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*Original Research*

# Heavy Metals Accumulation in Lettuce and Cherry Tomatoes Cultivated in Cities

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## Abstract

Vegetables cultivated in cities, carry the risk of absorbing pollutants generated by anthropogenic activities, increasing the health risk of those who consume them. Heavy metal concentrations (As, Cd, Cr, Ni and Pb) were analyzed in water, soil and in plant parts of lettuce (roots and leaves) and cherry tomatoes (roots, stem, leaves and tomato fruit) lettuce and cherry tomatoes, cultivated in urban gardens in Mexico City. In none of the studied sites was the heavy metal concentration in the soil above the permitted limits. In irrigation water, Cr surpassed the permitted limit in 5 sites and that of Cd in one site. Ni surpassed the established limit for lettuce and cherry tomato in the rank among 0.7 and 31.15 mg $kg^{-1}$ in 9 sites, Cr exceeded the allowed limits 1.45-38 mg $kg^{-1}$ in 11 sites, As go beyond the established limits between 5-52 mg $kg^{-1}$ in 4 sites and to a lesser extent, Pb was above the allowed limits between 15.5 and 26 mg $kg^{-1}$. According to the translocation factor, lettuce and cherry tomato could be an important phytoextractors of Cr and Cd respectively. The compound risk value for lettuce (*TTHQ*) was greater than one in three sites for lettuce and five sites for cherry tomato. Also, in gardens A, D, E and J, the Hazard Index (*HI*) showed a potential risk (*HI*>1), which reveals the danger of consuming both vegetables given the conditions of soil, water and air and taking into account all paths of exposure.

**Keywords**: urban agriculture, leafy vegetables, fruit vegetables, Nickel, Chrome

## Introduction

The urban and peri-urban agriculture generates multiple benefits for the population, contribute to food and economic security, strengthening social and ecological sustainability, species preservation and diversification, re-use of urban waste, among other ecological services [1]. However, soil and water resources contamination by heavy metals from anthropogenic activities such as vehicular emission, power plant, tire wear particles, auto repair shops, car wash centers, brake lining, coal combustion, chemical

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plants, weathering of building, atmospheric deposition, household solid waste, mining pesticides and fertilizers have been reported as a major environmental problem for last few decades [2]. Heavy metal (HM) pollution can produce deterioration of the soil environmental quality and fertility with irreversibility consequences [3] and pose a great concern due to their toxicity, persistence and biomagnification, they can easily be absorbed by plants and then having a big impact for their consumption even at lower levels. Besides, there is a deposition of particles (PM) suspended in the atmosphere from vehicles, burning fuel, and dust, as well as from sewage water and industrial waste [4]. Specifically the presence of $PM_{10}$ and $PM_{2.5}$ in the air is an environmental problem due to their high content of HM, [5] studied the toxicity of Cd and Ni applied as mist to the foliage of tomato suggested that HMs deposition can negatively affect tomatoes growth, quality and offering . Also [6] mentioned that lead (Pb), cadmium (Cd), chromium (Cr) and arsenic (As) can enter plant leaves via foliar transfer after deposition of atmospheric particles, the heavy metal uptake by foliar surfaces occurs through stomata, cuticular cracks, lenticels, ectodesmata and aqueous pores. Similar results are reported by [7] who assert that plant metal uptake may occur predominantly via foliar contamination by micro- and nanoparticles which provided insights on the fate of PM deposited on lettuce leaves. So, foliar absorption of metals due to PM depositions can greatly enhance metal levels in plants.

According to [8] leafy vegetables can accumulate As, Cd, Cr, and Pb in edible parts, and they can easily enter human body and cause some health disorders such as gastrointestinal cancer, bone fractures and malformations, weak immune system, retarded mental growth, hypertension, malnutrition, lung cancer and others [4, 9].

Worldwide studies have been conducted on heavy metals and metalloid concentrations in soil, water and their interaction with plants for the aims of phytoremediation and/or quantification of possible damage in crops. The River Bruigangan in the city of Dhaka in Bangladesh is the most polluted river containing huge amounts of As, Pb and Cd with 0.134, 0.119 and 0.059 $mg \cdot L^{-1}$, respectively [10]. Margenat and collaborators [11], in the city of Barcelona found elevated levels of heavy metals in tissues of lettuce and other leafy vegetables, with Pb being one of the predominant metals with 0.099 $mg \cdot kg^{-1}$; in the same study, tomato plants had higher accumulations of Cu, Zn and Pb in the root than in the shoot. In a study made in Autumn for different vegetables in Tehran, [9] found levels in mg $kg^{-1}$ of As (0.001), Cd (0.001), Cr (0.318), Ni (0.326) and Pb (0.136) in lettuce leaves and As (0.002), Cd (0.015), Cr (0.412), Ni (0.232) and Pb (0.241) in tomato, only Pb and Cr surpassed the Codex standards limits (Commission Regulation (EC) No 1881/2006 of 19 December 2006) for heavy metals in both vegetables.

The soil-root system is not the only means by which heavy metals and metalloids enter; access is also via the leaves and the cuticle and through the stoma, so there is a need for quantification of human risk assessment of consuming vegetables in urban areas [12]. Work on this topic in Mexico is scarce and refers to a specific medium such as soil, water or air. Mugica and colaborators [13] investigated atmospheric pollution inside the Azcapotzalco metro station in Mexico City, their study reveals concentrations of Cr (20.25 $ng \cdot m^{-3}$), Ni (7.58 $ng \cdot m^{-3}$), Pb (76.99 $ng \cdot m^{-3}$), and Zn (234.11 $ng \cdot m^{-3}$) respectively, with higher concentrations inside than outside the metro station. However, for the present study, it was not possible to check the current levels of heavy metals in the environment, because the air monitoring network in CDMX only registered $PM_{10}$, $PM_{2.5}$ in the last years.

Also [14] evaluated the concentration of heavy metals in topsoils of Mexico City. They found that the central and northern parts of the city are the most Pb, Cu, Zn, Ba and V polluted topsoils, because of the heavy traffic and the industrial zone. Moreover, plants to be used for phytoremediation, such as Ficus benjamina, have been studied in the north, center and south of the city, where [15] obtained concentrations of V (1.61 $mg \cdot kg^{-1}$), Cr(1.63 $mg \cdot kg^{-1}$), Co (0.24 $mg \cdot kg^{-1}$), Ni (1.81 $mg \cdot kg^{-1}$), Cu (12.3 $mg \cdot kg^{-1}$), Zn (34.8 $mg \cdot kg^{-1}$), Sb (0.302 $mg \cdot kg^{-1}$) and Pb (4.59 $mg \cdot kg^{-1}$) respectively. However, concentrations absorbed by vegetable plants cultivated in this area, such as lettuce and cherry tomato, have not been reported. For this reason, the objective of this study was to determine the concentration of heavy metals in soil, water and plant material for romaine lettuce (leaves, stem and roots) and cherry tomato [fruit, stem and leaves, roots] at 13 points in Mexico City and one site in the State of Mexico to obtain indexes of risk from consuming these vegetables.

## Material and Methods

### Study Area and Sample Collection

Mexico City is in the Valley of Mexico, which has an extension of 1, 485 $km^2$ and a population of 9’ 209, 944. It is one of the most populated cities in the world and generates major impact because of human activities. In this study, two vegetables were analyzed: romaine lettuce (*Lactuca sativa* L.) and cherry tomato (*Solanum lycopersicum* var. Cerasiforme) in 13 urban gardens located at 11 municipalities of Mexico City and one peri-urban garden in Chapingo, State of Mexico (Fig. 1).

Table 1 gives a list of the investigated localities and their distance to a main avenue. For sampling purposes, an average area of 1 $m^2$, per crop per repetition, in each urban garden was considered, lettuce and cherry tomato seeds were germinated in seedbeds and fertilized with initial Ultrasol in concentrations (15-30-15) of Nitrogen (N), Phosphorus (P) and Potassium (K) respectively.

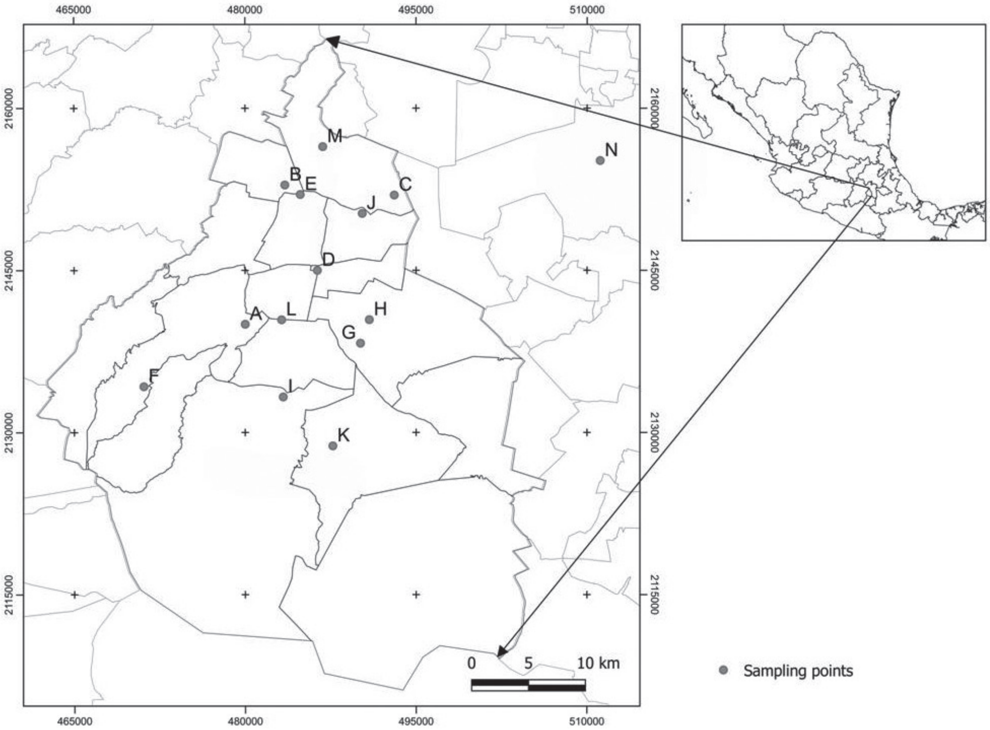


Fig. 1. Location of the studied gardens in Mexico City.

A mixture of soil and compost at 1:1 ratio was prepared at each site, and the seedlings were transplanted in a quincunx pattern one month after sowing. Simultaneously, initial soil samples were collected (0.5 kg) at a depth of 0 to 20 cm, and initial irrigation water (1 L) samples were collected at each site. After transplant, no chemical fertilizers were added. The growth period was divided into two parts: April 1st to August 23rd, 2018, for sites A, C, E, G, H, K, M and N and September 28th, 2018, to February 22 nd, 2019, in gardens B, D, F, I, J and L. The cherry tomato plants were left with three main stems with three clusters each. The vegetative material was divided into the edible part (*EP*) (fruit for cherry tomato and leaves for lettuce) and non-edible part (*NEP*) (lettuce: root and stem; cherry tomato: roots, stems and leaves), with two replicates for each vegetable in all urban gardens. The final samples of soil were taken near the roots (0 to 20 cm deep) for both vegetables at each site.

## Pretreatment and Analyses of Water, Soil and Plant Material

Soil samples were aired in the shade, sifted through a 2 mm mesh, and stored in polyethylene bags at 4ºC

Table 1. Description of the location of the urban and peri-urban gardens.

| Garden | Town hall | Distance from main avenue (m) | Main avenue | Garden | Town hall | Distance from main avenue (m) | Main avenue |
|---|---|---|---|---|---|---|---|
| *A* | Álvaro Obregón | 10 | Av. Revolución | *H* | Iztapalapa | 75 | Eje 5 Ote |
| *B* | Azcapotzalco | 200 | Av. Jardín | *I* | Tlalpan | 20 | Calz. Tlalpan |
| *C* | Gustavo A. Madero | 158 | Av. Oceanía | *J* | Venustiano Carranza | 340 | Av. Río Consulado |
| *D* | Iztacalco | 106 | Eje 1 Ote | *K* | Xochimilco | 126 | Av. Acueducto |
| *E* | Cuauhtémoc | 18 | Av. Insurgentes Norte | *L* | Coyoacán | 3 | Av. Río Churubusco |
| *F* | Magdalena Contreras | 1480 | Av. San Jerónimo | *M* | Cuauhtémoc | 143 | Av. Ticomán |
| *G* | Iztapalapa | 1500 | Av. Tláhuac | *N* | Municipio Texcoco (Edo. Méx) | 400 | Carr. Texcoco-Lechería |

until their analysis in the Laboratorio Nacional de Investigación y Servicio Agroalimentario y Forestal (LANISAF) at the Autonomous University of Chapingo.

Edible and non-edible parts of cherry tomato and lettuce were rinsed twice with distilled water to remove pollutant particles. Later, they were placed in an oven at 60ºC until they reached constant weight. After grinding the dehydrated parts, $HNO_3$ and $H_2O_2$ at a ratio of 1:5 (v/v) were added to 1 g of sample and placed in a microwave oven (Multiwave PRO, Anton Paar, Austria) for digestion at 200ºC for 60 min. The prepared soil and plant material samples, as well as the water, were analyzed with an atomic absorption spectrophotometer (SavantAA-GCB, Australia) to obtain the concentrations of heavy metals (As, Cd, Cr, Ni and Pb). The standard reference solutions (Accu Standard, USA), 1000 mg·L$^{-1}$ of each metal, had a linear regression value of 0.9972 ($R^2$). Measurements of each sample were repeated three times (LANISAF).

## Methods for Evaluating Risk and Transfer of Heavy Metals into the Soil-Plant System

The indexes reported by [4] for quantifying transfer and risk of pollutants present in the analyzed plants were applied using the mean concentration of the soil and plant material samples for each site.

### *Translocation Factor*

The translocation factor (TF) is the ratio of heavy metals in the EP over the concentration of the heavy metal in the NEP (Equation 1) [16].

$$TF = \frac{C_p}{C_r} \quad (1)$$

$C_p$ is the concentration of the heavy metal per unit of dry weight in the *EP* of the plant (mg·kg$^{-1}$)
$C_r$ is the concentration of the heavy metal per unit of dry weight in the *NEP* of the plant (mg·kg$^{-1}$)

### *Target Hazard Quotient and Risk Index*

The target hazard quotient (*THQ*) is a useful factor for the evaluation of potential health risk associated with the consumption of vegetables (Equation 2) [8].

$$THQ = \frac{W_{plant} \times C_f \times C_p}{R_f D \times BW} \quad (2)$$

Where: $W_{plant}$ is the daily fresh weight intake of vegetables 0.028 kg person$^{-1}$ d$^{-1}$ and 0.052 kg person$^{-1}$ d$^{-1}$ for lettuce and cherry tomato respectively taken from [9], $C_f$ is the conversion factor of fresh weight to dry weight (0.085), $R_fD$ is the edible reference dose of the heavy metal (mg·(kg of body weight)$^{-1}$·d$^{-1}$) (maximum acceptable oral dose of a toxic substance), and *BW* is the average weight of a human body (70 kg). $R_fD$ values for Cd (0.001 mg·kg$^{-1}$·d$^{-1}$), Ni (0.02 mg·kg$^{-1}$·d$^{-1}$), Cr (1.5 mg·kg$^{-1}$·d$^{-1}$), Pb (0.0035 mg·kg$^{-1}$·d$^{-1}$) and As (0.0003 mg·kg$^{-1}$·d$^{-1}$) were taken from [9].

The compound risk value (TTHQ) is a complex parameter used for the assessment of the heavy metal concentrations in the human body, following consumption of contaminated vegetables and it represents the summation of the target hazard quotient (THQ), for all heavy metals in each urban garden, as shown in Equation (3).

$$TTHQ = \sum THQ \quad (3)$$

### *USEPA Models*

According to [17], the main routes of Cd exposure into the human body are from diet (water and vegetables) and dust (air and soil), so it is necessary to evaluate the sources of heavy metal contamination in urban residential areas. The risk models established by the US Environmental Protection Agency (USEPA) are widely used for the estimation of the daily exposure to heavy metals taking into account five main pathways: 1) absorption through the skin by contact with water (Equation 4); 2) ingestion through soil particles (Equation 5); 3) absorption through skin by contact with soil particles (Equation 6); 4) uptake through the food chain (vegetables) (Equation 7); and 5) inhalation of soil particles (Equation 8) [18].

$$CDI_{dermal-water} = \frac{C_a \times Ev \times SA \times AF_a \times ABS \times EF \times ED \times CF_a}{BW \times AT} \quad (4)$$

$$CDI_{ingest-soil} = \frac{C_S \times IRS \times EF \times ED \times CF_S}{BW \times AT} \quad (5)$$

$$CDI_{dermal-soil} = \frac{C_S \times SA \times AF_S \times ABS \times EF \times ED \times CF_S}{BW \times AT} \quad (6)$$

$$CDI_{vegetables} = \frac{C_p \times W_{plant} \times EF \times ED}{BW \times AT} \quad (7)$$

$$CDI_{inhale-soil} = \frac{C_S \times ET \times EF \times ED}{PEF \times 24 \times AT} \quad (8)$$

Where: *CDI* is the daily chronic intake (mg·kg$^{-1}$·d$^{-1}$); $C_a$ is the metal concentration in water (mg·L$^{-1}$); $E_v$ are the contact events per day:1 event d$^{-1}$; *SA* is the area of skin exposed: 5,700 cm$^2$; $AF_a$ is the water adherence factor: 0.07 mg·cm$^{-2}$; *ABS* is the fraction of absorption through skin: 0.03 (As) and 0.001 (other metals); *EF* is the frequency of exposure: 365 d·yr$^{-1}$; *ED* is the duration of exposure: 30 yr; $CF_a$ is the conversion factor of units for water: $10^{-3}$ L·cm$^{-3}$; *BW* is body weight: 70 kg; *AT* is the average time for a carcinogen to cause cancer: 365 d yr$^{-1}$×70 yr; $C_s$ is the metal concentration in the soil (mg·kg$^{-1}$); *IRS* is the ingestion rate: 100 mg·d$^{-1}$; $CF_s$ is the unit factor for soil $10^{-6}$ kg·mg$^{-1}$; $AF_s$ is the factor of soil adherence to the skin (potted soil): 1.45 mg·cm$^{-2}$; $C_p$ is the concentration of the element per unit of dry weight in the *EP* of the plant; $W_{plant}$ is the average of plant material consumed per day per person (kg·d$^{-1}$); *ET* is the exposure time: 24 h·d$^{-1}$; *PEF* is the particle emission factor: 1.36×10$^{9}$ m$^{3}$·kg$^{-1}$.

To obtain the general potential effects of exposure to more than one chemical substance, the hazard index (*HI*) [19], was used with the *CDI*i values calculated in Equations (4-8).

$$HI = \sum_{i=1}^{n} \frac{CDI_i \times C_f}{R_f D_i} \quad (9)$$

Where:
$R_fD$ is the reference chronic dose of the metal$_i$ (mg·kg$^{-1}$·d$^{-1}$).
$C_f$ is the conversion factor of fresh weight to dry weight (0.085)

The hazard index (*HI*) assumes that there is a level of exposure ($R_fD$) below which it is unlikely that even a sensitive population will experience adverse effects on health. One of the limitations of this risk index is that it uses a sum that could be adequate if the compounds induce the same effect by means of the same mechanism. Therefore, the application of this index to exposure to different chemical substances can overestimate the potential effects.

### *Data Analysis*

The concentrations of heavy metals evaluated were compared with the maximum limits (Table 2) to estimate damage to health in the short and long term. The mean of two replications of plant material were used to obtain the indexes. The statistical analysis (Kruskal, Wallis and Wilcoxon) was implemented in Matlab v2018a for each sampling site with α = 0.05. To obtain the graphs, Excel and Sigma Plot were used with the mean of each site.

## Results and Discussion

### Heavy Metals in Water

According to the mean of all the sites, the ascending order of heavy metals concentration in the irrigation water supply, for the 13 sampled sites in Mexico City and one in the State of Mexico was Cr>Pb>Ni>As>Cd. Cr (0.000-0.370 mg·L$^{-1}$) surpassed the established limits (Table 2) in sites *A*, *B*, *F*, *I* and *J*, as well as Cd (0.029 mg·L$^{-1}$) in site *N* . The concentration for the rest of the HM were below the established limits.

Pb concentrations in the irrigation channels of Xochimilco were reported by [24], closed to site *K*, between 0.0029 a 0.0041 mg·L$^{-1}$ during the rainy season (July-October 2003). The authors assume that this concentration results from the contribution of ions to the soil and thus to groundwater by the unlined channels.

The content of As and Pb in irrigation water comply with the norms and are found below those reported for Bangladesh of 0.134 and 0.119 mg·L$^{-1}$, respectively [10]. Cd levels between 0.041 to 0.058 mg L$^{-1}$ were reported by [21] in water samples, which may be due to excessive use of phosphate fertilizers, in our study only site N presented Cd traces (0.029 mg·L$^{-1}$). The same authors found Ni levels in the water samples from 1.85 to 3.31 mg L$^{-1}$, above maximum allowable limit of 0.025 mg L$^{-1}$. An averages concentrations of Pb (0.82 mg L$^{-1}$), Cr (0.74 m/L), As (0.33 mg L$^{-1}$) and Cd (0.008 mg L$^{-1}$) for 12 samples of irrigation water in the industrial area in Bangladesh, were found by [20], which are above from the average levels of Pb (0.011 mg L$^{-1}$), Cr (0.101 m/L), As (0.003 mg L$^{-1}$) and Cd (0.002 mg L$^{-1}$) found in irrigation water in this study, the difference could be explained by the fact that vegetables in urban gardens are irrigated with tap water extracted from wells.

### Heavy Metals in the Soil

The concentrations of heavy metals under initial and final conditions at each site are presented in Fig. 2,

Table 2. International standards for heavy metal content limits in water, soil and plants.

| | Standards | Cr | As | Ni | Pb | Cd |
|---|---|---|---|---|---|---|
| Water (mg·L$^{-1}$) | [20][a] | 0.1 | 0.1 | | 5 | 0.01 |
| | [21][b] | | | 0.025 | 0.01 | 0.001 |
| Soil (mg·kg$^{-1}$) | [20] | 100 | 5 | 20-60 | 60 | 1 |
| Plants(mg·kg$^{-1}$) | [22] | 0.5 | 0.5 | - | 0.3 [c]<br>0.2 [d] | 0.2 [c]<br>0.05 [d] |
| | [23] | | | 1.5 | | |

[a] Irrigation water quality
[b] Irrigation water quality National Environmental Council in Brazil
[c] Limit for leaf vegetables
[d] Limit for fruit vegetables

the mean concentrations of the analyzed metals had the following order: Pb>Ni>Cr>As>Cd. In none of the studied sites was the heavy metal concentration in the soil above the permitted limits (Table 2). The metal with the highest concentration in the sampled sites was Pb (0.000-14.992 mg·kg$^{-1}$), while that of Cd was the lowest (0.000-0.440 mg·kg$^{-1}$), below from the Cd concentration in soils between 0.82-1.91 mg kg$^{-1}$ found by [3] in a study in Chongqing, China.

The highest concentrations of Pb and Cr in the soil at planting was found at site *E* in the north of the city followed by site *A*. The results in terms of site *E* is mainly based on the heavy traffic (Av. Insurgentes Norte), whereas site A could be influenced by the volatilization of waste of chromium hydroxide material, generated during the industrial activities of Cromatos de México, located in Tultitlán, State of Mexico [25]. This result agrees with [26] who mentioned that heavy metals found on the soil surface are mainly from anthropogenic activities and to a lesser degree from soil natural processes like translocation of inorganic and organic materials from one horizon to another, either up or down.

Moreover, in sites *E*, *H*, *L* and *M* the final Cr concentration decreased relative to the initial concentration (Fig. 2). The same was found under consideration of As in sites *A* and *D*; Ni in sites *A*, *C*, *E*, *G*, *H* and *J*; Pb in *A*, *C*, *E*, *H* and *N*; Cd in *A*, *C*, *E*, *H* and *N*. According to [27], this behavior could be caused by heavy metal uptake by the plants (lettuce and cherry tomato) from the soil. For the rest of the sites, the results were the opposite, possibly attributable to atmospheric pollution due to particulate matter ($PM_{10}$ and $PM_{2.5}$) as shown by [13].

The mean concentrations of heavy metals in soils (mg·kg$^{-1}$) for the thirteen urban gardens of Mexico City (Cr = 0.334, As = 0.113, Ni = 0.499, Pb = 2.244, Cd = 0.1) were low in comparison with the results obtained by [8] (Cr = 106, As = 19.2; Pb = 57.6 Cd = 0.22) in a study made in some cities of China; and [14] (Cr = 135; Ni = 49; Pb = 116) in random sampling of topsoil at 135 and 146 sites, respectively, in Mexico City. Specifically, [17] reported a mean Cd soil levels for United States of 0.32 mg kg$^{-1}$ , similar with the values for Spain (0.3-0.53 mg kg$^{-1}$) and Italy (0.3 mg kg$^{-1}$) but not comparable to the ones found in some cities in China like Kunming (2.087 mg kg$^{-1}$), Shenyang (1.161 mg kg$^{-1}$) and Shanghai (1.091 mg kg$^{-1}$). The authors mentioned found high concentrations of Pb, Ni and Cr, contrasting with those reported in our study.

Although the concentration of heavy metals does not exceed the permissible limits , there are characteristics that are worth highlighting: 1) the most abundant metal in soils was Pb, specially in sites (A, B, E, I, J, K) with a lot of traffic, this result agrees with [28] who mentioned that unleaded gasoline is a considerable anthropogenic source and it accounts for 8.4% of the total Pb emissions from fossil fuels; 2) organic matter has a high affinity for heavy metals, and it often acts as a store for heavy metals, and played a fundamental role in the control of Pb absorption by soils [29], this finding agree with our results because soil in site A has the highest content of organic matter (10%).

3) clay soils have a high buffering power, they can filter and transform the pollutants, therefore they have a high self-purification capacity. In our study we did not find a visible relationship between clay soil texture (B, F, K, L) and the content of heavy metals.

## Heavy Metals in Plant Material

From all urban gardens, it was not possible to establish lettuce in site M nor cherry tomato in sites B, F and H. None of the heavy metals studied was detected in the lettuce and cherry tomato seedlings, and thus the initial concentration will be referred to subsequently as 0.00 mg kg$^{-1}$. Fig. 3 presents the concentrations of heavy metals in the edible and non-edible parts of lettuce and

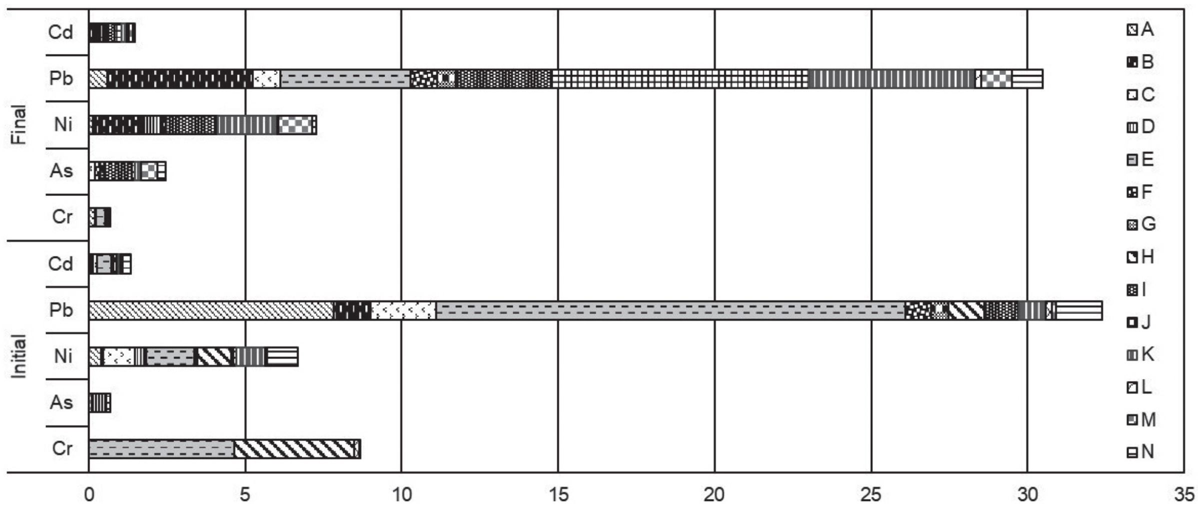


Fig. 2. Initial (planting) and final (harvest) mean concentrations of heavy metals (mg·kg$^{-1}$) in the soil of the sampled sites.

cherry tomato plants in the sampled sites of Mexico City.

*Lettuce*

In the average the *NEP* absorbed 57.4%, 38.4%, 42% 45.9%, 58.9 % of Cr, As, Ni, Pb and Cd respectively. The highest concentrations of Cr in *EP* and *NEP* were found at the same sites; the concentration in the *NEP* was higher than in the *EP* (Fig. 3). Nevertheless, atmospheric pollution could be the reason for the concentration of this heavy metal in both parts since the initial concentration in the soil was low, except for sites E and H. The above can be supported with the findings by [13] who reported a mean Cr concentration of 8.76 $\mu g \cdot m^{-3}$ in the metro station Azcapotzalco in Mexico City.

As concentrations in *NEP* and in *EP* of lettuce crop varied depending on the location (Fig. 3). At the sites B, J and N, the *NEP* had a higher As accumulation than analyzed in EP, while at sites A, D and K, it was opposite. In the remaining gardens the concentration of As was not detectable. Furthermore, the result obtained in our study for site K coincides with that found by [30], who evaluated root absorption of As in the southern part of Mexico City. They also detected no As in the *NEP*. On the other hand, [31] assume that the As accumulation in the shoot is mainly based on the atmospheric pollution.

The Ni concentration in *NEP* was higher in comparison to that measured in *EP,* especially in lettuce cultivated in the gardens G, H and K located at the Central East area of México City. At sites A, C, D, F, J, L and N the opposite results were found. Some traces of Ni in $PM_{10}$ (0.04 $\mu g \cdot m^{-3}$) were reported by [13] in the municipality Gustavo A. Madero (site C) and 4.32 $ng \cdot m^{-3}$ in Azcapotzalco (site B), which gives some precedent of Ni in the air.

The *NEP* of lettuce at the locations A, C, E, F, G, H, I, J and L accumulated more Pb compared to the other locations. This could be attributed to the absorption and translocation of this heavy metal, even though in the urban gardens F and G the Pb concentration in the soil was less than 1 $mg \cdot kg^{-1}$ in both samples (Fig. 2). At sites B, D, K and N the Pb concentration was higher in the *EP* compared to that in the *NEP.* Our results suggest various pathways to foliar uptake of Pb by lettuce leaves one is the metal traslocation from soil to plant and the other is the foliar transfer which is an important issue much less studied. The highest concentration of Pb in soils was (4.67 mg $kg^{-1}$) in Garden B which is lower than the concentration in leaves (14.65 mg $kg^{-1}$) meaning the soil-plant transfer of Pb could be low due to the high pH (7.47 to 8.40) suggesting low heavy metal availability. Therefore the Pb concentration could be attributed to foliar absorption. According to [7] plant metal uptake may occur predominantly via foliar contamination by micro- and nanoparticles, also [32] mentioned that the primary mechanism of Pb transfer is physical contamination. These findings are supported by [2] who found high levels of Pb (6.714-8.959 mg $kg^{-1}$) in parsley leaves and [13] who found a mean Pb concentration in the air of 84.21 $ng \cdot m^{-3}$ near site B.

In eight urban gardens Cd absorption in lettuce leaves was greater than in roots and stem (Fig. 3), this behavior cannot be attributed to translocation because the highest concentration of Cd for lettuce leaves (2.55 mg $kg^{-1}$) was found in garden K, with an initial Cd concentration in soils of 0.060 mg $kg^{-1}$. At site J, the Cd concentration in *EP* and *NEP* was the same.

If we concentrate our attention only in the *EP.* The mean of the heavy metal concentration in the *EP* for

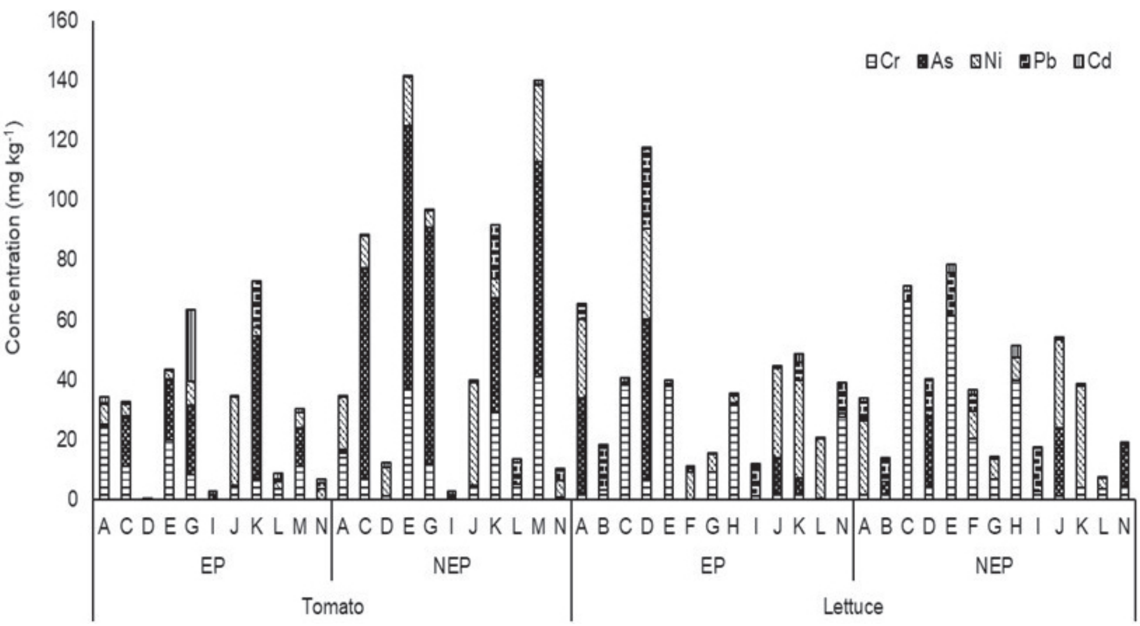


Fig. 3. Heavy metal concentrations ($mg \cdot kg^{-1}$) in *EP* and *NEP* of lettuce and cherry tomato cultivated in the studied gardens.

all sampled points and two repetitions (26 points), appear in the following order Ni>Cr>As>Pb>Cd (Table 3). The mean concentrations of Ni in the sampled sites were in *K>D>J>A>L>F>G>H>N*, from which only gardens *B*, *C*, *E*, *I* and *N* did not surpass the permitted limit. The mean concentration of Ni (12.26 $mg \cdot kg^{-1}$) in the *EP* of lettuce was higher of than that reported for other cities (Table 4). According to [39] Nickel is mainly released from anthopogenic sources as suspended particulate matter , the half life of very small particles of Nickel is about 30 years and it is transported over long distances, and the atmospheric residence time is from 5-8 days. Also [40] mentioned that the greatest presence of Nickel compounds in air derives from the combustion of fossil fuels. Currently, in Mexico City there are three stainless steel industries close from the sampling sites this could be the reason of high Ni concentrations in the air.

Cr was present in the *EP* in 12 of the 13 sites analyzed, varying between 0.00 and 45.00 $mg \cdot kg^{-1}$, surpassing the permitted limits in 11 urban gardens (Table 3) and with mean concentration in descending order as: *C>E>H>N>G>D>B>A>J>K>I>L*. A precedent of Cr in *EP* close to site K is given by [30] who found a concentration of 2.1 $mg \cdot kg^{-1}$ in lettuce cultivated in Xochimilco. As mentioned by [41] Chrome is mainly used in the metallurgical and chemical industries. These branches of industry have an important effect on air pollution so, the high concentration of Cr in most of the sites could be due to industrial residues from Cromatos de México, which has been dispersed in the atmosphere and soils [20]. Cr was not detected in lettuce leaves at site F, in the southern part of Mexico City, because is far away from the industrial zones and vehicle traffic, this area is mainly dedicated to agricultural activities.

As exceed the established limits in sites *D>A>J>K*, an excessive mean concentration of As was found in site D (53.72 $mg \cdot kg^{-1}$). From the 13 sampled points only four presented As but in high levels, this is the reason of the average As concentration presented in Table 4, which is higher than the rest of the cities.

Pb was above the permitted limit in gardens D>B>I>N>K>A>F>E>C. The above results can be attributed to the sources of airborne lead within Mexico City like lead smelters, battery manufacturing plants, battery repair shops, and paint factories. Also [28] reports unleaded gasoline as a new considerable anthropogenic source and it accounts for 8.4% of the total Pb emissions from fossil fuels. An extreme case of Pb concentration in lettuce leaves (335±50 $mg \cdot kg^{-1}$) is reported near a smelter in France after 43 days of exposure to atmospheric pollution, giving evidence of leaf absorption of Pb by Lactuca sativa L [7]. The Pb content in lettuce leaves in our study was below from that in lettuce grow in coalmine tailing soils (Belgrade, Servia), but it was higher than the one found in other cities (cities in China, Naples, Borno Nigeria) (Table 4).

The permitted limit of Cd was above in sites K>C>E>H>A> = J>F>G>I = L>B (Table 3), the maximum level in garden K (2.55 mg $kg^{-1}$) was far below to Cd concentration in lettuce leaves (29 mg $kg^{-1}$) found by [16] in the city of Bologna Italy. Lettuce is considered as Cd accumulator due to its high uptake and translocation, but this characteristic depends also on soil salinity, pH, clay, organic matter, Fe and Zn; Also, the Cd concentration in lettuce cultivated under different Cd levels in soils (1.38-18.1 mg $kg^{-1}$) ranged from 1.61-25.5 mg $kg^{-1}$, showing a positive correlation between them [17]. In general, the leafy vegetables accumulate Cd, as stated by [2], who found concentrations of this HM between 1.453-1.622 mg $kg^{-1}$ for parsley leaves in Tehran. A precedent of Cd in lettuce leaves was presented by [30] who collected samples of lettuce leaves cultivated on Chinampas with water from the irrigation canals, they obtained a mean Cd concentration below that obtained in our research for the same City Hall.

Leafy vegetables enhances the heavy metals absorption by roots and also there are more susceptible to pollutant accumulation from the atmosphere because of their larger leaf area with higher transpiration rates and stronger surface adsorption capacity, increasing internal metal content through foliar transfer [34, 42]. The present study confirms the finding by [6] that the aerial organs of plants can also absorb heavy metals, because this organs are equipped with heavy metal uptake mechanisms similar to the roots.

### *Cherry Tomato*

The heavy metals distribution in *EP* and *NEP* for cherry tomato is presented in Fig. 3, *NEP* has been the most contaminated and accumulated by Cr (62.9%), As (74.1%), Ni (67%), Pb (60.4%) and Cd (18.8%) respectively. This result coincides with [43] in the percentage of Cr (62%) absorbed by roots, in the case of Pb the authors reported that 38 % was absorbed in the roots which is quite different from our results.

With the exception of sites *A*, *C* and *J*, *NEP* had higher concentrations of Cr than *EP* (Fig. 3). This coincides with the research made by Rodríguez-Bocanegra and collaborators [44], who found a higher concentration of heavy metals in the roots than in the rest of the cherry tomato tissues, indicating that the concentration of Cr for this vegetable can be attributed to absorption by roots. However, in our case the highest concentration of Cr (4.64 mg $kg^{-1}$) in the soils was much lower than that found in the *NEP* of cherry tomato crop (24.6 mg $kg^{-1}$). This high concentration of Cr could be due to industrial residues from Cromatos de México, which has been dispersed in the atmosphere and soils [25].

In seven places the concentration of As was above the permitted limits with a higher concentration in *NEP* than in the *EP* in six sites. The As uptake and accumulation by plants depends on the chemical form

Table 3. Heavy metal concentrations in lettuce leaves (EP) in mg·kg$^{-1}$

| | | A | B | C | D | E | F | G | H | I | J | K | L | N |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cr | 1 | 1.90 | 3.00 | 45.00 | 3.30 | 41.00 | 0.00 | 10.00 | 34.00 | 1.20 | 2.60 | 1.80 | 1.10 | 19.50 |
| | 2 | 3.40 | 3.80 | 32.10 | 10.00 | 35.10 | 0.00 | 8.30 | 30.60 | 1.70 | 2.20 | 1.90 | 0.00 | 23.00 |
| Mean | | 2.65$^{a}$ | 3.40$^{a}$ | 38.55$^{b}$ | 6.65$^{a}$ | 38.05$^{b}$ | 0.00$^{a}$ | 9.15$^{a,c}$ | 32.30$^{b,c}$ | 1.45$^{a}$ | 2.40$^{a}$ | 1.85$^{a}$ | 0.55$^{a}$ | 27.50$^{b,c}$ |
| As | 1 | 60.20 | 0.00 | 0.00 | 32.10 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 4.80 | 0.00 | 0.00 | 0.00 |
| | 2 | 2.10 | 0.00 | 0.01 | 75.33 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 18.20 | 11.00 | 0.00 | 0.00 |
| Mean | | 31.15$^{a,b}$ | 0.00$^{a}$ | 0.00$^{a}$ | 53.72$^{b}$ | 0.00$^{a}$ | 0.00$^{a}$ | 0.00$^{a}$ | 0.00$^{a}$ | 0.00$^{a}$ | 11.50$^{a,b}$ | 5.50$^{a,b}$ | 0.00$^{a}$ | 0.00$^{a}$ |
| Ni | 1 | 28.00 | 0.00 | 0.00 | 44.00 | 0.00 | 5.40 | 7.00 | 3.50 | 0.00 | 26.90 | 27.90 | 14.60 | 0.00 |
| | 2 | 25.30 | 0.00 | 0.01 | 16.50 | 0.00 | 13.00 | 5.40 | 1.20 | 0.00 | 33.40 | 37.40 | 25.20 | 4.00 |
| Mean | | 26.65$^{a}$ | 0.00$^{b}$ | 0.01$^{b}$ | 30.25$^{a,b,c}$ | 0.00$^{b}$ | 9.20$^{c}$ | 6.20$^{c}$ | 2.35$^{b,c}$ | 0.00$^{b}$ | 30.15$^{a}$ | 32.65$^{a}$ | 19.90$^{a}$ | 1.33$^{b,c}$ |
| Pb | 1 | 0.00 | 17.20 | 0.00 | 19.30 | 0.00 | 1.20 | 0.00 | 0.00 | 7.30 | 0.00 | 0.00 | 0.00 | 0.00 |
| | 2 | 8.50 | 12.10 | 1.00 | 34.17 | 1.50 | 1.60 | 0.00 | 0.00 | 13.50 | 0.00 | 12.10 | 0.00 | 0.00 |
| Mean | | 4.25 | 14.65 | 0.50 | 26.74 | 0.75 | 1.40 | 0.00 | 0.00 | 10.40 | 0.00 | 6.05 | 0.00 | 10.17 |
| Cd | 1 | 0.80 | 0.30 | 2.50 | 0.00 | 1.50 | 1.20 | 0.00 | 1.50 | 0.40 | 0.80 | 4.00 | 0.50 | 0.00 |
| | 2 | 0.80 | 0.30 | 1.20 | 0.33 | 1.20 | 0.20 | 1.00 | 0.50 | 0.40 | 0.80 | 1.10 | 0.30 | 0.00 |
| Mean | | 0.80 | 0.30 | 1.85 | 0.17 | 1.35 | 0.70 | 0.50 | 1.00 | 0.40 | 0.80 | 2.55 | 0.40 | 0.00 |

1: replication 1, 2: replication 2, equal letters, there are no statistically significant differences for $p<0.05$.

Table 4. Mean heavy metal concentrations (mg·kg$^{-1}$) in lettuce leaves.

| | Place | Cr | As | Ni | Pb | Cd |
|---|---|---|---|---|---|---|
| [33] | Dukem, Etiopia | 3.77 | - | - | 5.50 | 3.68 |
| [34] | San Diego | | 0.42±0.055 | | | |
| [9] | Tehran, Iran | 0.279 | 0.001 | 0.203 | 0.123 | 0.005 |
| [35] | Naples, Italy | 1.65 | | 8.16 | 3.31 | 1.93 |
| [16] | Bologna, Italy | 29 | | 3 | 3 | |
| [30] | Xochimilco, Mexico City | 2.1 | 0.25 | 1.6 | 0.43 | 0.16 |
| [36] | Cities in China | | | | 0.154 | 0.061 |
| [37] | Yangling Shaanxi, Province in China | - | - | - | - | 2.70-3.62 |
| [7] | France | - | - | - | 335 | - |
| [38] | Belgrade, Servia | 9 | 1.7 | 27.1 | 6.1 | 1.4 |
| This study | Mexico City | 12.17 | 7.84 | 12.26 | 4.98 | 0.83 |

and concentration of the element in soil, soil properties, and plant species [45], these findings are not applicable in our case, given that As was not detected in the initial samples of the seedling, and the concentrations found in water and soil were low; therefore it is possible to consider atmospheric deposition as the reason for As in the *NEP* of tomatoes. Arsenic emissions are mainly from anthropogenic, in Mexico city there are some metal industries that could contaminate the air with this HM, however there is no evidence about the sources. In relation with the high concentration in the *EP* [26] mentioned that toxic metals can accumulate in different plant organs; however, the accumulation rate varies from organ to organ, and some organs accumulate more than others. Seems to be that stem and roots absorbed more As than the fruit for the case of cherry tomato plant.

Nickel had a similar behavior than As, eight out of ten sites had higher Ni concentration in *NEP* than in the *EP* (Fig. 3). The possible source of Ni emissions to the atmosphere could be the stainless steel industries with high temperature metallurgical operations in Mexico city.

At five locations, the Pb concentration was higher in *NEP* than in *EP* (Fig. 3). At site K, not only the lead concentration in *NEP* (18.05 mg·kg$^{-1}$) was higher, but also in the soil samples (3.083 mg·kg$^{-1}$). Therefore, the high concentration can be partially attributed to the concentration present in the soil even when it was lower than that found in the plant.

The mean Cd concentration in *EP* surpassed that in *NEP*, except for that found at sites *D* and *J*, which had a maximum concentration of 24.10 mg·kg$^{-1}$ in *EP* (Fig. 3). Because this metal did not have concentrations above one in soil samples, the accumulation of Cd in the *EP* could be attributed to absorption by leaves. There are at least four smelters in Mexico city, which are the most important sources of airborne cadmium, other sources of airborne cadmium include burning fossil fuels such as coal or oil and incineration of municipal waste such as plastics and nickel-cadmium batteries [46].

Specifically for the *EP* of the cherry tomato fruits the concentration of HM are presented in Table 5. The metal with the highest concentration was As, whose values oscillated between 0.00 and 50.6 mg·kg$^{-1}$, while Pb had the lowest concentrations, 0.00 to 18.0 mg·kg$^{-1}$. The *EP* of tomatoes had mean heavy metal concentrations in the following descending order: As>Cr>Ni>Cd>Pb. Cr and As were not present at sites *D*, *I* and *N*, nor was As present at site *L*. As concentrations were above the permitted limits in the following order: *K>G>E>C>M>A>J* (Table 5) with an average concentration far above from that found in an experiment with self-grafted tomato plants (0.05 mg kg$^{-1}$) irrigated with As-free nutrient solution in Catania Province [47] (Table 6) and also from the international standards for heavy metal content limits for vegetables displayed in Table 2.

Cr surpassed the established limits (Table 2) in the following order: *A>E>M>C>G>K>J>L*. Site *A* was one of the places closest to large avenues where automobile chrome is worn off and neighboring industrial activities use this metal.

The content of Ni in cherry tomato fruit surpassed the international standard for fruit vegetables (Table 2), with the exception of gardens *D* and *I*. The concentration of Ni in tomato crop was higher from that reported for Naples and Bologna Italy, Wukro in Ethiopia, and the North of Pakistan (Table 6).

The amount of Cd found in cherry tomato fruit was higher than the permitted limits in 10 of the 11 sampled sites: *G>L>A >N>I>M = C>E>D>J*. Dahunsi and collaborators [5] studied the effect of Cd and Ni in cherry tomato and find out that Cd has the weakest accumulation ability by the plant than Ni, but the

Table 5. Heavy metal concentrations in cherry tomato fruits in mg·kg$^{-1}$.

| | | A | C | D | E | G | I | J | *K* | *L* | *M* | *N* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cr | 1 | 26.00 | 16.50 | 0.00 | 35.00 | 15.00 | 0.00 | 3.80 | 6.10 | 3.80 | 18.50 | 0.00 |
| | 2 | 23.20 | 5.80 | 0.00 | 5.20 | 1.80 | 0.00 | 5.70 | 6.60 | 3.80 | 3.80 | 0.00 |
| Mean | | 24.60 | 11.15 | 0.00 | 20.10 | 8.40 | 0.00 | 4.75 | 6.35 | 3.80 | 11.15 | 0.00 |
| As | 1 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 46.00 | 0.00 | 0.00 | 0.00 |
| | 2 | 1.00 | 33.80 | 0.00 | 40.80 | 46.40 | 0.00 | 0.50 | 50.60 | 0.00 | 25.80 | 0.00 |
| Mean | | 0.50 | 16.90 | 0.00 | 20.40 | 23.20 | 0.00 | 0.25 | 48.30 | 0.00 | 12.90 | 0.00 |
| Ni | 1 | 8.00 | 6.50 | 0.60 | 4.50 | 14.50 | 0.00 | 27.60 | 3.00 | 2.20 | 8.00 | 2.00 |
| | 2 | 5.50 | 1.00 | 0.00 | 0.40 | 1.20 | 0.00 | 31.10 | 2.60 | 2.20 | 2.60 | 9.00 |
| Mean | | 6.75 | 3.75 | 0.30 | 2.45 | 7.85 | 0.00 | 29.35 | 2.80 | 2.20 | 5.30 | 5.50 |
| Pb | 1 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 2.40 | 0.00 | 18.00 | 1.00 | 0.00 | 3.50 |
| | 2 | 1.00 | 0.00 | 0.00 | 0.00 | 0.00 | 1.20 | 0.00 | 13.30 | 1.00 | 0.00 | 0.00 |
| Mean | | 0.50 | 0.00 | 0.00 | 0.00 | 0.00 | 1.80 | 0.00 | 15.65 | 1.00 | 0.00 | 1.75 |
| Cd | 1 | 1.00 | 2.00 | 0.40 | 1.00 | 48.00 | 1.60 | 0.30 | 0.00 | 2.00 | 2.00 | 1.50 |
| | 2 | 2.80 | 0.00 | 0.00 | 0.00 | 0.20 | 1.00 | 0.00 | 0.00 | 2.00 | 0.00 | 1.00 |
| Mean | | 1.90 | 1.00 | 0.20 | 0.50 | 24.10 | 1.30 | 0.15 | 0.00 | 2.00 | 1.00 | 1.25 |

cellular and molecular aspects of metal toxicity in plants are unknown.

Pb was above the permitted limits in five sites, with concentrations, from more to less, in sites *K>I>N>L>A*. In a study made Chongqing China [3] showed that under the same conditions of soils, the leafy vegetables accumulate more Pb than the solanaceous vegetable which coincides with our results in Tables 3 and 5. Only the mean concentration of Pb found in our study was lower than that found at Wukro, Ethiopia (Pb = 3.78 mg kg$^{-1}$) [49] the authors justified this high concentration of Pb by the fact that irrigation water was taken from a river where tannery wastes were dumped.

Deng and collaborators [3] showed that vegetables are most affected by external pollution of the Pb, Cd, and As, so attention must be paid specially to Cd levels in lettuce and cherry tomato, because according to [17] cadmium is listed by the US Environmental Protection Agency (EPA) as one of 126 priority pollutants, diet and house dust are the main routes of Cd exposure, it can be absorbed in various organs of the body such as kidney, liver, lungs, testes, spleen, thymus, heart, epididymis, prostate, and salivary glands, causing adverse effects on human health.

Even though lettuce and cherry tomato were grown in the same conditions the heavy metal content were different in the *EP* and *NEP* of the plants, which according with [12] is due to the difference in morphology and physiology of vegetables for heavy metal usage.

## Risk Indexes

### *Risk Indexes for Lettuce*

The translocation factor *TF* means the mobility of the heavy metal from *NEP* to *EP*. This factor for Cr in lettuce ($TF_L$) was higher than 1 at sites A, B, D, G, J and N, for As, at site D, for Ni at sites A, F, J and L, for Cd at sites I, K and L, and for Pb at sites B and D (Fig. 4a).

According to [51] and [52], a $TF$>1 means that the plant is a phytoextractor, which will accumulate heavy metals in its tissues. In our results ($TF_L$>1) indicate accumulation of As, Cd, Cr, Ni and Pb in lettuce tissues with subsequent health problems for those who consume them.

The compound risk value (*TTHQ*) represents the summation of the target hazard quotient (*THQ*), for all heavy metals in each urban garden. The assumptions behind *THQ* are presented in Equation (2), the different values of this quotient depends on the concentration of the heavy metal in lettuce and its reference dose $R_fD$ which is an estimate of a daily oral exposure for the human population, that does not cause deleterious effects during a lifetime. *TTHQ* should not be more than 1 to avoid harm to health from their consumption [4].

The highest *TTHQ* for lettuce ($TTHQ_L$) were found at sites D (6.4), A (3.64), and J (1.38) (Fig. 4b). It is worth noting that As (low $R_fD$ value) was the metal with the highest values for the target hazard quotient ($THQ_L$) at sites D (6.0), A (3.53), and J (1.3). Besides

Table 6. Heavy metal concentrations in cherry tomato fruits in different cities of the World (mg·kg$^{-1}$).

| | City | Cr | As | Ni | Pb | Cd |
|---|---|---|---|---|---|---|
| [48] | Bologna, Italy | 0.80 | - | 2.38 | 0.28 | 0.20 |
| [49] | Wukro, Ethiopia | 0.37 | - | 0.34 | 3.78 | 0.18 |
| [9] | Tehran, Iran | 0.234 | 0.011 | 0.161 | 0.0079 | 0.009 |
| [35] | Naples, Italy | 6.04 | | 2.45 | 1.33 | 0.28 |
| [36] | Southern, Pakistán | 2.72 | - | 7.00 | - | - |
| [50] | Vienna Austria | 0.052 | | 0.27 | 0.013 | 0.042 |
| [47] | Catania, Italy | | 0.05 | | | |
| [42] | Cities in China | | | | 0.052 | 0.019 |
| This study (mean) | Mexico City | 8.21 | 11.13 | 5.87 | 1.87 | 3.06 |

these places are close to main avenues in Mexico City, so attention must be paid to the vegetables produced in those sites.

The $TTHQ_L$ values at sites C, G, E, K and M were higher than those obtained by [42] (0.274) for vegetables consumption in Guizhou, China. Also, [54] in their study about vegetables cultivated in soils exposed to a long mining activities in Banat, Romania, report concentrations of Ni (18.4 mg kg$^{-1}$), Cd (2 mg kg$^{-1}$), and Pb (22 mg kg$^{-1}$) in soils and a values of the target hazard quotient ($THQ_L$) less than 1 for the three heavy metals.

*Risk Indexes for Cherry Tomatoes*

The translocation factor *TF* for cherry tomato fruit ($TF_T$) surpassed 1 in gardens A, C, E, G, J, K, L, M and N, with the highest value at site G for Cd (48.2); at D for As; at A, J and l for Ni, and at B and D for Pb (Fig. 5a). The *TF* for Cd was between 1.74±2.18 excluding the extreme value obtained in site G, these is comparable to the results reported by [55] (1.41±1.58) in tomato plants.

Twenty different plants were analyzed by [53] grown in areas affected by urban and industrial pollutants in Italy and conclude that translocation of the heavy metals can vary between species and ecotypes. Also, [56] mentioned that HM accumulation and translocation in vegetable species was regulated by the uptake capacity of the species, their specific parts, plant genotypes, metal types, environmental factors and edaphic factors. Specifically tomato satisfies the condition for a phytoextractor plant [51, 52], and thus when it grows in soil with available heavy metals, it will absorb and transport heavy metals from the soil to the above-ground parts of the plants and accumulate them in its tissues. An evidence was found by [43] about Pb and Cr translocation into tomato plants.

The compound risk value ($TTHQ_T$) given in Fig. 5b) is the summation of the target hazard quotient ($THQ_T$), for each heavy metal (Equation 4), this index surpassed 1 at sites C, E, G, K and M due to the high $THQ_T$ for As in cherry tomato fruits in those gardens. It was stated before (Fig. 3) that the most persistent heavy metal in cherry tomato fruit was As.

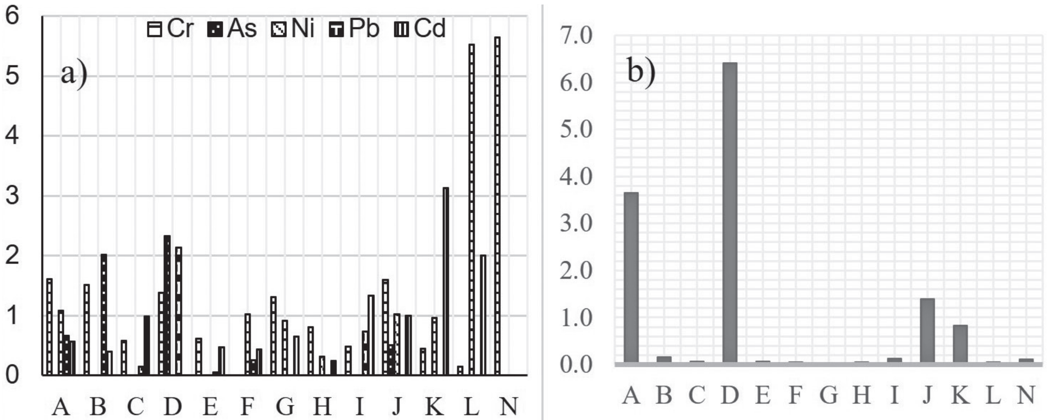


Fig. 4. Health risk indexes of lettuce cultivated in 13 gardens in Mexico City. a) Translocation Factor for lettuce ($TF_L$); b) The compound risk value for lettuce ($TTHQ_L$).

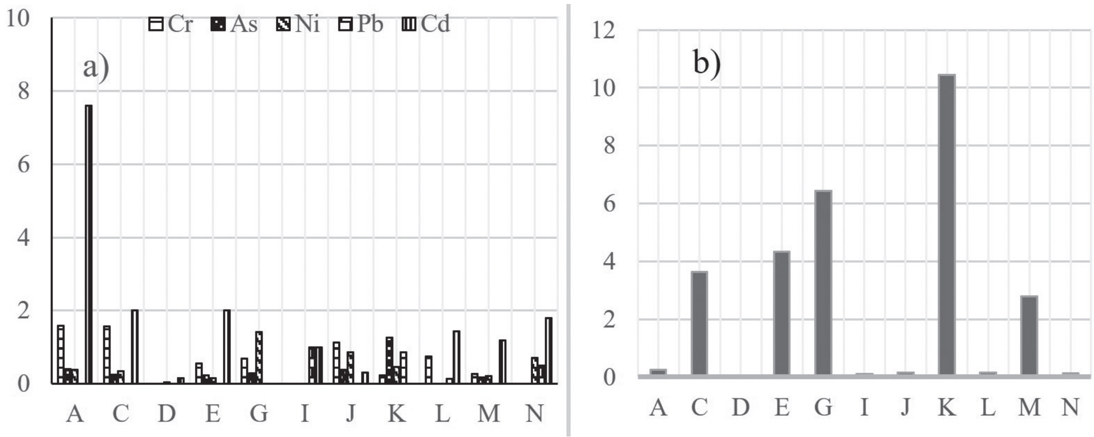


Fig. 5. Health hazard indexes for cherry tomato cultivated in Mexico City a) Translocation Factor for cherry tomato ($TF_T$); b) The compound risk value for cherry tomato ($TTHQ_T$).

These sites are near busy streets, except for garden G. Site K located at a distance of less than 500 m from busy streets and strong anthropogenic activities had the highest $TTHQ_T$ value (10.46).

*Hazard Index (HI)*

The hazard index (*HI*) reveals the danger of consuming vegetables given the conditions of soil, water and air. According to [19], *HI*<1 signifies an acceptable level of risk, while *HI*>1 represents an unacceptable hazard index. This index was calculated only for all sites in where lettuce and cherry tomato were established so urban gardens M (without lettuce) and B, F and H (without cherry tomato were excluded). *HI* was obtained by the summation of the daily chronic intake divided by the reference dose of each heavy metal, so its value like in the case of the *HI* index depends on the $R_fD$. Fig. 6 displays the *HI* index.

There is a considerable risk from consuming vegetables cultivated in most of the sampled sites, even when at some sites the heavy metal concentration in soils and water were within permitted values. Four out of ten sites exceeded the critical value (*HI*>1), in where As had the highest contribution to this index, in second place Cd, and in third place Pb, this results are due to the reference values ($R_fD$).

The highest value of *HI* in the case of urban garden D is mainly due to the high concentration of heavy metals in lettuce leaves (Table 3) which agrees with the values found for the compound risk value for lettuce ($TTHQ_L$) (Fig. 4b). The *HI* values obtained in garden G are similar to the one reported by [57] for a lettuce crop and six heavy metals (Pb, Zn, M, Cu, Cd, Cr) in Chongqing city in China.

The *HI* index takes into account all heavy metals (As, Ni, Cr, Pb and Cd ) with all sources of exposure and both vegetables, in this sense *HI* could be more reliable than the rest of the indices; however, depends on many assumptions and it can overestimate the potential effects of the heavy metals.

Plant cultivation within the cities may present environmental risk associated to both air and soil pollution, so cultivation of edible products may not be feasible in cities [16], however in our case taken into account the composition of the *HI*, only the uptake through the food chain (vegetables) (Equation 7) have a *CDI* values greater than zero with lettuce crop as a major contribution to *HI.*

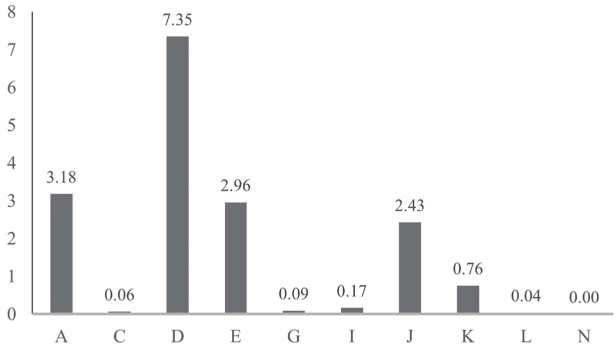


Fig. 6. Hazard index (*HI*) from consuming lettuce and cherry tomatoes grown in the sampled sites.

## Conclusions

Mexico City, together with its metropolitan area, is one of the most populated megacities in the world, with the problems associated with large cities. In this context, urban agriculture has been established as a beneficial activity that lowers temperatures, floods and runoff. However, anthropogenic activities generate pollutants that can accumulate in the soil, water air or plant material. We analyzed two crops: romaine lettuce and cherry tomato, in 13 urban gardens and one in the peri-urban zone. In our study, Cr and Ni were the heavy metals with the highest mean concentrations in lettuce leaves, while As and Cr were those with the highest concentrations in cherry tomato fruits. The absorption of heavy metals was higher in the *NEP* than in the *EP* for lettuce and cherry tomatoes. Our results show that both vegetables are bioaccumulators of HM, especially for Cr and As. The soil-water-plant system is not the only reason for heavy metal pollution in vegetables given that in the irrigation water only two metals (Cr, Cd) were above the established limits, and all soil samples had heavy metal concentrations below permitted limits. Thus, atmospheric pollution is left as the principal reason of the heavy metal accumulation in lettuce and cherry tomato plants. *TF* index is a measure of the translocation of the heavy metals from stems and roots to the edible parts of the plant, but it do not contemplate routes of plant access to metals such as atmospheric deposition. The daily chonic intake from vegetables ($CDI_{vegetables}$) is the main route access for heavy metals into human body. *HI* index relies on many assumptions and it can overestimate the potential effects of the heavy metals. The hazard indexes (*TF, TTHQ, HI*) confirm that the consumption of lettuce and cherry tomatoes grown in most of the urban gardens can be harmful to human health.

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## Conflict of Interest

The authors declare no conflict of interest.

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