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Effectiveness of Washing in Reducing Lead (Pb) Concentrations of Lettuce Grown in Urban Garden Soils

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Core Ideas:

- Best Management Practices (BMPs) for limiting crop contamination need evaluation
- We assessed washing techniques in high- and low-lead soils, with other BMPs
- All washing techniques significantly reduced lettuce lead concentrations
- An estimated 97% of lead from soil splash and 91% from atmospheric deposition were washed off
- Washing crops grown even in low lead soils is important in urban environments

Abstract

Urban gardeners contribute to sustainable cities and often take great care to limit exposure to soil contaminants like lead (Pb). While best management practices (BMPs) like mulching to reduce soil splash can limit crop contamination, they may not eliminate all contamination for leafy greens, which trap soil particles. How effective is washing at removing Pb contamination from leafy greens when using BMPs? Are certain washing techniques more effective than others? We present results from two experiments addressing these questions. We grew lettuce (*Lactuca sativa*) in homogenized high Pb (~1150 mg/kg) and low Pb (~90 mg/kg) soils in Brooklyn, New York and Ithaca, New York. Our results show that washing can remove 75-94% of Pb from lettuce, including that remaining after the use of contamination-reducing BMPs. It was estimated that washing removed 97% of Pb deposited by splash, the dominant source of Pb, and removed 91% deposited by downward deposition. All washing techniques were effective at reducing Pb levels, with differences in effectiveness ranked as: commercial soak>vinegar soak>water soak (and water rinse not significantly different from vinegar or water soak). Washing crops grown in low Pb soils is also important. Without washing, lettuces grown in low Pb soil may still have Pb levels above the European Commission comparison value. We offer these empirical findings and recommendations in support of urban growers.

Keywords: crop contamination, soil contamination, community gardening, urban agriculture, best management practices, atmospheric deposition

Abbreviations: Best Management Practices (BMPs), fresh weight (f.w.), lead (Pb), milligrams per kilogram (mg/kg)

1. Introduction

Urban gardeners have helped create more sustainable cities for decades, and indeed centuries, worldwide (Turner et al., 2011). The benefits and challenges of urban gardening are complex, yet well known by practitioners. Researchers from multiple fields have assessed urban gardening's benefits for individual health (Kingsley et al., 2009), community wellbeing (Saldivar-Tanaka & Krasny, 2004), and broader ecosystem services (Lin et al., 2015), yet many gardens are located in neighborhoods with ongoing legacies of race-, class- and gender-based inequities. In these neighborhoods, growers can grow their own culturally relevant, healthy, and affordable produce – thereby promoting food justice and food sovereignty (Bradley & Herrera, 2016). However, urban gardening may reinforce racial and economic disparities many practitioners seek to oppose (Checker, 2011; McClintock, 2018; Roman-Alcalá, 2015; Sbicca, 2019). Recognizing these dynamic tensions is essential for adequately understanding and supporting the important work that urban gardeners undertake.

In the midst of these social pressures, urban gardeners must also contend with biophysical challenges, as soils often hold the legacy of past activities associated with industry, manufacturing, incineration, building demolition, peeling paint, and vehicle emissions (Meuser, 2010). These activities – past and present – leave an array of inorganic and organic toxicants in soil (e.g., Cheng et al., 2015; Mitchell et al., 2014). While numerous elements and compounds may pose risks to human health, lead (Pb) is commonly found in urban soils worldwide, and adheres strongly to soil particles, persisting over time (Datko-

Williams et al., 2014). Lead-adhering to soil particles may move down a soil profile over decadal scales, or Pb concentrations may be diluted as organic matter and other amendments are added to surface layers (Mielke et al., 2019). However, the legacy of Pb in urban soils continues to pose risks to urban populations, especially young children (Egendorf et al., 2021b).

There is no known threshold for adverse health effects of Pb in children, and in October, 2021, the Center for Disease Control (CDC) lowered its Blood Lead Reference Value from 5 to 3.5 μg/dL (CDC, 2021; Ruckart et al., 2021). In 2018, the Food and Drug Administration (FDA) discontinued the use of their Provisional Tolerable Total Daily Intake (PTTDI) for dietary Pb exposure of children and women of childbearing age and created Interim Reference Levels (IRLs) based on the CDC reference value of 5 μg/dL. The IRLs were set as 3 and 12.5 μg/day (Flannery et al., 2020), which may be adjusted according to the CDC's changes from 2021. Long-term exposure to Pb can cause developmental effects on cognition, decreases in intelligence quotient (IQ) scores and academic achievement, and behavioral effects such as hyperactivity and decreased attention (NIEHS, 2013). In pregnant women, exposure to Pb is associated with reduced postnatal growth and height, and delayed puberty in offspring (ATSDR, 2020; NIEHS, 2013). Long-term exposure to Pb in adults is associated with kidney, cardiovascular, reproductive, hematological and central nervous system effects (ATSDR, 2020; NIEHS, 2013). Research also suggests that adult Pb exposure is an important cause of premature death worldwide, and is responsible for approximately 412,000 deaths in the United States per year (Lanphear et al., 2018). Given these health concerns, understanding and mitigating all potential sources of exposure is of the utmost importance especially given the inequitable exposures of low income communities and people of color (O'Connor et al., 2020).

The main pathways for Pb exposure in gardens are through incidental soil ingestion (i.e., from hand-to-mouth activity), inhalation, and consumption of produce (US EPA, 2014). While young children accompanying gardeners may be most at risk from incidental soil ingestion, adult urban gardener Pb intake is dominated by consumption of produce (Spliethoff et al., 2016). It is therefore essential to limit contaminated soil exposure and crop contamination. Fruiting crops are least likely to contain Pb and are most appropriate to grow if soil contaminant levels are unknown or high (i.e., above the EPA Soil Screening Level of 400 mg/kg) (McBride et al., 2014; US EPA, 2014). Root crops like carrots may take up Pb (Codling et al., 2015) and should not be grown in high Pb soils.

Lead contamination of leafy greens can be complex. While crops like lettuce, spinach, and kale generally have limited uptake of Pb through their roots, the primary concern for leafy greens may be Pb-containing particles adhered to or entrapped in their tissues (McBride et al., 2013; Uzu et al., 2014). Research conducted in New York City (NYC) urban gardens has shown that common best management practices (BMPs) can limit leafy green contamination. Mulching, for example, can effectively limit splash and significantly reduce levels of Pb for washed leafy crops (Egendorf et al., 2021a). While washing lettuce has been shown to be effective at reducing contamination levels in several studies conducted over the past decades (Al Jassir et al., 2005; Bassuk, 1986; Folens et al., 2017; Preer et al., 1980) and comparisons between "laboratory" and "kitchen cleaning" have been made (defined in section 4.3) (Attanayake et al., 2014, 2015, 2021), our recent findings prompted the following research questions: 1) How important is washing in achieving these lower Pb levels compared to other BMPs? 2) Is washing more important for some growing practices than others? And 3) Are certain home washing techniques more effective than others?

To answer these questions, we conducted two related experiments. First, we grew lettuce (*Lactuca sativa*) in high Pb (~1150mg/kg) and low Pb (~90mg/kg) soils in an urban community garden in Brooklyn, NYC, to evaluate the relative effectiveness of washing lettuces grown using two BMPs: mulching and hoophouse cover. We hypothesized that washing is an important BMP in reducing Pb and may be particularly important for high Pb soils and in treatments without soil covers. In the second experiment, we grew the same cultivar of lettuce in the same high Pb soil transported from NYC to a field site in Ithaca, NY, away from urban contamination sources. We grew lettuce without any soil cover and subjected the harvest to five different washing treatments: no wash (control), water rinse, water soak, dilute acetic acid (vinegar) soak, and commercial product soak. We hypothesized that there would be significant differences between washing techniques.

2. Materials and Methods

2.1 Evaluation of washing effectiveness in combination with soil cover treatment BMPs

2.1.1 Experimental Design

In a community garden in Brooklyn, NYC, in 2016, lettuce was grown in two different soils: one with high Pb concentration (~ 1150mg/kg; soils collected from the garden and removed from gardener use, likely contaminated from legacy paint, building debris, and gasoline emissions) and one with low Pb concentration (~ 90mg/kg; provided by NYC Parks' GreenThumb for gardener use and for the study). See experimental design and soil properties described in Egendorf et al. (2021a). Briefly, soils were homogenized with shovels on tarps, and 30 3.8-liter pots were filled with each soil. Pots were placed in trenches with their surfaces at ground level. Pots were used instead of beds to provide distinct replicates of plant and corresponding soil samples. Three or four seedlings of green loose-leaf lettuce (*Lactuca sativa*; Burpee 60355 Organic Lettuce, Leaf Salad Bowl) were germinated in the greenhouse at Brooklyn College and transplanted to each pot. Three treatments were applied (10 pots of lettuce for each soil Pb level and treatment, for a total of 60 pots): bare soil, mulched soil, and mulched soil under mini-hoophouses. Mulch was contiguous with surface level and placed on top of pots. Lettuce was watered several times each week by researchers and gardeners.

This field study was designed to evaluate and distinguish between processes that can potentially contaminate crops: uptake, splash, and atmospheric deposition. Lettuce grown in bare soil was subject to root uptake of Pb directly from the soil, root zone soil splash, and atmospheric wet and dry deposition. Lettuce grown in mulched soil was assumed to be primarily subject to root uptake of Pb and atmospheric wet and/or dry deposition, and lettuce grown in mulched soil with a hoophouse was predominantly subject to root uptake. Thus, we used the following equations (Egendorf et al., 2021a):

$$\text{Uptake} = \text{Lettuce Pb}_{(\text{hoophouse})} \tag{1}$$

$$\text{Splash} = \text{Lettuce Pb}_{(\text{bare})} - \text{Lettuce Pb}_{(\text{mulch})} \tag{2}$$

$$\text{Deposition} = \text{Lettuce Pb}_{(\text{mulch})} - \text{Lettuce Pb}_{(\text{hoophouse})} \tag{3}$$

Where Lettuce $\text{Pb}_{(\text{hoophouse})}$ is the concentration (mg/kg fresh weight (f.w.)) of Pb found on washed lettuce grown under a hoophouse and with mulch, Lettuce $\text{Pb}_{(\text{bare})}$ is the concentration of Pb found on washed lettuce grown in bare soil, and Lettuce $\text{Pb}_{(\text{mulch})}$ is the concentration of Pb found on washed lettuce grown with mulch. Here we use this experimental design to evaluate the role of washing in removing particles from splash and deposition.

2.1.2 Laboratory Analyses

After 50 days of growth, lettuces were harvested from all pots with stainless steel scissors. Approximately 15g of lettuce from each treatment (pooled from all 10 pots with the same treatment) were taken to the lab at Brooklyn College, divided into 3 replicate aliquots of 5g (+/- 0.05 g) each and placed in acid-washed 250-mL Nalgene vials with caps. Each vial with lettuce was filled with de-ionized (DI) water and shaken vigorously for at least 60 seconds to simulate washing of the lettuce. When all visible particles were washed from the lettuce tissues, the lettuce was removed from the vials with tweezers, dried carefully with clean paper towels, and frozen until analysis.

The DI water used for washing each lettuce aliquot was passed through a Whatman 42 cotton filter paper (2.5 μm pores), and then acidified to 1% HNO_3 for ICP-MS analysis. The filters with particulates, as well as the thawed lettuce samples, were dried in an oven at 105°C for 24 hours, followed by microwave oven assisted acid digestion (EPA 3051a). Filtered and acidified wash water solutions, digested lettuce samples and filter samples were then analyzed for trace metals by ICP-MS (EPA Method 6020). External reference materials SRM-1515 (apple leaves, Pb=0.470 ± 0.024 mg/kg) obtained from the National Institute of Standards and Technology were used for external quality control. Each digestion batch of up to 22 samples included two reference standards, two blanks, and at least one duplicate. Germanium, In, and Bi were used as internal standards for instrumental drift correction. Dried lettuce sample weights were converted to fresh weight mass by dividing by a conversion factor of 0.06 (Warming et al., 2015). Lead washed off lettuce was calculated as follows:

$$\text{Pb washed off} = (\text{Pb(wash)}+\text{Pb(filter)})/W_{lettuce} \tag{4}$$

Where Pb washed off is the Pb removed by washing expressed on a lettuce fresh weight basis (mg/kg f.w.), Pb(wash) and Pb(filter) are the amounts of Pb recovered in filtered wash water and on the digested filter (µg Pb) and $W_{lettuce}$ is the fresh weight of washed lettuce (5 g). We estimated total calculated Pb (as equivalent to unwashed lettuce) by adding Pb washed off lettuce to washed lettuce Pb. We calculated the % Pb removed by washing by dividing Pb washed off lettuce by total calculated Pb and multiplying by 100. We applied equations 1-3 to concentrations of washed lettuce Pb and Pb washed off lettuce from high Pb soils to estimate the Pb due to splash and deposition that was removed by washing (Table 1).

2.2 Evaluation of washing technique effectiveness:

In Ithaca, NY, in 2017, the same lettuce cultivar (*Lactuca sativa*) was grown in 30 pots of the same high-Pb bare soil, without any cover treatment. Watering protocols minimized splash. A total of 1100 g of lettuce was harvested from the 30 pots, randomly divided into five bulk samples, and sent on ice overnight to the New York State Department of Agriculture and Markets Food Laboratory for analysis. At the lab, the five bulk lettuce samples were processed for five different washing treatments: 1) unwashed (control), 2) rinsed with tap water, 3) water soak, 4) dilute acetic acid soak, and 5) commercial vegetable wash product soak. Each bulk sample was transferred to a 6.4-liter salad spinner. The rinse treatment involved spraying the lettuce with a faucet sprayer until all visible soil particles were rinsed away. Each soaking treatment involved five seconds of agitation, ten minutes of soaking, five seconds of agitation, draining, spinning dry, water rinse, and final spinning dry.

The acetic acid soak was carried out in one-part white vinegar and three-parts water. The commercial vegetable wash contained an emulsifier, citrus oil, glycerin and other ingredients, diluted to a 1% solution according to the manufacturer's directions. For each washing treatment, 10 sub-samples to assess within-batch variability were predigested in concentrated HNO_3 and hydrogen peroxide overnight, then digested in a CEM Mars 6 microwave. The acid solutions were then diluted and analyzed on a Thermo iCAP-Q ICP-MS. Online internal standards were added to compensate for any matrix effects or signal drift. Calibration integrity was checked by analyzing a standard after every 10 samples. External reference materials SRM-1575A (pine needles) from the National Institute of Standards and Technology (159 µg Pb/kg, 95% recovery and 156 µg Pb/kg, 93% recovery), and T07189QC (vegetable puree) from Food Analysis Performance Assessment Scheme (FAPAS, UK Department for Environment, Food and Rural Affairs) (285 µg Pb/kg, 113% recovery and 285 µg Pb/kg, 102% recovery) were used for external quality control. Spiked samples were also used for external quality control (2500 µg Pb/kg, 117% recovery and 1980 µg Pb/kg, 99% recovery).

2.3 Statistical analyses:

Statistical analyses were conducted with R 3.0.3 software (R Core Team, 2014). Shapiro and Bartlett tests were used to assess the normality and homogeneity of the concentration data. Since the data were not normally distributed, lettuce Pb concentration medians by treatment, soil type, and washing technique were compared using Wilcoxon Rank Sum tests. Pairwise comparisons were made between each treatment. To avoid false positive or false negative results from multiple comparisons (Type I or Type II errors), p-values were calculated using the Bonferroni correction method. Differences were considered significant when $p < 0.05$.

3. Results

3.1 Pb removed by washing lettuces grown with and without BMP soil cover treatments

Table 1 shows the Pb concentrations for the washed NYC lettuces and Pb removed by washing for each treatment (bare, hoophouse with mulch, and mulch) and soil Pb level (high and low). Washing was highly effective in removing Pb from lettuce grown in high or low Pb soil, as well as with or without soil cover BMPs. After washing, the Pb concentrations for lettuce grown in low Pb soil in each treatment were below 0.3 mg/kg, the European Commission (EC) standard for Pb in leafy vegetables (EC, 2006), used as a comparison value for this study. According to the European General Food Law (EC, 2006), EC standards, are "based on risk analysis" and "available scientific information and data," but also "facilitate the avoidance of unjustified barriers to the free movement of foodstuffs," and take "into account… the feasibility of controls." This standard thus provides a useful context for reported lettuce concentrations. In bare soil and mulch, Pb levels would be slightly higher than the EC standard (at 0.32 mg/kg and 0.44 mg/kg, respectively) without washing. Washing removed 75%, 75%, and 86% of the Pb from the bare, hoophouse, and mulch treatments respectfully. The lettuce grown in mulch had a lower concentration than the bare plot after washing (0.06 vs. 0.08 mg/kg) but had more Pb washed off (0.38 vs. 0.24 mg/kg). The higher Pb concentrations removed from the mulched lettuce indicates the variability and importance of surrounding aerial deposition (instead of immediate soil splash) given that the low Pb soil may be less influential for plant concentrations than the high Pb environment. For both of these treatments, washing removed sufficient Pb such that edible harvest was below the EC standard.

For lettuces grown in high Pb soil, washing removed 94%, 78%, and 85% of Pb from the bare, hoophouse, and mulch treatments. However, washed lettuce Pb concentrations for the bare and mulch treatments (at 0.8mg/kg and 0.5mg/kg) were still above the EC standard, even after washing removed an average of ~14 mg/kg (bare) or ~3 mg/kg of Pb (mulch treatment). The washed hoophouse lettuce Pb concentration (0.2 mg/kg) was below the EC standard and had an order of magnitude less Pb removed by washing (0.7 mg/kg removed from hoophouse vs. 13.5 mg/kg removed from bare soil lettuce), as a result of the hoophouse treatment limiting Pb from adhering to leaf surfaces prior to washing. Washing was generally as effective in removing Pb from lettuce grown in high Pb soil as the soil cover BMPs, but both BMPs combined were even more effective. For example, according to our calculated values, mulching would reduce Pb concentrations in unwashed lettuce by 76% (14.3 mg/kg vs. 3.4 mg/kg). Washing reduced this further by another 85%, for a combined reduction of 97% (14.3 vs. 0.5 mg/kg). Although Pb concentrations in unwashed lettuce grown in high Pb bare soil was the highest of all treatments, it was also the most effectively removed by washing (94%).

We used equations 1-3 and this experimental design to evaluate the effectiveness of washing in removing particles on lettuce adhered from splash and atmospheric deposition (Table 1). We did not present results for low Pb soils due to the variability of these processes in low Pb soils (i.e., higher Pb concentrations washed off mulch vs. bare plots). As indicated by equation 1, we assume that Pb concentrations on washed lettuce from the hoophouse and mulch treatment is a result of root uptake. We note that this BMP did not prevent all particle adherence, but much of the Pb was still washed off from these, as well as all other treatments. As shown in a previous study (Egendorf et al., 2021a), splash was a dominant process, highly limited by washing. We found that washing removed 10.6 mg Pb/kg due to splash, equivalent to removing 97% of the total contribution of splash. Washing removed 2.9 mg Pb/kg due to deposition, equivalent to removing 91% of the total contribution from this process.

3.2 Comparison of effectiveness of washing techniques for Pb removal from lettuce

The Pb concentrations in lettuces grown in the same homogenized bare high Pb soil used in the first experiment (transported from NYC to Ithaca) and subjected to different washing treatments (unwashed, water rinse, water soak, dilute acetic acid soak, commercial product soak) are shown in Figure 1. While there was a wide range of Pb concentrations (0.41-1.34 mg/kg f.w.) found on unwashed samples, concentrations in all 10 replicates of the unwashed lettuce were above the EC standard of 0.3mg/kg. These concentrations are lower than the total calculated Pb in the bare plot in Table 1 (14.3 mg/kg), and lower than the concentrations of washed lettuce found in the same bare plots in the year prior (median 3.5 mg/kg; Egendorf et al. 2021a). These findings indicate the variability of depositional processes from contaminated soils, particularly due to differences in weather and length of growing period. Atmospheric Pb deposition per day varied between these sites in Ithaca and NYC, with high variation across the growing season (see Table 2; Egendorf et al., 2021a).

Despite the variations in unwashed lettuce, each washing technique significantly reduced Pb concentrations when compared to the unwashed samples ($p<0.001$), and all Pb concentrations in the washed lettuce samples were below the EC standard. While each washing technique was shown to be highly effective, the Pb concentrations of lettuce treated with the commercial product soak were significantly lower than all the other washing treatments ($p<0.05$). Lettuce Pb concentrations from the dilute acetic acid soak were also significantly lower than the water soak ($p=0.04$), but not different from the water rinse.

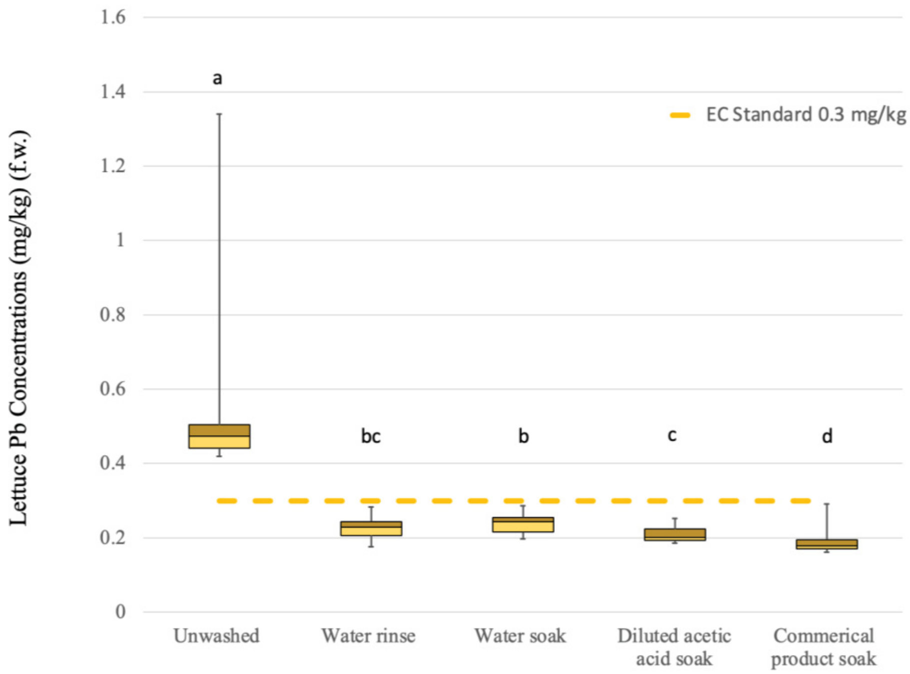

Figure 1. Comparison of Pb concentration in lettuce subjected to different washing techniques for lettuce grown in high Pb soil (n=10). Whiskers indicate minimum and maximum values, and boxes indicate 25th, median, and 75th percentiles. The presence of the same lowercase letters (a, b, c, d) indicate no significant differences between treatments ($p>0.05$), while different letters indicate significant differences ($p<0.05$). Horizontal dashed line indicates the EC standard used as a comparison value (0.3mg/kg).

4. Discussion

4.1 The importance of washing leafy vegetables

Washing leafy vegetables is an effective practice to reduce contaminant exposure. In this study, washing removed 73-94% of Pb from lettuce across all treatments and soil Pb levels. However, it is important to note that without washing even lettuces grown in low Pb soil (~90 mg/kg) would have had Pb levels at or above the EC standard of 0.3mg/kg (bare: 0.32 mg/kg f.w.; mulch: 0.44 mg/kg f.w.). Only Pb levels in lettuces grown in low Pb soil under a hoophouse (0.12 mg/kg f.w.) would have been below the EC standard without washing. While growing crops in relatively low Pb soil is recommended (US EPA, 2014), the higher total concentrations on mulched lettuce compared to the bare plots underscore the variability in urban environments, and the importance of washing leafy crops even when soil is considered "clean." These findings are supported by Attanayake et al. (2014; 2021), who show that washed leafy greens (Swiss chard and lettuce) grown in low Pb soils (~200 mg/kg) had Pb concentrations below 5 mg/kg d.w. (equivalent to 0.3 mg/kg f.w. with 94% moisture).

Several other studies evaluated crops grown in high Pb soils or with high levels of atmospheric Pb. Preer et al. (1980) demonstrated that washing removed 70% of Pb from lettuce grown in soil with Pb levels of 2200 mg/kg in Boston and Washington, D.C.. Ndiokwere (1984) similarly showed a 65% reduction in "grass and weeds" for washed compared to unwashed samples grown adjacent to a highway in Benin City, Nigeria in a time when leaded gasoline was in use. While the soil Pb in this study was relatively low (247 mg/kg), the high Pb in unwashed vegetation (243±13.6 mg/kg d.w.) was likely the result of aerosol deposition (collected 1.5 m from a highway). In our study, for crops grown in the high Pb soil urban environment, only those under the hoophouse with mulch cover had Pb levels below the EC standard (0.2 mg/kg f.w.) after washing. As such, soil Pb levels are extremely important to consider when growing leafy green crops – a conclusion supported by other published studies (e.g., Brown et al., 2016). Due to the widespread presence of Pb, urban soils should be evaluated by laboratory testing or screening before planting edible crops, especially leafy or root vegetables.

4.2 Effectiveness of washing vegetables grown under different management techniques

Even when lettuce Pb was reduced by using mulch and hoophouse as BMPs, it was further reduced by washing. Washing lettuce grown in high-Pb soil was as effective in removing Pb as growing the lettuce with mulch under hoophouse. Both approaches combined were even more effective. Several publications have pointed to the potential of airborne dusts (deposition) and splash contaminating crops, and a need to further evaluate these processes (Engel-Di Mauro, 2020). Ward & Savage (1994) found that 40-80% of Pb can be removed by washing plants, contending that these removable fractions reflect "both airborne dusts, and soil particle (probably via 'splash' during periods of precipitation)." Kim et al. (2017) found an 80% reduction of Pb comparing washed and unwashed Chinese cabbage leaves grown 5 m from a major road and point to "splash or water runoff from the road and/or the transport of airborne traffic-related particles" as the source of contamination. Nabulo et al. (2012) also compared washed and unwashed vegetables, finding that washing reduced 73% of Pb across 5 vegetables studied, and indicate that "soil splash may also have contributed substantially to the apparently high tissue Pb concentration."

Each of these studies compares washed and unwashed samples and points to the potential for splash and atmospheric deposition to contaminate crops, yet none empirically evaluate the contribution of nor the differences between these important processes. Our findings address this gap by providing quantitative metrics of the amount of Pb removed by washing derived from splash (10.6 mg/kg or 97%) as opposed to atmospheric deposition (2.9 mg/kg or 91%) (Table 1). To our knowledge, only one other study similarly analyzed wash water (Preer et al., 1980). These authors found that 65% of Pb was removed in wash water from lettuces grown in a high traffic area but did not quantify the extent to which this Pb was a result of soil splash or atmospheric deposition. Analyzing the wash water across different management treatments allows us to quantify that while removal efficiencies were similar (88-97%), the amount of Pb due to splash removed by washing was nearly five times as high as the amount of Pb due to atmospheric deposition in the high soil-Pb environment.

4.3 Effectiveness of different washing techniques

While washing is shown to reduce lettuce Pb concentrations in our first experiment, a finding supported by other studies (Al Jassir et al., 2005; Ferri et al., 2015; Folens et al., 2017; Nabulo et al., 2006; Sharma et al., 2008), it only evaluated the effectiveness of washing with water. The results from the second experiment show that different washing techniques can provide significantly different ($p<0.05$) results. The use of a commercial product or dilute acetic acid provided slightly greater efficacy and the lowest lettuce Pb concentrations. It is not clear whether a single ingredient of the commercial product was particularly important, or whether the mixture of ingredients (emulsifier, citrus oil, glycerin and other ingredients) was responsible for the greater effectiveness.

These findings align with the work of Bassuk (1986), who also found that dilute acetic acid and liquid detergent were the most effective washing techniques to remove Pb on lettuce leaves exposed to leaded gasoline exhaust under experimental conditions. Attanayake et al. (2014) found significant differences between "kitchen cleaning" (using tap water to remove visible particles) and "laboratory cleaning" (rinsing with tap water, with deionized water, with 5 g/kg sodium lauryl sulfate solution, and again with deionized water, to remove all soil dust particles) of the leafy green Swiss chard, with 2.6 to 4.6 times more Pb on the samples cleaned by the "kitchen cleaning" method. Similar to our results shown in Figure 1, these authors found all washed Swiss chard Pb concentrations to be below 0.3 mg/kg f.w.. Most importantly, like other authors (e.g., Finster et al. 2004), we find that any form of washing (including water rinse or water soak) can significantly lower lettuce Pb concentrations, with only slight variations in tissue concentrations between washing techniques.

5. Conclusion: implications for urban agriculture

Given the importance of urban gardening for many working-class communities of color and the environmental justice issues these communities face, it is essential that growers have access to strategies for safe and effective gardening. Here, we empirically evaluated easy to implement practices and highlight three priorities:

Know your soil. Gardeners should test their soils for a range of contaminants and/or grow crops in soils from trusted sources. While lettuce root uptake of Pb is minimal, particles containing Pb can be trapped in leaves. While washing removed up to 96% of Pb from lettuce grown in high Pb soil, some "cleaned" lettuce did not have all Pb washed off and contained Pb levels above the EC standard (Table 1).

Use mulch in beds to reduce splash. Our data support the understanding that mulch can effectively reduce (contaminated soil) splash on crops. Using a hoophouse or another method to limit atmospheric deposition is also recommended. In high Pb soils these practices reduced the amount of Pb needing to be washed off: nearly 5 times more Pb was washed off from soil splash (without mulch) than from atmospheric deposition (with mulch).

Wash your crops. Soaking lettuce with a commercial product produced the "cleanest" leaves, with statistically significant low levels of Pb. Using a dilute acetic acid (vinegar), rinsing, or soaking with water still reduced Pb levels of lettuce grown in high Pb soils below the EC standard (Figure 1), affirming that any washing is far better than none at all, and no specialized products are required. Washing crops grown in low Pb soils is also important (Table 1). Without washing, lettuces grown in low Pb soil may still have Pb levels above the EC standard. The effects of washing on removing other contaminants should also be evaluated.

We offer these findings for gardeners, farmers, land stewards, consumers of urban garden produce, agencies, and researchers to provide updated and empirical data for assessing the effects of washing and mulching leafy greens, with the ultimate aim of supporting urban growers in producing healthy, safe, affordable, and just food.

Conflict of Interest Statement:

The authors have no conflicts of interest to report.

Author Contributions:

Sara Perl Egendorf: conceptualization, methodology, formal analysis, investigation, writing – original draft, writing – review and editing, visualization. Emily Li: formal analysis, writing – original draft. Elise He: investigation, data curation. Zhongqi Cheng: conceptualization, methodology, resources, writing – review and editing. Henry M. Spliethoff: conceptualization, methodology, resources, writing – review and editing, funding acquisition. Hannah A. Shayler: conceptualization, methodology, investigation, data curation, writing – review and editing, project administration. Jonathan Russell-Anelli: conceptualization, methodology, investigation, writing – review and editing. Thomas King: investigation. Murray B. McBride: conceptualization, validation, resources.

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References:

Al Jassir, M. S., Shaker, A., & Khaliq, M. A. (2005). Deposition of Heavy Metals on Green Leafy Vegerables Sold on Roadsides of Riyadh City, Saudi Arabia. *Bulletin of Environmental Contamination and Toxicology*, *75*(5), 1020–1027. https://doi.org/10.1007/s00128-005-0851-4

ATSDR, A. for T. S. and D. R. (2020). *Toxicological Profile for Lead* (p. 583). U.S. Department of Health and Human Services, Public Health Service.

Attanayake, C. P., Hettiarachchi, G. M., Harms, A., Presley, D., Martin, S., & Pierzynski, G. M. (2014). Field evaluations on soil plant transfer of lead from an urban garden soil. *Journal of Environmental Quality*, *43*(2), 475–487. https://doi.org/10.2134/jeq2013.07.0273

Attanayake, C. P., Hettiarachchi, G. M., Martin, S., & Pierzynski, G. M. (2015). Potential bioavailability of lead, arsenic, and polycyclic aromatic hydrocarbons in compost-amended urban soils. *Journal of Environmental Quality*, *44*(3), 930–944. https://doi.org/10.2134/jeq2014.09.0400

Attanayake, C. P., Hettiarachchi, G. M., Palomo, M., Pierzynski, G. M., & Calderon, B. (2021). Phytoavailability of Lead for Vegetables in Urban Garden Soils. *ACS Agricultural Science & Technology*. https://doi.org/10.1021/acsagscitech.0c00068

Bassuk, N. (1986). Reducing lead uptake in lettuce. *Hortscience*, *21*, 993–995.

Bradley, K., & Herrera, H. (2016). Decolonizing Food Justice: Naming, Resisting, and Researching Colonizing Forces in the Movement. *Antipode*, *48*(1), 97–114. https://doi.org/10.1111/anti.12165

Brown, S. L., Chaney, R. L., & Hettiarachchi, G. M. (2016). Lead in Urban Soils: A Real or Perceived Concern for Urban Agriculture? *Journal of Environment Quality*, *45*(1), 26. https://doi.org/10.2134/jeq2015.07.0376

CDC, U. (2021, October 28). *CDC updates blood lead reference value to 3.5 µg/dL*. https://www.cdc.gov/nceh/lead/news/cdc-updates-blood-lead-reference-value.html

Checker, M. (2011). Wiped Out by the "Greenwave": Environmental Gentrification and the Paradoxical Politics of Urban Sustainability. *City & Society*, *23*(2), 210–229. https://doi.org/10.1111/j.1548-744X.2011.01063.x

Cheng, Z., Paltseva, A., Li, I., Morin, T., Huot, H., Egendorf, S., Su, Z., Yolanda, R., Singh, K., Lee, L., Grinshtein, M., Liu, Y., Green, K., Wai, W., Wazed, B., & Shaw, R. (2015). Trace Metal Contamination in New York City Garden Soils. *Soil Science*, *180*, 167–174. https://doi.org/10.1097/ss.0000000000000126

Codling, E. E., Chaney, R. L., & Green, C. E. (2015). Accumulation of Lead and Arsenic by Carrots Grown on Lead-Arsenate Contaminated Orchard Soils. *Journal of Plant Nutrition*, *38*(4), 509–525. https://doi.org/10.1080/01904167.2014.934477

Datko-Williams, L., Wilkie, A., & Richmond-Bryant, J. (2014). Analysis of U.S. soil lead (Pb) studies from 1970 to 2012. *Science of The Total Environment*, *468–469*, 854–863. https://doi.org/10.1016/j.scitotenv.2013.08.089

EC. (2006). *Commission Regulation (EC) No 1881/2006 of 19 December 2006 setting maximum levels for certain contaminants in foodstuffs*.

Egendorf, S. P., Groffman, P., Cheng, Z., Menser, M., Mun, J., & Mielke, H. (2021b). Applying a novel systems approach to address systemic environmental injustices: Constructing soil for limiting the legacy of lead (Pb). *Elementa: Science of the Anthropocene*, *9*(1). https://doi.org/10.1525/elementa.2020.00174

Egendorf, S. P., Spliethoff, H. M., Shayler, H. A., Russell-Anelli, J., Cheng, Z., Minsky, A. H., King, T., & McBride, M. B. (2021a). Soil lead (Pb) and urban grown lettuce: Sources, processes, and implications for gardener best management practices. *Journal of Environmental Management*, *286*, 112211. https://doi.org/10.1016/j.jenvman.2021.112211

Engel-Di Mauro, S. (2020). Atmospheric sources of trace element contamination in cultivated urban areas: A review. *Journal of Environmental Quality*. https://doi.org/10.1002/jeq2.20078

Ferri, R., Hashim, D., Smith, D. R., Guazzetti, S., Donna, F., Ferretti, E., Curatolo, M., Moneta, C., Beone, G. M., & Lucchini, R. G. (2015). Metal contamination of home garden soils and cultivated vegetables in the province of Brescia, Italy: Implications for human exposure. *Science of The Total Environment*, *518–519*, 507–517. https://doi.org/10.1016/j.scitotenv.2015.02.072

Finster, M. E., Gray, K. A., & Binns, H. J. (2004). Lead levels of edibles grown in contaminated residential soils: A field survey. *Science of The Total Environment*, *320*(2–3), 245–257. https://doi.org/10.1016/j.scitotenv.2003.08.009

Flannery, B. M., Dolan, L. C., Hoffman-Pennesi, D., Gavelek, A., Jones, O. E., Kanwal, R., Wolpert, B., Gensheimer, K., Dennis, S., & Fitzpatrick, S. (2020). U.S. Food and Drug Administration's interim reference levels for dietary lead exposure in children and women of childbearing age. *Regulatory Toxicology and Pharmacology*, *110*, 104516. https://doi.org/10.1016/j.yrtph.2019.104516

Folens, K., Labeke, M.-C. V., & Laing, G. D. (2017). Impact of an Urban Environment on Trace Element Concentrations in Domestically Produced Lettuce (Lactuca sativa L.). *Water, Air, & Soil Pollution*, *228*(12), 457. https://doi.org/10.1007/s11270-017-3635-7

Kim, H. S., Kim, K.-R., Kim, W.-I., Owens, G., & Kim, K.-H. (2017). Influence of Road Proximity on the Concentrations of Heavy Metals in Korean Urban Agricultural Soils and Crops. *Archives of Environmental Contamination and Toxicology*, *72*(2), 260–268. https://doi.org/10.1007/s00244-016-0344-y

Kingsley, J. 'Yotti,' Townsend, M., & Henderson-Wilson, C. (2009). Cultivating health and wellbeing: Members' perceptions of the health benefits of a Port Melbourne community garden. *Leisure Studies*, *28*(2), 207–219. https://doi.org/10.1080/02614360902769894

Lanphear, B. P., Rauch, S., Auinger, P., Allen, R. W., & Hornung, R. W. (2018). Low-level lead exposure and mortality in US adults: A population-based cohort study. *The Lancet Public Health*, *3*(4), e177–e184. https://doi.org/10.1016/S2468-2667(18)30025-2

Lin, B. B., Philpott, S. M., & Jha, S. (2015). The future of urban agriculture and biodiversity-ecosystem services: Challenges and next steps. *Basic and Applied Ecology*, *16*(3), 189–201. https://doi.org/10.1016/j.baae.2015.01.005

McBride, M. B., Shayler, H. A., Spliethoff, H. M., Mitchell, R. G., Marquez-Bravo, L. G., Ferenz, G. S., Russell-Anelli, J. M., Casey, L., & Bachman, S. (2014). Concentrations of lead, cadmium and barium in urban garden-grown vegetables: The impact of soil variables. *Environmental Pollution*, *194*, 254–261. https://doi.org/10.1016/j.envpol.2014.07.036

McBride, M. B., Simon, T., Tam, G., & Wharton, S. (2013). Lead and Arsenic Uptake by Leafy Vegetables Grown on Contaminated Soils: Effects of Mineral and Organic Amendments. *Water, Air, and Soil Pollution*, *224*(1). https://doi.org/10.1007/s11270-012-1378-z

McClintock, N. (2018). Urban agriculture, racial capitalism, and resistance in the settler-colonial city. *Geography Compass*, *12*(6), e12373. https://doi.org/10.1111/gec3.12373

Meuser, H. (2010). Causes of Soil Contamination in the Urban Environment. In H. Meuser (Ed.), *Contaminated Urban Soils* (pp. 29–94). Springer Netherlands. https://doi.org/10.1007/978-90-481-9328-8_3

Mielke, H. W., Gonzales, C. R., Powell, E. T., Laidlaw, M. A. S., Berry, K. J., Mielke, P. W., & Egendorf, S. P. (2019). The concurrent decline of soil lead and children's blood lead in New Orleans. *Proceedings of the National Academy of Sciences*, *116*(44), 22058–22064. https://doi.org/10.1073/pnas.1906092116

Mitchell, R. G., Spliethoff, H. M., Ribaudo, L. N., Lopp, D. M., Shayler, H. A., Marquez-Bravo, L. G., Lambert, V. T., Ferenz, G. S., Russell-Anelli, J. M., Stone, E. B., & McBride, M. B. (2014). Lead (Pb) and other metals in New York City community garden soils: Factors influencing contaminant distributions. *Environmental Pollution*, *187*, 162–169. https://doi.org/10.1016/j.envpol.2014.01.007

Nabulo, G., Black, C. R., Craigon, J., & Young, S. D. (2012). Does consumption of leafy vegetables grown in peri-urban agriculture pose a risk to human health? *Environmental Pollution*, *162*, 389–398. https://doi.org/10.1016/j.envpol.2011.11.040

Nabulo, G., Oryem-Origa, H., & Diamond, M. (2006). Assessment of lead, cadmium, and zinc contamination of roadside soils, surface films, and vegetables in Kampala City, Uganda. *Environmental Research*, *101*(1), 42–52. https://doi.org/10.1016/j.envres.2005.12.016

Ndiokwere, C. L. (1984). A study of heavy metal pollution from motor vehicle emissions and its effect on roadside soil, vegetation and crops in Nigeria. *Environmental Pollution Series B, Chemical and Physical*, *7*(1), 35–42. https://doi.org/10.1016/0143-148X(84)90035-1

NIEHS. (2013). *Lead and Your Health* (p. 4). National Institute of Environmental Health Sciences, National Institutes of Health, U.S. Department of Health and Human Services. https://www.niehs.nih.gov/health/materials/lead_and_your_health_508.pdf

O'Connor, D., Hou, D., Ok, Y. S., & Lanphear, B. P. (2020). The effects of iniquitous lead exposure on health. *Nature Sustainability*, *3*(2), 77–79. https://doi.org/10.1038/s41893-020-0475-z

Preer, J. R., Sekhon, H. S., Stephens, B. R., & Collins, M. S. (1980). Factors affecting heavy metal content of garden vegetables. *Environmental Pollution Series B, Chemical and Physical*, *1*(2), 95–104. https://doi.org/10.1016/0143-148X(80)90030-0

R Core Team. (2014). *R 3.0.3 Software*.

Roman-Alcalá, A. (2015). Concerning the Unbearable Whiteness of Urban Farming. *Journal of Agriculture, Food Systems, and Community Development*, *5*(4), 179–181. https://doi.org/10.5304/jafscd.2015.054.031

Ruckart, P. Z., Jones, R. L., Courtney, J. G., LeBlanc, T. T., Jackson, W., Karwowski, M. P., Cheng, P.-Y., Allwood, P., Svendsen, E. R., & Breysse, P. N. (2021). Update of the Blood Lead Reference Value—United States, 2021. *MMWR. Morbidity and Mortality Weekly Report*, *70*(43), 1509–1512. https://doi.org/10.15585/mmwr.mm7043a4

Saldivar-Tanaka, L., & Krasny, M. E. (2004). Culturing community development, neighborhood open space, and civic agriculture: The case of Latino community gardens in New York City. *Agriculture and Human Values*, *21*(4), 399–412. https://doi.org/10.1023/B:AHUM.0000047207.57128.a5

Sbicca, J. (2019). Urban Agriculture, Revalorization, and Green Gentrification in Denver, Colorado. In T. Bartley (Ed.), *Research in Political Sociology* (Vol. 26, pp. 149–170). Emerald Publishing Limited. https://doi.org/10.1108/S0895-993520190000026011

Sharma, R. K., Agrawal, M., & Marshall, F. M. (2008). Heavy metal (Cu, Zn, Cd and Pb) contamination of vegetables in urban India: A case study in Varanasi. *Environmental Pollution*, *154*(2), 254–263. https://doi.org/10.1016/j.envpol.2007.10.010

Spliethoff, H. M., Mitchell, R. G., Shayler, H., Marquez-Bravo, L. G., Russell-Anelli, J., Ferenz, G., & McBride, M. (2016). Estimated lead (Pb) exposures for a population of urban community gardeners. *Environmental Geochemistry and Health*, *38*(4), 955–971. https://doi.org/10.1007/s10653-016-9790-8

Turner, B., Henryks, J., & Pearson, D. (2011). Community gardens: Sustainability, health and inclusion in the city. *Local Environment*, *16*(6), 489–492. https://doi.org/10.1080/13549839.2011.595901

US EPA. (2014). *Technical Review Workgroup Recommendations Regarding Gardening and Reducing Exposure to Lead-Contaminated Soils*. OSWER 9200.2–142.

Uzu, G., Schreck, E., Xiong, T., Macouin, M., Lévêque, T., Fayomi, B., & Dumat, C. (2014). Urban Market Gardening in Africa: Foliar Uptake of Metal(loid)s and Their Bioaccessibility in Vegetables; Implications in Terms of Health Risks. *Water, Air, & Soil Pollution*, *225*(11), 2185. https://doi.org/10.1007/s11270-014-2185-5

Ward, N. I., & Savage, J. M. (1994). Metal dispersion and transportational activities using food crops as biomonitors. *Science of The Total Environment*, *146–147*, 309–319. https://doi.org/10.1016/0048-9697(94)90251-8

Warming, M., Hansen, M. G., Holm, P. E., Magid, J., Hansen, T. H., & Trapp, S. (2015). Does intake of trace elements through urban gardening in Copenhagen pose a risk to human health? *Environmental Pollution*, *202*, 17–23. https://doi.org/10.1016/j.envpol.2015.03.011

Table 1: Mean ± se of washed lettuce Pb concentration (mg/kg f.w.) and Pb removed by washing (mg/kg) (n=3) for both low Pb and high Pb soils across treatments (bare, hoophouse & mulch, mulch only). Contributions of splash and deposition are estimated for lettuce Pb and Pb washed off lettuce in high Pb soils.

		Bare	Hoophouse & Mulch	Mulch Only	Splash[3]	Deposition[4]
Low Pb Soil	Washed Lettuce Pb (mg/kg f.w.)	0.08 ± 0.01	0.03 ± 0.08	0.06 ± 0.02		
	Pb Washed Off Lettuce (mg/kg)	0.24 ± 0.007	0.09 ± 0.008	0.38 ± 0.04		
	Total Calculated Pb[1] (Equivalent to Unwashed) (mg/kg f.w.)	0.32	0.12	0.44		
	% Pb Removed by Washing[2]	75.0	75.0	86.0		
High Pb Soil	Washed Lettuce Pb (mg/kg f.w.)	0.8 ± 0.1	0.2 ± 0.1	0.5 ± 0.05	0.3	0.3
	Pb Washed Off Lettuce (mg/kg)	13.5 ± 2.2	0.7 ± 0.2	2.9 ± 1.1	10.6	2.9*
	Total Calculated Pb (Equivalent to Unwashed) (mg/kg f.w.)	14.3	0.9	3.4	10.9	3.2
	% Pb Removed by Washing	94.0	78.0	85.0	97.0	91.0

[1] Total calculated Pb (equivalent to unwashed lettuce) = washed lettuce Pb + Pb washed off lettuce.

[2] % Pb removed by washing = (Pb washed off lettuce / total calculated Pb) *100.

[3] Splash calculated according to equation 2, Splash = Bare – Mulch (calculated for washed lettuce and Pb washed off lettuce in high Pb soils)

[4] Deposition calculated according to equation 3, Deposition = Mulch – Hoophouse (calculated for washed lettuce in high Pb soils).

* Pb washed off lettuce from mulch treatment (2.9 mg/kg) was used to estimate Pb washed off due to deposition.