How Healthy Are Horticultural Plants Grown in Polluted Cities? The Case of Mexico City

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Abstract

Soil to plant metal(loid) accumulation has been highly evaluated in recent years due to its significant impact on human health. This study reports the concentrations of 15 metal(loid)s in four vegetables (tomato, onion, chili, and lettuce) cultivated in one greenhouse, one top garden, and two roof gardens, rooftop urban gardens in four locations within the metropolitan area of Mexico City. In this experiment, the contribution of metals and metalloids due to atmospheric deposition and irrigation may be negligible. It is considered that the concentration of metals depends only on transfer from the soil. Soil analysis indicates that only vanadium in one location (a rooftop garden in V. Carranza) exceeds the permissible limits recommended by the Mexican government. For most metals, lettuce shows the highest concentrations and transfer factors compared to the other vegetables studied. The transfer factors were exceptionally high for Cd (lettuce) and Hg (tomato), presenting values above 1.

The concentrations of As, Cd, Hg, and Pb were compared with permissible limit values recommended for vegetables by different international agencies. It was observed that, except for As, these values are exceeded in various vegetables harvested in this study. This information must be corroborated with more detailed studies evaluating the chemical species in which those metal(loid)s is present and identifying the physicochemical parameters of the soil that caused the enrichment of these metal(loid)s to exceed the permissible limit values.

Introduction

Inequalities and impoverishment of the world population have caused a constant acceleration of human migration to large urban areas, which has led to such megalopolises becoming home to more than 50% of the world population (UN 2019).

This phenomenon usually results in a lack of access to green and agricultural areas, which has led to a search for alternative sources of these. One alternative source is urban agriculture (UA) (FAO 2007; SAGARPA 2020), comprising a set of practices that aim to produce food within cities, occupying their resources (Figueroa-Vera and Izquierdo 2003; García-Céspedes et al. 2016; Miranda et al. 2008). UA also represents, on certain occasions, support for the family economy.

However, the increase in urbanization and industrialization caused by migration has reduced the environmental quality (Bringezu et al. 2014). Urban activities release particles into the environment that can contain considerable amounts of metals and metalloids [metal(loid)s] (Edelstein and Ben-Hur 2018), which may enter the trophic chain including humans, potentially negatively affecting health (Arif et al. 2019; Rai et al. 2019).

In this sense, although the practice of UA is increasing as an ecological and economic alternative, it must be considered that urban contamination can represent a human health problem.

In Mexico City, the practice of UA has been promoted by the local government since 2016 (ALDF 2016; Government of Mexico City 2019; SEDEMA 2016) while making minimal or no mention of the considerations required to prevent crops from being contaminated with metal(loid)s.

The health impact derived from ingesting vegetables contaminated with metal(loid)s depends on the concentration of the element accumulated in them. This is generally determined by the concentration of metal(loid)s in the soil, and its specific properties, such as organic material content, pH, and the soil-plant transfer factor (TF) of metal(loid)s. The TF expresses the uptake capacities of plants. It is evaluated from the ratio of the content of metal(loid)s in the plant to that in the soil (Gall et al. 2015) and is an important criterion for assessing global human health concerns (Khan et al. 2008; Rothenberg et al. 2007; Woldetsadik et al. 2017). If the TF $\leq$ 1.00, this indicates the plant can only absorb but not accumulate metal(loid)s. Heavy metal hyperaccumulation is defined as the accumulation of more than 0.1% by dry weight in plant tissue.

Several hazardous metal(loid)s are classified as non-essential to metabolic and other biological functions. Such metals are deleterious in various respects (Gall et al. 2015). Therefore, they have been included in the top 20 list of dangerous substances by the United States Environmental Protection Agency and the Agency for Toxic Substances and Disease Registry (ATSDR 2007; Khalid et al. 2017; Rai 2018 Xiong et al. 2017). Different national and international agencies have established metal concentration guideline values regulating the metal content of edible grown produce (FAO/WHO, Codex Alimentarius; Food Safety Law of the People's Republic of China 2009).

This research aimed to investigate the presence of 16 metal(loid)s in four widely consumed horticultural species (lettuce, onion, tomato, and chili) cultivated under different modalities of UA: a greenhouse, one top garden in a botanical garden, and two rooftop gardens in different locations in the urban area of Mexico City, presumably exposed to different environmental pollution conditions. These concentrations were compared with existing permissible limit values for As, Cd, Hg, and Pb recommended by international agencies to evaluate the possible health risk derived from the consumption of these horticultural plants grown in the urban area of Mexico City.

Materials And Methods

Horticultural plants and cultivation locations. Plants of onion, tomato, chili, and lettuce were obtained from commercial seeds sown in seedbeds; the seedlings were planted in pots in a greenhouse. When the seedlings reached a height of 10–15 cm, they were transplanted into hydropots placed for growth in four different locations in the urban area under different conditions and presumably under different contamination levels: control site – greenhouse; Coyoacán – on the ground in a botanical garden; Azcapotzalco – in a rooftop garden; V. Carranza – in a rooftop garden. Two or three hydropots with each cultivar were placed at each site.

When the fruits of tomatoes and chili, onion bulbs, and lettuce leaves reached a size and maturity to be edible, five samples of each species and different individuals were collected. They were stored in brown paper bags and taken to the laboratory, where they were washed with distilled water and subsequently dried in an oven at50 ± 3°C (UN 750 single screen Brand: Memmert, USA). The dry material was ground first in a mortar and later in a mill.

At each study site, 20 g of soil was taken from each pot, mixed (160 g in total), and 100 g was taken. Soil samples were obtained at the time of planting and during the dry season (three repetitions in each case). Each sample was dried in an oven at 40°C for 24 or 48 hours.After this time, each sample was sieved with a 0.25 mm mesh and later crushed and ground; samples were stored in a cool place before processing.

Metal analysis. Samples of horticultural plants and soil were analyzed by mass spectrometry with inductively coupled plasma (ICP-MS). The metal(loid)s studied were Al, As, Ba, Cd, Co, Cr, Cu, Fe, Hg, Mn, Mo, Ni, Pb, Sb, V, and Zn. All metal measurements were performed on an iCAP Qc mass spectrometer (Thermo Scientific, Germany).

Horticultural plants. For each sample, 0.5 g was weighed into Teflon vials, and 5 ml of ultrapure grade HNO_3 was added. Microwave oven-assisted digestion (Ultrawave digester, Milestone, Italy) was conducted in two stages: 1) a ramping stage for 20 min at 1,500 W, 230°C, and 110 bar pressure and 2) a holding stage of 15 min with the same power, temperature, and pressure values. Once the program was completed, the samples were allowed to cool before volumetrically diluting to 25 mL with deionized water, filtering, labeling, and storing at 4°C for later analysis by ICP-MS.

Soil. We weighed 0.2 g of sample of soil and added 4 mL of inverted aqua regia (3 ml HNO_3:1 ml HCl) and 1 ml HF. Subsequently, microwave oven-assisted digestion was conducted in two stages: 1) 20 min ramping at 1,500 W, 260°C, and 110 bar pressure and 2) a 15 min holding stage with the same power, temperature, and pressure values. Once the program was finished, the samples were placed in Teflon vessels to evaporate in a heating grid. Twice, 1 ml of HCl was added during evaporation. Once the program was finished, the samples were cooled and made up to 50 mL with a solution of 2% HNO_3. They were then filtered, labeled, and stored at 4°C.

For every ten plant samples, two certified reference materials (CRMs), 1547 peach leaves and 1573a tomato leaves (National Institute of Standards Technology [NIST]), two duplicates of samples chosen at random, and a reagent blank were digested to monitor possible contaminant input. For the soil samples, CRM 2709a soil San Joaquin (NIST) was digested.

The instrument was optimized before sample analysis, with a certified aqueous solution of the High Purity Standards brand containing a wide range of masses (Li, Co, In, Ba, Bi, Ce, and U of 1 μg L^{-1}). For the metal analysis, a calibration curve was constructed with 16 points (0, 0.1, 0.25, 0.5, 0.75, 1, 2.5, 5, 7.5, 10, 25, 50, 75, 100, 250, and 500 μg L^{-1}) from a certified aqueous multi-element solution of the High Purity Standards brand (QCS-26). The instrumental drift was corrected with the Indio internal standard (In of 10 μg L^{-1}).

Results And Discussion

Table 1 shows metal(loid)s concentrations in representative soil samples from the crop locations considered in this study, with the intervention guideline values dictated by the Mexican Environmental Regulations (SEMARNAT 2007). Most of the analyzed metal(loid)s were enriched in the control site (greenhouse). The concentrations of metal(loid)s in the other three locations considered in this study were similar. Table 1 shows that vanadium (V) was the only metal(loid) exceeding guideline values in three locations. This result has been frequently reported in soils not impacted by anthropogenic sources in the area. It can be attributed to the high V concentration of the andesitic host rock surrounding the urban area (Morton-Bermea et al. 2009).

Soils are fundamental substances for food crops (Rai et al. 2019; Shah et al. 2019). Heavy metal(loid)s concentrations in soils mainly depend on the geology of the area where they originate, while atmospheric deposition and wastewater or polluted water irrigation can be considered as anthropogenic metal(loid)s sources (Chary et al. 2008; Elgallal et al. 2016; Kim et al. 2015; Schreck et al. 2012). For this study, the soils were brought from a plant nursery located in a rural area near the metropolitan area of Mexico City.

When calculating the possible contribution of metal(loid)s in the analyzed soils to atmospheric deposition, it must be considered that the soil was placed immediately before crop cultivation during conditioning of crop locations. The soil was sampled at the beginning and end of the process, such that the maximum time between collections was between 4 and 8 months. Thus, the contribution of metal(loid)s by atmospheric deposition can be neglected since the samples were not exposed to long-term deposition. However, it can also be observed that the average metal(loid)s concentrations in the analyzed soil samples were similar to the background values reported by Morton-Bermea et al. (2009) for soils in the area.

The contribution of metal(loid)s generated by long-term use of partially treated or untreated wastewater could result in accumulation of heavy metal(loid)s in the soil (Elgallal et al. 2016). The contribution generated by irrigation could also be depressed since the irrigation system applied during growth used only potable water and rainwater. Thus, it can be considered that the translocation of metal(loid)s to plants is only determined by the content of metal(loid)s in the soils. Moreover, the increase in the concentration of metal(loid)s in horticultural plants depends on their capacity to assimilate the metal(loid)s (TF), the total concentration of metal(loid)s in the soil, their chemical form, and other physicochemical parameters of the soil (e.g., pH and organic matter content).

The TFs of the analyzed metal(loid)s are presented in Table 2 for each of the analyzed horticultural plants; the values are in the range of TFs compiled by Khan et al. (2015), reported in recent studies. Table 2 shows that lettuce presents the highest TF for almost all metal(loid)s except for Pb and Hg, which are higher for tomato, and Mo, whose TF is higher for onion. It is frequently reported that leafy horticultural plants can absorb and accumulate metal(loid)s more quickly and readily than other upland crop types. For many elements, leafy horticultural plants have been classified as hyperaccumulators.

Especially revealing in this study is that Hg in the tomato presented a TF of 1.5; values above 1.0 indicate a higher uptake of metal(loid)s in horticultural plants than in the soil. Therefore, tomato can be classified as a Hg bioaccumulator under these soil conditions. Metal(loid)s concentrations in horticultural plants are reported in Table 3. Additionally, Fig. 1 shows a comparison of the concentrations found in each vegetable from each locality for each metal(loid). Data assessment shows that indoor cultivation of crops in a controlled environment cannot guarantee food safety; for some metal(loid)s in horticultural plants harvested at the control site, the concentration was higher than in other areas. In this study, this may be related to the metal(loid)s concentration being higher in soils of this locality. However, this effect has been previously reported, and the increase is due to growth under reduced illumination (Li et al. 2017).

Especially important is the quantification of hazardous metal(loid)s, such as As, Cd, Hg, and Pb, classified as non-essential to metabolic functions and included in the top 20 list of dangerous substances by the Agency of Toxic Substances and Disease Registry (ATSDR, 2007). The permissible limits for different countries and organizations vary regarding concentrations of different heavy metal(loid)s. In this study, metal(loid)s concentrations in the analyzed horticultural plants were compared with the permissible limits recommended by the Codex Alimentarius Commission (CAC); FAO/WHO 2019) for As, Cd, and Pb. Since this regulation does not recommend permissible values for Hg, the Hg content was compared with the limit values recommended by the Food Safety Law of the People's Republic of China (Table 4). All analyzed samples exceeded the CODEX recommended permissible values for Pb and Cd except for one sample (chili collected in Coyoacán). The mercury concentrations in tomato and lettuce samples exceeded the recommended permissible values recommended by the Food Safety Law of the People's Republic of China (2009).

Metal(loid)s accumulation in vegetables growing in agricultural soils irrigated with wastewater or cultivated in the vicinity of industrial zones frequently exceeds the permissible values. However, the accumulation of metal(loid)s in vegetables growing in urban areas is infrequent. The highly enriched Cd, Pb, and Hg concentrations found in the analyzed horticultural plants considered in this study may be due to the high FT values since the concentrations of these elements in the soils do not exceed the permissible values (SEMARNAT 2007). An explanation for this may be that the enriched metal(loid)s are present in the soils in an available chemical form or that these soils possess physicochemical parameters favoring metal(loid)s translocation.

Horticultural plants are an important source of human diets. Toxicological effects from consumption of metal(loid)s-contaminated food by humans depend on various factors: metal(loid) chemical form, dose, and exposure route. A human health hazard is closely linked to the intake of metal(loid)s-contaminated food crops. Excess Pb levels in the human body cause neurological and cardiovascular effects in humans, especially children (Dotaniya et al. 2020; Manisalidis et al. 2020). Health risk effects due to As exposure range from acute to chronic effects, including cancer, hyperkeratosis, melanosis, peripheral vascular diseases, lung diseases, and hypertension. Excessive As levels can cause skin and lung cancer (Bundschuh et al. 2021; Shahab and Zaheer 2019). High concentrations of Cd can cause kidney dysfunction and other serious liver diseases. Therefore, Cd is suspected to cause cancer (Lv et al. 2017). Consumption of Hg-contaminated horticultural plants have been associated with damage to the central nervous system, kidneys, and thyroid gland. The primary consequence of chronic oral exposure to low amounts of inorganic Hg compounds is renal damage (ATSDR 1999; Clarkson 2002; UNEP 2002).

Conclusion

This study contributes relevant information that must be considered regarding the growing trend in highly populated metropolitan areas of cultivating horticultural plants in urban gardens and on green rooftops. The analyzed horticultural plants cultivated on soils that do not exceed the Mexican regulations for heavy metal(loid)s concentrations in agricultural soils exceed the permissible limits recommended for Cd, Pb, and Hg, which are included in the list of dangerous substances by the ATSDR (ATSDR 2007). The possible health risk derived from consuming horticultural plants must be evaluated together with the soil and environmental conditions or parameters that led to the increased soil-plant transfer.

Declarations

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Authors' contributions: IAD and MCO conceived and designed the experiment; IAD conducted fieldwork; EHA determined the metal(loids); IAD, EHA, OMB, JCL, and MCO analyzed and discussed the results, and wrote the article.

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Tables

Table 1 Concentration of metals in vegetables. Concentrations above the permissible limit values are marked in bold.

Metal	Localzation	Vegetable (mg Kg^{-1})			
		Tomato	Onion	Chili	Lettuce
As	Control Site	0.008			0.012
	Coyoacán	0.011			0.013
	V. Carranza	0.006	0.021	0.009	0.043
	Azcapotzalco				0.047
Ba	Control Site	5.34	16.52	3.63	21.22
	Coyoacán	4.94	9.88	4.52	49.14
	V. Carranza	3.17	18.19		36.74
	Azcapotzalco				78.70
Cd	Control Site	**0.197**	**0.082**	**0.071**	**0.350**
	Coyoacán	**0.181**	**0.130**	0.026	0.154
	V. Carranza	**0.071**	**0.122**		0.141
	Azcapotzalco				**0.291**
Co	Control Site	0.112	0.053	0.076	0.083
	Coyoacán	0.076	0.048	0.044	0.168
	V. Carranza	0.049	0.023		0.173
	Azcapotzalco				0.177
Cr	Control Site	0.099	0.166	0.165	0.266
	Coyoacán	0.103	0.076	0.102	0.360
	V. Carranza	0.058	0.060		0.926
	Azcapotzalco				0.613
Cu	Control Site	4.13	4.82	5.08	8.01
	Coyoacán	3.13	3.34	5.71	5.32
	V. Carranza	3.78	3.60		5.64
	Azcapotzalco				4.71
Fe	Control Site	39.9	71.7	60.1	149.3
	Coyoacán	44.2	48.4	47.2	139.0
	V. Carranza	32.5	44.5		378.8

	Azcapotzalco				217.6
Hg	Control Site	**0.022**	0.006	0.006	**0.019**
	Coyoacán	**0.020**	0.001	0.004	0.005
	V. Carranza	0.004	0.005		**0.010**
	Azcapotzalco				**0.016**
Mn	Control Site	9.34	11.70	11.13	63.37
	Coyoacán	12.15	12.40	11.93	140.25
	V. Carranza	6.86	9.18		29.46
	Azcapotzalco				110.11
Mo	Control Site	0.107	0.085	0.082	0.233
	Coyoacán	0.282	0.156	0.263	0.266
	V. Carranza	0.410	0.841		0.576
	Azcapotzalco				0.208
Ni	Control Site	0.788	1.180	0.770	1.053
	Coyoacán	0.304	1.159	0.489	0.455
	V. Carranza	0.542	0.383		0.979
	Azcapotzalco				0.915
Pb	Control Site	**1.435**	**0.627**	**0.421**	0.181
	Coyoacán	**1.068**	**0.254**	**0.252**	**0.584**
	V. Carranza	**0.687**	**0.179**		**0.514**
	Azcapotzalco				0.219
Sb	Control Site	0.015	0.008	0.007	0.057
	Coyoacán	0.018	0.023	0.005	0.073
	V. Carranza	0.010	0.025		0.139
	Azcapotzalco				0.129
V	Control Site	0.023	0.100	0.025	0.297
	Coyoacán	0.023	0.022	0.020	0.318
	V. Carranza	0.011	0.014		1.006
	Azcapotzalco				0.532

Zn	Control Site	20.70	26.66	20.75	76.90
	Coyoacán	21.30	25.64	20.90	34.87
	V. Carranza	17.03	26.31		43.91
	Azcapotzalco				32.95

Table 2 Metal(loid)s concentration in soils. For each metal the location with the highest concentration is indicated in bold. Concentrations above the permissible values are indicated in italics.

	Location			
	Control Site	Coyoacán	V. Carranza	Azcapotzalco
	mg Kg^{-1}	mg Kg^{-1}	mg Kg^{-1}	mg Kg^{-1}
As	**5.99**	5.92	4.94	3.87
Ba	293.21	349.72	**412.31**	284.41
Cd	**0.26**	0.22	0.24	0.23
Co	19.56	**19.57**	14.90	12.44
Cr	129.42	**143.46**	111.12	96.87
Cu	**23.44**	23.20	21.01	16.69
Fe	**36054.1**	34931.0	28078.5	22004.4
Hg	0.01	**0.01**	0.01	0.08
Mn	812.4	**822.7**	707.7	508.3
Mo	**2.83**	2.24	1.67	2.54
Ni	75.41	**76.20**	57.06	46.51
Pb	**15.34**	11.79	14.97	14.07
Sb	**0.92**	0.75	0.61	0.56
V	***119.77***	*118.45*	*88.32*	71.05
Zn	**76.81**	70.38	70.00	55.82

Table 3 Transfer factor (TF) calculated for the vegetables considered in this study. For each metal the highest TF is indicated in bold.

Metal	Tomato	Onion	Chili	Lettuce
As	0.0014	0.0014	0.0009	**0.0063**
Ba	0.0133	0.0429	0.0117	**0.1447**
Cd	0.6208	0.4693	0.1880	**0.9657**
Co	0.0043	0.0022	0.0034	**0.0097**
Cr	0.0007	0.0008	0.0011	**0.0048**
Cu	0.1638	0.1737	0.2442	**0.2803**
Fe	0.0012	0.0017	0.0017	**0.0079**
Hg	**1.5490**	0.4493	0.5431	0.9784
Mn	0.0120	0.0141	0.0153	**0.1267**
Mo	0.1363	**0.2011**	0.0933	0.1570
Ni	0.0080	0.0125	0.0094	**0.0142**
Pb	**0.0767**	0.0248	0.0221	0.0278
Sb	0.0192	0.0269	0.0080	**0.1547**
V	0.0002	0.0004	0.0002	**0.0060**
Zn	0.2718	0.3624	0.2844	**0.6786**

Table 4

a) Limit concentration of metals in vegetables recommended by Codex, Alimentarius Commission for As, Cd y Pb and for Hg recommended by Food Safety Law of the People's Republic of China

Metal	Fruit vegetables (tomato, chili)	Onion	Leafy vegetables	Arroz pulido	Reference
	mg kg^{-1}				
As				0,2	Codex Alimentarius Food Sytandard[1]
Cd	0.05	0.05	0.05		
Pb	0.05	0.1	0.3		
Hg	0.01	0.01	0.01		Food Safety Law of the People's Republic of China[2]

[1]FAO/WHO Codex Alimentarius Food Sytandard (2019)

[2]Food Safety Law of the People's Republic of China. (2009).

b) Limit concentration of metals in soils dictated by Mexican Environmental regulation (SEMARNAT 2007)

NOM-147[1]														
As	Ba	Cd	Co	Cr	Cu	Fe	Hg	Mn	Mo	Ni	Pb	Sb	V	Zn
mg kg^{-1}														
22	5400	37	n.i.	80 (Cr V	n.i.	n.i.	23	n.i.	n.i.	1500	400	n.i.	78	n.i.

n.i.: No indicate

Figures

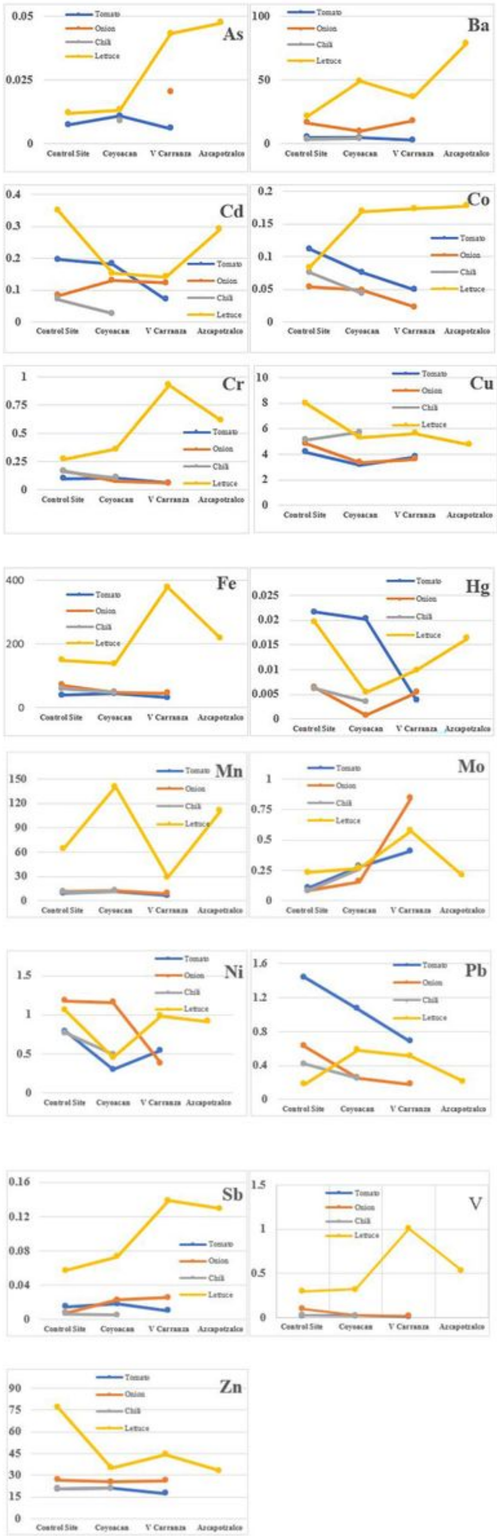

Figure 1

Metal(loid)s concentration (mg kg-1) comparison between locations and analyzed vegetables