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HEAVY METALS AND THEIR ADVERSE EFFECTS: SOURCES, RISKS, AND STRATEGIES TO REDUCE ACCUMULATION IN TEA HERB - A SYSTEMATIC REVIEW

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ABSTRACT

Heavy metals (HMs) such as arsenic, cadmium, chromium, lead, mercury, aluminum, iron, and barium can accumulate in tea herbs and pose health risks to consumers. This systematic review analyzes research from 2000-2022 on HM contamination in tea, associated health effects, and strategies to minimize exposure. Initial searches yielded 961 articles, with 157 selected for final review after the screening. HMs have no biological role; their toxicity depends on metal type, oxidation state, and solubility. Chronic ingestion of HM-contaminated tea can impair numerous organs and biochemical processes, potentially causing cancer, cardiovascular, neurological, reproductive, and developmental damage. Factors influencing HM levels in tea herbs include soil, air, and water contamination, proximity to pollution sources, genetic differences, brewing methods, and steeping time. Strategies to reduce HM uptake and toxicity include using cleaner irrigation water, avoiding acidic fertilizers, liming soil, and restricting tea cultivation near pollution sources. Processing methods and shorter brewing can also decrease HMs extracted into tea infusions. Ongoing research should further investigate phytoremediation and genetically engineering tea cultivars. Consuming contaminated tea poses cumulative risks, so sustainable agriculture and pollution control are vital to minimize HM exposure and protect public health. This review enhances understanding HM dynamics, toxicity, and mitigation strategies for producing safer tea.

1. Introduction

1.1. Tea Herb

The use of essential oils and extracts from medicinal plants has significantly increased recently due to growing awareness of the health benefits of herbs and the negative effects of synthetic chemicals. Medicinal herbs have been utilized in traditional medicine since ancient time (Aali *et al.*, 2017; Kazeminia *et al.*, 2017; Mahmoudi *et al.*, 2017).

Camellia sinensis is an evergreen shrub belonging to the *Theaceae* family. Its leaves are used to produce black tea, made by fermenting the leaves, and green tea, made by drying the leaves (Görür *et al.*, 2011). As the second most consumed beverage globally after water, tea contains bioactive polyphenols with medicinal functions (Hayat *et al.*, 2015). Tea herb (TH) has different properties due to its various compounds (Zhang *et al.*, 2019). Flavonoids, antioxidants, and minerals in TH positively impact health. The polyphenol epigallocatechin-3-gallate has antioxidant effects (Bitu Pinto *et al.*, 2015). TH extract may benefit diabetes (Q.-Y. Fu *et al.*, 2017) and blood lipids levels (El-Bassossy *et al.*, 2016), and reduce risks of immune disorders, cardiovascular disease, stroke, and various cancers (Zhang et al., 2019). Thus, consuming black and green tea infusions is recommended. Table 1 outlines the medicinal compounds in TH.

Table 1. Effective medicinal compounds in tea herb

Ingredients	Medicinal effect
Polyphenols	Control of severe postprandial hypertension through inhibition of alpha-amylase production (Liu *et al.*, 2016), anti-inflammatory properties (Oz *et al.*, 2013), anti-cancer effects (Miyata *et al.*, 2019), immune-boosting, diuretic, and antimicrobial effects (Oz, Chen, *et al.*, 2005; Oz, McClain, *et al.*, 2005).
Epigallocatechin gallate	Antioxidants properties (Bitu Pinto et al., 2015), anti-inflammatory effects (Oz & Ebersole, 2010), cardioprotective effects in cardiovascular diseases (Widlansky *et al.*, 2007), insulin-sensitizing and anti-diabetic effects (Lin & Lin, 2008; Yamabe *et al.*, 2009), weight loss effects (Tabrez *et al.*, 2015), neuroprotective effects in Alzheimer's disease (Meng *et al.*, 2010), and anti-inflammatory effects in inflammatory bowel disease (Oz et al., 2013).
Catechin, chlorogenic acid, Caffeine, Theaflavin	Hypoglycemic effects through inhibition of α-glucosidase and α-amylase. Reduction of lipid metabolites and albuminuria (Liu et al., 2016).
Geraniol	Improvement of vascular function (El-Bassossy et al., 2016). Renoprotective effects in diabetic nephropathy (Yamabe et al., 2009).
Polysaccharides	Antioxidants properties (H. Chen *et al.*, 2009).
Catechins	Antioxidants properties (Liang *et al.*, 2008).
Gallic acid	Antioxidants properties (Kongpichitchoke *et al.*, 2016).
Caffeine	Weight loss effects (Zheng *et al.*, 2015).

TH is cultivated in around 45 countries spanning latitudes from 45°N to 34°S (Karak & Bhagat, 2010). Global tea production is estimated at 1.74 billion kg, with China as the largest producer and consumer, followed by India in production. Other producing countries include Sri Lanka, Kenya, Turkey, Indonesia, and Japan (Layomi Jayasinghe *et al.*, 2019).

As one of the most widely consumed beverages worldwide, approximately 98% of the global population considers tea their first hot drink, with around twenty billion cups consumed daily (Dufresne & Farnworth, 2001). Tea's popularity stems from its potential health benefits. However, heavy metals (HMs) in tea raise safety concerns, as they may adversely impact health. In modern times, HMs are hazardous substances. This review identifies the negative effects of HMs in tea and ways to minimize exposure, so consumers can be assured of a safe, uncontaminated product. Additionally, the methods discussed could inform policies aimed at reducing HMs contamination in the food chain.

1.2. Heavy Metals

There are 35 metals (Ms), of which 23 are classified as HMs. HMs include: Arsenic (symbol As), Aluminum (symbol Al), Antimony (symbol Sb from Latin: *stibium*), Barium (symbol Ba), Beryllium (symbol Be), Bismuth (symbol Bi), Chromium (symbol Cr), Cadmium (symbol Cd), Germanium (symbol Ge), Gallium (symbol Ga), Gold (symbol Au from Latin: *aurum*), Silver (symbol Ag from the Latin: *argentum*), Lead (symbol Pb from the Latin:

plumbum), Indium (symbol In), Lithium (symbol Li), Nickel (symbol Ni), Mercury (symbol Hg from the Latin: *hydrargyrum*), Platinum (symbol Pt), Strontium (symbol Sr), Tellurium (symbol Te), Titanium (symbol Ti), Thallium (symbol Tl), Tin (symbol Sn), Uranium (symbol U), and Vanadium (symbol V). HMs have relatively high density and electrical conductivity. HM levels in TH may vary by region (Khlifi & Hamza-Chaffai, 2010; Mahmoudi et al., 2017; F. Yang & Massey, 2019). Other Ms such as Copper (symbol Cu from Latin: *cuprum*), Zinc (symbol Zn), Iron (symbol Fe from Latin: *Ferrum*), Cobalt (symbol Co), Manganese (symbol Mn), Molybdenum (symbol Mo), Iodine, Bromine (symbol Br), and Selenium (symbol Se) are also present in TH. These are essential in trace amounts but can be toxic if intake exceeds thresholds (Mahmoudi et al., 2017; Nagajyoti *et al.*, 2010).

Recently, HM exposure has become an environmental and public health concern due to increased industrial and agricultural use. HMs are typically classified as non-essential (Fasae & Abolaji, 2022). Urbanization and technology have led to HM accumulation in soil and water, allowing entry into the food chain via plants and animals, including tea. This poses a health risk. It is critical to limit HM uptake and modulate plant response. Updating knowledge on HM dynamics in the soil-plant-environment is key (Thakur *et al.*, 2022). This review critically analyzes strategies to address HMs in tea and possible health risks. Understanding the risks of HM tea consumption and developing mitigation measures is imperative.

2. Materials and methods

The objective of this systematic review is to evaluate articles published from 2000-2022 that examine the adverse effects of HMs and potential solutions to reduce HM exposure. The search strategy involved keyword searches using terms such as "heavy metal," "side effects," "Cadmium," "Arsenic," "Mercury," "Chromium," "Lead," "Aluminum," "Iron," "Barium," "tea," "health effects," and "public health" in the Science Direct, PubMed, and Google Scholar databases. This review examined epidemiological, clinical, and experimental studies from different geographical areas that analyzed the toxic effects of various HMs on human health. It also looked at strategies proposed in these studies to reduce human exposure to harmful levels of HMs via contaminated food, water, air, and consumer products. The health impacts analyzed included effects on mortality, cancer, cardiovascular, neurological, kidney, bone, and developmental outcomes. The sources of exposure evaluated were drinking water contamination, polluted soil, industrial pollution, mining activities, herbal products, and metal cookware. By synthesizing key findings from the extensive literature on heavy metal (HM) toxicity and exposure reduction, this review aims to inform public health policies and interventions focused on protecting human health from the dangers of HM exposure.

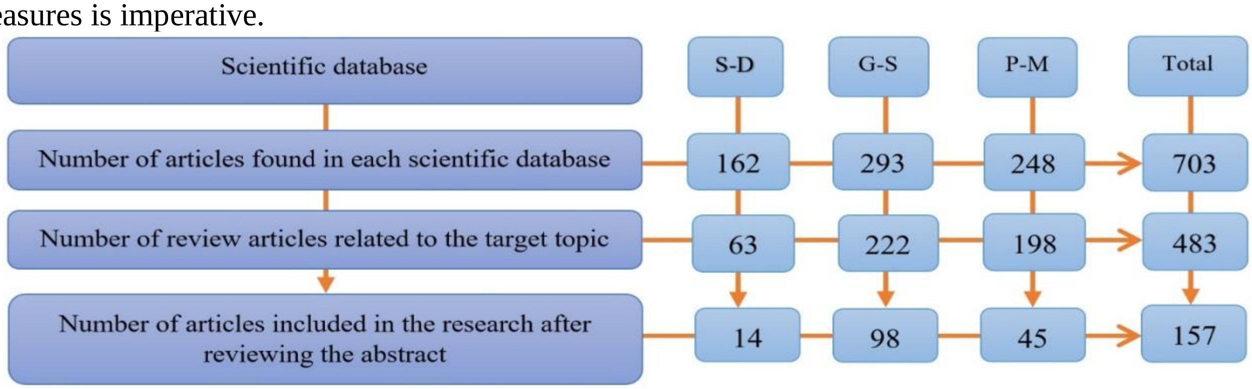

Figure 1. Procedures for selecting and entering studies into our research by searching scientific databases, including Science Direct (S-D), Google Scholar (G-S), and PubMed (P-M)

3. Results and discussions

This systematic review investigated the adverse health and environmental effects of several HMs, including As, Cd, Cr, Pb, Hg, Al, Fe, and Ba. It also aimed to identify effective solutions to reduce exposure. Initial searches yielded 961 potentially relevant articles. After screening titles and abstracts, 703 remained. Further screening for appropriateness eliminated 220 articles, leaving 483 for full-text review. To avoid duplicative findings and focus on current data, 326 additional articles were excluded. The final sample comprised 157 articles selected for analysis.

3.1. Tolerable daily intake of HMs

Health risk from HM contamination in foods can be assessed using the health risk index (HRI). This is calculated by dividing the estimated average daily intake by the tolerable daily intake. An HRI below 1 indicates food safety, while above 1 signals potential health risks (Apau *et al.*, 2014). The provisional tolerable daily intake (PTDI) and weekly intake (PTWI) for HMs were calculated using established methods (Tables 2 and 3).

Table 2. The maximum concentration of HMs for weekly and daily tolerable tolerance of raw black tea.

DDW[a] (unit) / HM	Ni	Co	Cr	Cd	Pb	Ar
PTDI (mg/kg×d)	0.51	0.39	0.18	0.018	0.16	0.006
PTWI (mg/kg×w)	3.60	2.73	1.30	0.13	1.12	0.042

[a]Dose daily and weekly

Table 3. The maximum concentration of HMs for weekly and daily tolerable tolerance of black tea infusion.

DDW[a] (unit) / HM	Ni	Co	Cr	Cd	Pb	Ar
PTDI (mg/kg× d)	0.13	0.073	0.06	0.009	0.002	0.001
PTWI (mg/kg× w)	0.91	0.51	0.42	0.064	0.016	0.009

[a]Dose daily and weekly

Two equations were used to evaluate the health risks from HM contamination in tea:
Equation 1: calculates the provisional tolerable daily intake of HM (mg/kg body weight/day). The PTDI is calculated for an average body weight of 65 kg.
Equation 2: calculates the target hazard quotient (THQ) to assess HM health risks in tea. THQ values <1 indicate low risks, values around 1 indicate chronic risks, and values >10 indicate high risks.

Measuring HM levels in tea is important for evaluating safety and potential health risks. Comparing HM types and concentrations to toxicity thresholds judges the overall safety status of tea samples.

Equation 1: $\text{PTDI}=\frac{P\times H}{W}$

P: as per capita consumption of HT, H: as HM concentration, W: as average body weight

Equation 2: $\text{THQ}=\frac{P\times H\times D}{L\times W}$

P: as per capita consumption of TH, H: as HM level, D: as duration of TH consumption, L: as average lifespan, W: as body average weight

3.2. Adverse effects and the entry routes of HMs

There are important links between food security, safety, pollution, and public health. In developed nations, major agriculture pollution sources include particle deposition on crops and using industrial effluents as fertilizers. In both developed and developing countries, irrigating with untreated wastewater (WW) causes contamination (Morais *et al.*, 2012).

Consuming contaminated vegetables poses greater health risks than contaminated fruits (Shaheen *et al.*, 2016). Main HM exposure routes are ingestion, inhalation, and skin contact. Increased environmental HM deposition can accumulate in food and drinks, entering the food chain and endangering safety and health (Zwicker *et al.*, 2010). HMs are absorbed and stored faster than excreted, potentially leading to poisoning, illness, or death (W.-Y. Han *et al.*, 2007).

HMs do not break down chemically or biologically, persisting in the environment (Soomro *et al.*, 2008). Even low concentrations have harmful effects due to persistence and bioaccumulation (Kaličanin & Velimirović, 2013). Prolonged exposure raises cancer risks including prostate, liver, lung, nose, laryngeal, and gastrointestinal (GI). HMs accumulate in tissues, potentially causing disorders in skeletal, nervous, cerebral, GI, dermal, renal, reproductive, circulatory systems, and immunodeficiency (Sofuoglu & Kavcar, 2008; Amouei *et al.*, 2012; Zhao *et al.*, 2014; El-Kady & Abdel-Wahhab, 2018).

3.2.1. Arsenic

As is the 20th most plentiful element on our planet and has metallurgical applications due to its semi-metallic properties (Singh *et al.*, 2007). As is present in minimal amounts in TH due to low water solubility. Predominant forms are arsenate III (As^{3+}) and arsenate V (As^{5+}) (Karak & Bhagat, 2010).

Humankind may be exposed to As through natural resources, industrial resources, or unwanted resources. Drinking water (DW) contamination occurs through minerals, chemicals, and pesticides. As exposure is a global issue, especially in Asia and South America where millions consume As-contaminated water for drinking and irrigation (Edition, 2011). The WHO set a 0.01 mg/L maximum for As in DW. Levels 10-100 times higher pose hazards (Hoque *et al.*, 2011).

High As doses via ingestion or inhalation can cause acute to severe poisoning, as shown in Figure 2 (Martin & Griswold, 2009). As impairs cellular respiration, enzymes, and mitosis as a protoplasmic toxin (Amouei et al., 2012). Recently, As exposure has become a key health concern due to associations with decreased male fertility (de Araújo Ramos *et al.*, 2017; Udagawa *et al.*, 2019) and reduced learning in children (Desai *et al.*, 2020; Hamadani *et al.*, 2011).

3.2.2. Cadmium

Cd is a toxic HM with high carcinogenicity (Oh *et al.*, 2015). Environmental Cd exposure is more likely in industrialized nations (J.-X. Han *et al.*, 2009). The WHO set a 0.003 mg/L maximum for Cd in DW (Joint *et al.*, 2007).

Cd is a byproduct of Zn production, first used in World War I to replace tin and as a pigment. Today it is used in batteries and alloys. Ingestion and inhalation are main exposure routes, with acute to severe effects (Figure 2). Cd persists in sediments and soil for years (Bernard, 2008; Mutlu *et al.*, 2012). Herbs uptake and transfer Cd to the food chain gradually (Olympio *et al.*, 2018). Cd accumulates in the body slowly, potentially impairing liver, kidneys, and bones (Boonprasert *et al.*, 2018; Tola *et al.*, 2007).

Cd and Zn have similar oxidation states. Cd can replace Zn in metallothionein, inhibiting Cd's free radical scavenging (Irfan *et al.*, 2013). Cd absorption is low in the gastrointestinal tract (GIT) but high in the lungs. Prenatal Cd increases risks of premature birth, low birth weight, and lower IQ (Henson & Chedrese, 2004; Kippler *et al.*, 2012). High Cd in children raises cancer likelihood and slows growth. Prolonged exposure also increases cardiovascular disease risks (Edition, 2011; Hoque et al., 2011).

Cd is more water-soluble than other Ms. Tobacco provides significant Cd exposure in smokers as it accumulates soil Cd. Non-smokers also ingest Cd through diet, although other absorption is unlikely (Mudgal *et al.*, 2010).

Cd exposure can lead to miscarriage and sexual issues like low semen quality, testicular/ovum defects (Udagawa et al., 2019). Cd rapidly accumulates in tissues, especially testes, strongly impacting reproduction (Cupertino *et al.*, 2017; De Franciscis *et al.*, 2015).

3.2.3. Chromium

Cr, the seventh most abundant element, exists in solid, liquid, and gaseous environmental forms (Monalisa & Kumar, 2013). Cr is widely used in industries like plating, metallurgy, wood protection, tanning, pigments, paints, and paper, contributing to environmental release (Ghani & Ghani, 2011). Industrial discharges and irrigating with

WW/Cr-contaminated water causes Cr transfer from soil to plants to food (Duan *et al.*, 2010).

Cr toxicity depends on the ion's charge. Cr^{3+} has low solubility, mobility, and toxicity. Cr^{6+} is highly water-soluble and toxic (Gardea-Torresdey *et al.*, 2004). Both harm health in excess (Gürkan *et al.*, 2017; Karaulov *et al.*, 2019). High Cr causes reduced root growth, chlorosis, necrosis, and inhibits germination in plants. It accumulates in tissues, causing organ damage and death (Ghani & Ghani, 2011). Compounds with Cr^{6+} like $ZnCrO_4$, $SrCrO_4$, $PbCrO_4$, and $CaCrO_4$, are highly poisonous and cancer-causing, damaging DNA and chromosomes (Matsumoto *et al.*, 2006). Cr^{3+} is an essential nutrient for glucose metabolism in trace amounts. However, Cr^{6+} absorbs faster in the GIT and lungs, increasing toxicity risks (Martin & Griswold, 2009).

The WHO set 0.2-1 μg/g and 0.05 mg/L maximums for Cr in vegetables and DW, respectively (Mahvi *et al.*, 2011; Narin *et al.*, 2004). In oxygen-rich environments, Cr^{3+} oxidizes to the highly toxic and water-soluble Cr^{6+} (Cervantes *et al.*, 2001).

3.2.4. Lead

Pb is a toxic, carcinogenic metal extensively used in industry, causing pollution and health issues globally (Amouei et al., 2012). Major Pb sources include bullet/casting production, dyeing, cable sheathing, battery manufacturing, brass alloys, and gasoline combustion (Pruvot *et al.*, 2006).

Pb limits in food/drink vary - Japan: 20 mg/kg, Canada/Australia/India: 10 mg/kg, Europe/China: 5 mg/kg (Joint et al., 2007). Pb is not biologically essential. High plant Pb, especially in shoots/leaves, creates reactive oxygen species damaging membranes and photosynthesis while suppressing growth (Najeeb *et al.*, 2017).

Pb disrupts nucleic acid metabolism (Achudume & Owoeye, 2010). Pb ions substitute for monovalent cations like Na^+ and divalent cations like Mg^{2+}, Ca^{2+}, Fe^{2+}, impairing protein folding, cell adhesion, apoptosis, transport, enzymes, and neurotransmitters (Flora *et al.*, 2008). Approximately 95% of absorbed Pb precipitates in bones as insoluble phosphate (Papanikolaou *et al.*, 2005).

Historically, Pb pipes contaminated water, causing poisoning (Brochin *et al.*, 2014). Pb toxicity primarily affects the GIT and nervous system (Markowitz, 2000). Fetuses and children are more vulnerable than adults (Sanders *et al.*, 2009). Childhood Pb exposure is linked to increased violence and criminality later in life (J. Sampson & S. Winter, 2018; Meyer & Rogers, 2018).

3.2.5. Mercury

Hg is a silvery, odorless liquid metal that evaporates into an invisible, toxic vapor when heated (C.-W. Chen *et al.*, 2012). The behavior of Hg in different forms is shown in Table 4.

Hg is widely applied in barometers, thermometers, lamps, and batteries. It is mainly available in three forms: metallic elements, inorganic compounds, and organic compounds, each with varying toxicity levels. These Hg forms occur in surface and groundwater, where they are absorbed by organisms and converted to methylmercury (MeHg), disrupting aquatic life. Human MeHg exposure is primarily through consumption of contaminated marine food (Trasande *et al.*, 2005).

Hg is present in beverages and foods at levels ranging from <1 to 50 μg/kg, often higher in seafood, especially fatty fish and fish liver (Reilly, 2006). The WHO sets the maximum permissible Hg level in DW at 0.002 mg/L (Joint & Additives, 2003).

Hg vapors can cause irritating breathing issues like bronchitis and asthma. Hg also damages tertiary and quaternary protein structures and inhibits cellular functions by binding to selenohydryl and sulfhydryl groups, which react with MeHg. Hg disrupts ribosomes, destroys the endoplasmic reticulum, and inhibits natural killer cell activity through effects on transcription and translation (Ynalvez *et al.*, 2016).

Table 4. The performance of Hg in different forms (Patrick, 2002).

Metal state	Hg	MeHg	Non-organic-Hg
Source	Fossil fuels, latex paints, incinerators, thermometers	Pesticides, fish, poultry	Oxidation of Hg, demethylation of MeHg by gut microflora
Absorption pathway	75-85% through inhalation	95-100% through GIT	7-15% through GIT, 2-3% through skin
Distribution areas	Throughout the body, crosses placental and blood-brain barriers	Throughout the body, crosses placental and blood-brain barriers	Kidney accumulation, cannot cross placental or blood-brain barriers
Excretion procedure	Feces, urine, saliva, sweat	10% urine, 90% feces/bile	Feces, urine, saliva, sweat
Causes of toxicity	Conversion to inorganic Hg	Demethylation to inorganic Hg, free radical formation, binds to enzyme/protein thiols	Binds to enzyme/protein thiols

3.2.6. Aluminium

Al, the third most abundant element on our planet, is dispersed in water, soil, and air. The extraction and processing of Al can increase its levels in the environment (Gupta *et al.*, 2013). Al has no biological function and is a toxic metal to humans. The main ways for humans to absorb Al are through inhalation, ingestion, and skin contact. Sources of Al exposure include DW, beverages, food, and Al-containing medications. Al is naturally present in many foods. Al and its compounds are poorly absorbed by the human body (Olaniran *et al.*, 2013).

Al toxicity increases with decreasing pH. Acid rain containing Al ions and increasing atmospheric acidification can have devastating effects on the environment, leading to deforestation, plant poisoning, crop failure, and destruction of aquatic organisms (Barabasz *et al.*, 2002).

Al intoxication results from an interaction between Al and the plasma membrane (Kochian *et al.*, 2005). The effect of Al on nerve cells is similar to that seen in alzheimer's disease. Replacement of Mg^{2+} and Fe^{2+} by Al^{3+} disrupts intercellular communication, cell growth, and gland secretory function (Vardar & Ünal, 2007).

Al poisoning can be exacerbated by living in environments with Al-containing dust, impaired kidney function, hemodialysis, and consuming Al-containing food, drinks or medications (Cannata Andia, 1996).

3.2.7. Iron

Iron, the second most abundant element on Earth, is vital for growth and survival of living organisms. Fe deficiency during growth and adulthood can affect the development and function of the nervous system (Baltussen *et al.*, 2004). Fe is an ideal transition metal for oxidation-reduction reactions because it can readily interconvert between ferrous (Fe^{2+}) and ferric (Fe^{3+}) ions (Phippen *et al.*, 2008).

Lithuanians are exposed to high Fe levels in DW due to accumulation of Fe in Lithuanian groundwater above allowable limits (Grazuleviciene *et al.*, 2009). Environmental Fe deposits can cause significant damage by preventing fish from breathing properly (Clesceri *et al.*, 1998).

If Fe absorbed by the human body fails to bind to proteins, it generates high levels of harmful free radicals that can damage internal organs including the brain, liver, and heart. Unbound ferrous iron converts to ferric iron, disrupting oxidative phosphorylation, releasing hydrogen ions, and increasing metabolic acidity. Free Fe promotes lipid peroxidation, causing severe damage to microsomes, mitochondria, and other cellular components (Albretsen, 2006).

The clinical course of Fe toxicity is divided into four phases: (i) In the first phase (6 hours after Fe overdose), patients primarily exhibit GI symptoms such as diarrhea, vomiting, and GI bleeding. (ii) The second phase (6 to 24 hours) indicates a recovery stage. (iii) The third phase (12 to 96 hours) follows acute symptoms and is characterized by shock, hypotension, malaise, heart damage, liver necrosis, metabolic acidosis, and sometimes death. (iv) The fourth phase (2 to 6 weeks) involves GI ulcer formation. Excess Fe beyond the body's needs increases cancer risk (Nelson, 1992).

The formation of free radicals, including hydrogen peroxide and superoxide, occurs continuously during normal cellular processes. Superoxide releases Fe from ferritin. This free Fe reacts with hydrogen peroxide and superoxide to produce highly toxic hydroxyl radicals (Fine, 2000).

The adverse effects of HMs like lead (Kim *et al.*, 2016; Kuang *et al.*, 2020; Martin & Griswold, 2009; Pfadenhauer *et al.*, 2016; Reuben *et al.*, 2017; Sanders et al., 2009; Zeng *et al.*, 2019), mercury (Haley, 2005; Morais et al., 2012; Patrick, 2002; Schumacher & Abbott, 2017; Wallin *et al.*, 2017; Qin *et al.*, 2021), aluminium (Barabasz et al., 2002; Krewski *et al.*, 2007), iron (Agrawal *et al.*, 2017; Ayton & Lei, 2014; Ghadery *et al.*, 2015; Li & Reichmann, 2016), arsenic (Roh *et al.*, 2018; Smith *et al.*, 2000; Román-Ochoa *et al.*, 2021; Q. Yang et al., 2022), chromium (Buters & Biedermann, 2017; Nath *et al.*, 2008; Rasoul *et al.*, 2017; Sofuoglu & Kavcar, 2008; Bjørklund *et al.*, 2022) are shown in Figure 2.

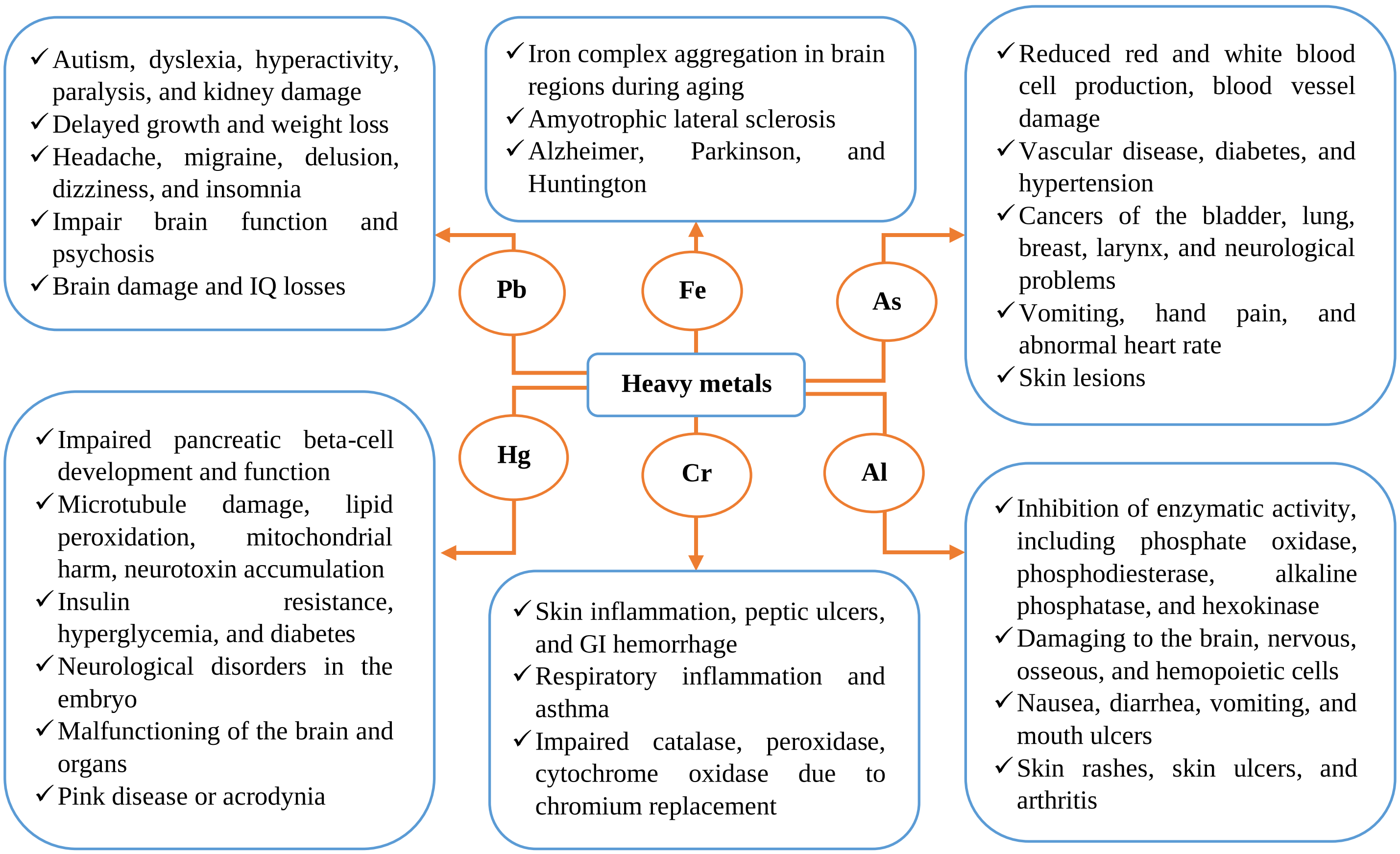

Figure 2. Adverse effects of exposure to HMs including Pb, Hg, Al, Fe, As, and Cr

3.2.8. Barium

Ba is an unnecessary and rare element in food and DW (Schroeder & Kraemer, 1974). In the environment, Ba is usually found as Ba sulfate and Ba carbonate. Ba sulfate is used in plastics and paints due to its neutrality, low toxicity, high density, and low solubility. Exposure to Ba occurs through ingestion of food or DW, or breathing Ba-contaminated air. Skin absorption of Ba is negligible. Ba bloodstream entry depends on solubility. Highly soluble Ba compounds like Ba nitrate and chloride can enter faster than insoluble sulfate and carbonate (Landsiedel *et al.*, 2014; F. Yang & Massey, 2019).

The body's reaction to Ba depends on its water solubility. Insoluble Ba compounds have minimal adverse effects. In contrast, soluble compounds are harmful, causing irregular heartbeat, paralysis or death, respiratory inflammation, vomiting, diarrhea, and cramps (Schwotzer *et al.,* 2017; F. Yang & Massey, 2019). Ba has low pulmonary toxicity (Olaniran et al., 2013). The cardiovascular system is a primary Ba toxicity target. Thus, consistent Ba monitoring in DW and food is critical (Afonso *et al.*, 2008). The WHO sets the maximum permissible Ba level in DW at 0.7 mg/L (Organization, 1990).

Ba poisoning occurs by disrupting potassium metabolism through two mechanisms: (i) Blocking potassium pumping channels. (ii) Increasing plasma membrane sodium permeability (F. Yang & Massey, 2019).

3.3. Presence of heavy metals in tea herb

HMs have serious adverse human health and environmental effects. Reducing HM levels in the environment and food chain is considered the most effective mitigation step. Thus, identifying factors causing HM accumulation in plants is a first step. Based on various papers, the following contribute to HM presence in TH: chemical fertilizer, improper waste, and fossil fuel use (Nazemi & Khosravi, 2011); HM presence in soil (Y. Yang *et al.*, 2018), water (Lokeshwari & Chandrappa, 2006), and air (Nabulo *et al.*, 2006); geographical location (Chabukdhara *et al.*, 2016; Saha *et al.*, 2015); planting and harvest time (Shekoohiyan *et al.*, 2012); tea brewing duration (Zazouli *et al.*, 2010); metal processing equipment in production (Seenivasan et al. 2008); HM amount and type (Gardea-Torresdey et al., 2004); and plant genetic diversity (Rattan *et al.*, 2005). These factors cause differences in herb HM concentrations and composition.

3.4. Strategies to control the value of heavy metals in tea herb

The accumulation of HMs in water and soil is one of the chief problems caused by inorganic contaminants. Their presence in high quantities in agricultural soils has substantially impacted food safety and human health. Among various physicochemical methods to reduce HMs in tea brews, the following have been most effective (Oladoye et al., 2022).

HM-contaminated water is a major environmental hazard. Using pre-treated WW effluent for irrigation can reduce HM levels (Cherfi *et al.*, 2015; Khan *et al.*, 2015). Various technologies remove HMs from WW, including solvent extraction, solid-phase extraction, gravity precipitation, electrodialysis, ion exchange, reverse osmosis, chemical precipitation, flotation, membrane separation, and adsorption (Bishnoi *et al.*, 2004; Dimoglo *et al.*, 2019). Ion exchange, adsorption, and membrane purification are among the most effective methods (F. Fu & Wang, 2011).

Plant roots play a vital role in HM uptake and transport (Antoniadis et al., 2017). HMs have low mobility in alkaline soils and are poorly absorbed by herbs. However, HM mobility increases in acidic soils, allowing root absorption and translocation to other plant parts. Soil acidification directly impacts HM transfer to TH (Mandiwana *et al.*, 2011; Moseti *et al.*, 2013). One study found liming acidic soil reduced Pb accumulation in TH (W.-Y. Han et al., 2007). Acid rain significantly lowers soil pH, so cultivating TH in industrial areas should be avoided or products experimented for HMs (Barabasz et al., 2002). Growing plants away from highways, mines, and industrial areas substantially reduces HM levels in products, as proximity to mines and roads increases Cu, Cd, Pb, Cr, and As in TH (Obiora *et al.*, 2016; Petit *et al.*, 2013; Rock *et al.*, 2017).

Longer brewing times directly increase HM concentration in tea (Shekoohiyan et al., 2012). Decreasing phosphorous fertilizer application also lowers HM levels in TH (Tola et al., 2007).

As transfer from leaves to tea depends on water temperature and steeping time. Higher temperatures reduce As extraction (Karak & Bhagat, 2010).

Tea from China and Japan, the leading exporters, should be consumed carefully due to their high environmental Cd contamination from industrialization (J.-X. Han et al., 2009). TH tannins form HM complexes, reducing their levels (Yuan *et al.*, 2007).

Cd concentrations in TH are low due to limited root-to-shoot translocation. TH roots also accumulate Cd, preventing transfer to upper plant organs (Gardea-Torresdey et al., 2004).

Phytoremediation uses plants to remove and accumulate HMs in harvestable sections. Strategies include phytoextraction, phytoevaporation, phytostabilization, rhizodegradation, and rhizofiltration. Using edible plants introduces HMs into the food chain, so ornamentals are better for phytoextraction to reduce soil HMs and prepare for food crops (Shao *et al.*, 2022; L. Wang *et al.*, 2022).

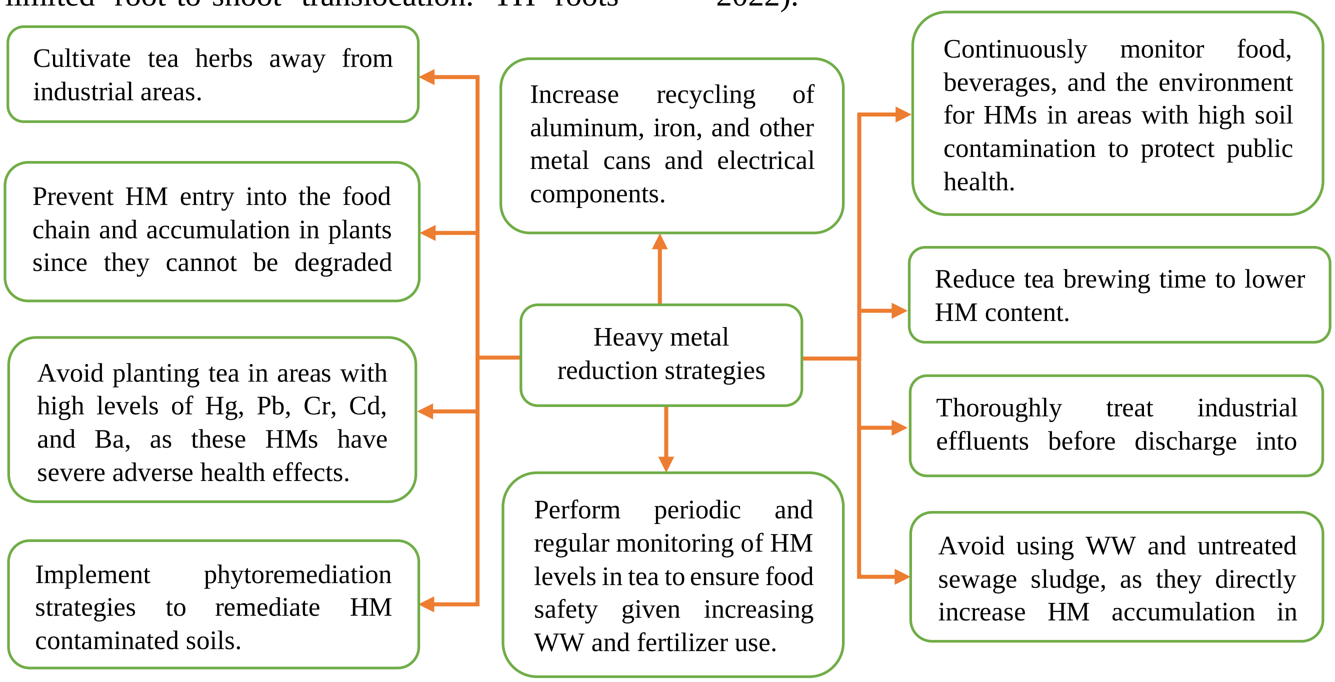

Figure 3. Main strategies to reduce exposure to HMs

4. Conclusions

The global concentration of HMs in soil and water has been increasing due to their stable, non-degradable nature. HM pollution and remediation remain major challenges for researchers. Consuming brewed tea containing HMs is a primary route of human exposure. HMs can also enter the body through contaminated air inhalation, skin contact, food ingestion, and drinking contaminated water. Once inside, HMs accumulate in fat and bone, then slowly release, potentially causing various illnesses.

Measures to reduce HM levels in the environment and TH include: recycling metal cans; properly treating industrial WW; avoiding fertilizers that acidify soil; avoiding planting TH in areas with high Hg, Pb, Cr, Cd, or Ba; growing TH in uncontaminated soil; and continuously monitoring HM levels in food, DW, and the environment.

In summary, HM contamination of TH is a complex issue involving many human and environmental factors. Careful monitoring, sustainable agricultural practices, and waste management can help mitigate risks. Ongoing research into optimal cultivation conditions and remediation strategies is important to support the safe production and consumption of TH.

5. References

Aali, E., Mahmoudi, R., Kazeminia, M., Hazrati, R., Azarpey, F. (2017). Essential oils as natural medicinal substances. *Tehran University*

Medical Journal TUMS Publications, 75(7), 480-489.

Achudume, A., Owoeye, D. (2010). Quantitative assessment of heavy metals in some tea marketed in Nigeria. *Health,* 2(9), 1097-1100.

Afonso, C., Lourenço, H. M., Pereira, C., Martins, M. F., Carvalho, M. L., Castro, M., Nunes, M. L. (2008). Total and organic mercury, selenium and α‐tocopherol in some deep‐water fish species. *Journal of the Science of Food and Agriculture,* 88(14), 2543-2550.

Agrawal, S., Berggren, K. L., Marks, E., Fox, J. H. (2017). Impact of high iron intake on cognition and neurodegeneration in humans and in animal models: a systematic review. *Nutrition reviews,* 75(6), 456-470.

Albretsen, J. (2006). The toxicity of iron, an essential element. *Veterinary medicine-bonner springs then edwardsville-,* 101(2), 82.

Amouei, A. I., Yousefi, Z., Mahvi, A. H., Naddafi, K., Tahmasbizadeh, M. (2012). Heavy metal concentrations in industrial, agricultural, and highway soils in northern Iran. *Environmental Justice,* 5(3), 153-157.

Antoniadis, V., Shaheen, S. M., Boersch, J., Frohne, T., Du Laing, G., Rinklebe, J. (2017). Bioavailability and risk assessment of potentially toxic elements in garden edible vegetables and soils around a highly contaminated former mining area in Germany. *Journal of Environmental Management,* 186, 192-200.

Apau, J., Acheampong, A., Appiah, J., Ansong, E. (2014). Levels and health risk assessment of heavy metals in tubers from markets in the Kumasi metropolis, Ghana. *Int J Sci Technol,* 3(9), 534-539.

Ayton, S., Lei, P. (2014). Nigral iron elevation is an invariable feature of Parkinson's disease and is a sufficient cause of neurodegeneration. *BioMed research international,* 2014.

Baltussen, R., Knai, C., Sharan, M. (2004). Iron fortification and iron supplementation are cost-effective interventions to reduce iron deficiency in four subregions of the world. *The Journal of nutrition,* 134(10), 2678-2684.

Barabasz, W., Albinska, D., Jaskowska, M., Lipiec, J. (2002). Ecotoxicology of aluminium. *Polish journal of environmental studies,* 11(3), 199-204.

Bernard, A. (2008). Cadmium & its adverse effects on human health. *Indian Journal of Medical Research,* 128(4), 557.

Bishnoi, N. R., Bajaj, M., Sharma, N., Gupta, A. (2004). Adsorption of Cr (VI) on activated rice husk carbon and activated alumina. *Bioresource technology,* 91(3), 305-307.

Bitu Pinto, N., da Silva Alexandre, B., Neves, K. R. T., Silva, A. H., Leal, L. K. A., Viana, G. S. (2015). Neuroprotective properties of the standardized extract from Camellia sinensis (green tea) and its main bioactive components, epicatechin and epigallocatechin gallate, in the 6-OHDA model of Parkinson's disease. *Evidence-Based Complementary and Alternative Medicine,* 2015.

Bjørklund, G., Rahaman, M. S., Shanaida, M., Lysiuk, R., Oliynyk, P., Lenchyk, L., Chirumbolo, S., Chasapis, C. T., Peana, M. (2022). Natural dietary compounds in the treatment of arsenic toxicity. *Molecules,* 27(15), 4871.

Boonprasert, K., Vesey, D. A., Gobe, G. C., Ruenweerayut, R., Johnson, D. W., Na-Bangchang, K., Satarug, S. (2018). Is renal tubular cadmium toxicity clinically relevant? *Clinical kidney journal,* 11(5), 681-687.

Brochin, R., Leone, S., Phillips, D., Shepard, N., Zisa, D., Angerio, A. (2014). The cellular effect of lead poisioning and its clinical picture. *Management,* 8(1).

Buters, J., Biedermann, T. (2017). Chromium (VI) contact dermatitis: getting closer to understanding the underlying mechanisms of toxicity and sensitization! *Journal of Investigative Dermatology,* 137(2), 274-277.

Cannata Andia, J. (1996). Aluminium toxicity: its relationship with bone and iron metabolism. *Nephrology Dialysis Transplantation,* 11(supp3), 69-73.

Cervantes, C., Campos-García, J., Devars, S., Gutiérrez-Corona, F., Loza-Tavera, H., Torres-Guzmán, J. C., Moreno-Sánchez, R. (2001). Interactions of chromium with microorganisms and plants. *FEMS microbiology reviews,* 25(3), 335-347.

Chabukdhara, M., Munjal, A., Nema, A. K., Gupta, S. K., Kaushal, R. K. (2016). Heavy metal contamination in vegetables grown around peri-urban and urban-industrial clusters in Ghaziabad, India. *Human and Ecological Risk Assessment: An International Journal,* 22(3), 736-752.

Chen, C.-W., Chen, C.-F., Dong, C.-D. (2012). Distribution and accumulation of mercury in sediments of Kaohsiung River Mouth, Taiwan. *APCBEE Procedia,* 1, 153-158.

Chen, H., Qu, Z., Fu, L., Dong, P., Zhang, X. (2009). Physicochemical properties and antioxidant capacity of 3 polysaccharides from green tea, oolong tea, and black tea. *Journal of food science,* 74(6), C469-C474.

Cherfi, A., Achour, M., Cherfi, M., Otmani, S., Morsli, A. (2015). Health risk assessment of heavy metals through consumption of vegetables irrigated with reclaimed urban wastewater in Algeria. *Process safety and environmental protection,* 98, 245-252.

Clesceri, L., Greenberg, A., Eaton, A. (1998). Standard Methods for the Examination of Water and Wastewater, APHA, Washington, DC. *Standard methods for the examination of water and wastewater. 20th ed. APHA, Washington, DC.*, -.

Cupertino, M. C., Novaes, R. D., Santos, E. C., Neves, A. C., Silva, E., Oliveira, J. A., Matta, S. L. (2017). Differential susceptibility of germ and leydig cells to cadmium-mediated toxicity: impact on testis structure, adiponectin levels, and steroidogenesis. *Oxidative Medicine and Cellular Longevity,* 2017.

de Araújo Ramos, A. T., Diamante, M. A. S., de Almeida Lamas, C., Dolder, H., de Souza Predes, F. (2017). Morphological and morphometrical changes on adult Wistar rat testis caused by chronic sodium arsenite exposure. *Environmental Science and Pollution Research,* 24(36), 27905-27912.

De Franciscis, P., Ianniello, R., Labriola, D., Ambrosio, D., Vagnetti, P., Mainini, G., Trotta, C., Mele, D., Campitiello, M., Caprio, F. (2015). Environmental pollution due to cadmium: measure of semen quality as a marker of exposure and correlation with reproductive potential. *Clin Exp Obstet Gynecol,* 42(6), 767-770.

Desai, G., Barg, G., Vahter, M., Queirolo, E. I., Peregalli, F., Mañay, N., Millen, A. E., Yu, J., Kordas, K. (2020). Executive functions in school children from Montevideo, Uruguay and their associations with concurrent low-level arsenic exposure. *Environment International,* 142, 105883.

Dimoglo, A., Sevim-Elibol, P., Dinç, Ö., Gökmen, K., Erdoğan, H. (2019). Electrocoagulation/electroflotation as a combined process for the laundry wastewater purification and reuse. *Journal of Water Process Engineering,* 31, 100877.

Duan, N., Wang, X., Liu, X., Lin, C., Hou, J. (2010). Effect of anaerobic fermentation residues on a chromium-contaminated soil-vegetable system. *Procedia Environmental Sciences,* 2, 1585-1597.

Dufresne, C. J., Farnworth, E. R. (2001). A review of latest research findings on the health promotion properties of tea. *The Journal of nutritional biochemistry,* 12(7), 404-421.

Edition, F. (2011). Guidelines for drinking-water quality. *WHO chronicle,* 38(4), 104-108.

El-Bassossy, H. M., Elberry, A. A., Ghareib, S. A. (2016). Geraniol improves the impaired vascular reactivity in diabetes and metabolic syndrome through calcium channel blocking effect. *Journal of Diabetes and its Complications,* 30(6), 1008-1016.

El-Kady, A. A., Abdel-Wahhab, M. A. (2018). Occurrence of trace metals in foodstuffs and their health impact. *Trends in food science & technology,* 75, 36-45.

Fasae, K. D., Abolaji, A. O. (2022). Interactions and toxicity of non-essential heavy metals (Cd, Pb and Hg): lessons from Drosophila melanogaster. *Current Opinion in Insect Science,* 100900.

Fine, J. S. (2000). Iron poisoning. *Current problems in pediatrics,* 30(3), 71-90.

Flora, S., Mittal, M., Mehta, A. (2008). Heavy metal induced oxidative stress & its possible reversal by chelation therapy. *Indian Journal of Medical Research,* 128(4), 501.

Fu, F., Wang, Q. (2011). Removal of heavy metal ions from wastewaters: a review. *Journal of Environmental Management,* 92(3), 407-418.

Fu, Q.-Y., Li, Q.-S., Lin, X.-M., Qiao, R.-Y., Yang, R., Li, X.-M., Dong, Z.-B., Xiang, L.-P., Zheng, X.-Q., Lu, J.-L. (2017). Antidiabetic effects of tea. *Molecules,* 22(5), 849.

Gardea-Torresdey, J., Peralta-Videa, J., Montes, M., De la Rosa, G., Corral-Diaz, B. (2004). Bioaccumulation of cadmium, chromium and copper by Convolvulus arvensis L.: impact on plant growth and uptake of nutritional elements. *Bioresource technology,* 92(3), 229-235.

Ghadery, C., Pirpamer, L., Hofer, E., Langkammer, C., Petrovic, K., Loitfelder, M., Schwingenschuh, P., Seiler, S., Duering, M., Jouvent, E. (2015). R2* mapping for brain iron: associations with cognition in normal aging. *Neurobiology of aging,* 36(2), 925-932.

Ghani, A., Ghani, A. (2011). Effect of chromium toxicity on growth, chlorophyll and some mineral nutrients of brassica juncea L. *Egyptian Academic Journal of Biological Sciences, H. Botany*, 2(1), 9-15.

Görür, F. K., Keser, R., Akçay, N., Dizman, S., Okumuşoğlu, N. T. (2011). Radionuclides and heavy metals concentrations in Turkish market tea. *Food control*, 22(12), 2065-2070.

Grazuleviciene, R., Nadisauskiene, R., Buinauskiene, J., Grazulevicius, T. (2009). Effects of elevated levels of manganese and iron in drinking water on birth outcomes. *Polish journal of environmental studies*, 18(5).

Gupta, N., Gaurav, S. S., Kumar, A. (2013). Molecular basis of aluminium toxicity in plants: a review. *American Journal of Plant Sciences*, 2013.

Gürkan, R., Ulusoy, H. İ., Akçay, M. (2017). Simultaneous determination of dissolved inorganic chromium species in wastewater/natural waters by surfactant sensitized catalytic kinetic spectrophotometry. *Arabian Journal of Chemistry*, 10, S450-S460.

Haley, B. E. (2005). Mercury toxicity: genetic susceptibility and synergistic effects. *Medical Veritas*, 2(2), 535-542.

Hamadani, J. D., Tofail, F., Nermell, B., Gardner, R., Shiraji, S., Bottai, M., Arifeen, S., Huda, S. N., Vahter, M. (2011). Critical windows of exposure for arsenic-associated impairment of cognitive function in pre-school girls and boys: a population-based cohort study. *International journal of epidemiology*, 40(6), 1593-1604.

Han, J.-X., Shang, Q., Du, Y. (2009). Effect of environmental cadmium pollution on human health. *Health*, 1(03), 159.

Han, W.-Y., Shi, Y.-Z., Ma, L.-F., Ruan, J.-Y., Zhao, F.-J. (2007). Effect of liming and seasonal variation on lead concentration of tea plant (Camellia sinensis (L.) O. Kuntze). *Chemosphere*, 66(1), 84-90.

Hayat, K., Iqbal, H., Malik, U., Bilal, U., Mushtaq, S. (2015). Tea and its consumption: benefits and risks. *Critical reviews in food science and nutrition*, 55(7), 939-954.

Henson, M. C., Chedrese, P. J. (2004). Endocrine disruption by cadmium, a common environmental toxicant with paradoxical effects on reproduction. *Experimental biology and medicine*, 229(5), 383-392.

Hoque, M., Burgess, W., Shamsudduha, M., Ahmed, K. (2011). Delineating low-arsenic groundwater environments in the Bengal Aquifer System, Bangladesh. *Applied Geochemistry*, 26(4), 614-623.

Irfan, M., Hayat, S., Ahmad, A., Alyemeni, M. N. (2013). Soil cadmium enrichment: Allocation and plant physiological manifestations. *Saudi journal of biological sciences*, 20(1), 1-10.

J. SAMPSON, R., S. WINTER, A. (2018). Poisoned development: assessing childhood lead exposure as a cause of crime in a birth cohort followed through adolescence. *Criminology*, 56(2), 269-301.

Joint, F., Additives, W. E. C. o. F. (2003). Sixty-first meeting Rome, 10-19 June 2003. Summary and conclusions. *http://www. who. int/pcs/jecfa/Summaries. htm.*

Joint, F., Bend, J., Bolger, M., Knaap, A., Kuznesof, P., Larsen, J., Mattia, A., Meylan, I., Pitt, J., Resnik, S. (2007). Evaluation of certain food additives and contaminants. *World Health Organization technical report series*(947), 1.

Kaličanin, B., Velimirović, D. (2013). The content of lead in herbal drugs and tea samples. *Open Life Sciences*, 8(2), 178-185.

Karak, T., Bhagat, R. (2010). Trace elements in tea leaves, made tea and tea infusion: A review. *Food Research International*, 43(9), 2234-2252.

Karaulov, A. V., Renieri, E., Smolyagin, A. I., Mikhaylova, I. V., Stadnikov, A., Begun, D., Tsarouhas, K., Djordjevic, A. B., Hartung, T., Tsatsakis, A. (2019). Long-term effects of chromium on morphological and immunological parameters of Wistar rats. *Food and Chemical Toxicology*, 133, 110748.

Kazeminia, M., Mahmoudi, R., Ghajarbeygi, P. (2017). A review on using essential oil of Labiatae species in food products. *The Journal of Qazvin University of Medical Sciences*, 21(1), 73-61.

Khan, A., Khan, S., Khan, M. A., Qamar, Z., Waqas, M. (2015). The uptake and bioaccumulation of heavy metals by food plants, their effects on plants nutrients, and associated health risk: a review. *Environmental Science and Pollution Research*, 22(18), 13772-13799.

Khlifi, R., Hamza-Chaffai, A. (2010). Head and neck cancer due to heavy metal exposure via tobacco smoking and professional exposure: a review. *Toxicology and applied pharmacology*, 248(2), 71-88.

Kim, K.-N., Kwon, H.-J., Hong, Y.-C. (2016). Low-level lead exposure and autistic behaviors in school-age children. *Neurotoxicology,* 53, 193-200.

Kippler, M., Tofail, F., Hamadani, J. D., Gardner, R. M., Grantham-McGregor, S. M., Bottai, M., Vahter, M. (2012). Early-life cadmium exposure and child development in 5-year-old girls and boys: a cohort study in rural Bangladesh. *Environmental health perspectives,* 120(10), 1462-1468.

Kochian, L. V., Pineros, M. A., Hoekenga, O. A. (2005). The physiology, genetics and molecular biology of plant aluminum resistance and toxicity. In *Root physiology: from gene to function* (pp. 175-195): Springer.

Kongpichitchoke, T., Chiu, M.-T., Huang, T.-C., Hsu, J.-L. (2016). Gallic acid content in Taiwanese teas at different degrees of fermentation and its antioxidant activity by inhibiting PKCδ activation: in vitro and in silico studies. *Molecules,* 21(10), 1346.

Krewski, D., Yokel, R. A., Nieboer, E., Borchelt, D., Cohen, J., Harry, J., Kacew, S., Lindsay, J., Mahfouz, A. M., Rondeau, V. (2007). Human health risk assessment for aluminium, aluminium oxide, and aluminium hydroxide. *Journal of Toxicology and Environmental Health, Part B,* 10(S1), 1-269.

Kuang, W., Chen, Z., Shi, K., Sun, H., Li, H., Huang, L., Bi, J. (2020). Adverse health effects of lead exposure on physical growth, erythrocyte parameters and school performances for school-aged children in eastern China. *Environment International,* 145, 106130.

Landsiedel, R., Ma-Hock, L., Hofmann, T., Wiemann, M., Strauss, V., Treumann, S., Wohlleben, W., Gröters, S., Wiench, K., van Ravenzwaay, B. (2014). Application of short-term inhalation studies to assess the inhalation toxicity of nanomaterials. *Particle and fibre toxicology,* 11(1), 1-26.

Layomi Jayasinghe, S., Kumar, L., Sandamali, J. (2019). Assessment of Potential Land Suitability for Tea (Camellia sinensis (L.) O. Kuntze) in Sri Lanka Using a GIS-Based Multi-Criteria Approach. *Agriculture,* 9(7), 148.

Li, K., Reichmann, H. (2016). Role of iron in neurodegenerative diseases. *Journal of Neural Transmission,* 123(4), 389-399.

Liang, Y., Ye, Q., Jin, J., Liang, H., Lu, J., Du, Y., Dong, J. (2008). Chemical and instrumental assessment of green tea sensory preference. *International Journal of Food Properties,* 11(2), 258-272.

Lin, C. L., Lin, J. K. (2008). Epigallocatechin gallate (EGCG) attenuates high glucose‐induced insulin signaling blockade in human hepG2 hepatoma cells. *Molecular nutrition & food research,* 52(8), 930-939.

Liu, S., Yu, Z., Zhu, H., Zhang, W., Chen, Y. (2016). In vitro α-glucosidase inhibitory activity of isolated fractions from water extract of Qingzhuan dark tea. *BMC complementary and alternative medicine,* 16(1), 378.

Lokeshwari, H., Chandrappa, G. (2006). Impact of heavy metal contamination of Bellandur Lake on soil and cultivated vegetation. *Current science,* 622-627.

Mahmoudi, R., Kazeminia, M., Kaboudari, A., Pir-Mahalleh, S., Pakbin, B. (2017). A review of the importance, detection and controlling of heavy metal in milk and dairy products. *MJS,* 36(1), 1-16.

Mahvi, A. H., Malakootian, M., Fatehizadeh, A., Ehrampoush, M. H. (2011). Nitrate removal from aqueous solutions by nanofiltration. *Desalination and Water Treatment,* 29(1-3), 326-330.

Mandiwana, K. L., Panichev, N., Panicheva, S. (2011). Determination of chromium (VI) in black, green and herbal teas. *Food Chemistry,* 129(4), 1839-1843.

Markowitz, M. (2000). Lead poisoning. *Pediatrics in Review,* 21(10), 327.

Martin, S., Griswold, W. (2009). Human health effects of heavy metals. *Environmental Science and Technology briefs for citizens,* 15, 1-6.

Matsumoto, S. T., Mantovani, M. S., Malaguttii, M. I. A., Dias, A. L., Fonseca, I. C., Marin-Morales, M. A. (2006). Genotoxicity and mutagenicity of water contaminated with tannery effluents, as evaluated by the micronucleus test and comet assay using the fish Oreochromis niloticus and chromosome aberrations in onion root-tips. *Genetics and Molecular Biology,* 29(1), 148-158.

Meng, F., Abedini, A., Plesner, A., Verchere, C. B., Raleigh, D. P. (2010). The flavanol (−)-epigallocatechin 3-gallate inhibits amyloid formation by islet amyloid polypeptide, disaggregates amyloid fibrils, and protects cultured cells against IAPP-induced toxicity. *Biochemistry,* 49(37), 8127-8133.

Meyer, M., Rogers, C. (2018). The relationship between exposure to lead and criminal behavior.

Miyata, Y., Shida, Y., Hakariya, T., Sakai, H. (2019). Anti-cancer effects of green tea polyphenols against prostate cancer. *Molecules,* 24(1), 193.

Monalisa, M., Kumar, P. H. (2013). Effect of ionic and chelate assisted hexavalent chromium on mung bean seedlings (Vigna radiata L. wilczek. var k-851) during seedling growth. *Journal of Stress Physiology & Biochemistry,* 9(2).

Morais, S., Costa, F. G., Pereira, M. d. L. (2012). Heavy metals and human health. *Environmental health–emerging issues and practice,* 10, 227-246.

Moseti, K., Kinyanjui, T., Wanyoko, J., Kurgat, J., Too, J., Omondi, K., Wachira, F. (2013). Fe, Zn, Cu, Pb and Cd in tea grown and marketed in Kenya; a quantitative assessment. *International Journal of Environmental Protection,* 3(6), 24.

Mudgal, V., Madaan, N., Mudgal, A., Singh, R., Mishra, S. (2010). Effect of toxic metals on human health. *The Open Nutraceuticals Journal,* 3(1).

Mutlu, A., Lee, B.-K., Park, G.-H., Yu, B.-G., Lee, C.-H. (2012). Long-term concentrations of airborne cadmium in metropolitan cities in Korea and potential health risks. *Atmospheric environment,* 47, 164-173.

Nabulo, G., Oryem-Origa, H., Diamond, M. (2006). Assessment of lead, cadmium, and zinc contamination of roadside soils, surface films, and vegetables in Kampala City, Uganda. *Environmental research,* 101(1), 42-52.

Nagajyoti, P. C., Lee, K. D., Sreekanth, T. (2010). Heavy metals, occurrence and toxicity for plants: a review. *Environmental chemistry letters,* 8(3), 199-216.

Najeeb, U., Ahmad, W., Zia, M. H., Zaffar, M., Zhou, W. (2017). Enhancing the lead phytostabilization in wetland plant Juncus effusus L. through somaclonal manipulation and EDTA enrichment. *Arabian Journal of Chemistry,* 10, S3310-S3317.

Narin, I., Colak, H., Turkoglu, O., Soylak, M., Dogan, M. (2004). Heavy metals in black tea samples produced in Turkey. *Bulletin of environmental contamination and toxicology,* 72(4), 844-849.

Nath, K., Singh, D., Shyam, S., Sharma, Y. K. (2008). Effect of chromium and tannery effluent toxicity on metabolism and growth in cowpea (Vigna sinensis L. Saviex Hassk) seedling. *Research in Environment and Life Sciences,* 1(3), 91-94.

Nazemi, S., Khosravi, A. (2011). A study of heavy metals in soil, water and vegetables.

Nelson, R. L. (1992). Dietary iron and colorectal cancer risk. *Free Radical Biology and Medicine,* 12(2), 161-168.

Obiora, S. C., Chukwu, A., Davies, T. C. (2016). Heavy metals and health risk assessment of arable soils and food crops around Pb–Zn mining localities in Enyigba, southeastern Nigeria. *Journal of African Earth Sciences,* 116, 182-189.

Oh, J., Jo, S.-H., Kim, J. S., Ha, K.-S., Lee, J.-Y., Choi, H.-Y., Yu, S.-Y., Kwon, Y.-I., Kim, Y.-C. (2015). Selected tea and tea pomace extracts inhibit intestinal α-glucosidase activity in vitro and postprandial hyperglycemia in vivo. *International journal of molecular sciences,* 16(4), 8811-8825.

Oladoye, P. O., Olowe, O. M., Asemoloye, M. D. (2022). Phytoremediation technology and food security impacts of heavy metal contaminated soils: A review of literature. *Chemosphere,* 288, 132555.

Olaniran, A. O., Balgobind, A., Pillay, B. (2013). Bioavailability of heavy metals in soil: impact on microbial biodegradation of organic compounds and possible improvement strategies. *International journal of molecular sciences,* 14(5), 10197-10228.

Olympio, K. P. K., da Rocha Silva, J. P., da Silva, A. S., de Oliveira Souza, V. C., Buzalaf, M. A. R., Barbosa Jr, F., Cardoso, M. R. A. (2018). Blood lead and cadmium levels in preschool children and associated risk factors in São Paulo, Brazil. *Environmental Pollution,* 240, 831-838.

Organization, W. H. (1990). Environmental health criteria 107: barium. *Sponsored by United Nations Environment Program, International Labour Organisation, and World Health Organization. Geneva, Switzerland,* 13-19.

Oz, H. S., Chen, T., de Villiers, W. J. (2013). Green tea polyphenols and sulfasalazine have parallel anti-inflammatory properties in colitis models. *Frontiers in immunology,* 4, 132.

Oz, H. S., Chen, T. S., McClain, C. J., de Villiers, W. J. (2005). Antioxidants as novel therapy in a murine model of colitis. *The Journal of nutritional biochemistry,* 16(5), 297-304.

Oz, H. S., Ebersole, J. L. (2010). Green tea polyphenols mediated apoptosis in intestinal epithelial cells by a FADD-dependent pathway. *Journal of cancer therapy,* 1(3), 105.

Oz, H. S., McClain, C. J., Nagasawa, H. T., Ray, M. B., de Villiers, W. J., Chen, T. S. (2005). Diverse antioxidants protect against acetaminophen hepatotoxicity. *Journal of biochemical and molecular toxicology*, 18(6), 361-368.

Papanikolaou, N. C., Hatzidaki, E. G., Belivanis, S., Tzanakakis, G. N., Tsatsakis, A. M. (2005). Lead toxicity update. A brief review. *Medical science monitor*, 11(10), RA329-RA336.

Patrick, L. (2002). Mercury toxicity and antioxidants: Part I: Role of glutathione and alpha-lipoic acid in the treatment of mercury toxicity.(Mercury Toxicity). *Alternative Medicine Review*, 7(6), 456-472.

Petit, D., El Houari, W., Jacobs, K., Baeyens, W., Leermakers, M. (2013). Trace element content in tea brewed in traditional metallic and stainless steel teapots. *Environmental monitoring and assessment*, 185(11), 8957-8966.

Pfadenhauer, L. M., Burns, J., Rohwer, A., Rehfuess, E. A. (2016). Effectiveness of interventions to reduce exposure to lead through consumer products and drinking water: a systematic review. *Environmental research*, 147, 525-536.

Phippen, B., Horvath, C., Nordin, R., Nagpal, N. (2008). Ambient water quality guidelines for iron: overview. *Ministry of Environment Province of British Columbia*.

Pruvot, C., Douay, F., Hervé, F., Waterlot, C. (2006). Heavy metals in soil, crops and grass as a source of human exposure in the former mining areas (6 pp). *Journal of soils and sediments*, 6(4), 215-220.

Qin, G., Niu, Z., Yu, J., Li, Z., Ma, J., Xiang, P. (2021). Soil heavy metal pollution and food safety in China: Effects, sources and removing technology. *Chemosphere*, 267, 129205.

Rasoul, G. M. A., Abou Salem, M. E., Allam, H. K., Kasemy, Z. A., Younis, F. E. (2017). Health-related disorders on occupational exposure to chromium in a leather tanning factory (Menoufia, Egypt). *Menoufia Medical Journal*, 30(1), 92.

Rattan, R., Datta, S., Chhonkar, P., Suribabu, K., Singh, A. (2005). Long-term impact of irrigation with sewage effluents on heavy metal content in soils, crops and groundwater—a case study. *Agriculture, ecosystems & environment*, 109(3-4), 310-322.

Reilly, C. (2006). Pollutants in food—Metals and metalloids. In *Mineral Components in Foods* (pp. 370-395): CRC Press.

Reuben, A., Caspi, A., Belsky, D. W., Broadbent, J., Harrington, H., Sugden, K., Houts, R. M., Ramrakha, S., Poulton, R., Moffitt, T. E. (2017). Association of childhood blood lead levels with cognitive function and socioeconomic status at age 38 years and with IQ change and socioeconomic mobility between childhood and adulthood. *Jama*, 317(12), 1244-1251.

Rock, B., Suriyan, J., Vijay, B., Thalha, N., Elango, S. (2017). Organic Food and Health: A Systematic Review. *Community Med. Health Educ*, 7, 2161-2711.

Roh, T., Steinmaus, C., Marshall, G., Ferreccio, C., Liaw, J., Smith, A. H. (2018). Age at exposure to arsenic in water and mortality 30–40 years after exposure cessation. *American journal of epidemiology*, 187(11), 2297-2305.

Román-Ochoa, Y., Delgado, G. T. C., Tejada, T. R., Yucra, H. R., Durand, A. E., Hamaker, B. R. (2021). Heavy metal contamination and health risk assessment in grains and grain-based processed food in Arequipa region of Peru. *Chemosphere*, 274, 129792.

Saha, S., Hazra, G., Saha, B., Mandal, B. (2015). Assessment of heavy metals contamination in different crops grown in long-term sewage-irrigated areas of Kolkata, West Bengal, India. *Environmental monitoring and assessment*, 187(1), 4087.

Sanders, T., Liu, Y., Buchner, V., Tchounwou, P. B. (2009). Neurotoxic effects and biomarkers of lead exposure: a review. *Reviews on environmental health*, 24(1), 15.

Schroeder, H. A., Kraemer, L. A. (1974). Cardiovascular mortality, municipal water, and corrosion. *Archives of Environmental Health: An International Journal*, 28(6), 303-311.

Schumacher, L., Abbott, L. C. (2017). Effects of methyl mercury exposure on pancreatic beta cell development and function. *Journal of Applied Toxicology*, 37(1), 4-12.

Schwotzer, D., Ernst, H., Schaudien, D., Kock, H., Pohlmann, G., Dasenbrock, C., Creutzenberg, O. (2017). Effects from a 90-day inhalation toxicity study with cerium oxide and barium sulfate nanoparticles in rats. *Particle and fibre toxicology*, 14(1), 1-20.

Seenivasan, S., Manikandan, N., Muraleedharan, N. N. (2008). Chromium contamination in black tea and its transfer into tea brew. *Food Chemistry*, 106(3), 1066-1069.

Shaheen, N., Irfan, N. M., Khan, I. N., Islam, S., Islam, M. S., Ahmed, M. K. (2016). Presence of heavy metals in fruits and vegetables: health risk implications in Bangladesh. *Chemosphere*, 152, 431-438.

Shao, H., Cui, G., Bhat, S. A. (2022). Phytoremediation A Green Technology for Treating Heavy Metal Contaminated Soil. In *Bioremediation of Toxic Metal (loid) s* (pp. 81-94): CRC Press.

Shekoohiyan, S., Ghoochani, M., Mohagheghian, A., Mahvi, A. H., Yunesian, M., Nazmara, S. (2012). Determination of lead, cadmium and arsenic in infusion tea cultivated in north of Iran. *Iranian journal of environmental health science & engineering*, 9(1), 37.

Singh, N., Kumar, D., Sahu, A. P. (2007). Arsenic in the environment: effects on human health and possible prevention. *Journal of Environmental Biology*, 28(2), 359.

Smith, A. H., Lingas, E. O., Rahman, M. (2000). Contamination of drinking-water by arsenic in Bangladesh: a public health emergency. *Bulletin of the World Health Organization*, 78, 1093-1103.

Sofuoglu, S. C., Kavcar, P. (2008). An exposure and risk assessment for fluoride and trace metals in black tea. *Journal of Hazardous Materials*, 158(2-3), 392-400.

Soomro, M. T., Zahir, E., Mohiuddin, S., Khan, A. N., Naqvi, I. (2008). Quantitative assessment of metals in local brands of tea in Pakistan. *Pakistan journal of biological sciences: PJBS*, 11(2), 285-289.

Tabrez, S., Al‐Shali, K. Z., Ahmad, S. (2015). Lycopene powers the inhibition of glycation‐induced diabetic nephropathy: A novel approach to halt the AGE‐RAGE axis menace. *Biofactors*, 41(5), 372-381.

Thakur, M., Praveen, S., Divte, P. R., Mitra, R., Kumar, M., Gupta, C. K., Kalidindi, U., Bansal, R., Roy, S., Anand, A. (2022). Metal tolerance in plants: Molecular and physicochemical interface determines the "not so heavy effect" of heavy metals. *Chemosphere*, 287, 131957.

Tola, A., Ofodile, L., Beyene, F. (2007). Microbial quality and chemical composition of raw whole milk from Horro cattle in East Wollega, Ethiopia. *Ethiopian Journal of Education and Sciences*, 3(1), 1-10.

Trasande, L., Landrigan, P. J., Schechter, C. (2005). Public health and economic consequences of methyl mercury toxicity to the developing brain. *Environmental health perspectives*, 113(5), 590-596.

Udagawa, O., Okamura, K., Suzuki, T., Nohara, K. (2019). Arsenic exposure and reproductive toxicity. In *Arsenic Contamination in Asia* (pp. 29-42): Springer.

Vardar, F., Ünal, M. (2007). Aluminum toxicity and resistance in higher plants.

Wallin, A., Di Giuseppe, D., Orsini, N., Åkesson, A., Forouhi, N. G., Wolk, A. (2017). Fish consumption and frying of fish in relation to type 2 diabetes incidence: a prospective cohort study of Swedish men. *European journal of nutrition*, 56(2), 843-852.

Wang, L., Yang, D., Chen, R., Ma, F., Wang, G. (2022). How a functional soil animal-earthworm affect arbuscular mycorrhizae-assisted phytoremediation in metals contaminated soil? *Journal of Hazardous Materials*, 128991.

Widlansky, M. E., Hamburg, N. M., Anter, E., Holbrook, M., Kahn, D. F., Elliott, J. G., Keaney Jr, J. F., Vita, J. A. (2007). Acute EGCG supplementation reverses endothelial dysfunction in patients with coronary artery disease. *Journal of the American College of Nutrition*, 26(2), 95-102.

Yamabe, N., Kang, K. S., Hur, J. M., Yokozawa, T. (2009). Matcha, a powdered green tea, ameliorates the progression of renal and hepatic damage in type 2 diabetic OLETF rats. *Journal of medicinal food*, 12(4), 714-721.

Yang, F., Massey, I. Y. (2019). Exposure routes and health effects of heavy metals on children. *Biometals*, 32(4), 563-573.

Yang, Q., Zhang, L., Wang, H., Martín, J. D. (2022). Bioavailability and health risk of toxic heavy metals (As, Hg, Pb and Cd) in urban soils: A Monte Carlo simulation approach. *Environmental research*, 214, 113772.

Yang, Y., Chang, A. C., Wang, M., Chen, W., Peng, C. (2018). Assessing cadmium exposure risks of vegetables with plant uptake factor and soil property. *Environmental Pollution*, 238, 263-269.

Ynalvez, R., Gutierrez, J., Gonzalez-Cantu, H. (2016). Mini-review: toxicity of mercury as a consequence of enzyme alteration. *Biometals*, 29(5), 781-788.

Yuan, C., Gao, E., He, B., Jiang, G. (2007). Arsenic species and leaching characters in tea (Camellia sinensis). *Food and Chemical Toxicology*, 45(12), 2381-2389.

Zazouli, M. A., Bandpei, A. M., Maleki, A., Saberian, M., Izanloo, H. (2010). Determination of cadmium and lead contents in black tea and

tea liquor from Iran. *Asian Journal of Chemistry,* 22(2), 1387.
Zeng, X., Xu, X., Qin, Q., Ye, K., Wu, W., Huo, X. (2019). Heavy metal exposure has adverse effects on the growth and development of preschool children. *Environmental geochemistry and health,* 41(1), 309-321.
Zhang, J.-Y., Liao, Y.-H., Lin, Y., Liu, Q., Xie, X.-M., Tang, L.-Y., Ren, Z.-F. (2019). Effects of tea consumption and the interactions with lipids on breast cancer survival. *Breast Cancer Research and Treatment,* 176(3), 679-686.
Zhao, Q., Wang, Y., Cao, Y., Chen, A., Ren, M., Ge, Y., Yu, Z., Wan, S., Hu, A., Bo, Q. (2014). Potential health risks of heavy metals in cultivated topsoil and grain, including correlations with human primary liver, lung and gastric cancer, in Anhui province, Eastern China. *Science of The Total Environment,* 470, 340-347.
Zheng, X., Dai, W., Chen, X., Wang, K., Zhang, W., Liu, L., Hou, J. (2015). Caffeine reduces hepatic lipid accumulation through regulation of lipogenesis and ER stress in zebrafish larvae. *Journal of biomedical science,* 22(1), 1-12.
Zwicker, R., Promsawad, A., Zwicker, B., Laoharojanaphand, S. (2010). Cadmium content of commercial and contaminated rice, Oryza sativa, in Thailand and potential health implications. *Bulletin of environmental contamination and toxicology,* 84(3), 285-288.

Conflict of interest

The authors declare that they have no conflict of interest.

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Abbreviation

Tea Herb: TH, Heavy Metals: HMs, Heavy Metal: HM, Metals: Ms, Arsenic: As, Aluminum: Al, Chromium: Cr, Cadmium: Cd, Zinc: Zn, Lead: Pb, Mercury: Hg, Barium: Ba, Target hazard quotient: THQ, Health Risk Index: HRI, Provisional Tolerable Daily Intake: PTDI, Provisional Tolerable Weekly Intake (PTWI), World Health Organization: WHO, Drinking-Water: DW, Gastrointestinal: GI, Gastrointestinal Tract: GIT, Methylmercury: MeHg, Wastewater: WW