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The influence of atmospheric particles on the elemental content of vegetables in urban gardens of Sao Paulo, Brazil☆

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ABSTRACT

Although urban horticulture provides multiple benefits to society, the extent to which these vegetables are contaminated by the absorption of chemical elements derived from atmospheric deposition is unclear. This study was designed to evaluate the influence of air pollution on leafy vegetables in community gardens of Sao Paulo, Brazil. Vegetable seedlings of *Brassica oleracea* var. *acephala* (collard greens) and *Spinacia oleracea* (spinach) obtained in a non-polluted rural area and growing in vessels containing standard uncontaminated soil were exposed for three consecutive periods of 30, 60 and 90 days in 10 community gardens in Sao Paulo and in one control site. The concentrations of 17 chemical elements (traffic-related elements and those essential to plant biology) were quantified by Inductively Coupled Plasma Mass Spectrometry (ICP-MS). *Tillandsia usneoides* L. specimens were used as air plant biomonitors. The concentrations of As, Cd, Cr and Pb found in vegetables were compared to the recommended values for consumption. Principal Component Analysis (PCA) was used to cluster the elemental concentrations, and Generalized Linear Models (GLMs) were employed to evaluate the association of the factor scores from each PCA component with variables such as local weather, traffic burden and vertical barriers adjacent to the gardens. We found significant differences in the elemental concentrations of the vegetables in the different community gardens. These differences were related to the overall traffic burden, vertical obstacles and local weather. The Pb and Cd concentrations in both vegetables exceeded the limit values for consumption after 60 days of exposure. A strong correlation was observed between the concentration of traffic-related elements in vegetables and in *Tillandsia usneoides* L. An exposure response was observed between traffic burden and traffic-derived particles absorbed in the vegetables. Traffic-derived air pollution directly influences the absorption of chemical elements in leafy vegetables, and the levels of these elements may exceed the recommended values for consumption.

1. Introduction

The popularization of community gardening for growing food in urban centres has fostered multiple health benefits, such as better social integration and eating habits and an increase in physical activity (George et al., 2015; Guitart et al., 2014; Harris et al., 2014; Nitta et al., 2015; Whatley et al., 2015). Furthermore, urban gardens can potentially improve the resilience of urban food systems, considering the United Nations projection that by 2050, more than 6 billion people or 65 percent of the world's population will live in cities, generating an unprecedented requirement for sustainable food production (United Nations, 2014). The Food and Agriculture Organization estimates that urban agriculture is currently practiced by 800 million people worldwide (FAO, 2016).

Sao Paulo has experienced a tremendous growth in the number of community gardens in the last 5 years. In this city, air pollution

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sources are primarily derived from the vehicular fleet (CETESB, 2015), frequently exceeding the levels established by WHO guidelines (WHO, 2006). Therefore, the practice of horticulture in urban areas must address the issue of potential contamination hazards of the produced food by the absorption of chemical elements derived from particulate matter present in the urban environment (De Temmerman et al., 2015; Säumel et al., 2012).

Chemical elements present in vegetable crops grown in urban environments are usually derived from previous soil contamination or airborne-derived pollution. Metal absorption may occur by root or foliar uptake and is influenced by several physico-chemical and physiological conditions. Earlier studies on this topic analysed the metal content of vegetables grown in the local soil (Peris et al., 2007; Säumel et al., 2012). Moreover, in these studies, the period of air exposure was not controlled, which did not enable a full comprehension of the isolated role of air pollution in the metal concentrations in vegetables.

Therefore, the contamination of crops as a result of traffic-related air pollution poses the following questions: To what extent are vegetables contaminated by the absorption of chemical elements from atmospheric deposition? What is the influence of the local urban environment on elemental absorption?

Brassica oleracea var. *acephala* (collard greens) and *Spinacia oleracea* (spinach) are frequently cultivated in community gardens and are extensively consumed in Brazil (Ministry of Health of Brazil, 2014; Tomita and Cardoso, 2002). These vegetables accumulate higher concentrations of metals compared with root vegetables (*Umbelliferae* and *Liliaceae*) and legumes (*Fabaceae*) (Alexander et al., 2006; Kachenko and Singh, 2006; Leake et al., 2009; Szolnoki and Farsang, 2013).

Therefore, in this study, we quantified the concentrations of 17 elements (traffic-related and those essential to plant biology) in the edible tissues of *Brassica oleracea* var. *acephala* (collard greens) and *Spinacia oleracea* (spinach) in 10 urban community gardens in Sao Paulo. We used multivariate analysis to correlate the elemental concentrations and the characteristics of the local urban environment, such as weather variables, traffic burden and vertical obstacles adjacent to the gardens.

In addition, to verify a correlation between the chemical elements found in collard greens and spinach and those from air pollution particles, we simultaneously exposed specimens of the air plant *Tillandsia usneoides* L. (TU) (*Bromeliaceae*), widely used as an air pollution biomonitor (Alves et al., 2008; Figueiredo et al., 2007; Martínez-Carrillo et al., 2010).

2. Methods

2.1. Study sites description

Ten community gardens within the inner city neighbourhoods of Sao Paulo, Brazil (Fig. 1a) and one control site – an organic farm in Piracaia, Brazil, a city with low atmospheric pollution in the rural area of the Sao Paulo state province - were selected for this study. These sites were chosen due to their different local settings (presence or absence of vertical obstacles, such as buildings or trees/hedges surrounding the gardens), geographical distribution and availability of the surrounding traffic data.

A geographical information system (GIS) census tract was used to establish a 500 m buffer from each garden to locate roads, major avenues, trees/hedges and buildings in the surrounding areas of the community gardens. These data were linked to a geocoded database created in ArcGIS software (version 10.3 ESRI, Redlands, CA, USA). An overall traffic burden (OTB) was calculated as proposed by von Hoffen and Säumel (2014) considering traffic-related variables within the buffer area, such as the daily average speed (km/h) during morning/afternoon periods, the number of vehicular fleets per day (buses, cars, trucks, motorcycle parcels) classified as 1 (low) $\leq$ 5000; 2 = 5001–10,000; 3 = 10,001–15.000; 4 = 15,001–20000; 5 = 20,001–30000; 6 = 30,001–40000; and 7 (high) $\geq$ 40,001, the presence or absence of vertical obstacles, such as buildings and trees/hedges, as well as their average height/width (m), and the Euclidean distance (m) relative to the gardens and the closest roads/avenues (Fig. 1b). Traffic data were obtained from the Traffic Engineering Company of Sao Paulo (CET, 2013).

The daily mean values of temperature (°C), relative humidity (%), rainfall (mm) and wind velocity ($m\ s^{-1}$) in the region surrounding each garden were obtained from the Emergency Management Centre of Sao Paulo Municipality during the study period.

2.2. Exposure experiment and sampling design

Organic seedlings of *Brassica oleracea* var. *acephala* (collard greens) and *Spinacia oleracea* (spinach) were cultivated for 15 days in a non-polluted rural area without the previous use of fertilizers or chemical pesticides. After this period, six parallel replicates of each species were transplanted simultaneously to washed and decontaminated (20% – HNO_3) high density polyethylene vessels (width: 50 cm, length: 90 cm and volume: 0.1 m^3) using an uncontaminated standard soil substrate (density of 500 kg cm^{-3}; 9% organic matter, pH of 5.8 ± 0.5 and electric conductivity of 2.5 ± 0.3 mS cm^{-1}). The seedlings and soil were characterized by Inductively Coupled Plasma Mass Spectrometry (ICP-MS) to detect the background concentration (BG) of the chemical elements prior to exposure in the gardens. The vessels were located in a central area of each community garden, 1 m above soil level (Fig. 1c). To avoid soil suspension by water droplets, we covered the soil in the vessels with coir (a natural fibre extracted from the husk of coconuts, which is used in horticulture – Fig. 1d). This material was also analysed prior to exposure and did not show signs of metal contamination.

The vegetables were exposed from September to November 2014. After every 30 consecutive days of exposure (for three periods of 30, 60 and 90 days), the "oldest" leaves were harvested from the bottom of the vegetables, washed for 3 min with distilled and ionic load-free water, gently brushed with a soft nylon dental brush, frozen (−20 °C) and submitted to elemental characterization using ICP-MS. The soil was also sampled every 30 days at eight defined points in each vessel at a depth extraction range of 0–30 cm, and a total amount of 500 g was collected, as recommended by Boulding (1994). The pH measurements of the sampled soils were obtained using a glass electrode (2:1 soil to water ratio by weight) according to the methodology proposed by Van Raij et al. (1987) to verify the correlation of the soil pH and the elemental concentrations in the vegetables over time. No manure, fertilizers or pesticides were used throughout the study period. In addition, samples of these two species offered in four local supermarkets were analysed as a comparative study. The results were compared to the limit values of As, Pb, Cr and Cd for washed green pods established by the Joint FAO/WHO (Codex Alimentarius), ANVISA (Brazilian Health Surveillance Agency), EU (Commission regulation (EC)) and AU/NZ (Australia and New Zealand Food Standards Code).

All vegetable sample analyses in this study are reported as fresh weight (f.w.).

2.3. Bromeliaceae biomonitoring

The specimens were collected at an unpolluted control site (Atlantic Rainforest), and the elemental content was characterized prior to exposure to determine the background values. TU plants were transplanted adjacent to the raised-bed vegetables at a height