Orchards for edible cities: Cadmium and lead content in nuts, berries, pome and stone fruits harvested within the inner city neighbourhoods in Berlin, Germany

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**A R T I C L E I N F O**

Article history:
Received 28 August 2013
Received in revised form 21 November 2013
Accepted 22 November 2013
Available online 25 January 2014

Keywords:
Urban horticulture
Agroforestry
Fruit trees
Trace metals
Traffic burden

**A B S T R A C T**

Today’s urban gardening focuses mainly on vegetable production and rarely includes fruit trees. Health effects of consuming urban crops are questioned due to high local pollution loads. Here, we determined cadmium and lead content in the edible parts of nuts, berries, pome, and stone fruits harvested from fruit trees and shrubs within inner city neighbourhoods of Berlin, Germany. We analysed how local settings at sampling sites shaped the trace metal content. We revealed significant differences in trace metal content depending on species, fruit type, local traffic, and parameters related to barriers between the sampling site and neighbouring roads. Higher overall traffic burden and proximity to roads increased whereas buildings or vegetation as barriers reduced trace metal content in the edible biomass. We demonstrate, that the consumption of non-vegetable fruits growing in inner city sites in Berlin does not pose a risk on human health as long as the fruits are thoroughly washed and it is provided that site pollutions and impacts are considered in garden concepts and guidelines.

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1. Introduction

Urban gardening is booming worldwide and enhances food security, particularly in developing countries (FAO (Food and Agriculture Organisation of the United Nations), 2007). The interest of city dwellers for producing their own fresh food is also rising in developed countries (Leake et al., 2009) and food production for low-income citizens is supported by self-organisation and local authorities (Hancock, 2001).

Beyond local food production, urban gardening provides a broad range of ecosystem services and is recognised as a key instrument in environmental education (Krasny and Bonney, 2005), for community building (Bendt et al., 2013; Glover et al., 2005), and for enhancing urban biodiversity (Galluzzi et al., 2010).

Fruit tree species have been used for ornamental purposes as a reminiscence of rural landscapes (Lenné, 1825) and fruit trees along urban roads or in parks have been leased to get financial support for street or park maintenance in the 19th century (Schmidlin, 1852). Currently, fruit trees remain unused although abundant in public urban green spaces (see Fig. 1A for Berlin) and the urban gardeners focus mainly on vegetable production (Bendt et al., 2013; Hough et al., 2004).

The effect on human health caused by the consumption of urban gardening products is discussed controversially, mainly due to the high pollution loads in urban areas (Alloway, 2004; Finster et al., 2004; Hough et al., 2004; Leake et al., 2009). Studies of vegetables demonstrated, that the uptake and accumulation of trace metals differed among crop type, species, and among plant parts (Alexander et al., 2006; Finster et al., 2004; Säumel et al., 2012). Few studies investigated the relation between trace metal content in the edible parts of vegetables and local traffic burden (Kloke et al., 1984; Säumel et al., 2012). Planting and building structures (i.e. hedges, shrubs, lead free painted houses or walls) can function as barrier between planting site and road, decreasing trace metal content in the crops (Säumel et al., 2012).

Yet, there are only few studies analysing trace metal content in fruit tree products growing in urban environments (Li et al., 2006; Rossini Oliva and Valdés, 2003; Rossini Oliva et al., 2008; Samsøe-Petersen et al., 2002). Consequently, the aim of this study was to analyse the cadmium (Cd) and lead (Pb) content in the edible parts of different non-vegetable fruit types and fruit tree species. We determined the influence of traffic burden (i.e. traffic burden of the nearest and the nearest main arterial road, distances from the planting site to nearest and nearest main arterial road, overall traffic burden at sampling site) on trace metal content in the fruits. We evaluated whether characteristics of the planting site (i.e. sampling height, presence or absence of barriers between planting site and roads, barrier width or height, degree of enclosure of the sampling site by barriers) influence the trace metal content in the fruit trees.
metal content. Furthermore, we compared the trace metal content of the urban non-vegetable fruits with supermarket products to assess health risks by consuming these urban fruits.

2. Materials and methods

We collected nuts, berries, pome and stone fruits of nine different species at 172 randomly chosen sites in the inner city of Berlin, Germany (Fig. 1B). The sampling sites represented different urban conditions (Fig. 1C) and were characterised by the following parameters: distance to nearest road (d1) and to nearest main arterial road (d2) in meters, traffic burden on the nearest road (tb1) and on the nearest main arterial road (tb2) according to the number of vehicles per day (1 ≤ 5000; 2 = 5001–10000; 3 = 10001–15000; 4 = 15001–20000; 5 = 20001–30000; 6 = 30001–40000; 7 = ≥ 40000; Berlin Department for Urban Development, 2009), presence and absence of barriers between planting sites and nearest roads (b); height of barrier (bh) and width of barrier (bw) in meters; the degree of enclosure of the sampling site by barriers (eb), and sampling height in meters (sh). Furthermore, we classified the overall traffic burden (ob) within a radius of 250 m around the planting sites: low: low traffic burden, existing barriers or high distance between planting site and nearest street; medium: low to medium traffic burden and lacking barriers between planting sites and streets, low distance to the nearest street; high: high traffic burden and lacking barriers, small distance between planting site and nearest street.

All fruits were collected in 2012 at the usual harvest time of each fruit species. We classified fruit types as follows: ‘nuts’ (dry fruits with a hard woody shell including almond nuts); ‘berries’ (fleshy fruits including aggregate fruits such as blackberries or strawberries); ‘stone fruits’ (drupes with an outer edible fleshy part surrounding a seed containing shell); and ‘pome fruits’ (fruits with an outer edible fleshy part surrounding cores). In total, we sampled nuts: walnut (Jugland regia, N = 18), hazel (Corylus avellana, N = 13), ginkgo (Ginkgo biloba, N = 3); berries: blackberry (Rubus fruticosus agg, N = 16), seabuckthorn (Hippophae rhamnoides, N = 12), elder (Sambucus nigra, N = 27); and pome and stone fruits: apple (Malus domestica, N = 29), mirabelle (Prunus domestica subsp. syriaca N = 28), plum (Prunus domestica subsp. domestica, N = 26). For each fruit species, we collected mixed samples of common supermarket fruits (N = 3) except for ginkgo, elder, and seabuckthorn. Elder and seabuckthorn were not available in supermarkets; therefore we harvested samples from rural sites far away from potential pollution sources. In ginkgo, no trace metals were detected. We used these samples to compare the potential dietary exposure to trace metals of someone consuming urban horticulture products versus supermarket products.

Directly after the harvest, the edible parts of the berries, pome and stone fruits were thoroughly washed and afterwards frozen similar to the supermarket samples. The nuts were stored dry in their nutshells. Edible parts of all fruits were dried at a temperature of 60 °C for 72 h to 14 d depending on sample size and fruit species. After drying, the samples were ground (< 100 µm) and stored in a dehydrator. Then the samples were dried at a temperature of 105 °C for 48 h. Approximately 500 mg dry fruit powder and creamy nut powder was digested in 10 ml HNO3 (69 percent) in a drying chamber at a temperature of 185 °C. After the digestion, the samples were filled up to a volume of 40 ml with ultrapure water. The determination of the trace metal content in the biomass was made with an atomic absorption spectroscopy using the Atomic Absorption Spectrometer AA680Z (Varian, Australia). The used wave lengths/detection limits of the elements were 228.8/2.0 mg/l for Cd and 217.0/3.0 mg/l for Pb. We used a melon powder (IPE 950) as standard to assess the quality of our measurement (reference/measured values in mg/kg DW for N = 20: Cd: 1.03/1.34; Pb: 3.50/3.55).

We used analysis of variance (ANOVA) for data analysis. Cd or Pb content in the dried biomass is the response variables and species, fruit type, and the parameters characterising local settings at sampling site (overall traffic burden, distance to the nearest road and number of vehicles of the nearest road, distance to the nearest arterial road and the number of vehicles per day of the nearest arterial road, presence and absence of a barrier and type, height, width and degree of enclosure.
of the sampling site by barriers, sampling height) were taken as explanatory variables. Homogeneity of data (Brown-Forsythe’s test) and normal distribution of data (Shapiro–Wilk test) were tested before applying the ANOVA. Log transformations were applied if necessary to comply with the assumptions of the residual normality and variance homogeneity needed for the analysis. We used the Tukey test for the comparison of means. Effects were considered significant at \( p < 0.05 \) level. The statistical analysis was done by using R version 2.15.2 (R Foundation for Statistical Computing, Vienna, Austria).

3. Results

The trace metal contents differed significantly among species and fruit types (Table 1) and depended on traffic related and on barrier related parameters (Table 2).

Table 1

<table>
<thead>
<tr>
<th>Species</th>
<th>N</th>
<th>Cd</th>
<th>Pb</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nuts</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Juglans regia</td>
<td>18</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Corylus avellana</td>
<td>13</td>
<td>0.0</td>
<td>0.5</td>
</tr>
<tr>
<td>Ginkgo biloba</td>
<td>3</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Berries</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rubus fruticosus agg</td>
<td>16</td>
<td>4.5</td>
<td>8.1</td>
</tr>
<tr>
<td>Sambucus nigra</td>
<td>27</td>
<td>0.0</td>
<td>9.2</td>
</tr>
<tr>
<td>Pome and stone fruits</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Malus domestica</td>
<td>29</td>
<td>0.0</td>
<td>1.1</td>
</tr>
<tr>
<td>Prunus domestica subsp. Syriaca</td>
<td>28</td>
<td>0.0</td>
<td>9.3</td>
</tr>
<tr>
<td>Prunus domestica subsp. Domestica</td>
<td>26</td>
<td>0.0</td>
<td>1.2</td>
</tr>
</tbody>
</table>

Table 2

ANOVA results of the species, fruit type (i.e., nuts, berries and pome and stone fruits) and site effects as well as the interactions between species and site effects on content of Cd and lead in \( \mu \text{g/kg biomass dry weight (DW)} \). Minimum adequate linear models were chosen using a step-by-step reduction of the maximum model to the variance of the group means and the mean of the within group variances. F and p values of the ANOVA are given (ns, not significant). F value is the ratio between the variance of the group means and the variance of the group means.

Cd content of blackberry and seabuckthorn berries were up to 26 times higher compared to nuts, pome and stone fruits, and elder berries (Fig. 2A). Compared to the inner city fruit samples, the Cd content in control samples was higher in hazel (39 times), blackberry (2 times) and mirabelle (3 times), similar in walnut, elder, plum and apple—and lower in seabuckthorn (2 times; Table 1).

Pb content of pome and stone fruits was 8 times higher and up to 17 times higher in berries than in nuts (Table 1, Fig. 2B). Compared to the inner city fruit samples, Pb content in control samples was higher in apple (2 times), mirabelle (4 times) and plum (16 times) and was in the same range in seabuckthorn and elder (Table 1).

The sampling height of the fruits affected the trace metal contents significantly (Table 2). A decreasing sampling height
increased Pb and Cd content of blackberries ($P_{cd}=0.01$; $P_{pb}=0.001$).

Some traffic related parameters of sampling sites (i.e. overall traffic burden, distance to the nearest road, the number of vehicles per day on the nearest main arterial road) affected the trace metal contents of the fruits (Table 2). Cd content in apple, plum, blackberry and seabuckthorn increased significantly with increasing overall traffic burden at the sampling site (Fig. 3A, B, E–F). Pb content of fruits increased with increasing overall traffic burden at sampling sites for plum, mirabelle, and blackberry (Fig. 3H–L). Trace metal contents of other fruits varied largely among different overall traffic burdens and were not related to different traffic burdens (Fig. 3C, D and G).

The presence or absence of a barrier, the height of a barrier, and the degree of site enclosure by barriers influenced the Cd and Pb contents of fruits (Table 2). Apples growing behind a barrier had significantly lower Cd content and blackberries had lower Cd and Pb content, than fruits at sampling sites without a barrier between planting sites and roads (Fig. 3M, Q, and V).

4. Discussion

Our study highlighted that (1) urban non-vegetable fruits in Berlin accumulated considerably less Cd or Pb in the edible tissues compared to urban vegetables and partially to supermarket products (i.e. hazel, mirabelle, apple, plum) and did not exceed European standards for trace metals; (2) accumulation of health relevant trace metals differed among fruit types (i.e. nuts < pome and stone fruits < berries); and (3) beyond general urban pollution load, site-specific parameters (i.e. traffic burden, characteristics of barriers between sampling site and road, sampling height) affected the trace metal contents of fruits.

Previous studies on trace metal contents in edible fruits focused mainly on rural sites with diverse pollution sources such as spill contamination (Madejón et al., 2006), sewage irrigation (Batarseh et al., 2010; Menti et al., 2006a, 2006b), usage of compost and fertilisers (Merino et al., 2006; Pinamonti et al., 1997) or vicinity of contaminating industries (Arik and Yaldız, 2010).

In general, Cd and Pb content of non-vegetable fruits from Berlin’s inner city were similar or lower compared to fruits from uncontaminated rural sites (Ademoroti, 1986; Bi et al., 2010; Yaman et al., 2000) and significantly lower compared to fruits irrigated with sewage water or sludge (Batarseh et al., 2010; Menti et al., 2006a, 2006b). Cd and Pb content of stone fruits from Berlin were lower compared to unwashed mango fruits growing on rural sites that were classified as uncontrolled (Bi et al., 2010). Cd and Pb content of orange fruits growing in the inner city of Seville and Palermo were higher or similar to our berry samples (Rossini Oliva and Valdés, 2003). Fruits from Copenhagen, Denmark, had higher trace metal contents compared to our samples (Samsoe-Petersen et al., 2002).

A previous study on trace metal contents of vegetables grown in Berlin’s inner city demonstrated that urban crops are not automatically ‘healthy’ or ‘safe’ compared to vegetables harvested in uncontaminated rural areas (Ademoroti, 1986; Bi et al., 2010). Cd content of six vegetable crops in the inner city of Berlin accumulated considerably less Cd than vegetables harvested in the inner city of Seville and Palermo (Oliva and Valdés, 2003). Fruits from Copenhagen, Denmark, had higher trace metal contents compared to our samples (Samsoe-Petersen et al., 2002).

Almost all urban fruits analysed in this study had significantly lower Cd and Pb content compared to vegetables harvested in the same study area (Samsoe-Petersen et al., 2012). Similar differences between non-vegetable fruits and vegetables have been reported for medium contaminated urban sites (Samsoe-Petersen et al., 2002).

None of our samples exceeded the EU standards for Cd in fruits (0.05 mg/kg FW) and only one sample of the 172 samples exceeded the EU standards for Pb (0.20 mg/kg FW for berries and small fruits and 0.10 mg/kg FW for other fruits; European Commission, 2006). The WHO dietary intake limits for adults are 0.060 mg for Cd and 0.214 mg for Pb per day (FAO/WHO Joint Expert Committee on Food Additives, 1999). The recommended daily vegetable and fruit consumption is 400 g for adults. Thus, an adult consuming an average of 200 g of non-vegetable urban fruits would be ingesting less than 0.3 percent and 2 percent of the accepted daily intake of Cd and Pb, respectively. Thus, we did not prove a human health risk by consuming fruits from inner city areas. In contrast to our results, Cd content of the edible fruits from orchards in a large Chinese metropolis markedly exceeded Chinese and European standards (Li et al., 2006).

A further important finding of our study is that accumulation of health relevant trace metals differed between non-vegetable fruit types. Similar to our samples, carambola berries had generally...
higher Cd content compared to pome and stone fruits (i.e. wampee and longan fruits; Li et al., 2006). Menti et al. (2006a, 2006b) reported higher Cd contents in lemons than in almonds. Adapting the concept of low and high accumulators from vegetable crops to address species-specific differences in the capacity for uptake, accumulation, and tolerance of trace metals (e.g. Alexander et al., 2006; Finster et al., 2004), our results provide evidence that non-vegetable fruits can be addressed as low accumulators for both trace metals. Nuts with a compact protecting shell accumulate almost no Pb or Cd. Pome and stone fruits accumulate more Pb compared to nuts. Blackberry and seabuckthorn accumulate more Cd compared to the other fruit types whereas elder berries did not (Fig. 2). Our data provide evidence, that the higher sampling height of the elder berries compared to the other berries reduced trace metal contents (Table 2). Shielding properties of nut and fruit shells isolate the edible parts during growth from the environment and reduce airborne pollution (Wyttenbach and Tobler, 1998; Rodushkina et al., 2008). In contrast to our results, nuts from Copenhagen, Denmark, had higher Pb contents compared to berries and stone fruits (Samsøe-Petersen et al., 2002). However, more research is needed to highlight the mechanisms beyond these patterns.

The high variability of our data seen in Table 1 might be due to the heterogeneity of urban soil. Contaminated sites in urban environments can increase trace metal contents in fruits growing in a low overall traffic burden (Alloway, 2004). However, trace metal contents of urban fruits and vegetables were not always correlated with different degrees of soil contaminations (Samsøe-Petersen et al., 2002). Pb uptake from soils is generally passive and Pb is not directly translocated to the edible parts of a fruit tree (Ward and Savage, 1994). The atmospheric deposition of trace metals on the fruit surfaces apparently has a stronger effect than uptake from the soils (Madedjón et al., 2006; Samsøe-Petersen et al., 2002) and more traffic related Pb was deposited on rough surfaces such as tree bark compared to rather smooth fruit skins (Ademoroti, 1986). Consequently, unwashed olive fruits growing in spill-affected soils compared to non-affected soils showed no significant differences with regard to Cd and Pb contents (Madedjón et al., 2006).
Traffic related pollutants are strongly enhanced along roads compared to background values. Pollutants deposited in the soil remain there for a long time and acting as a source of further pollution in urban environments (Hjortenkrans et al., 2008; Querol et al., 2007). We revealed that a high traffic burden and proximity to the nearest road significantly increased the Cd and Pb contents in non-vegetable fruits (Table 2, Fig.3). The accumulation of Pb and Cd in the soils decreased with increasing distance from the road (Hjortenkrans et al., 2008). Cd and Pb contents in apple and grape fruits did not decrease with increasing distances to roads but with decreasing traffic densities (Bakirdere and Yaman, 2008). Pb deposits on unwashed fruit skin varied according to traffic volume in Benin City, Nigeria (Ademoroti, 1986).

Furthermore, our study revealed that barriers between planting sites and road reduced Pb and Cd in the edible parts of fruit trees (Fig. 3M, Q, and V). As particles washed off of painted houses and walls doubled Pb contents in the topsoil (Alloway, 2004), closeness of buildings and walls can also increase trace metal contents in the topsoil. Our data showed that the increasing height and width of a barrier decrease the trace metal contents in the edible part of fruits. Traffic related particles could be immobilised on plant surfaces of vegetation barriers such as hedges and thus reduce the deposition of traffic related pollution on the fruits (Hodel and Chang, 2004). Studies from the 1970s already demonstrated, that hedges or trees near roads efficiently reduced traffic related Pb emissions (Keller, 1974). However, the function of barriers was discussed controversially and it was assumed that the windbreak effect and the related higher deposition rates inside the hedges might be more important than the filtration effects of hedges (Keller, 1974; Bouvet et al., 2007).

The integration of productive fruit trees in urban gardening can support long-term establishment of local production and thus urban sustainability efforts (Deelstra and Girardet, 2000) and strengthen the environmental benefit of gardens for city-dwellers, urban flora, and fauna. Horticultural studies on rural landscapes have demonstrated benefits derived from an integration of productive fruit trees in gardens: shading and cooling effects of fruit trees between vegetable patches increased the crop yields (Huang et al., 1990), reduced soil erosion and functioning of leaf litter as organic fertiliser (Marten, 1986), enhanced agrobiodiversity (Altieri, 1999) as fruit trees attract a wide range of insect and bird species (e.g. Davies et al., 2009). In addition to these benefits, urban trees improve air quality (Akbari et al., 2001).

Finally, our study provides evidence for the development of planting concepts for urban gardens. Hedges or walls minimise contamination effects, especially within high traffic areas. Nut trees can form the outer and pome and stone fruits the medium boundary of urban garden areas, whereas berries and vegetables should preferably be cultivated in the central area of urban gardens.

5. Conclusion

Our study demonstrated that the Cd and Pb contents in fruits harvested from trees growing within inner city neighbourhoods were below the EU standards for fruits (European Commission, 2006), partially below values found in fruit samples from supermarkets and were considerably lower in urban non-vegetable fruits than in urban vegetables (Samsøe-Petersen et al., 2002; Säumel et al., 2012). However, more research is needed to identify harmless and risky fruit species for urban gardening. Based on our data, the consumption of urban fruits is not harmful to human health and fruit trees and shrubs can be considered more suitable for urban gardening in highly polluted areas compared to vegetables.

Overall, our study gives evidence that the consumption of non-vegetable fruits growing on inner city sites in Berlin does not pose a risk on human health, as long as the fruits are thoroughly washed and it is provided that site pollutions are considered in garden concepts and guidelines (e.g. minimum distance to roads, usage of barriers, planting concepts).

Capsule

Urban non-vegetable fruits accumulated less cadmium or lead in the edible tissues compared to urban vegetables and to some supermarket products and did not exceed European limits for trace metals in fruits.

Acknowledgments

This study was funded by Peter Dornier Stiftung Lindenau and by the Freunde der TU Berlin e.V. Special thanks go to Christa Müller and the Stiftungsgemeinschaft Anstiftung & Ertomis for supporting our research. We want to thank Claudia Kuntz, Iris Pieper, and Kotan Yildiz for technical assistance.

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