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Does intake of trace elements through urban gardening in Copenhagen pose a risk to human health?

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ABSTRACT

This study investigates the potential health risk from urban gardening. The concentrations of the trace elements arsenic (As), cadmium (Cd), chromium (Cr), copper (Cu), lead (Pb), nickel (Ni), and zinc (Zn) in five common garden crops from three garden sites in Copenhagen were measured. Concentrations (mg/kg dw) of As were 0.002–0.21, Cd 0.03–0.25, Cr < 0.09–0.38, Cu 1.8–8.7, Ni < 0.23–0.62, Pb 0.05–1.56, and Zn 10–86. Generally, elemental concentrations in the crops do not reflect soil concentrations, nor exceed legal standards for Cd and Pb in food. Hazard quotients (HQs) were calculated from soil ingestion, vegetable consumption, measured trace element concentrations and tolerable intake levels. The HQs for As, Cd, Cr, Cu, Ni, and Zn do not indicate a health risk through urban gardening in Copenhagen. Exposure to Pb contaminated sites may lead to unacceptable risk not caused by vegetable consumption but by unintentional soil ingestion.

1. Introduction

Urban gardening is experiencing growing popularity in Europe and North America (Kessler, 2013; Leake et al., 2009; Saeumel et al., 2012; Witzling et al., 2011). In Copenhagen, gardening activities take place in well-established associations like school and allotments gardens, as well as new concepts such as rooftop gardening and gardening in movable containers are developed (Copenhagen Municipality, 2014a). The sites are often situated on former landfills in previously peripheral areas, in parks, brown fields, backyards, along railway lines, or on roofs. Due to the sites' exposure to possible soil and air pollution, public attention concerning adverse health effects of urban garden produce is also growing, and it is recommended that bare soil is covered, the produce is washed or peeled, hands are carefully washed, and soil ingestion is avoided (Capital Region of Denmark, 2014).

Trace elements are among the contaminants frequently found in urban soils and crops (e.g. Alloway, 2004; Saeumel et al., 2012; Samsoe-Petersen et al., 2002). In Denmark, all urban soils are categorized either as diffusively contaminated or as contaminated based on knowledge about recorded activities or point source pollution. Several studies have shown that consumption of vegetables grown in (peri-)urban areas might pose a risk to human health due to elevated levels of trace elements (Hough et al., 2004; Kachenko and Singh, 2006; Nabulo et al., 2012; Saeumel et al., 2012). A study on risk assessment of trace element exposure through vegetables in Copenhagen found that the intake of lead through urban vegetables grown in highly Pb-contaminated soil was above acceptable levels (Samsoe-Petersen et al., 2000), while the intake of other trace elements was assessed not to pose a health risk.

The aim of this study was to evaluate whether the intake of trace elements through urban gardening constitutes a health risk to urban gardeners. Exposures were calculated for both children and women since they represent susceptible groups in the general population (Landrigan et al., 2004; WHO, 2007). Soil and vegetable samples from three representative gardens in the inner city of Copenhagen were analysed for concentrations of selected trace elements (As, Cd, Cr, Cu, Ni, Pb, and Zn). The trace element concentrations in vegetables were compared to legal standards and concentrations found in conventional produce in order to elucidate if consumption of urban vegetables grown in Copenhagen city causes an increased health risk.

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2. Materials and methods

2.1. Plant and soil sample preparation

Three representative garden sites in inner Copenhagen were chosen based on the availability of vegetable crops, location and site history. Site descriptions are given in Table 1. Edible parts of carrot (*Daucus carota* subsp. *sativus*), potato (*Solanum tuberosum*) and kale (*Brassica oleracea* var. sabellica) were harvested in September 2012. Radish (*Raphanus sativus* var. Delikat) and lettuce (*Lactuca sativa* var. American Brown) were sown in April 2013 and harvested after 6 and 8 weeks, respectively. The vegetable samples were washed according to a 'normal kitchen procedure', minced and dried at room temperature in a fume hood until constant weight. Carrots and potatoes were not peeled.

Soils were sampled as composite samples consisting of 9 subsamples distributed on three points and three depths (5, 15, and 30 cm) within 2 m around each of the sampled vegetables. At each garden site, several composite soil samples were taken in order to obtain soil samples for all vegetables. Soil samples were dried in a fume hood at room temperature for 3 weeks, sieved with a 2 mm mesh and the sample size was reduced using a sample splitter.

Prior to analysis of total elemental concentrations, soil and plant material samples were digested according to the principles of the USEPA method 3052. For each sample, 0.5 g plant- or soil-material, 9 ml HNO_3 (65% Suprapur, Merck), 0.5 ml H_2O_2 (30% Suprapur, Merck) and 0.5 ml H_2O were transferred to Teflon vessels and digested in a microwave assisted system (Multiwave 3000 SOLV, Anton Paar). A certified reference soil (VKI loam soil A, batch: VKI-20-2-0495) and a certified reference plant material (spinach; NCS ZC73013 China Analysis Center for Iron and Steel, LGC Standards) were included in the digestion series. For each microwave run (15 samples), at least 1 blank was included. Digestives were subsequently cooled, transferred to volumetric flasks, and diluted with Milli Q water to 50 ml.

Table 1
Sampling site descriptions and soil characteristics.

Site ID	Site description[a]	Clay[b] (%)	Silt[b] (%)	$CaCO_3$ (%)	SOM (%)	pH ($CaCl_2$)
1	School gardens located in a small park. Sampling area approximately 100 m from a trafficked road. Trees and bushes between gardens and road. Traffic burden of the road is 20,500 vehicle count/d	6.2	16.2	0.4	3.3	6.2
2	Old university gardens located approximately 90 m from a highly trafficked road (48,700 vehicle count/d) only separated by a belt of tree	9.3	15.0	2.5	5.9	7.2
3	Allotment gardens located on a former landfill. Sampling site located approximately 90 m from a limited trafficked road (7500 vehicle count/d) separated by vegetation and garden houses	4.3	10.5	4.3	19.3[c]	7.2

[a] Data on annual average daily traffic as an expression for the traffic burden from Copenhagen Municipality (2014b).
[b] Clay: <2 μm; silt: 2–20 μm.
[c] Soil had previously been amended with commercial garden soil containing a high amount of SOM.

2.2. Sample analysis

Soil characteristics as pH, total and organic carbon content and texture were determined in triplicates. Soil pH was determined in a soil:solution (0.01 M $CaCl_2$) ratio of 1:2.5. Total carbon content was determined by dry combustion at 1300 °C (ELTRA CS 500). The soil organic matter (SOM) was calculated after correction from soil carbonates (Calcimeter Bernard method), assuming that 58% of SOM is soil organic carbon. The hydrometer method was used for determination of soil texture.

All plant and soil samples were analysed in triplicates by inductively-coupled plasma with an optical emission spectrophotometer detector (ICP-OES, Varian VISTA-MPX). Selected duplicates during the analysis were included to check for reproducibility. Two standard solutions were analysed for every 25 samples in order to control for drifting. Spiked samples were included to control for matrix effects. The buffer solution contained 1 mg/L Yttrium (Y) as internal standard and 1% $CsNO_3$ in 1% HNO_3. Calibration curves were made from 8 to 11 standards in the concentration range of 0.26–5200 μg element/L. Due to quantification problems with especially As and Pb, all plant samples were reanalysed by inductively coupled plasma mass spectrometry (ICP-MS, Agilent 8800 QQQ-ICP-MS). This instrument has a significant better sensitivity and is very efficient in removal of interferences for elements like As and Pb found in very low concentrations in a complex matrix. Interferences were removed by running the analysis in helium, hydrogen or oxygen mode. A selected sample was analysed for every 17 samples and corrections were made if drifting was above 5%. A 12 point calibration was made by use of the two commercially available standard solutions P/N 4400-132565 and P/N 4400-ICP-MSCS (CPI International, Amsterdam Holland). These standards reflect the concentration ratios found in plants and soils. Certified reference material consisting of wheat (NCS ZC 73009) and spinach (NCS ZC 73013) (China National Analysis for Iron and Steel) was used to evaluate the precision and accuracy of the analysis. Using 8–9 true samples precision was found to be within a 5% RSD (relative standard deviation) criteria and the accuracy within ± 10% of the average certified value.

2.3. Risk assessment

Critical effects and health-based reference values like tolerable daily intake levels (TDI) were selected for each element (Table 2). If several values were available, the lowest value corresponding to the critical effect was chosen for use in the further assessment (Table 2).

The exposure was calculated by multiplying average vegetable consumption from Danish food surveys (Lyhne et al., 2005; Poulsen et al., 2005) with mean vegetable concentrations. Vegetable trace element concentrations were converted from dry weight to fresh weight concentrations with the following conversion factors (determined in this study); carrot 0.138, kale 0.124, potato 0.233, lettuce 0.060, and radish 0.050. In case of vegetable trace element concentrations being < method detection limit (LOD), the LOD was used as concentration for the exposure calculation (see Table S1 for LOD). Consumption data for Danish consumers are given in Table S2. In cases where 95th percentile consumption rates were not available, the rates were calculated by assuming that the ratio between specific and total vegetable consumption is the same for mean and 95th percentile consumers. Soil ingestion rates were 0.2 g d^{-1} for children (Nielsen et al., 1995) and 0.05 g d^{-1} for adults (USEPA, 2011). For risk characterisation, hazard quotients (HQs) were calculated for both soil and vegetable ingestion by the following equation (1):