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HOW HEALTHY ARE HORTICULTURAL PLANTS CULTIVATED IN URBAN GARDENS IN POLLUTED CITIES? THE CASE OF MEXICO CITY

¿Qué tan saludables son las plantas hortícolas que se cultivan en huertos urbanos en ciudades contaminadas? El caso de la Ciudad de México

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Key words: metal(oid)s, urbanization, transference factor, food plants.

ABSTRACT

Soil-to-plant metal(loid) accumulation has been highly evaluated recently due to its significant impact on human health. This study reports the concentrations of 15 metal(oid)s in four vegetables (tomato, onion, chili, and lettuce) cultivated in a greenhouse and three shade houses (two roofs of buildings and one in the UNAM Botanical Garden) in four locations in the metropolitan area of Mexico City. In this experiment, the contribution of metals and metalloids due to atmospheric deposition and irrigation may be negligible. Hence, the concentration of metals depends only on transfer from the soil. Soil analysis indicates that only vanadium in one location (a rooftop garden in the municipality of Venustiano Carranza) exceeds the permissible limits according to Mexican regulations. Lettuce shows the highest concentrations and transfer factors for most metals compared to the other vegetables studied. Transfer factors were exceptionally high for Cd (lettuce) and Hg (tomato), presenting values above 1. Concentrations of As, Cd, Hg, and Pb were compared with limit values recommended by different international agencies for vegetables. 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(oid)s are present and identify the physical and chemical parameters of the soil that may have interfered with the soil-plant transfer factor.

Palabras clave: metal(loides), urbanización, factor de transferencia, plantas alimenticias.

RESUMEN

La acumulación de metales y metaloides del suelo a la planta ha sido extensamente evaluada en los últimos años por su impacto significativo en la salud humana. Este estudio reporta las concentraciones de 15 metales y metaloides en cuatro vegetales (tomate, cebolla, chile y lechuga) cultivados en un invernadero y tres casas de sombra (dos techos de edificios y otra en el Jardín Botánico de la UNAM), en cuatro localidades del área metropolitana de la Ciudad de México. En este experimento la contribución de metales y metaloides debida a la sedimentación atmosférica y el riego puede ser insignificante y se considera que la concentración de metales depende únicamente de la transferencia desde el suelo. El análisis del suelo indica que sólo el vanadio en la Alcaldía Venustiano Carranza excede los límites permisibles según las normas mexicanas. Para la mayoría de los metales, la lechuga muestra las concentraciones y factores de transferencia más altos en comparación con las otras hortalizas estudiadas. Los factores de transferencia fueron excepcionalmente altos para Cd (lechuga) y Hg (tomate), con valores > 1. Las concentraciones de As, Cd, Hg y Pb se compararon con los valores límite recomendados por diferentes organismos internacionales para hortalizas. A excepción del As, estos valores se superan en varios vegetales cosechados en este estudio. Esta información debe ser corroborada con estudios más detallados que evalúen las especies químicas en las que están presentes esos metaloides y se identifiquen los parámetros físicos y químicos del suelo que pudieron haber interferido en el factor de transferencia suelo-planta.

INTRODUCTION

Inequalities and impoverishment have caused a constant acceleration of human migration to urban areas, with megalopolises becoming home to more than 50% of the world's population (Dorling 2021). This phenomenon usually results in a lack of access to green and agricultural areas, which has led to a search area to resolve this problem. Urban agriculture (UA) is one alternative (FAO 2015, SAGARPA 2020), including a set of practices that aim to produce food within cities, using town resources (Figueroa-Vera and Izquierdo 2003, Miranda et al. 2008, García-Céspedes et al. 2016). UA also represents, in some cases, support for the household economy.

However, the increase in urbanization and industrialization caused by migration has reduced the environmental quality (García et al. 2014). Urban activities release particles into the environment that can contain considerable amounts of metals and metalloids (metal(oid)s) (Edelstein and Ben-Hur 2018), which may get in the trophic chain, including humans, and potentially and negatively affect the health of living beings (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 local government has promoted the practice of UA since 2016 (ALDF 2016, SEDEMA 2016, GCDMX 2020) while making minimal or no mention of the considerations required to prevent contamination of the crops by metal(oid)s.

The health impact derived from ingesting vegetables contaminated with metal(oid)s depends on the concentration of the accumulated element. This is generally determined by the concentration of metal(oid)s and soil specific properties, such as organic material content, pH, and the soil-plant transfer factor (TF) of metal(oid)s. The TF expresses the uptake capacities of plants and is an important criterion for assessing global human health concerns (Rothenberg et al. 2007, Khan et al. 2008, Woldetsadik et al. 2017).

Several hazardous metal(oid)s are classified as non-essential to metabolism 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 (US-EPA) and the Agency for Toxic Substances and Disease Registry (ATSDR) (Moffett et al. 2007, Khalid et al. 2017, Xiong et al. 2017, Rai 2018). Various international agencies have established metal concentration guidelines to regulate the metal contents of cultivated esdible products, sucha as the "General standard for contaminants and toxins in food and feed" (Wu 2014, Buijs et al. 2018).

This research aimed to investigate the presence of 15 metal(oid)s in four widely consumed horticultural species (lettuce, onion, tomato and chili) cultivated in four UA localities, presumably exposed to different environmental pollution conditions: a greenhouse, a top garden in a botanical garden, and two rooftop gardens in different locations in the urban area of Mexico City. These concentrations were compared with 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 urban agriculture locations

Plants of onion, tomato, chili, and lettuce were obtained from commercial seeds and 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 with a mixed soil of tepojal (a material derived from volcanic foam, very light and with high porosity, used to improve soil drainage, coming from Perote, Veracruz) and black soil (from Xochimilco, Mexico City) in a 1:1 ratio. Tomato, chili, and onion were put on two hydropots, and lettuce was placed on three hydropots at each location and watered with tap water each week. A 35 % black shadow mesh house (roof and walls) was placed in all localities, with 1.2 m on each side. All sites were located in the urban area, presumably under different contamination levels:

- Control site: greenhouse at Faculty of Sciences of the National Autonomous University of Mexico (UNAM). The greenhouse is sealed with a glass roof and windows, with controlled temperature between 18 and 28 ºC.
- Coyoacán: on the ground in a botanical garden. This site is located within the Botanical Garden of UNAM. It is surrounded by the West Core Zone of the Pedregal de San Angel Ecological Reserve, so vehicular traffic is reduced compared to the next two sites.
- Azcapotzalco: in a rooftop garden. It is on the roof of a house located 60 m from an avenue with high vehicular traffic, and 1.5 km from a park.
- Venustiano Carranza: in a rooftop garden. It is located on the roof of a building located 250 and 100 m from two avenues, both considered road axes, which have between four and six vehicular lanes.

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 paper bags and taken to the laboratory, where they were washed with distilled water and subsequently dried in an oven at 50 ± 3 ºC (UN 750 single screen Brand, Memmert, USA). The fruits and soil samples were analyzed according to Milestone (2022). The dry material was first ground in a mortar and later in a mill. It is important to note that not all samples were obtained because some plants did not reach their point of maturation.

Soil samples were obtained at the time of planting and during the dry season (three repetitions in each case). In addition, 20 g soil samples were taken from each pot before planting and at harvest. Each sample was dried in an oven at 40 ºC for 24 or 48 h. After this time, each sample was sieved with a 0.25 mm mesh and later crushed and ground. Then 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(oid)s studied were 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 and soils were analyzed according to the general method for biological and soil samples (Milestone 2022).

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) by duplicate was conducted in two stages: (1) a ramping stage for 20 min at 1500 W, 230 ºC, 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 ºC for later analysis by ICP-MS.

Soil

At the beginning and end of the experiment 0.2 g of soil were weighed and added 4 mL of inverted aqua regia (3 mL HNO_3:1 mL HCl) and 1 mL of HF. Subsequently, microwave oven-assisted digestion was conducted in two stages: (1) 20 min ramping at 1500 W, 260 ºC, 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. Then, they were filtered, labeled, and stored at 4 ºC.

For every 10 plant samples, two certified reference materials (CRMs), 1547 peach leaves and 1573 tomato leaves, were used (National Institute of Standards Technology, NIST). Two sample duplicates were chosen randomly, and a reagent blank was digested to monitor possible contaminant input. CRM 2709a soil San Joaquin (NIST) was digested for the soil samples.

The instrument was optimized before sample analysis with a certified aqueous solution (High Purity Standards) containing a wide range of masses (Li, Co, In, Ba, Bi, Ce, and U of 1 µg/L. 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) from a certified aqueous multi-element solution (High Purity Standards brand [QCS-26]). The instrumental drift was corrected with the Indio internal standard (In of 10 µg/L).

Transfer factor (TF)

The TF was evaluated by the ratio of the plant's metal(oid)s content to that in the soil (Gall et al. 2015). Heavy metal hyperaccumulation is defined as the accumulation of more than 0.1% by dry weight in plant tissue (Brooks et al. 1977, Assunção et al. 2003). If the TF ≤ 1.00, the plant can only absorb but not accumulate metal(oid)s.

RESULTS AND DISCUSSION

Table I presents the metal(oid) concentrations in representative soil samples at the beginning of the experiment 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(oid)s were enriched in the control site (greenhouse). The metal(oid)s concentrations in the other three locations considered in this study were similar. **Table I** 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 and Wu 2019). Natural heavy metal(oid) 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 anthropogenic metal(oid) sources (Chary et al. 2008,

TABLE I. METAL(OID)S CONCENTRATIONS IN SOILS OF THE PLANTING PERIOD AND PERCENTAGE OF RECUPERATION.

		Location and recuperation percentage				
	Control site mg/kg	Coyoacán mg/kg	Venustiano Carranza mg/kg	Azcapotzalco mg/kg	Kabata-Pendias and Szteke (2015) worldwide concentration ranges in different soil types mg/kg	% recuperation
As	**5.99**	5.92	4.94	3.87	<0.1-67	79.665
Ba	293.21	349.72	**412.31**	284.41	10-1500	34.702
Cd	**0.26**	0.22	0.24	0.23	0.06-1.1	101.379
Co	19.56	**19.57**	14.90	12.44	4.5-12	80.879
Cr	129.42	**143.46**	111.12	96.87	20-80	81.276
Cu	**23.44**	23.20	21.01	16.69	14-110	98.986
Fe	**36 054.1**	34 931.0	28 078.5	22 004.4	1-5%	106.219
Hg	0.01	**0.01**	0.01	0.08	0.01-1.5	105.766
Mn	812.4	**822.7**	707.7	508.3	10-9000	83.283
Mo	**2.83**	2.24	1.67	2.54	< 1-2	NR
Ni	75.41	**76.20**	57.06	46.51	4-95	88.915
Pb	**15.34**	11.79	14.97	14.07	3-90	96.821
Sb	**0.92**	0.75	0.61	0.56	0.05-4	96.242
V	***119.77***	*118.45*	*88.32*	71.05	70-320	91.960
Zn	**76.81**	70.38	70.00	55.82	30-100	94.910

Note: the location with the highest concentration for each metal is indicated in bold. Concentrations above the permissible values are indicated in italics. Only four metal(oid)s (marked in red) are outside the concentration ranges reported by Kabata-Pendias and Szteke (2015).
NR: not reported.

Schreck et al. 2012, Kim et al. 2015, Elgallal et al. 2016).

When calculating the possible contribution of metal(oid)s in the analyzed soils to atmospheric deposition, it must be considered that the soil was placed immediately before crop cultivation during the 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 four and eight months. Thus, the contribution of metal(oid)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(oid) concentrations of Cr, Cu, Ni, Pb, V, and Zn in the analyzed soil samples were similar to the background values reported by Morton-Bermea et al. (2009) for soils in similar zones in Mexico City (110.5, 33, 47.5, 50.5, 92 and 147.5 mg/kg, respectively).

The contribution of metal(oid)s generated by long-term use of partially treated or untreated wastewater could result in the accumulation of heavy metal(oid) s in the soil (Elgallal et al. 2016). The concentrations of heavy metal(oid)s in potable water were bigger in the control site than in the three locations, but in all were higher than in rainwater (**Tables SI** and **SII** in the supplementary material). The irrigation time was short (less than eight months), so the contribution of metal(oid)s generated by irrigation could also be depressed and it can be considered that the translocation of metal(oid)s to plants is only determined by the content of metal(oid)s in soils; moreover, the increase in the concentration of metal(oid)s in horticultural plants depends on their capacity to assimilate the metal(oid)s (TF), the total concentration of metal(oid)s in the soil, their chemical form and other physical and chemical parameters of the soil (e.g., pH and organic matter content). The concentration of metal(oid)s in soils (except for Co, Cr, Fe, and Mo, were inside the range reported by Kabata-Pendias and Szteke (2015).

The TFs of the analyzed metal(oid)s are presented in **Table II** for each of the evaluated plants. Thier values are in the ranges compiled by Khan et al. (2015). **Table II** shows that lettuce presents the highest TF for almost all metal(oid)s except for Pb and Hg, which are higher for tomato, and Mo, which is higher in onion. Moral et al. (1994) reported that leafy horticultural plants can absorb and accumulate metal(oid)s more quickly and readily than other upland crop types. For many metals, leafy horticultural plants have been classified as hyperaccumulators (Loredo-Tovías et al. 2022).

TABLE II. TRANSFER FACTORS (TF) CALCULATED FOR THE VEGETABLES CONSIDERED IN THIS STUDY.

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**

The highest TF for each metal is shown in bold.

In this study, it is especially revealing that Hg presented a TF of 1.5 in tomatoes since values > 1.0 indicate a higher uptake of metal(oid)s in horticultural plants than in soil. Therefore, tomatoes can be classified as Hg bioaccumulators under these soil conditions. Metal(oid) concentrations in horticultural plants are reported in **table III**. Additionally, **figure 1** shows a comparison of the concentrations found in each vegetable from all localities for all metal(loid)s. Data assessment shows that indoor cultivation of crops in a controlled environment can not guarantee food safety. The concentration was higher for some metal(oid)s in horticultural plants harvested at the control site than in other areas, which may be related in this study to the metal(oid)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(oid)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 ATSDR (Moffett et al. 2007). The permissible limits for different countries and organizations vary regarding concentrations of different heavy metal(oid)s. In this study, metal(oid)s concentrations in the analyzed horticultural plants were compared with the permissible limits recommended by the CODEX-STAN (FAO-WHO 2014) for As, Cd, and Pb. Since this regulation does not recommend permissible values for Hg, the contents

TABLE III. METAL CONCENTRATIONS IN VEGETABLES AND PERCENTAGE OF RECUPERATION.

Metal	Percentage of recuperation	Location	Vegetable (mg/kg)			
			Tomato	Onion	Chili	Lettuce
As	123.810	Greenhouse (control site)	0.008	ND	ND	0.012
		Botanical Garden (Coyoacán)	0.011	n.d	ND	0.013
		Rooftop garden (Venustiano Carranza)	0.006	0.021	0.009	0.043
		Rooftop garden (Azcapotzalco)	ND	ND	ND	0.047
Ba	91.057	Greenhouse (control site)	5.34	16.52	3.63	21.22
		Botanical Garden (Coyoacán)	4.94	9.88	4.52	49.14
		Rooftop garden (Venustiano Carranza)	3.17	18.19	ND	36.74
		Rooftop garden (Azcapotzalco)	ND	ND	ND	78.70
Cd	80.913	Greenhouse (control site)	**0.197**	**0.082**	**0.071**	**0.350**
		Botanical Garden (Coyoacán)	**0.181**	**0.130**	0.026	0.154
		Rooftop garden (Venustiano Carranza)	**0.071**	**0.122**	ND	0.141
		Rooftop garden (Azcapotzalco)	ND	ND	ND	**0.291**
Co	118.549	Greenhouse (control site)	0.112	0.053	0.076	0.083
		Botanical Garden (Coyoacán)	0.076	0.048	0.044	0.168
		Rooftop garden (Venustiano Carranza)	0.049	0.023	ND	0.173
		Rooftop garden (Azcapotzalco)	ND	ND	n..d	0.177
Cr	107.249	Greenhouse (control site)	0.099	0.166	0.165	0.266
		Botanical Garden (Coyoacán)	0.103	0.076	0.102	0.360
		Rooftop garden (Venustiano Carranza)	0.058	0.060	ND	0.926
		Rooftop garden (Azcapotzalco)	ND	ND	ND	0.613
Cu	102.602	Greenhouse (control site)	4.13	4.82	5.08	8.01
		Botanical garden (Coyoacán)	3.13	3.34	5.71	5.32
		Rooftop garden (Venustiano Carranza)	3.78	3.60	ND	5.64
		Rooftop garden (Azcapotzalco)	ND	ND	ND	4.71
Fe	120.479	Greenhouse (control site)	39.9	71.7	60.1	149.3
		Botanical garden (Coyoacán)	44.2	48.4	47.2	139.0
		Rooftop garden (Venustiano Carranza)	32.5	44.5	ND	378.8
		Rooftop garden (Azcapotzalco)	ND	ND	ND	217.6
Hg	108.194	Greenhouse (control site)	0.022	0.006	0.006	0.019
		Botanical garden (Coyoacán)	0.020	0.001	0.004	0.005
		Rooftop garden (Venustiano Carranza)	0.004	0.005	ND	0.010
		Rooftop garden (Azcapotzalco)	ND	ND	ND	0.016
Mn	109.755	Greenhouse (control site)	9.34	11.70	11.13	63.37
		Botanical garden (Coyoacán)	12.15	12.40	11.93	140.25
		Rooftop garden (Venustiano Carranza)	6.86	9.18	ND	29.46
		Rooftop garden (Azcapotzalco)	ND	ND	n.d	110.11
Mo	113.141	Greenhouse (control site)	0.107	0.085	0.082	0.233
		Botanical garden (Coyoacán)	0.282	0.156	0.263	0.266
		Rooftop garden (Venustiano Carranza)	0.410	0.841	ND	0.576
		Rooftop garden (Azcapotzalco)	ND	ND	ND	0.208
Ni	108.584	Greenhouse (control site)	0.788	1.180	0.770	1.053
		Botanical garden (Coyoacán)	0.304	1.159	0.489	0.455
		Rooftop garden (Venustiano Carranza)	0.542	0.383	ND	0.979
		Rooftop garden (Azcapotzalco)	ND	ND	ND	0.915

Concentrations above the permissible limits are marked in bold.
ND: not determined.

TABLE III. METAL CONCENTRATIONS IN VEGETABLES AND PERCENTAGE OF RECUPERATION.

Metal	Percentage of recuperation	Location	Vegetable (mg/kg)			
			Tomato	Onion	Chili	Lettuce
Pb	N.R.	Greenhouse (control site)	1.435	0.627	0.421	0.181
		Botanical garden (Coyoacán)	1.068	0.254	0.252	0.584
		Rooftop garden (Venustiano Carranza)	0.687	0.179	ND	0.514
		Rooftop garden (Azcapotzalco)	ND	ND	ND	0.219
Sb	108.191	Greenhouse (control site)	0.015	0.008	0.007	0.057
		Botanical garden (Coyoacán)	0.018	0.023	0.005	0.073
		Rooftop garden (Venustiano Carranza)	0.010	0.025	ND	0.139
		Rooftop garden (Azcapotzalco)	ND	ND	ND	0.129
V	114.928	Greenhouse (control site)	0.023	0.100	0.025	0.297
		Botanical garden (Coyoacán)	0.023	0.022	0.020	0.318
		Rooftop garden (Venustiano Carranza)	0.011	0.014	ND	1.006
		Rooftop garden (Azcapotzalco)	ND	ND	ND	0.532
Zn	67.879	Greenhouse (control site)	20.70	26.66	20.75	76.90
		Botanical garden (Coyoacán)	21.30	25.64	20.90	34.87
		Rooftop garden (Venustiano Carranza)	17.03	26.31	ND	43.91
		Rooftop garden (Azcapotzalco)	ND	ND	ND	32.95

Concentrations above the permissible limits are marked in bold.
ND: not determined.

of this element were compared with the limit values recommended by Buijs (2018) (**Tables IV** and **V**). All analyzed samples exceeded the CODEX-STAN (FAO-WHO 2014) recommended permissible values for Pb and Cd except for one sample (chili collected in Coyoacán). Hg concentrations in tomato and lettuce samples exceeded the permissible values recommended by Buijs (2018).

Metal(oid)s accumulation in vegetables growing in agricultural soils irrigated with wastewater or cultivated in the vicinity of industrial zones frequently exceeds the permissible values. The highly enriched Cd, Pb, and Hg concentrations found in the analyzed horticultural plants considered in this study may be due to the high TF 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(oid)s are present in the soils in an available chemical form or that these soils possess physical and chemical parameters favoring metal(oid)s translocation.

Horticultural plants are an important source of nutrients in the human diet. The toxicological effects of human consumption of metal(oid)s-contaminated food depend on various factors, such as the metal(loid) chemical form, dose, and exposure route. A human health hazard is closely linked to the intake of metal(oid)s-contaminated food crops. High Pb levels in blood in the human body cause neurological and cardiovascular effects, especially in 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 (Shahab et al. 2019, Bundschuh et al. 2021). 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 has been associated with damage to the central nervous system, kidneys, and the thyroid gland. The primary consequence of chronic oral exposure to low amounts of inorganic Hg compounds is renal damage (Risher and DeWoskin 1999, Clarkson 2002, UNEP 2002).

The sites with the highest TF values (≥ 0.5) for two vegetables during the rainy season coincide with sites with the highest heavy metal concentrations. Lettuce and tomato samples reported Cd (one of the metals with the highest TF values) in concentrations that exceeded the limits allowed by the different legislations consulted, this being. On the other hand, during the dry season, lettuce reported high TF values (≥ 0.5) of Cd, Hg, and Zn, which coincide with the concentrations of these metals per site.

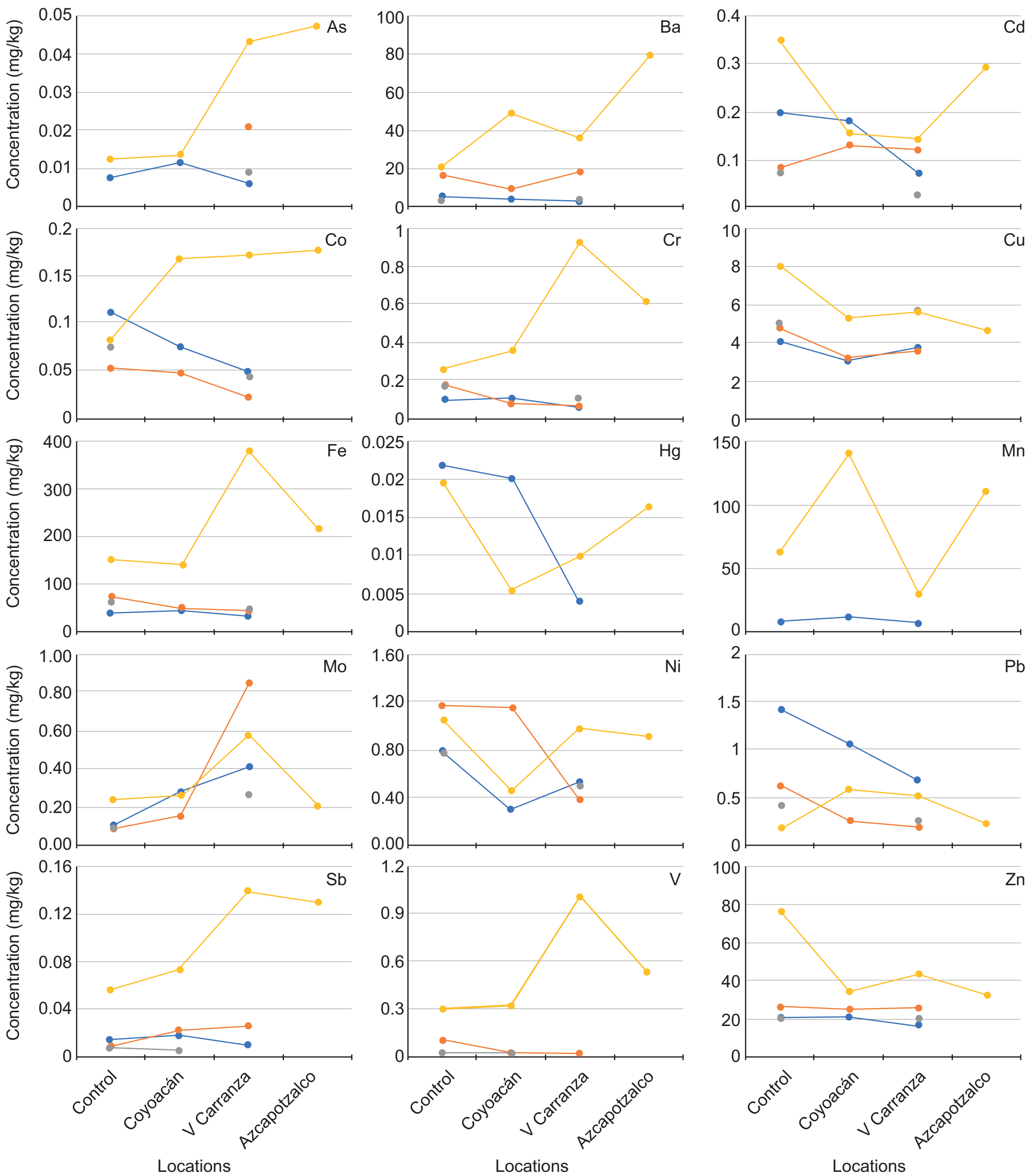

Fig. 1. Comparison of metal(oid)s concentrations (mg/kg) between locations and analyzed vegetables.

TABLE IV. PERMISSIBLE LIMITS OF As, Cd, Pb, and Hg (mg/kg) IN VEGETABLES ACCORDING TO THE CODEX-STAN.

Metal	Fruit vegetables (tomato, chili)	Onion	Leafy vegetables	Polished rice	Reference
As	–	–	–	0.2	CODEX-STAN
Cd	0.05	0.05	0.05	–	
Pb	0.05	0.1	0.3	–	
Hg	0.01	0.01	0.01	–	Buijs et al. (2018)

CODEX-STAN: General Standard for Contaminants and Toxins in Food and Feed (Wu 2015).

TABLE V. PERMISSIBLE LIMITS OF METALS IN SOILS (mg/kg) ACCORDING TO MEXICAN OFFICIAL STANDARD NOM-147-SEMARNAT/SSA1-2004 (SEMARNAT 2007).

As	Ba	Cd	Co	Cr	Cu	Fe	Hg	Mn	Mo	Ni	Pb	Sb	V	Zn
22	5400	37	NE	80 (Cr V)	NE	NE	23	NE	NE	1500	400	NE	78	NE

NE: not established.

Although the transfer of metals to the plant does not depend solely on their concentration in the substrate, it is a good starting point to measure how exposed we are to these metals.

CONCLUSIONS

This study contributes relevant information regarding the growing trend of cultivating horticultural plants in urban gardens and green rooftops in highly populated metropolitan areas. The analyzed horticultural plants cultivated on soils that do not exceed the Mexican regulations for heavy metal(oid)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 (Moffett et al. 2007). The possible health risks 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.

Different legislations, like the CODEX-STAN (FAO-WHO 2014), do not assign values to the permissible limits of diverse metals such as Co, Cr, and Sb. So, it is important to consider those metals and others that are in plants and soil to help determine their permissible limits.

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SUPPLEMENTARY MATERIAL

TABLE SI. METAL(OID)S CONCENTRATIONS IN POTABLE WATER IN THE CONTROL SITE AND RAINWATER IN THREE LOCATIONS DURING THE RAINY SEASON.

Rain and potable water (µg/L)				
Metal	Potable water	Rainwater		
	Control site	Coyoacán	Venustiano Carranza	Azcapotzalco
As	**2.449**	0.505	0.375	0.888
Ba	34.276	7.472	8.52	12.372
Cd	0.023	0.0531	0.046	0.0439
Co	0.087	**0.107**	0.0373	0.08
Cr	1.626	0.493	0.62	0.286
Cu	228.071	7.107	4.636	7.695
Fe	14.623	**190.468**	58.3475	41.528
Hg ($\mu g\ kg^{-1}$)	NR	NR	NR	NR
Mn	0.842	5.487	2.751	5.489
Mo	1.083	0.45	0.316	**2.218**
Ni	137.504	0.558	0.912	1.443
Pb	3.484	1.698	0.847	0.139
Sb	0.887	1.017	1.242	1.152
V	**11.56**	1.962	1.46	1.855
Zn	1156.108	138.529	23.515	51.677

The location with the highest concentration for each metal is indicated in bold.
NR: not reported.

TABLE SII. METAL(OID)S CONCENTRATIONS IN POTABLE WATER IN THE CONTROL SITE AND THE THREE LOCATIONS DURING THE DRY SEASON.

Potable water (µg/L)				
Metal	Control site	Coyoacán	Vensutiano Carranza	Azcapotzalco
As	3.667	2.892	1.796	1.391
Ba	34.233	23.039	32.69	**55.821**
Cd	0.117	0.111	0.081	0.57
Co	0.359	0.128	0.25	0.948
Cr	0.738	1.646	1.639	**2.258**
Cu	**694.416**	59.636	365.965	173.921
Fe	63.295	43.322	151.013	163.263
Hg ($\mu g\ kg^{-1}$)	NR	NR	NR	NR
Mn	7.289	14.042	**16.065**	11.155
Mo	NR	NR	NR	NR
Ni	**90.708**	1.509	5.502	11.468
Pb	10.569	26.318	23.237	20.482
Sb	1.171	0.66	0.848	1.04
V	12.182	**31.807**	4.5	8.798
Zn	843.534	**5672.467**	174.295	392.866

The location with the highest concentration for each metal is indicated in bold.
NR: not reported.