	local retailers	5.11	2.12	0.07	0.108	NA	NA	Bagdatlioglu et.at (2010)

mg/kg fw: miligram per kilogram fresh vegetable weight; NA: Not available

Table 6 Comparison of the EDI of heavy metals from highly consumed leafy vegetable samples with the corresponding maximum tolerable daily intake (MTDI) in the Bangladeshi population, *green cells* for values under the reference standard and *red cells* for those exceeding the standard

Sample	Consumption Rate (g/day/person)	Ca	Mg	Zn	Mn	Fe	Cu	Cd	Pb	Cr	Co	Ni
Indian spinach	146.67	1.59E+00	1.88E+00	2.32E-02	2.94E-02	8.80E-02	6.59E-03	9.77E-05	2.40E-03	1.30E-03	7.33E-05	1.90E-03
Stem amaranth	135	3.19E+00	1.63E+00	9.90E-02	1.67E-01	3.47E-01	6.50E-03	5.00E-04	3.90E-03	1.70E-03	2.00E-04	2.00E-03
Spinach	131.67	1.49E-01	9.20E-01	1.97E-02	4.15E-02	3.15E-01	5.60E-03	9.87E-05	2.70E-03	1.90E-03	2.00E-04	1.10E-03
Water spinach	116.67	2.80E-01	3.11E-01	9.50E-03	2.85E-02	1.39E-01	6.40E-03	9.72E-06	2.40E-03	8.00E-04	9.71E-05	8.00E-04
Mint	38.05	7.06E-01	4.94E-01	7.40E-03	1.26E-02	6.91E-02	2.80E-03	3.17E-06	8.00E-04	1.10E-03	4.44E-05	1.10E-03
Taro	101.67	8.76E-01	6.42E-01	1.90E-02	6.86E-02	8.81E-02	4.50E-03	1.69E-05	1.50E-03	2.40E-03	1.00E-04	1.40E-03
Fern	72.28	1.55E-01	3.66E-01	1.13E-02	4.30E-03	2.71E-02	4.70E-03	3.61E-05	3.00E-04	7.00E-04	6.02E-05	6.00E-04
Bottle gourd	126.94	1.05E+00	6.37E-01	2.08E-02	3.46E-02	1.05E-01	3.20E-03	2.00E-04	3.40E-03	2.40E-03	8.00E-04	1.30E-03
Cabbage	236.11	2.08E+00	4.95E-01	5.90E-02	1.08E-02	5.49E-02	1.90E-03	1.97E-05	7.00E-04	3.50E-03	1.97E-05	1.00E-03
Radish	99.17	2.36E+00	8.32E-01	1.48E-02	1.72E-02	2.43E-01	2.10E-03	6.61E-05	1.90E-03	3.50E-03	1.00E-04	1.80E-03
Coriander leave	25	2.65E-01	9.62E-02	1.70E-03	2.00E-03	7.96E-02	3.12E-05	2.00E-05	1.00E-04	1.10E-03	4.00E-05	4.00E-04
Marsh herb	110	7.48E-01	7.77E-01	1.54E-02	3.65E-02	1.26E-01	1.35E-03	9.00E-06	6.00E-04	1.80E-03	9.00E-06	9.00E-04
Jute leaf	131.11	2.80E+00	8.09E-01	3.39E-02	9.53E-02	8.30E-02	3.20E-03	9.89E-05	1.20E-03	2.50E-03	2.18E-05	2.60E-03
Garden purslane	94.44	6.45E-01	1.30E+00	9.70E-03	2.51E-02	9.20E-02	3.02E-03	2.30E-05	3.00E-04	7.40E-03	1.00E-04	3.50E-03
Lettuce	52.22	4.35E-01	2.52E-01	1.67E-02	8.30E-03	2.71E-02	1.56E-03	4.35E-05	3.00E-04	6.00E-04	3.48E-05	5.00E-04
Red amaranth	166.67	4.18E+00	5.02E-01	2.19E-02	2.33E-02	1.87E-01	6.05E-03	1.00E-04	1.30E-03	4.40E-03	2.00E-04	2.70E-03
MTDI		1000[e]	420[e]	60[b]	11[c]	0.8[d]	30[c]	0.046[c]	0.2 1[c]	0.2[a]	2.5[f]	0.3[b]

MTDI: Maximum tolerable daily intake

[a] RDA 1989

[b] WHO 1996

[c] JECFA 2003, 2023

[d] Evaluations of the Joint FAO/WHO Expert Committee on Food Additives (JECFA),

[e] U.S. Department of Health and Human service, [f] Food and Drug Administration (FDA) USA

Table 7 Estimation of THQ and total TTHQ of heavy metals from highly consumed leafy vegetables of Dhaka City, Bangladesh

Sample name	THQ							TTHQ
	Zn	Mn	Cu	Cd	Pb	Cr	Ni	
Indian spinach	7.75×10^{-2}	2.1×10^{-1}	1.65×10^{-1}	3.26×10^{-2}	6.98×10^{-1}	8.47×10^{-4}	9.41×10^{-2}	1.28×10^{0}
Stem amaranth	3.3×10^{-1}	1.19×10^{0}	1.64×10^{-1}	1.65×10^{-1}	1.13×10^{0}	1.14×10^{-3}	1.0×10^{-1}	3.09×10^{0}
Spinach	6.56×10^{-2}	2.96×10^{-1}	1.40×10^{-1}	3.29×10^{-2}	7.71×10^{-1}	1.29×10^{-3}	5.6×10^{-2}	1.36×10^{0}
Water spinach	3.12×10^{-2}	2.33×10^{-1}	1.62×10^{-1}	03.24×10^{-3}	7.0×10^{-1}	5.57×10^{-4}	4.18×10^{-2}	1.42×10^{0}
Mint	4.48×10^{-2}	9.03×10^{-2}	7.11×10^{-2}	1.06×10^{-3}	2.30×10^{-1}	7.39×10^{-4}	5.45×10^{-2}	4.73×10^{-1}
Taro	6.33×10^{-2}	4.9×10^{-1}	1.13×10^{-1}	5.65×10^{-3}	4.36×10^{-1}	1.57×10^{-3}	7.20×10^{-2}	1.18×10^{0}
Fern	3.76×10^{-2}	3.1×10^{-2}	1.19×10^{-1}	1.2×10^{-2}	7.61×10^{-2}	4.49×10^{-4}	3.13×10^{-2}	3.11×10^{-1}
Bottle gourd	6.95×10^{-2}	2.7×10^{-1}	8.2×10^{-2}	5.64×10^{-2}	9.85×10^{-1}	1.58×10^{-3}	6.45×10^{-2}	1.5×10^{0}
Cabbage	1.97×10^{-1}	7.73×10^{-2}	4.82×10^{-2}	6.56×10^{-3}	2.14×10^{-1}	2.36×10^{-3}	4.92×10^{-2}	5.94×10^{-1}
Radish	4.96×10^{-2}	1.23×10^{-1}	5.33×10^{-2}	2.20×10^{-2}	5.34×10^{-1}	2.31×10^{-3}	8.76×10^{-2}	8.72×10^{-1}
Coriander leave	5.6×10^{-3}	1.45×10^{-2}	7.81×10^{-3}	6.95×10^{-3}	2.97×10^{-2}	7.35×10^{-4}	1.94×10^{-2}	8.74×10^{-2}
Marsh herb	5.14×10^{-2}	2.6×10^{-1}	3.41×10^{-2}	3.06×10^{-3}	1.57×10^{-1}	1.17×10^{-3}	4.31×10^{-2}	5.50×10^{-1}
Jute leaf	1.13×10^{-1}	6.81×10^{-1}	8.14×10^{-2}	3.28×10^{-2}	3.56×10^{-1}	1.67×10^{-3}	1.23×10^{-1}	1.39×10^{0}
Garden purslane	3.23×10^{-2}	1.79×10^{-1}	7.56×10^{-2}	7.87×10^{-3}	8.94×10^{-2}	4.91×10^{-3}	1.74×10^{-1}	6.64×10^{-1}
Lettuce	5.56×10^{-2}	5.09×10^{-2}	3.92×10^{-2}	1.45×10^{-2}	8.7×10^{-2}	3.77×10^{-4}	2.65×10^{-2}	2.82×10^{-1}
Red amaranth	7.32×10^{-2}	1.67×10^{-1}	1.51×10^{-1}	4.17×10^{-2}	3.81×10^{-1}	2.96×10^{-3}	1.36×10^{-1}	9.53×10^{-1}
TTHQ	1.28×10^{0}	4.33×10^{0}	1.51×10^{0}	4.44×10^{-1}	6.87×10^{0}	2.45×10^{-2}	1.18×10^{0}	

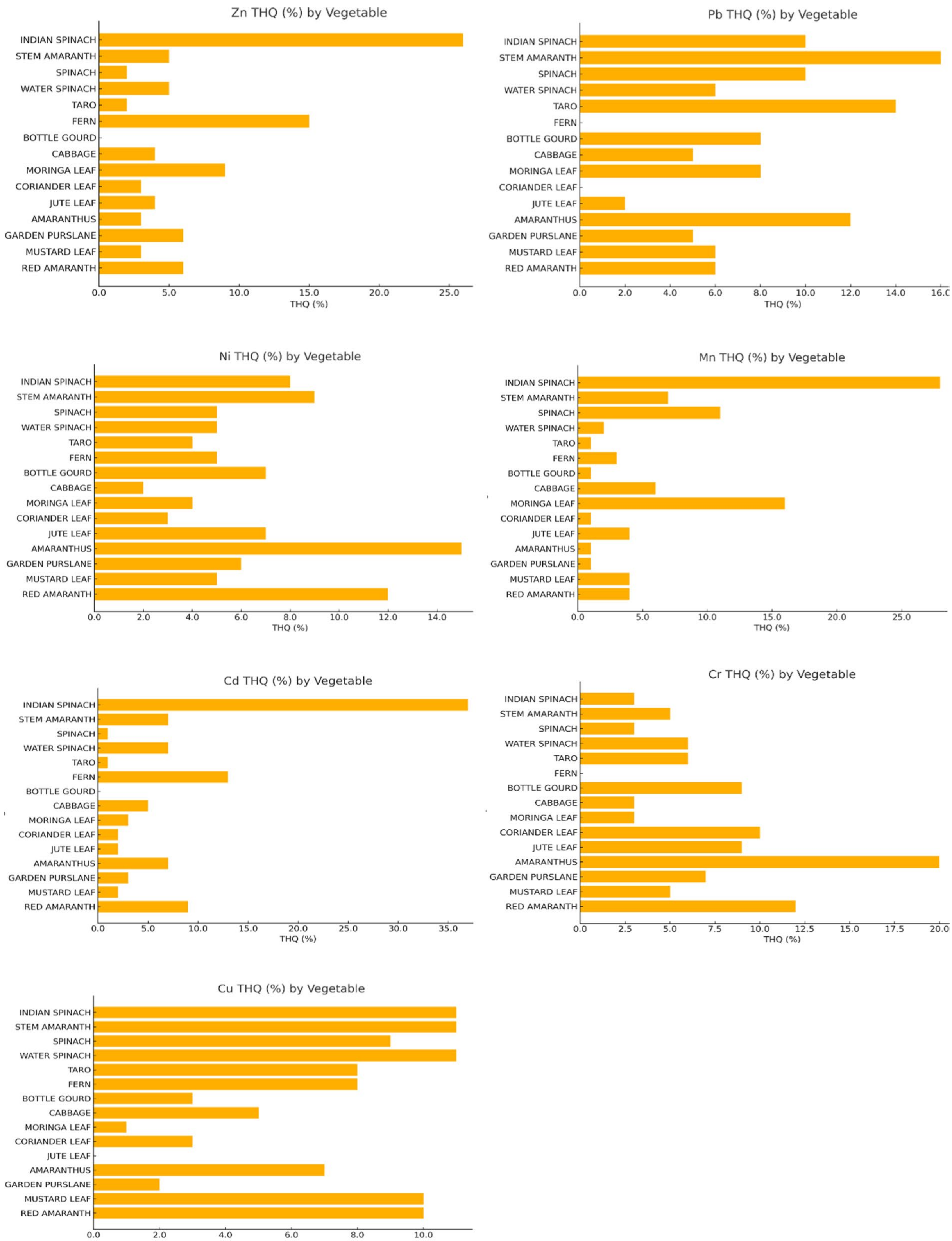

Fig. 2 Percentage contribution of each foodstuff to the THQ of Zn, Pb, Ni, Mn, Cd, Cr and Cu

(13%), spinach (7%), fern (3%), and taro (1%). Still, 68% of the THQ comes from just six food crops. The leafy vegetables stem amaranth, Indian spinach and spinach account for 14% each of the THQ for cadmium with 1% cabbage and 13% bottle gourd. In the case of lead, steam amaranth content accounted for 16% of the total THQ followed by Indian spinach (10%), bottle gourd (14%), Taro (6%) and cabbage (3%). The estimated consumption patterns of THQ indicate Chromium contributing garden purslan (20%), red amaranth (12%), 6% bottle gourd, 9% radish, 5% marsh herb and 10% cabbage. Almost all leafy vegetables contain a close amount (garden purslan 15%, red amaranth 12%, steam amaranth 9%, Indian spinach 8%, spinach 5%, marsh herb 4%, taro 6%, mint 5% and bottle gourd 5%) of THQ in the case of Ni. Authorities may also establish monitoring programs to evaluate the concentrations of these metals in foods and inform the public about potential health hazards linked to their intake. This may include recommending specific groups, such as pregnant women or children, reduce their consumption of foods containing high levels of these metals.

Estimation of the CR for Pb and relative risk

The cancer risk value is a crucial parameter in assessing environmental and health risks since it quantifies the probability of an individual developing cancer due to exposure to specific substances. The cancer risk factors for Pb, Cd, Cr, and Ni from the consumption of vegetable samples over a lifetime are presented in Table 8 of the study. The tolerable threshold for lifetime carcinogenic risk, as established by the United States Environmental Protection Agency (US EPA 2023), is set at 10^{-5}. According to the study, the cancer risk linked to Pd is low for all veggies, as they fall below this level. However, various vegetable samples detected a significant cancer hazard associated with Cd, Cr, and Ni. The observation above underscores the heightened concentrations of certain metallic elements within the specimens, potentially presenting a substantial risk to human well-being. Cd, Cr and Ni are recognized for their high density and toxicity, which can result in significant health consequences, particularly when ingested over a prolonged period of time. Exposure to these metals has been associated with various health implications, such as neurological impairment, developmental challenges in children, and an elevated susceptibility to cancer.

Table 8 Estimated Cancer Risk of rice grain for analyzed metals of collected samples from three different fields

Name of the vegetable	The target CR factor			
	Cd	Pb	Cr	Ni
Indian spinach	2.50×10^{-4}	3.4×10^{-6}	1.11×10^{-4}	2.73×10^{-4}
Stem amaranth	1.18×10^{-3}	5.1×10^{-6}	1.33×10^{-4}	2.64×10^{-4}
Spinach	2.27×10^{-4}	3.4×10^{-6}	1.45×10^{-4}	1.41×10^{-4}
Water spinach	1.98×10^{-5}	2.7×10^{-6}	5.44×10^{-5}	9.15×10^{-5}
Mint	2.1×10^{-6}	3.0×10^{-7}	2.44×10^{-5}	4.1×10^{-5}
Taro	3.01×10^{-5}	1.5×10^{-6}	1.42×10^{-4}	1.39×10^{-4}
Fern	4.57×10^{-5}	2.0×10^{-7}	2.95×10^{-5}	4.25×10^{-5}
Bottle gourd	4.44×10^{-4}	4.2×10^{-6}	1.77×10^{-4}	1.61×10^{-4}
Cabbage	8.14×10^{-5}	1.6×10^{-6}	4.82×10^{-4}	2.31×10^{-4}
Radish	1.14×10^{-4}	1.8×10^{-6}	2.02×10^{-4}	1.74×10^{-4}
Coriander leave	8.8×10^{-4}	4.0×10^{-8}	1.6×10^{-5}	9.8×10^{-6}
Marsh herb	1.73×10^{-5}	6.0×10^{-7}	1.15×10^{-4}	9.70×10^{-5}
Jute leaf	2.25×10^{-4}	1.5×10^{-6}	1.91×10^{-4}	3.34×10^{-4}
Garden purslane	3.9×10^{-5}	3.0×10^{-6}	4.07×10^{-4}	3.23×10^{-4}
Lettuce	3.98×10^{-5}	2.7×10^{-7}	1.83×10^{-5}	2.56×10^{-5}
Red amaranth	2.91×10^{-4}	2.1×10^{-6}	4.27×10^{-4}	4.41×10^{-4}

Conclusion

Metal contamination in vegetables is a growing concern in many countries, as people are greatly interested in ensuring the quality and safety of their food. This study demonstrated the potential scenario of metal contamination from natural and artificial sources and its impact on human health particularly non-carcinogenic health risk assessment. The results presented here indicate that the Pb and Cr content of vegetables in Dhaka city, the capital of Bangladesh, exceeded the permissible limit suggested by various health organizations. The majority of these vegetables were transported to the capital from the surrounding region. The cultivation of leafy vegetables in the vicinity of Dhaka city is at a high risk of contamination as a result of the high industrial density and intense traffic and a densely populated area. It was also observed that the leafy vegetables have the high tendency to accumulate heavy metals that is quite alarming for human consumption. The potential human risk for several vegetables was indicated by the presence of specific metals including As, Cd, and Pb, according to the non-carcinogenic health risk. Interval monitoring of trace elements in vegetables needs to be monitored continually for the control and prevention of heavy metals contamination as well as ensuring food safety. Furthermore, we should closely follow a comprehensive waste management system to prevent industrial effluent from polluting arable land.

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Author contribution
Anowar Hosen: Conceptualization, Investigation, Methodology, Writing original draft, Rumana Akther Jahan: Resources, Writing review & editing, Hasina Akther Simol: Investigation, Data curation, Muhammad Nurul Huda: Resources, Investigation, Data analysis and curation, editing.

Data Availability
The data of the experiments will be available from the authors if required.

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