Heavy metals contamination through consumption of contaminated food crops

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Abstract

Contamination of food crops by heavy metals (HMs) is a public health concern that is gradually becoming a global challenge. There is rising concern about food safety and human health due to the unceasing release of HMs into the environment by various forms of anthropogenic activities and natural processes. HMs are highly persistent and when they contaminate the food chain a sustainable circle is created in the food web, the metals will be revolving between the environment, food crops and the human body. This article intended to provide an overview of the sources of HMs and their consumption through food crops. The study reviewed relevant literature published online between January 2018 and December 2020. The leading sources of food crop contamination are sewage and industrial effluents, mining, smelting, illicit dumping of solid waste, abuse of agrochemicals, atmospheric deposit and chemical processing. Leafy vegetables in general and wheat grains are the most contaminated food crops. Pb, Cr and Cd were the most reported HMs in food crops in the last three years. The rate of food crops HMs contamination in the last three years was found to be in the following order: Pb>Cd>Cr>As>Zn>Ni>Cu>Mn>Fe>Hg>Co>Al.

Keywords: Chemical contaminant, food safety, food contamination, soil contamination, heavy metals in food

INTRODUCTION

Food is a basic requirement for life, its safety is a basic right to human (Fung *et al.*, 2018) and food security cannot exist without food safety (Vipham *et al.*, 2020; Sharma and Nagpal, 2020). Food safety, human health and environmental contamination are intimately connected (Rai *et al.*, 2019).

The contamination of food crops by HMs possess a serious challenge to human health (Vatanpour *et al.*, 2020; Zwolak *et al.*, 2019). HMs are potentially harmful substances that are highly persistence and non-biodegradable (Garrigues *et al.*, 2019; Liao *et al.*, 2016), their presence in food can be dangerous to human health (Massoud *et al.*, 2019) and when consumed can accumulate in different body organs (Ngure and Kinuthia, 2020).

The geochemical behaviour and health risk indices of many HMs are not well understood in agro-system (H. Wang *et al.*, 2020). Understanding their effects on human health is even more complicated because of the diversity of their sources and some own some biological functions at minute and regulated quantities (Afonne and Ifediba, 2020). The consequences of environment and food HMs contaminations attracted public attention (L. Wang *et al.*, 2020), meanwhile professionals and regulatory bodies have great concern on the safety of foods since many foods can mask chemicals that a dangerous to human health (Gallo *et al.*, 2020).

Sources of heavy metals

The most common sources of HM to food crops are contaminated sewage and industrial effluents, mining, smelting, illicit solid waste dumping, misused of agrochemicals, atmospheric deposit, rock weathering, traffic pollution and chemical processing such as leather and textile processing wastes (Table 1). The sources identified in this research are very similar to those reported by Sawut *et al.* (2018), El-Radaideh and Al-Taani (2018) and Zwolak *et al.* (2019).

In addition to the aforementioned, thermal power plant, e-wastes and electroplating were also reported by Rai *et al.* (2019). HMs have their ways into soil and food crops through wastewater irrigation and production in contaminated soil. Soil HM concentration significantly increased in recent decades due to the hasty urbanisation and industrialisation (Rai *et al.*, 2019; Hanfi *et al.*, 2020). Irrigation water is contaminated with HMs from natural and anthropogenic sources (M. Deng *et al.*, 2020).

The incessant use of wastewater for irrigation (Chaoua *et al.*, 2019) and excessive use of agrochemical allied are among the major reasons for food crops HM-contamination (Margenat *et al.*, 2018). Areas with a history of industrial activities possess higher levels of HMs contaminants (J. Peng *et al.*, 2019; Liu *et al.*, 2020) and chances of contamination for both humans and animals are higher in these areas and its environs (Bala *et al.*, 2020). The activities of chemical and mining industries continue to intensify environmental contamination since the inception of the industrial revolution (Saadati *et al.*, 2020). Atmospheric deposit, use of sewage sludge and industrial effluent as fertilization and irrigation with untreated industrial effluent also contributed (Rai *et al.*, 2019). The variation in the HM concentration in different locations is an indicator of anthropogenic activities intensity (S. Sharma *et al.*, 2018), hence, the rate of food crops HMs contamination can, to some extent, be related to the population of a location. China, Pakistan and Nigeria were the most reported nations with the highest levels of food crops metal contamination in recent years (Table 1).

Food Crops HMs Contamination

HMs contamination of food crops is more common in developing nations with limited access to foods and clean water (Shakoor *et al.*, 2017). Most of these countries don't have established guidelines for regulations of HM concentrations in foods and environments (Edogbo *et al.*, 2020). Nevertheless, the menace is also affecting developed nations (El-Hassanin *et al.*, 2020; Y. Sun *et al.*, 2019). Weber *et al.* (2019) reported that the Pb, Zn, Cu, As, and Cr contents of the soil in some private vegetable gardens in Sheffield exceed England permissible limits, also the concentration of Mo, Ni, Pb, and As in the soil of gardens around Barcelona exceed Spanish permissible limit (Margenat *et al.*, 2018). Amazingly, illicit waste dumping and burning in agricultural land is still a habit in Giugliano, Italy (Melai *et al.*, 2018). Deviller *et al.* (2020) also identified shortfalls (that can lead to health and environmental problems) that were not properly addressed by the existing EU regulations on the use of the recycle wastewater for agricultural purposes. Also, many European countries lack definite regulations for wastewater reuse (Chojnacka *et al.*, 2020).

Food crops normally absorb HMs through their roots and in rare cases through the leaves (Edelstein and Ben-Hur, 2018). Transpiration rate, plant species and soil conditions such as pH, organic matter content, temperature, texture, cation exchange capacity, presence of microorganisms and other metals affect bioavailability and mobility of trace elements in the soil (Gupta *et al.*, 2019). HMs can accumulate in food crops and subsequently have their way into the food chain (Rai *et al.*, 2019). Once a food chain is contaminated it will become very difficult to be safe, a sustainable circle is created in the food web where the metals will be revolving between the environment, food crops and the human body (S. Kumar *et al.*, 2019). The contamination can be severe and can rich all the nooks and crannies in the food chain, down to the level of milk production and oil extraction as reported by Samiee *et al.* (2019) in human breastmilk, X. Zhou *et al.* (2019) in cow milk and Zaanouni *et al.* (2018) in olive oil. Even the organic foods which are now considered the safest foods can be contaminated with HMs when off-farm manure is used in their production (Zhen *et al.*, 2020). Nevertheless, Tibu *et al.* (2019) recommended the use of compost from municipal solid waste in the production of organic vegetables. Likewise, the concentrations Cd and Pb in local and imported organic cereal-based products sold in Thessaloniki, Greece exceed recommended thresholds (Skendi *et al.*, 2020). Abdallah *et al.* (2020) discovered nanoscale HMs fragments in plants naturally grown in HMs-contaminated soil, similarly, Singh *et al.* (2018) recommend bio-extraction of HM nanoparticles from the plant.

There is variation in the global distribution of HM (Afonne and Ifediba, 2020). HMs contamination levels varies with location and depend greatly on the HMs properties of the growing locations (Jafari *et al.*, 2018). Ebrahimi-Najafabadi *et al.* (2019) reported variation in the HM contents between local and imported rice in Iran. Rapid urbanisation and vigorous industrial activities make China the global epicentre for food crops HMs contamination. China reported dangerous levels of HMs in food crops than any other nation in the last three years (Table 1).

HMs Consumption Through Food Crops

Consumption of foods contaminated with HMs presents critical challenges to global food security and human health (Afonne and Ifediba, 2020), it causes complicated health problems including cancers (Yu *et al.*, 2019). Some HMs have no known biological role and can disrupt biological processes even at minute concentrations, and their rate of accumulation in biological tissues is always higher than the rate of excretion (Ngure and Kinuthia, 2020). Other species of HMs such as Co, Cu, Fe, Mn, Ni, Mo, Se and Zn are essential micronutrients and at required concentrations, they play important roles in many biological processes (Giri *et al.*, 2020). HMs with great health worries are As, Cd, Cr, Pb and Hg (Bhagwat, 2019), they can cause severe health problems even in a small quantity (Vardhan *et al.*, 2019). Pb contamination is now a global challenge, it was the most reported HM in food crops, other toxic HMs reported by researchers in recent years were Cr and Cd (Table 1). The data in Table 1 shows that the rate of food crops HMs contamination in the last three years was found to be in the following order: Pb>Cd>Cr>As>Zn>Ni>Cu>Mn>Fe>Hg>Co>Al. Pb, Cd, As and Hg contaminated foods and beverages more than any other HM (Massoud *et al.*, 2019). Cd, As, Cr and Ni are the most consumed HMs with high cancer risks (V. Kumar *et al.*, 2019). Arsenic is the most ingested HM by both children and adults (V. Kumar *et al.*, 2019), while Cd and Pb are the most soluble and mobile HMs (Elmi *et al.*, 2020). Cd and Hg are the potential dangerous HMs due to their bioavailability caused by their high solubility and exchange capability (L. Sun *et al.*, 2019). Cd and Pb are dangerous and cause serious health problems to both humans and livestock even at minute levels (Sharifan *et al.*, 2020). Hg, Pb and Cd are associated with kidney and neural damages (Fung *et al.*, 2018). Arsenic is a chronic carcinogen, and its toxicity can also cause respiratory disorder, skin lesion, diabetes and heart-related diseases (Nachman *et al.*, 2017). Direct consumption of As either through foods or drinking water is considered a life-threatening issue (Shakoor *et al.*, 2017). Mercury in the form of methylmercury can cause severe health problems that can lead to loss of consciousness and death (Reis and Mizusawa, 2019). Food contaminated with Pb, Mn and Cd can lower immunity and affect the functions of vital organs (Obiora *et al.*, 2019) Increase blood Pb level in children damage kidney and lead to the formation of cancer cells (Obiora *et al.*, 2019).

Table 1 : Contamination sources and HMs species in different food crops produced/consumed in different parts of the World

Location	Contamination Source	Food Crop	HM Species	Remark	Reference
Mangla, Pakistan	Sewage & industrial wastewater, repair workshops	Common wheat, Arugula	Cd, Cr, Pb	Conc. exceed EU standard,	(Mehmood *et al*., 2019)
Dingshu, China	Ceramic factories & chemical plants	Rice, Wheat	Cd, Ni, Pb, Zn	Conc. exceed Chinese standard	(Y. Zhou *et al*., 2019)
Ishiagu, Nigeria	Lead & zinc mining	leafy and tuber crops	Pb, Zn, Cr, Cd	Conc. exceed EU and WHO/FAO PL, DIM exceed USEPA limit, HRI >1	(Obiora *et al*., 2019)
Kafr El-Sheikh, Egypt	Sewage & industrial wastewater	Maize grains	Pb,	Conc. exceed WHO/FAO PL	(El-Hassanin *et al*., 2020)
Xuyi County, China	Rocks weathering	Wheat, Rice	Ni	Conc. exceed Chinese standard	(H. Wang *et al*., 2020)
Khyber, Pakistan	Agrochemicals, wastewater & groundwater	fruit, leaf and root vegetables	Cr	Conc. exceed Chinese and EU PL	(Z. U. Rehman *et al*., 2018)
North Anhui, China	Multi-metal mining	soybean	Ni, Cr, Cu, Pb	Conc. exceed Chinese standard	(Zhang *et al*., 2019)
Sibate, Colombia	Industrial wastewater	Commonly consumed vegetables	As, Pb and Cr	Conc. exceed WHO/FAO PL	(Lizarazo *et al*., 2020)
Punjab, India	Industrial wastes from cement industry & thermal power plant, agrochemicals.	wheat, rice, maize and mustard seeds	Pb, Co	Conc. exceed WHO PL	(S. Sharma *et al*., 2018)
Bushehr, Iran	Sewage & industrial wastewater, underground water	Lettuce, spinach, cabbage, onion, potato, tomato and green pepper	Cd, Pb	Conc. exceed EU standard, THQ is >1	(Cheshmazar *et al*., 2018)
Yangtze River Delta, China	Mining, chemical industries	Rice	As, Ni	Conc. exceed Chinese standard	(Hu *et al*., 2019)
Sahiwal, Pakistan	Sewage & industrial wastewater, underground water	Mustard leaf, carrot, turnip, cabbage, spinach and cauliflower	Pb, Cd, Mn, Fe	Conc. exceed WHO PL, HRI is >1 for Mn	(ur K. Rehman *et al*., 2019)
Kermanshah, Iran	Atmospheric deposit from vehicles & industries, petrochemical wastes	Wheat and rice	Cr, Ni	TCR > 10^{-4}	(Doabi *et al*., 2018)
Baluchistan, Pakistan	Rocks weathering	Tomato, onion, wheat and apple	Cd, Ni	HQ is >1	(Muhammad *et al*., 2019)
Guangdong Province, China	Industrial wastes	Commonly consumed vegetables	As, Cd, Cr and Pb	Conc. exceed Chinese standard	(Liang *et al*., 2018)
Kano, Nigeria	Tanneries, textiles, food and cement industries wastes	the lettuce, tomato, onion, potato and spinach	Cd, Cr, Pb	Conc. exceed EU standard and FAO/WHO PL, HQ is >1	(Edogbo *et al*., 2020)
Kilembe, Uganda	Mining	Beans, yam, amaranth, and groundnut	Cu, Zn, Pb	Conc. exceed EU standard and FAO/WHO PL	(Mwesigye *et al*., 2019)
Beijing, China	Market samples	commonly consumed cereals and legumes products	Cr, Cu and Mn	HI >1	(Wei and Cen, 2020)
Tajan, Iran	Agrochemicals, wastewater, mining and atmospheric deposit from dust	Rice	Pb, Fe, Cr, Cd	THQ >1, HI >1	(Vatanpour *et al*., 2020)
Migori, Kenya	Gold mining	Cabbage and mango	Cd	Conc. exceed FAO/WHO PL	(Ngure and Kinuthia, 2020)
China	Not mention	Chestnut	Pb, As, Cd, Cr, Hg	Exceed Chinese standard for children	(Wu *et al*., 2019)
Niger-Delta, Nigeria	Not mention	Wheat	As	Conc. exceed FAO/WHO PL	(S. Wang *et al*., 2019)
EU-28 except Croatia	Not mention	Wheat	As	Conc. exceed FAO/WHO PL	(S. Wang *et al*., 2019)
Veles, Macedonia	Not mention	Wheat	Cd	Conc. exceed FAO/WHO PL	(S. Wang *et al*., 2019)

Table 1 (Cont'd): Contamination sources and HMs species in different food crops produced/consumed in different parts of the World

Location	Contamination Source	Food Crop	HM Species	Remark	Reference
Murcia, Spain	Not mention	Wheat	Cd	Conc. exceed FAO/WHO PL	(S. Wang *et al*., 2019)
Thessaloniki, Greece	Market samples for locally produced and EU-imported cereals	Organic wheat, rye, barley, oat, rice and maize	Cd, Pb	Conc. exceed EU standard	(Skendi *et al*., 2020)
Avdiivka and Zmiiv, Ukraine	Coke and chemical plant emissions, thermal power plant	Wheat, corn, sunflower, barley, oat, ray and buckwheat	Cu	Conc. exceed Ukrainian standard	(Semenov *et al*., 2019)
Shiraz, Iran	Vehicle emission from highways	Spinach, dill, cress and cilantro	Pb	Conc. exceed Iranian and FAO/WHO PL	(Rahmdel *et al*., 2018)
Gyeongsangnam-do, Korea	Atmospheric deposit from particulate matter	Chrysanthemum and spinach	Pb	Conc. exceed Korean and EU standards,	(Noh *et al*., 2019)
Ibadan, Nigeria	Market samples	Cowpea	Zn, Cr, Cu, Pb, Fe	Conc. exceed FAO/WHO PL	(Olutona and Aderemi, 2019)
Tarnaveni, Romania	Chemical factory	Lettuce, green onion	Cr, Mn, Pb	Conc. exceed Romanian standard	(Mihaileanu *et al*., 2019)
Tolon, Ghana	Contaminated soil, agrochemicals and milling plate.	Maize and millet	Pb,	Conc. exceed FAO/WHO PL	(Larsen *et al*., 2020)
Uthai, Thailand	Wastes from industrial estate	Basil and coriander	Hg, Cu	Conc. exceed Thailand PL, THQ >1, HI >1	(Kladsomboon *et al*., 2020)
Antalya, Turkey	Market samples	Red pepper	Pb	Conc. exceed EU standard	(Kilic *et al*., 2018)
Mardan Khyber Pakhtunkhwa, Pakistan	Market samples	Instant noodles	Cd, Cr	Conc. exceed FAO/WHO PL, THQ for Cr is >1	(Idrees, 2020)
Huludao, China	Zinc smelter	Maize	Pb, Cd	Conc. exceed Chinese National Standard	(Hou *et al*., 2019)
Sitakunda, Bangladesh	Ship scraps	Olive, okra, papaya, guava, rice, banana, Teasle gourd, Bottle gourd	Pb, Cd, Zn, Cu,	THQ is >1	(Hasan *et al*., 2020)
Sagamu, Nigeria	Waste dumpsite, cement factory, oil depot, vehicular emission from highway	Plumb cockscomb and jute mallow leaves	Pb, Cd	Conc. exceed EU standard and WHO PL	(Oguntade *et al*., 2020)
Kayseri, Turkey	Market samples	Ginger	As, Cd	Conc. exceed WHO PL	(Tokalıoğlu *et al*., 2018)
Arab-El-Madabegh, Egypt	Sewage water	Lettuce, spinach	Zn, Pb, Cd, Ni	Conc. exceed EU standard and FAO/WHO PL	(Eissa and Negim, 2018)
San Diego, USA	Urban soil	Blood orange, Mexican lime, black mission fig	Pb, As	Conc. exceed FAO PL	(Cooper *et al*., 2020)
Mbale, Uganda	Dumpsite	Spinach, maize	Pb, Cr, Al, Zn	Conc. exceed FAO/WHO PL	(Awino *et al*., 2020)
Tamale, Ghana	Market samples	Cabbage, carrot, green pepper, onion, tomato	Cd, Cr, Mn	HQ is >1	(Ametepey *et al*., 2018)
Peshawar, Pakistan	Market samples	Lettuce, coriander, carrot	Cd, Cr, Pb	Conc. exceed FAO/WHO PL, THQ >1	(Alam *et al*., 2018)
Mojo, Ethiopia	Industrial wastewater	Cabbage, tomato	As, Pb, Cd, Cr, Hg, Co	Conc. exceed EU standard, THQ >1, HI >1, TCR > 10^{-4}	(Gebeyehu and Bayissa, 2020)
Enugu, Nigeria	Dumpsite	Maize, scent leaves, bitter leaves, water leaves	Cd, Pb, Cr, Zn, Fe, Al	Conc. exceed FAO/WHO PL, THQ for Cd is >1	(Ekere *et al*., 2020)
Nevşehir, Turkey	Atmospheric deposit from chimneys	Parsley, lettuce, spinach, leek, onion	Mn, As, Cu, Zn, Ni, Pb, Cd	Conc. exceed EU standard and FAO/WHO PL, THQ is >1 except for Pb and Cd	(Leblebici *et al*., 2020)

PL: permissible limit; HQ: Hazard Quotient; HI: Hazard Index; TCR: Target cancer risks; DIM: Daily In-Take of Metals

HMs are consumed more through staple foods; cereals and vegetables are the most common carriers (Liu *et al*., 2019; Yu *et al*., 2019; Zheng *et al*., 2020). Lower amounts are consumed through tree-fruits and their nuts (Wu *et al*., 2019). Y. Huang *et al*. (2019) reported that vegetables and paddy farms accumulate more HMs than other upland areas. HMs intake through rice consumption is becoming a threat to human health (X. Deng *et al*., 2020). Contamination of rice is now a global concern and many health problems are associated with the consumption of contaminated rice due to its ability to accumulate dangerous HMs such as As, Cd, Pb, Ni, and Cr among others (Ali *et al*., 2020; Khanam *et al*., 2020). Wheat consumption also contributed greatly and account for over 60 % of human health risks (S. Wang *et al*., 2019). Baruah *et al*. (2019) reported a higher transfer rate for Pb, Cu and Cd in wheat seedling. Leafy and other vegetables are the most contaminated foods with Pb among all other foods consumed in Northern Italy (Malavolti *et al*., 2020). Infant foods and vegetables contain more Pb than other food categories in Brazil (Neto *et al*., 2019). Dangerous levels of different HMs were reported in various food crops by many researchers in different parts of the World. A summary of recent findings reported dangerous levels of HMs were presented in Table 1. Different standards, both local and international, were used by researchers in arbitrating the toxicity levels of different HMs in different food crops. The international standards commonly used as references are the Joint FAO/WHO Food Standards published by Codex Alimentarius Commission in 2001, 2007, 2010, 2011, 2013 and 2016, and European Commission regulations published in 1997 (194/97), 2006 (1881/2006) and 2008 (629/2008).

Recommendations

• Effective monitoring and enforcement of environmental protection laws and the establishment of operational food safety inspection and investigation systems can minimize the consumption of HMs and other food contaminants.

• Massive awareness through socio-environmental campaign can change the attitude of people that are careless about the soil and water safety.

• Sensitisation campaigns to the farmers and other stakeholders in the production chain on the dangers associated with food production on the contaminated field and that of using contaminated water for irrigation will contribute a lot.

• Creating awareness on the danger associated with consuming contaminated food will guide consumers to make a better decision on choosing good quality foods.

• Dangers associated with HMs contamination can be minimised by choosing crops with less metal accumulation capacity and those with low affinity to most dangerous HM species.

• Organic foods are healthier than food produced through conventional agriculture, they contain less HMs and other contaminants, and possess better nutritional qualities.

CONCLUSION

Vigorous industrial activities, hasty urbanization, poor environmental policy, failure to enforce environmental protection laws, illiteracy, poverty, and food scarcity are among the leading factors that caused HMs contamination in food crops. The leading sources of food crop contamination are sewage and industrial effluents, mining, smelting, illicit dumping of solid waste, abuse of agrochemicals, atmospheric deposit and chemical processing. Leafy vegetables in general and wheat grains are the most contaminated food crops. Pb, Cr and Cd were the most reported HMs in food crops in the last three years. The rate at which food crops are contaminated with HMs in recent years is observed to be in this order: Pb>Cd>Cr>As>Zn>Ni>Cu>Mn>Fe>Hg>Co>Al.

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