Food safety considerations of urban agroforestry systems grown in contaminated environments

Olga Romanova | Sarah Lovell

Center for Agroforestry, University of Missouri–Columbia, Columbia, MO 65211, USA

Correspondence
Sarah Lovell, Center for Agroforestry, University of Missouri–Columbia, Columbia, MO, 65211, USA.
Email: slovell@missouri.edu

Assigned to Associate Editor Sabino Bufo.

Funding information
USDA Agricultural Research Service.

Abstract
The interest in and establishment of urban gardens and food forests has been growing in recent years. Food production in urban environments has its challenges, however, particularly regarding the safety of edible crops grown in environments that contain potential contaminants. While some studies exist on urban agriculture food safety for annual crops, the literature is limited on relative risks in urban food forests that include fruit- and nut-producing trees and shrubs. This review provides an overview of the potential capacity of woody species (trees and shrubs) to accumulate polycyclic aromatic hydrocarbons (PAHs), heavy metals (HMs), and metalloids considering the safety of food production in the urban environment. The general trends found in a review of existing literature indicate (a) a lower risk for woody species to accumulate HMs and PAHs compared with vegetables, and (b) less accumulation in the fruit of woody species compared with other plant parts in those same species. However, these trends are not always consistent, and the accumulation of contaminants depends on variety of factors such as the concentration of a given element in the environment, type of contaminant, type of species, and species variety. This study highlights the critical need for more research on the safety of growing edible fruits and nuts on trees and shrubs in urban environments that may contain contaminants.

1 | INTRODUCTION

Agroforestry is the integration of trees and shrubs with crops or livestock such as in windbreaks and forested riparian buffers. While typically applied in rural settings, the practice of urban food forests has been encouraged as an agroforestry application for cities (Lovell et al., 2020). Urban food forests or other forms of urban agroforestry can address a wide range of environmental and social issues. They contribute to local food security, cultural heritage, and community development (Taylor et al., 2017). From an environmental perspective, edible gardens with trees and shrubs can reduce urban heat stress, sequester carbon, reduce noise contamination, and serve the function protecting streams and other water resources (Lovell & Taylor, 2013). These spaces contribute to green infrastructure that is required to maintain ecosystem services in areas with growing population and urbanization (Maes et al., 2015). This green infrastructure, for example, offers a sustainable solution for stormwater management (Kramer, 2014; Staddon et al., 2018) with perennial plants used in urban food forests further encouraging infiltration as a result of their deep root systems.

Abbreviations: FPRB, food-producing riparian buffer; HM, heavy metal; PAH, polycyclic aromatic hydrocarbon.

This is an open access article under the terms of the Creative Commons Attribution License, which permits use, distribution and reproduction in any medium, provided the original work is properly cited.

© 2020 The Authors. Urban Agriculture & Regional Food Systems published by Wiley Periodicals LLC on behalf of American Society of Agronomy and Crop Science Society of America
Currently in the United States, much of the green infrastructure incorporated into public spaces along streets, near parking lots, and within parks does not include species with edible products (Kramer, 2014; National Research Council, 2009). Thus, the extent, and hence the mitigation potential of urban agroforestry, is limited. Yet, the potential for urban agroforestry to provide desired products such as food, nontoxic products, visual quality, and wildlife habitat may motivate people to adopt these systems in their private residential spaces. For the greater community, a stronger focus on fruit- and nut-producing trees and shrubs in urban spaces might begin to address food insecurity by providing access to fresh food for vulnerable populations, especially if grown in food-desert areas.

Agroforestry systems designed to grow fruits and nuts in an urban environment would face similar challenges as other forms of urban agriculture: altered climatic conditions; water access; and increased levels of pollution in urban soil, air, water (Gori et al., 2019; Wortman & Lovell, 2013). The presence of the contaminants in the urban environment constitutes one of the main concerns for the safety of food produced in cities. Urban air, soil, and stormwater runoff are known to contain various types of toxins, and plants are capable of accumulating certain chemicals that are potentially harmful to human health. Before designing and promoting urban food forests and other agroforestry systems with edible components, the question of food safety should be addressed. The food safety research of urban agriculture in the United States is limited and mostly focuses on accumulation of contaminants in vegetables and nonwoody crops grown in community gardens. Trees and shrubs are likely to show different patterns of accumulation, particularly in the edible portion (i.e., fruits or nuts) that are spatially separated from the soil.

The purpose of this paper is to synthesize the literature that would shed light on the potential of agroforestry systems to produce safe food in urban settings considering the risks of accumulation of heavy metals (HMs), metalloids, and polycyclic aromatic hydrocarbons (PAHs). We reviewed the literature on species suitable for the urban agroforestry systems that produce edible flowers, nuts, berries, or fruits, considering their potential to accumulate toxins in unsafe qualities in their edible parts. A unique aspect of the paper is the inclusion of literature written in Russian covering regions of the former Soviet Union where a considerable body of work has been published on the topic (relative to other regions). This review paper also seeks to propose future research perspectives in urban edible landscaping that can contribute to the development of standard guidelines and best management practices for urban agroforestry systems.

### Core Ideas
- Urban agroforestry has the potential to contribute to food security if done safely
- Foods grown in the urban environment have some risk of accumulating heavy metals and PAHs
- Contamination risk is generally less with the fruits and nuts of woody species than vegetables
- Results are sometimes contradictory regarding the risk of accumulation of toxic substances
- More research is needed to understand risks of growing edible fruits and nuts in urban settings

### LITERATURE REVIEW

#### 2.1 Species suitable for urban agroforestry

A wide variety of edible woody species can be incorporated into urban spaces. Species that are commonly grown and considered appropriate for many areas of the United States include cultivated varieties of apple (*Malus* spp.), pear (*Pyrus* spp.), plum (*Prunus* spp.), cherry (*Prunus* spp.), and blueberry (*Vaccinium corymbosum* L.). However, this list can be expanded to lesser known native species like American hazelnut (*Corylus americana* Marshall), black walnut (*Juglans nigra* L.), black chokeberry (*Aronia melanocarpa* (Michx.) Elliott), persimmon (*Diospyros virginiana* L.), mulberry (*Morus* spp.), pawpaw (*Asimina triloba* (L.) Dunal), wild plum (*Pr. americana* Marshall), wild cherry (*Pr. avium* (L.) L.), pecan (*Carya illinoinensis* (Wangenh.) K. Koch), and American black elderberry (*Sambucus canadensis* L.; syn. *S. nigra* L. subsp. *canadensis* (L.) Bolli). A number of berry-producing shrubs in genera of *Rubus*, *Ribes*, and *Vaccinium* could also be included in urban gardens and orchards.

Clark and Nicholas (2013) analyzed the appropriateness of seventy perennial woody species for urban food forestry applications, and they highlighted 30 species that would be considered highly suitable based on their drought and cold tolerance as well as a high edibility ranking. Because spatial factors and context affect patterns of edible landscaping in urban environment (Lee et al., 2017), the size and form of the plant (i.e., tree, small tree, shrub, ground cover) and characteristics of its fruit (e.g., spikes, weight, smell) can also influence its suitability to different urban agroforestry systems. Another factor that should be considered in the suitability of a given species for an urban edible system is its ability to accumulate common...
urban contaminants. Specifically, plant species with a low risk of accumulating contaminants into their edible portions might be prioritized for areas that potentially contain these toxic substances in the environment. This particular aspect of suitability has been almost entirely overlooked in the study of urban food forests.

### 2.2 Example of an edible riparian buffer

In this section, the example of an edible riparian buffer is used to demonstrate the opportunities and challenges of growing food in a system designed for improving water quality in urban areas. While riparian buffers are known to supply a range of public benefits, urban landowners are often hesitant to implement them (Armstrong & Stedman, 2012). One proposed solution for increasing acceptance and adoption is to design a buffer system to provide products that are desirable to the residential landowners themselves, such as consumable food. Adding species that can be harvested by urban residents, such as fruits, nuts, and berries, could make buffer installation more appealing, ultimately increasing adoption. With the recent growth of urban agriculture, urban food forestry, and urban edible landscaping (Castro et al., 2018; Park et al., 2018), an edible riparian buffer might move beyond its primary function of stormwater mitigation to become part of multifunctional urban agriculture that can potentially contribute to food security and sustainability (Armanda et al., 2019; Lovell, 2010).

The ecosystem services traditionally provided by riparian buffers include the provision of food and habitat for wildlife and aquatic communities, mitigation and control of nonpoint source pollution and erosion, nutrient management, improvement of water quality, and carbon sequestration (Schultz et al., 2009; USDA–NRCS, 1996; Welsch, 1991). The functional performance of the buffer depends on a number of design factors including the width of the planting, but even buffers <1 m in width can trap a significant amount of sediment and soluble nutrients, with infiltration increased by the roots of perennial plants (Dabney et al., 2006). Considering the versatility of an agroforestry system design, backyard riparian buffer designs can be developed to suit the needs and desires of the residential landowners. For the design to meet the intended primary function of the stormwater mitigation, the system should contain a diverse set of plants that provide efficient trapping of runoff water, debris, excess nutrients, and pollutants to protect adjacent water resources (Schultz et al., 2009). This functionality also presents a challenge, however, in that the plants themselves can uptake and translocate those harmful substances.

Literature on riparian buffers has rarely emphasized the potential of the buffers to provide edible products. The information from riparian buffer literature and studies in urban food forests have been compiled together to generate the list of the trees and shrub species suitable for food-producing riparian buffers (FPRBs) in a temperate climate of the U.S. Mid-west (Supplemental Material). Taking into account the possibility to integrate FPRB in different locations and, thus, different soil moisture conditions, the list was expanded to include species common for production in urban horticulture even if they are uncommon in traditional riparian buffers. Species such as apple, pear, and even Chinese chestnut (Castanea mollissima Blume), for example, could be incorporated into an urban buffer on a well-drained soil where the area is not flooded during wet seasons (Hunt et al., 2012).

Following the models of the multifunctional buffers on urban farms (Wortman & Lovell, 2013) and riparian buffer models for the agricultural landscape (Bentrup, 2008; Dabney et al., 2006; Schultz et al., 2009), the species of FPRBs can be incorporated in the riparian urban buffers in various ways and different locations to simultaneously improve water quality and provide edible products. They can be located at the edges throughout public or private urban property in the form of (a) vegetation in higher elevations to serve as upland buffers, (b) vegetated ditches to serve as infiltration swales, and (c) linear features at lower elevations or the stream edge to serve as the riparian forest buffer. For stream protection, it is best to plant locally available, erosion-resistant species that are suited to the soil, moisture, and climatic conditions of a particular site. Native species are generally preferred (USDA–NRCS, 1996) for optimal stream protection, low-input in chemicals use, and reduced labor intensity.

The logical combination of edible species into riparian buffers can become a valuable strategy to begin to address the problem of food insecurity in urban areas as long as the fruits, nuts, or other edible products are safe to eat. Since cities, in general, experience a higher load of certain pollutants (i.e., HMs, PAHs) than rural areas and riparian buffers are specifically designed to capture pollutants, the food safety risks must be considered. The edible riparian buffer is a specific example demonstrating the value of including food-producing plants but also the challenges with regard to food safety.

### 2.3 Contamination risks in the urban environment

The urban environment has elevated levels of pollutants in the air, soil, and water because of the presence of heavy traffic, industries, buildings, and pavement. The pollutants often cycle between the air, soil, and water during natural and anthropogenic activities and disturbances. Therefore, pollutants that exist in one medium will often enter another one over time (United Nations Economic Commission for Europe, 2020).
Urban air contains a diverse array of contaminants including metals (e.g., copper, chromium, lead, mercury, and zinc), nutrients (e.g., nitrogen and phosphorus), and organic compounds (e.g., PAHs, polychlorinated biphenyls, and pesticides). These pollutants are introduced into the atmosphere by variety of sources like industrial and power plant emissions, motor vehicle emissions, wind eroded materials, application of chemicals for fertilization and pest control, and inappropriate discharge of waste materials (National Research Council, 2009). Through wet (rain or snowfall) and dry (by gravity or by diffusion) depositions, these atmospheric contaminants enter soil and water. According to the USEPA, pollutants in urban runoff include sediments, toxic chemicals, nutrients from lawns and gardens, pathogens, road salts, heavy metals, and others (USEPA, 2015). Metals and petroleum hydrocarbons such as plasticizers, flame retardants, pharmaceuticals, and many other potentially toxic substances can be found in urban runoff entering streams and depositing in soils (Feist et al., 2011). As a result of water runoff, deposition from the air, and direct dumping, urban soils have been found to contain a wide range of contaminants including PAHs, HMs, industrial chemicals, asbestos, coal, wood ash deposits, used motor oil residues, and pesticides (Kay et al., 2008; USEPA, 2011a, 2011b).

The concern about the safety of food grown in the urban environment would be logical, especially for perennial species like shrubs and trees that are exposed to high pollution loads over an extended period across multiple years. At the same time, woody species might present lower risk of accumulation in the edible portions of the plant since they are physically separated from the soil. Within the plant itself, soil contaminants would need to translocate to the fruits and nuts that are often spatially distanced from the root system. Outside of the plant, the separation of the fruits and nuts from soil reduces the likelihood of contaminated soil adhering to the outside of the edible portion (Lovell & Taylor, 2021). And finally, the perennial growth of woody plants would result in less disturbance of the soil (e.g., tillage) that could create airborne particles with potential for movement to the fruits and nuts or inhaled by the gardener.

Despite the various risks and benefits with woody plants grown in the urban environment, the majority of studies are conducted with annual crops grown in urban and semirural community gardens, and of all potential contaminants, the emphasis is usually on HMs (Gori et al., 2019; Szolnoki et al., 2013; Wortman & Lovell, 2013). The ubiquitous presence of HMs in the urban environment, along with the potential of plants to accumulate them (Thakur et al., 2016), poses a potential health risk to humans consuming them.

The effect of an array of HMs and metalloids (As, Cd, Cr, Cu, Pb, Ni, Hg, V, and Zn) on human health has been studied and well documented, proving they can be carcinogenic, toxic, and neurotoxic (Khanna & Khanna, 2011; Peralta-Videa et al., 2009). For example, even low concentrations of Cd and Pb can cause cancer (Järup, 2003). Consumption of As-contaminated rice (Oryza sativa L.) can promote cancer of the bladder, lung, and skin, and Pb and Hg consumed via vegetables and rice exert neurotoxic effects (Peralta-Videa et al., 2009). Prolonged consumption of vegetables containing trace amounts of HMs may lead to their chronic accumulation in kidneys and liver, causing cardiovascular and nervous disorders (Khan et al., 2015).

Other urban pollutants also likely pose a risk to human health through the intake of fruits and vegetables. Some PAHs, such as benzo[a]pyrene, are recognized as a carcinogenic and mutagenic class of compounds (Phillips, 1999). Asbestos, pesticides, and microplastics are known to cause cancer and induce a toxic effect on the human body. However, the studies regarding the accumulation of those pollutants in urban- and semirural-grown food are scarce.

For urban and semirural edible landscapes, the pollutants in soil, air, and water can pose a potential threat to the safety of the grown products. Polycyclic aromatic hydrocarbons can enter fruits and vegetables through atmospheric deposition, contaminated soil, and uptake of contaminated water (Bansal & Kim, 2015; Paris et al., 2018). Plants can uptake HMs from soil solution via selective absorption of ions by roots (Clemens et al., 2002; Peralta-Videa et al., 2009) and from air via folia transfer through the stomata, cuticular cracks, ectodesmata, and aqueous pores after deposition of particular matter on leaf surfaces (Edelstein & Ben-Hur, 2018). Polycyclic aromatic hydrocarbons and HMs are the contaminants studied most often in terms of the safety of urban-grown food.

The bioaccessibility of HMs to plants depends on soil characteristics such as soil texture, presence of chelating agents, organic matter content, and soil-pH, as well as presence and activity of soil microorganisms in rhizosphere and enzymes they secrete (Ge et al., 2000; Thakur et al., 2016). The uptake and further translocation of HMs depends on a number of factors including the type of metal and the plant characteristics. Several physiological barriers prevent pollutants from entering reproductive organs (fruits and seeds): soil-root, shoot-root, shoot-leave, and shoot-fruit barriers (Shayler et al., 2009; Vetrova et al., 2014). The efficiency of those barriers depends on genetic features of plant species and its varieties or cultivars (Alexander et al., 2006; Shevchenko & Doroshenko, 2016; Vetrova et al., 2014).

Plants can employ three main strategies when they grow on polluted soils: exclusion, passive accumulation, and active accumulation (Baker, 1981). However, more research is needed to understand the underlying mechanisms of trace metal uptake, transfer, and redistribution within the plant (Murray et al., 2009). Interactions between different species of plants in an intercropped system can also influence accumulation of HMs by individual crops (An et al., 2011). These variations in factors of soil characteristics, plant traits, and crop
interaction that affect accumulation of HMs in plants creates a challenge for generalizing information about the safety of growing plants in the contaminated environments. Even so, with urban agriculture, urban food forests, and edible landscapes gaining momentum, there is value in reviewing available studies to summarize existing knowledge on the matter of food safety.

### 2.4 Safety of garden crops grown in contaminated environments

Studies of contaminants found in garden crops grown in urban or contaminated environments can provide initial clues into the safety risks with urban agroforestry even though woody crops are rarely included. Considering the wide variety of factors that affect pollutant accumulation in plants, it is unsurprising that studies report contradictory results when evaluating the safety of urban crops. A meta-analysis by the German Environment Agency in 1995 revealed that garden crops in Germany frequently exceeded the recommended safety HMs threshold in leafy stem and root vegetables (Säumel et al., 2012). In the study by Säumel et al. (2012), a number of crop samples [e.g. carrot (Daucus carota subsp. sativus) (Hoffm.) Schübl. & G. Martens], swiss chard (Beta vulgaris L. subsp. vulgaris), potato (Solanum tuberosum L.), parsley (Petroselinum crispum (Mill.) Fuss) from inner-city Berlin gardens exceeded European Union standards for Pb, and many had higher trace-metal content than supermarket samples.

Opposite results were shown in the study by Assad et al. (2017), where cucumber (Cucumis sativus L.), bell pepper (Capsicum annuum L. var. annuum), cabbage (Brassica oleracea L. var. capitata L.), and lettuce (Lactuca sativa L.) grown on HM-contaminated soil did not show a high level of accumulation in the edible parts. In a similar study on Pb-contaminated soils, the fruiting vegetables like strawberry (Fragaria ×ananassa Duchesne ex Rozier), common bean (Phaseolus vulgaris L.), bell pepper, corn (Zea mays L.), squash (Cucurbita spp.), and tomato (S. lycopersicum L.), as well as the leafy vegetables and herbs like cabbage, basil (Ocimum basilicum L.), and sage (Salvia officinalis L.) had Pb concentrations less than the limit of detection (Finster et al., 2004). However, the same study showed that leafy vegetables like cilantro (coriander) (Coriandrum sativum L.), collard greens (B. oleracea L. var. viridis L.), mint (Mentha spp.), rhubarb (Rheum ×rhabarbarum L.), and swiss chard had Pb levels that could contribute to the total body burden of Pb if consumed. Based on samples of crops grown in HM-contaminated semiurban gardens of Kampala City in Uganda, consumption of tropical leafy vegetables was concluded to be safe if washed properly (Nabulo et al., 2010). Also considered safe were strawberry cultivars grown in the HM-contaminated soils, which accumulated Pb, Ni, Zn, and Cu in amounts less than maximum permissible concentrations (Vetrova et al., 2014).

Studies on the relative distribution of the HM between different parts of the plant can shed light on translocation potential. In general, studies have shown a decrease of HM accumulation in the following order: soil > root > shoot > leave and fruit (Finster et al., 2004; McBride et al., 2014). Some studies, however, have shown inconsistency in this pattern depending on the metal type, plant species, and even plant cultivar (Alexander et al., 2006; Säumel et al., 2012; Vetrova et al., 2014). Thus, the general assumption that fruiting vegetables are safer than root and leafy ones should be viewed with caution. In fact, dry or wet deposition from the air may be more likely to impact fruits than roots, although most studies did not specifically test this mechanism.

Studies on PAH contamination of fruits and vegetables from urban gardens, similar to HMs, report inconsistent findings in terms of which types of crops (root vegetables, leafy vegetables, fruiting vegetables, or tree fruits) accumulate higher rates of the materials. Table 1 compares results within each study by the type of vegetable and fruit. Typically leafy vegetables display higher concentrations than other types, and fruit vegetables usually accumulate more PAH than root vegetables (Abou-Arab et al., 2014; Jánksá et al., 2006; Rojo Camargo & Toledo, 2003; Soceanu et al., 2014; Wennrich et al., 2002; Zhong & Wang, 2002). Importantly, the results show that in some instances, the concentration of PAH in tree fruits can exceed that for fruit vegetables (Jánksá et al., 2006; Wennrich et al., 2002) and root vegetables (Wennrich et al., 2002). Yet in other situations, tree fruits exhibit lower concentrations than fruit vegetables (Rojo Camargo & Toledo, 2003) and root vegetables (Abou-Arab et al., 2014). Basically, a particular species in any edible type group can be an exception from the common trend, or as in the work of Ashraf and Salam (2012), the whole group might not follow trend compared with other research. The results of these studies indicate that the general idea of safe low accumulators based on type edible plant part cannot be supported. Dangerous concentrations of PAHs can be found in some instances in a variety of vegetables but also in the tree fruits grown in urban gardens. Again, the potential for airborne contamination is typically not studied separately from soil contamination, which could account for some of the inconsistencies.

### 2.5 Woody species potential to accumulate contaminants

To understand the risks with tree crops specifically, other areas of research, such as phytoremediation, offer some insight. Trees have been considered for the purpose of phytoremediation because of their tolerance of pollutants and...
| Crop                  | Concentration of PAH<sup>a</sup> | Germany | Romania<sup>b</sup> | Brazil | China | Saudi Arabia<sup>b</sup> | Egypt | Czech Republic<sup>c</sup> |
|----------------------|----------------------------------|---------|---------------------|--------|-------|-------------------------|-------|-------------------------|
|                      |                                  | Wennrich et al., 2002 | Soceanu et al., 2014 | Rojo Camargo & Toledo, 2003 | Zhong & Wang, 2002 | Ashraf & Salam, 2012 | Abou–Arab et al., 2014 | Jánská et al., 2006 |
| **Leafy vegetable**   |                                  |         |                     |        |       |                         |       |                         |
| Parsley              | 38.91                            | 6.16–6.78 | –                   | –      | –     | –                       | –     | –                       |
| Kale                 | 12.75                            | –        | –                   | –      | –     | –                       | –     | –                       |
| Lettuce              | 2.54                             | –        | 17.93               | –      | –     | –                       | –     | –                       |
| Cabbage              | –                                | 10.06    | 13.27               | 23     | 8.3   | –                       | 20.09 | –                       |
| Spinach              | –                                | 8.88     | –                   | –      | –     | 10.2                    | 8.98  | –                       |
| Dill                 | –                                | 4.36–5.17| –                   | –      | –     | –                       | –     | –                       |
| Celery               | –                                | 0.36–5.81| –                   | 31     | –     | –                       | –     | –                       |
| Garlic, green        | –                                | 6.3      | –                   | –      | –     | –                       | –     | –                       |
| Onion, green         | –                                | 4.45     | –                   | –      | –     | –                       | –     | –                       |
| Cauliflower          | –                                | –        | –                   | –      | –     | –                       | 16.06 | –                       |
| Chinese cabbage      | –                                | –        | –                   | 29     | –     | –                       | –     | –                       |
| **Root vegetable**   |                                  |          |                     |        |       |                         |       |                         |
| Potato               | 4.47                             | 3.15     | –                   | 12.54  | 10.5–15.0 | 6.2                  | –     | –                       |
| Kohlrabi             | 2.6                              | –        | –                   | –      | –     | –                       | –     | –                       |
| Carrot               | –                                | 1.17–5.28| –                   | –      | 11.6–17.4 | –                   | –     | –                       |
| Garlic, bulb         | –                                | 7.05     | –                   | –      | –     | –                       | –     | –                       |
| Onion, bulb          | –                                | 3.57     | –                   | –      | –     | –                       | –     | –                       |
| Turnip               | –                                | –        | –                   | 9.3    | –     | –                       | –     | –                       |
| **Fruit vegetable**  |                                  |          |                     |        |       |                         |       |                         |
| Tomato               | 3.55                             | –        | 14.62               | 14.81  | 7.9   | –                       | 12.3  | –                       |
| Strawberry           | 3.73                             | –        | –                   | –      | –     | –                       | –     | –                       |
| Cucumber             | –                                | 6.69     | –                   | 12     | 7.6–11.6 | –                   | 10.29 | –                       |
| Gourd                | –                                | –        | –                   | 15     | 5.2–6.4 | –                       | –     | –                       |
| Eggplant             | –                                | –        | –                   | 9.79   | 8.8–10.9 | –                   | –     | –                       |
| **Tree fruit**       |                                  |          |                     |        |       |                         |       |                         |
| Apple                | 6.64                             | –        | 4.05                | –      | –     | 2.87                    | 15.42 | –                       |
| Grape                | –                                | –        | 3.87                | –      | –     | –                       | –     | 10.61                   |
| Pear                 | –                                | –        | 3.77                | –      | –     | –                       | –     | –                       |
| Apricot              | –                                | –        | –                   | –      | –     | –                       | –     | 7.82                    |
| Guava                | –                                | –        | –                   | –      | –     | 2.33                    | –     | –                       |

<sup>a</sup>Concentration indicated as mean (unless otherwise indicated).

<sup>b</sup>Concentration as mean for peel and core.

<sup>c</sup>Concentration as median;

their ability to uptake HMs (Pulford, 2003; Rockwood et al., 2004) and PAHs (Howse et al., 2001; Wang et al., 2008; Widdowson et al., 2005) over time. Species like poplar (Populus spp.) and willow (Salix spp.) are commonly studied for this purpose because they grow quickly, pulling toxic materials from the soil. Nevertheless, the proven ability of woody species to accumulate HMs and PAHs raises the question of the extent to which tree crops have similar capacities and if toxic elements accumulate in their edible parts.

A number of studies have demonstrated that woody species are capable of accumulating PAHs from urban environments not only into their bark and leaves (Roba et al., 2016; Yin et al., 2011) but also into their edible fruiting parts like with apple, pear, apricot (Pr. armeniaca L.), and grape (Vitis vinifera L.) (Abou–Arab et al., 2014; Jánská et al., 2006; Rojo Camargo & Toledo, 2003; Wennrich et al., 2002). However, main sources of PAH contamination in tree fruits are likely the result of wet or dry deposition from the atmosphere (Salinas et al., 2010;
Srogi, 2007), as opposed to the soil, because of relatively low root uptake of PAHs (Edwards, 1983). Overall, there are few studies on PAH accumulation in urban-grown tree fruits.

Compared with data on PAHs, studies on HM contamination of tree fruits in urban and industrialized areas is somewhat more extensive although not abundant. Most toxic metals are primarily excluded from accumulation in reproductive parts of crops (fruits and seeds), instead remaining in other vegetative parts of a plant (Shayler et al., 2009). Several studies have shown that, unlike vegetables, trees store a large proportion of absorbed HMs in organs other than fruits, for example, roots and leaves (Cheng et al., 2015; Roba et al., 2016). Nonetheless, other studies have demonstrated that fruiting trees are able to accumulate HMs in fruits above safe limits or in higher concentrations than in fruits from local markets. Tables 2 and 3 summarize the data from studies comparing the accumulation of HMs in plant parts or edible portions.

In a study of plants grown in reclaimed mining soils, the amount of Cd accumulated in carambola, or starfruit, (Averrhoa carambola L.) fruit exceeded the safety limit (Li et al., 2006). The concentrations of HMs and metalloids (Cu, Zn, Pb, As, Cd, and Ni) in peach [Pr. Persica (L.) Batsch] fruits sampled from various distances from the Bor copper smelter in Serbia (a heavy urban industrial site) exceeded the allowed limits and were regarded as not safe for consumption (Dimitrijević et al., 2016). Samples of apple fruits gathered from trees planted along streets of Orenburg city in Russia contained Zn and Cu in amounts exceeding permissible limits, and some of the samples exceeded the permissible limits for Pb, Cd, and Cr (Rusanov et al., 2011). Similarly, apple fruits sampled from Drenas town in Kosovo considerably exceeded allowed maximum limits for Pb, Cd, Cr, and Ni (Imeri et al., 2019).

For fruits of trees grown in fields with increasing concentrations of Cd, concentrations increased for peach and pear but not for plum and apple (Korcak, 1989). In gardens of Copenhagen, the level of Pb in pear fruits and Cd in elderberry was significantly higher than in market fruits (Samsoe-Petersen et al., 2002). On the other hand, the same study showed that concentrations of Ni, Cd, and PAHs in pear, plum, blackberry (Rubus spp.), red currant (Ribes rubrum L.), black currant (R. nigrum L.), and gooseberry (R. uva-crispa L.) were generally at the same or lower level than in market fruits. These studies suggest that pome and stone fruits like apple, peach, and pear are capable of HMs accumulation in their edible parts.

The studies on berry-producing woody species also showed their potential to accumulate HMs. Sea-buckthorn (Hipppophae rhamnoides L.) berries collected from the former fruit tree nursery of urban Kemerovo and remediated soils of the opencast coal mines in Belovsky district (Russia) contained three to five times higher levels of Pb than local sanitary norms and regulations, while some samples also exceeded the norm for Cr, Ba, and Co (Astrakova & Khitova, 2014). Concentrations of Fe, Zn, Ni, and Pb exceeded the maximum permissible level in fruits of bilberry (Vaccinium myrtillus L.) and lingonberry (Vaccinium vitis-idaea L.) growing in the wild along Lena river in the Saha Republic (Russia) (Ksenofontova, 2014). Heavy metal (Pb, Cd, Ni, Cu, Zn, Mn, and Co) concentrations in white mulberry (Morus alba L.) and black mulberry (M. nigra L.) gathered from trees in urban and semi-urban sites of Gumushane province (Turkey) were generally higher than the tolerable levels and presented potential health risk for consumers (Kalkisim et al., 2019). The concentration of HMs in fruits and berries growing near large plants, cities, and roads of Kirov region (Russia) exceeded the maximum permissible level of various HMs for a number of fruit crops, and the extent and variability of HMs in edible fruits was considered to pose a possible health risk for gleaning consumers (Egoshina et al., 2004). Heavy metal (Cu, Zn, Cd, and Pb) concentrations in berries gathered in Revda town (Russia) located near the copper-smelting plant exceeded maximum permissible limits of Cd and Pb for dog rose (Rosa canina L.), lingonberry, bilberry, and raspberry (R. idaeus L.) (Bezel et al., 2012). However, the authors concluded that based on average consumption, this would not influence a toxic load on human health.

Considering the distribution of HM accumulation and further translocation in different plant parts of woody species, the order does not always follow the expected pattern of root > shoot > leaf > fruit. In the Cheng et al. (2015) study of navel orange [Citrus ×sinensis (L.) Osbeck], Cd concentration decreased in the order of root > leaf > peel > pulp, while in the study of starfruit, Cd accumulation order was twig > leaf > root > fruit (Li et al., 2006). In Dimitrijević et al. (2016), the contents of HMs in peach parts decreased as follows: leaf > root > branch > fruit. The content of HMs in plant parts of apple from polluted urban sites near the mining and smelting complex Bor (Serbia) varied depending on the specific element, but, in general, the levels in fruit were the lowest and did not exceed maximum allowable concentrations (except in the case of metalloid As in the unwashed dry fruits) (Tošić et al., 2016). The concentration of HMs (Pb, Ni, Zn, Fe, and Cu) in leaves of black currant, raspberry, and gooseberry grown on HMs-contaminated soils was five to fifty times higher than in berries and was species dependent (Leonicheva et al., 2010). In the study of a peach orchard in Bursa province (Turkey) irrigated with water from HMs-polluted river, the content of HMs in leaves was generally at tolerable levels, but Ni and Pb accumulated in the fruits (flesh and peel) at toxic levels (Başar & Aydinalp, 2005). Such variability can be related to differences in metal types, plant species, and airborne or soil sources of contamination; however, more research focused on that issue is needed. Nevertheless, it is worth emphasizing that in the majority of comparative studies, the tree fruits accumulate considerably lower amounts of HMs than other parts of the same plant (Table 2).
The variability among types of edible parts of woody species raises the question of how nuts (with a protective shell) compare with stone fruits and soft-skinned berries in the accumulation of pollutants. A study on Cd and Pb content in nuts, berries, pome, and stone fruits harvested within the inner city of Berlin (Germany) showed the accumulation followed this pattern: nuts [walnut (J. regia L.) and European hazelnut (Co. avellana L.)] < pome and stone fruits {apple, mirabelle [Pr. domestica L. subsp. syriaca (Borkh.) Janch. ex Mansf.], and plum} < berries [blackberry, sea-buckthorn, except elderberry (von Hoffen & Säumel, 2014)]. However, contrasting results were found in Copenhagen urban gardens, where content of Cd was higher for hazelnut than for pear, plum, and berries (Samsøe-Petersen et al., 2002). Nevertheless, neither study found concentrations of HMs exceeding European Union standards for fruits.
### TABLE 3  
Studies comparing concentrations of heavy metals in different edible crops (root vegetable, leafy vegetable, tree and shrub fruit) grown in contaminated soils

| Article                     | Soil concentration | Element | Concentration in plants mean (or median) values for different plants or sites | mg kg$^{-1}$ dry wt. |
|-----------------------------|--------------------|---------|--------------------------------------------------------------------------------|----------------------|
|                             |                    |         | Root vegetable                                                                 | Leafy vegetable      |
|                             |                    |         |                                                                                | Fruit vegetable or herb | Tree or shrub fruit |
|                             | mg kg$^{-1}$ dry wt. |         |                                                                                | mg kg$^{-1}$ dry wt.  |
| Finster et al., 2004 (USA)  | 27–4580            | Pb      | <10                                                                           | <10–60               |
|                             |                    | Ni      | <10                                                                           | <10–81               |
|                             |                    | Pb      | <0.4                                                                          | <10                  |
|                             |                    | Zn      | <3.5                                                                          |                      |
| Vetrova et al., 2014 (Russia)| 69.0 ± 2.53        | Cu      | –                               | –                    |
|                             |                    | Ni      | –                               | –                    |
|                             |                    | Pb      | –                               | –                    |
|                             |                    | Zn      | –                               | –                    |
| Nabulo et al., 2010 (Uganda)| 0.098–2.13         | Cd      | –                               | 0.04–0.48            |
|                             | 53.8–196            | Cr      | –                               | 0.40–4.12            |
|                             | 42.8–249            | Cu      | –                               | 5.86–19.0            |
|                             | 19.1–41.1           | Ni      | –                               | 0.78–3.59            |
|                             | 9.44–770            | Pb      | –                               | 0.16–4.46            |
|                             | 58.6–1060           | Zn      | –                               | 25.9–182             |
| Assad et al., 2017 (France) | 174 ± 2             | Cr      | –                               | 0.89–18.4$^1$        |
|                             |                    | Cd      | <0.035$^a$                       | <0.035$^a$           |
|                             |                    | Ni      | 0.05–0.23$^a$                    | <0.08$^c$            |
|                             |                    | Pb      | 0.01–0.53$^a$                    | 0.01–0.12$^c$        |
| Samsoe–Petersen et al., 2002| 0.33–2.4            | Cd      | <0.035$^a$                       | <0.035$^a$           |
| (Denmark)                   | >30                | Ni      | 0.05–0.23$^a$                    | <0.08$^c$            |
|                             | 20–1000             | Pb      | 0.01–0.53$^a$                    | 0.01–0.12$^c$        |
| Egoshina et al., 2004 (Russia)| Wild fruits, berries| Cr      | –                               | 0.89–18.4$^1$        |
|                             | gathered from polluted areas (urban and industrial sites) | Cu | – | up to 82.1$^d$ |
|                             | Ni | – | up to 18.9$^d$ |
|                             | Pb | – | 3.24, up to 5.1$^d$ |
|                             | Zn | – | up to 101.5$^d$ |
| Bezel et al., 2012 (Russia) | 14.44–21.29         | Cd      | –                               | 0.323 ± 0.030        |
|                             | 4335.79–5528.64     | Cu      | –                               | 1.19 ± 0.15          |
|                             | 1423.91–1960.61     | Pb      | –                               | 5.83 ± 3.33          |
|                             | 610.61–931.24       | Zn      | –                               | 0.612–0.308          |
| Rusanov et al., 2011 (Russia)| 0.35–0.37           | Cd      | –                               | 0.03–0.07            |
|                             | 62.22–63.8          | Cr      | –                               | 0.08–3.93            |
|                             | 1.75–5.27           | Cu      | –                               | 4.87–51.46           |
|                             | 39.97–50.10         | Ni      | –                               | 0.19–10.25           |
|                             | 4.43–5.58           | Pb      | –                               | 0.09–1.63            |
|                             | 28.35–35.03         | Zn      | –                               | 3.82–17.73           |
| Tantzereva et al., 2006 (Russia)| 3.35–4.2            | Cd      | –                               | 0.68–0.91            |
|                             | 171.85–200.1        | Cr      | –                               | 0.31–0.54            |
|                             | 202.12–300.2        | Cu      | –                               | 2.43–2.6             |
|                             | 67.1–68.7           | Ni      | –                               | 0.43–0.51            |
|                             | 39.49–68.75         | Pb      | –                               | 0.21–0.72            |
|                             | 167.17–198.7        | Zn      | –                               | 3.41–4.79            |

(Continues)
Some studies have focused specifically on HMs in nuts from trees grown in nonurban areas such as old orchards or wild in a forest. English walnut was found to have the potential to excessively accumulate Zn (Antonijević et al., 2012), Cu, and Co but not Cd, which stops accumulating in nut meat from pericarp after its concentration in pericarp reaches 0.2 mg kg\(^{-1}\) (Malysheva, 2014). The research from nonurban walnut-producing areas of China polluted with Pb and Cd did not show dangerous consumption levels of these metals in nuts (Han et al., 2018) nor did a study of hazelnut produced in the Eastern Black Sea Region of Turkey with known Fe, Sn, and Pb contamination (Cevik et al., 2009). However, studies of Chinese chestnut \([Ca. \ henryi (Skan) \ Rehder & E. H. Wilson]\) cultivated on nonurban HM-contaminated soils found that Cd and Pb concentrations in edible parts of the nut exceeded the safety limits and were not safe for human consumption (Li et al., 2007; Wu et al., 2019). The number of studies specifically exploring the accumulation of toxic substances in edible nuts and fruits are limited, and more research is clearly needed before specific recommendations might be made.

### 3 | DISCUSSION

The rapidly growing urban population requires greater efforts to improve the performance of existing and new urban areas through sustainable and multifunctional approaches; urban agroforestry offers a unique solution. Involving residents in the development and adoption of such systems on their properties, in addition to encouraging the introduction into public urban spaces, can aid in reconnecting the landscape and supporting ecosystem services. Multifunctionality of the agroforestry systems would address an array of urbanization issues, making cities more resilient through mitigating stormwater, reducing urban warming, improving water and air quality, curbing erosion, enhancing biodiversity, and enabling food security. In addition to resilience, edible urban landscapes help build and strengthen local communities (Glover et al., 2005; Lwasa et al., 2015), promote inclusion (McLain et al., 2012), and provide environmental education (Krasny & Tidball, 2009).

Food produced from urban agroforestry, however, would not be appropriate if the edible products pose a risk to the consumers because of contamination. The study of food safety of fruits and nuts produced by woody species in urban settings requires deeper exploration. Considering that cities in general experience a higher load of pollutants than rural areas, the risk of grown food contamination is higher, especially by PAHs and HMs, which are known toxins in human bodies and cause health issues.

Questions still remain in our understanding of specific mechanisms of pollutant uptake by plants and further translocation within the plant. Based on the reviewed studies, the general trend of accumulation in urban-grown vegetables decreases as soil > root > shoot > leaf and fruit for HMs and as leaf > root > shoot > fruit for PAHs. Tree fruits, in general, accumulate a lower level of both HMs and PAHs than vegetables, and the fruits grown on trees and shrubs accumulate the lowest amounts compared with other parts of the plant.

For trees specifically, the broad trend of pollutant accumulation within the plant is root and leaf > shoot > fruit. However, these trends are not always consistent, and even in the small pool of literature, exceptions can be found to nearly every general trend. Many factors have been identified as influential for the process of uptake and translocation such as pollutant physicochemical properties, industrial region, contamination level of soil and air, soil type and characteristics, species of crops, cultivation strategy, and growing conditions (Alexander et al., 2006; Imeri et al., 2019; Säumel et al., 2012). The variation of pollutant concentrations among species can be the result of their different accumulation capacity, and differences can be found not only among...
species but also among cultivars within a species and among the same cultivar at various development stages (Alexander et al., 2006; Säumel et al., 2012; Shevchenko & Doroshenko, 2016; Vetrova et al., 2014). Further studies are required to develop a better understanding of these interactions so that the most suitable species can be chosen for urban food forests.

Even though some fruiting trees have shown the capacity to accumulate HMs and PAHs in amounts exceeding permissible level, the actual risk to human health will depend on many factors. The examples of excess accumulation in woody species fruits were limited to the findings found in a small set of studies (Astrakova & Khitova, 2014; Dimitrijević et al., 2016; Egoshina et al., 2004; Imeri et al., 2019; Ksenofontova, 2014; Rusanov et al., 2011; Samsøe-Petersen et al., 2002). In some of these studies, the level of environmental contamination was excessively high—beyond that levels that would typically be found in the urban environment. Some studies that did compare their findings with tolerable daily intake recommendations have demonstrated a low risk of negative human health implications from cultivating and consuming produce grown in contaminated areas (Assad et al., 2017; Bezel et al., 2012; Nabulo et al., 2010), although others came to contrary conclusions (Finster et al., 2004; Kalkisim et al., 2019). The determination of a safe level of exposure is a very complex matter, and it is another prospect for future research to identify safe and risky fruit species for urban gardening and their tolerable levels of intake.

4 | CONCLUSIONS

This synthesis of relevant literature reveals that the production and consumption of fruits and nuts from woody species would be safe in many circumstances. Most of the studies that found unsafe levels of pollutant accumulation in the edible portions of woody species were conducted in locations in close proximity to industries or mines or in developing countries where lower standards of fuel and automobile emissions may still exist. Considering these general trends, it is possible to conclude that most woody species would likely be safe for U.S. urban food forests unless the location is too close to an excessive pollutant source or is already heavily contaminated. However, the risk of HM and PAH accumulation in dangerous amounts in the edible parts of trees and shrubs grown in the urban areas exists and should be seriously considered, especially in larger cities with heavier traffic load and towns with industries present nearby, including closed mines and tailing pits. Prior to establishing food production systems in the urban environment, both the soil and the air should be tested for the presence of the contaminants such as HMs and PAHs because of the possibility of translocating through the root system and through deposition on leaves and fruits.

A clear need exists to establish standard guidelines for producing healthy fruits in urban areas and for developing knowledge on traditional and innovative design and management of tree-based edible landscaping (Gori et al., 2019) and multifunctional urban buffers (Wortman & Lovell, 2013). Although urban gardening is gaining attention from the science community, the studies of woody food-producing species are still limited. The promising and much-needed direction in urban edible landscaping is the identification of species and cultivars capable of growing in contaminated environments without accumulating a dangerous level of pollutants in edible parts. More research is needed to understand the mechanisms that prevent the transfer of pollutants to edible components. Attempting to fix current problems like stormwater mitigation and food security in urban areas by developing edible landscapes, without considering food safety risks, could potentially create new problems in the future for the health of people consuming those products. Thus, a systematic and analytical approach should be undertaken in research of urban edible landscapes to fill the existing gaps. This paper might serve as a call for more funding to support research on this topic.

Even without a full understanding of the food safety risks, urban agroforestry can be promoted to urban residents based on the support of biodiversity conservation, stormwater mitigation, aesthetics, and other benefits. Nonfood producing species like perennial florals can be incorporated in such systems and provide habitat for birds and insects, aesthetic benefits, and perhaps alternative income. Smart designs and species combinations can create aesthetically pleasing landscapes that protect water resources from nonpoint source pollution. New urban agroforestry plantings can be integrated into to green infrastructure to encourage a dialogue, advance education, and further the dissemination of practice.

ACKNOWLEDGMENTS

This work is supported by the University of Missouri Center for Agroforestry and the USDA–ARS Dale Bumpers Small Farm Research Center, Agreement number 58-6020-6-001 from the USDA Agricultural Research Service.

AUTHOR CONTRIBUTIONS

Olga Romanova: Conceptualization; Data curation; Methodology; Writing-original draft; Writing-review & editing.
Sarah Taylor Lovell: Conceptualization; Funding acquisition; Methodology; Supervision; Writing-review & editing.

CONFLICT OF INTEREST STATEMENT

The authors declare that there is no conflict of interest.

ORCID

Sarah Lovell https://orcid.org/0000-0001-8857-409X
REFERENCES

Abou-Arab, A., Abou-Donia M., El-Dars F., Ali O., & Gouda H. (2014). Levels of polycyclic aromatic hydrocarbons (PAHs) in some Egyptian vegetables and fruits and their influences by some treatments. *International Journal of Current Microbiology and Applied Sciences*, 3, 277–293.

Alexander, P. D., Alloway B. J., & Dourado A. M. (2006). Genotypic variations in the accumulation of Cd, Cu, Pb and Zn exhibited by six commonly grown vegetables. *Environmental Pollution*, 144, 736–745. https://doi.org/10.1016/j.envpol.2006.03.001

An, L., Pan Y., Wang Z., & Zhu C. (2011). Heavy metal absorption status of five plant species in monoculture and intercropping. *Plant and Soil*, 345, 237–245. https://doi.org/10.1007/s11104-011-0775-1

Antonijević, M. M., Dimitrijević M. D., Milić S. M., & Nujkić M. M. (2012). Metal concentrations in the soils and native plants surrounding the old flotation tailings pond of the Copper Mining and Smelting Complex Bor (Serbia). *Journal of Environmental Monitoring*, 14, 866. https://doi.org/10.1039/c2em10803h

Armanda, D. T., Guinée J. B., & Tukker A. (2019). The second Green Revolution: Innovative urban agriculture’s contribution to food security and sustainability—A review. *Global Food Security*, 22, 13–24. https://doi.org/10.1016/j.gfs.2019.08.002

Armstrong, A., & Stedman R. C. (2012). Landowner willingness to implement riparian buffers in a transitioning watershed. *Landscape and Urban Planning*, 105, 211–220. https://doi.org/10.1016/j.landurbplan.2011.12.011

Asfah, M. W., & Salam A. (2012). Polycyclic aromatic hydrocarbons (PAHs) in vegetables and fruits produced in Saudi Arabia. *Buletin of Environmental Contamination and Toxicology*, 88, 543–547. https://doi.org/10.1007/s00128-012-0528-8

Assad, M., Tatin-Froux F., Blaudez D., Chalot M., & Parellé J. (2017). Accumulation of trace elements in edible crops and poplar grown on a titanium ore landfill. *Environmental Science and Pollution Research*, 24, 5019–5031. https://doi.org/10.1007/s11356-016-8242-4

Astrakova, T. V., & Khitova N. V. (2014). Determination of the heavy metals ions in sea-buckthorn berries/Определение ионов тяжелых металлов в ягодах облепихи. *Tekhnika i Tekhnologiya Pishchevykh Proizvodstv*, 32, 121–125.

Baker, A. J. M. (1981). Accumulators and excluders—Strategies in the response of plants to heavy metals. *Journal of Plant Nutrition*, 3, 643–654. https://doi.org/10.1080/01904168109362867

Bansal, V., & Kim K. H. (2015). Review of PAH contamination in food products and their health hazards. *Environment International*, 84, 26–38. https://doi.org/10.1016/j.envint.2015.06.016

Başar, H., & Aydinalp C. (2005). Heavy metal contamination in peach trees irrigated with water from a heavily polluted creek. *Journal of Plant Nutrition*, 28, 2049–2063. https://doi.org/10.1080/01904160500311169

Bentrup, G. (2008). *Conservation buffers: Design guidelines for buffers, corridors, and greenways*. USDA, Forest Service, Southern Research Station

Bezel, V. S., Mukhacheva S. V., Trubina M. R., & Vorobechik E. L. (2012). Environmental chemical pollution: Accumulation of heavy metals in berries and edible mushrooms, risk assessment by their consumption for population of middle Urals /Химическое загрязнение среды: накопление тяжелых металлов дикорастущими ягодами и грибами, оценка риска их потребления населением среднего Урала. *Problemy biogeokhimii i geokhimicheskoi ekologii*, 3, 39–47.

Castro, J., Ostoïc S. K., Cariñanos P., Fini A., & Sitzia T. (2018). “Edible” urban forests as part of inclusive, sustainable cities. *Unasyla*, 69, 59–65.

Cevik, U., Celik N., Celik A., Damla N., & Coskuncelbele K. (2009). Radioactivity and heavy metal levels in hazelnut growing in the Eastern Black Sea Region of Turkey. *Food and Chemical Toxicology*, 47, 2351–2355. https://doi.org/10.1016/j.fct.2009.06.029

Cheng, J., Ding C., Li X., Zhang T., & Wang X. (2015). Heavy metals in navel orange orchards of Xinfeng County and their transfer from soils to navel oranges. *Ecotoxicology and Environmental Safety*, 122, 153–158. https://doi.org/10.1016/j.ecosafe.2015.07.022

Clark, K. H., & Nicholas K. A. (2013). Introducing urban food forestry: A multifunctional approach to increase food security and provide ecosystem services. *Landscape Ecology*, 28, 1649–1669. https://doi.org/10.1007/s10139-013-0905-z

Clemens, S., Palmgren M. G., & Krämer U. (2002). A long way ahead: Understanding and engineering plant metal accumulation. *Trends in Plant Science*, 7, 309–315. https://doi.org/10.1016/S1360-1385(02)02295-1

Dabney, S. M., Moore M. T., & Locke M. A. (2006). Integrated management of in-field, edge-of-field, and after-field buffers. *JAWRA Journal of the American Water Resources Association*, 42, 15–24. https://doi.org/10.1111/j.1752-1688.2006.tb03819.x

Dimitrijević, M. D., Nujkić M. M., Alagić S. Č., Milić S. M., & Tošić S. B. (2016). Heavy metal contamination of topsoil and parts of peach-tree growing at different distances from a smelting complex. *International Journal of Environmental Science and Technology*, 13, 615–630. https://doi.org/10.1007/s13762-015-0905-z

Edelstein, M., & Ben-Hur M. (2018). Heavy metals and metalloids: Sources, risks and strategies to reduce their accumulation in horticultural crops. *Scien tia Horticulturae*, 234, 431–444. https://doi.org/10.1016/j.scienta.2017.12.039

Edwards, N. T. (1983). Polycyclic aromatic hydrocarbons (PAHs) in the terrestrial environment—A review. *Journal of Environmental Quality*, 12, 427–441. https://doi.org/10.2134/jeq1983.0047245500120004001x

Egoshina, T. L., Skopin A. E., & Shulatjeva N. A. (2004). The peculiarities of heavy metals accumulation by wild species of berries and mushrooms/Oсобенности аккумуляции тяжелых металлов дикорастущими видами ягод и грибов. *Sovremennye problemy prirodopol'zovaniya, okhotovedeniya i zverovedstva*, 1, 128–131.

Feist, B. E., Buhle E. R., Arnold P., Davis J. W., & Scholz N. L. (2011). Heavy metal concentrations in the soils and native plants surrounding the old flotation tailings pond of the Copper Mining and Smelting Complex Bor (Serbia). *Prozvani i zemljovodstvo*, 02, 31–38.

Ge, Y., Murray P., & Hendershot W. H. (2000). Trace metal speciation and bioavailability in urban soils. *Environmental Pollution*, 107, 137–144. https://doi.org/10.1016/S0269-7491(99)00119-0

Glover, T. D., Shinew K. J., & Parry D. C. (2005). Association, co-localization, and bioavailability in urban soils. *Science of The Total Environment*, 320, 245–257. https://doi.org/10.1016/j.scitotenv.2003.08.009

Go, T. K., Bezuglyi M. Y., & Romanova O. (2015). Dissolution and bioavailability of heavy metals in soils from the old flotation tailings pond of the Copper Mining and Smelting Complex Bor (Serbia). *Environmental Monitoring and Assessment*, 176, 309–315. https://doi.org/10.1007/s10661-013-3186-7

Gorokhov, S. A., & Romanova O. (2018). Accumulation of heavy metals in edible plants and poplar grown on a titanium ore landfill. *Environmental Science and Pollution Research*, 25, 10191–10199. https://doi.org/10.1007/s11356-018-1240-y

Gorokhov, S. A., & Romanova O. (2019). Accumulation of heavy metals in edible plants and poplar grown on a titanium ore landfill. *Environmental Science and Pollution Research*, 26, 14264–14271. https://doi.org/10.1007/s11356-018-3239-4

Goro, A., Ferrini F., & Fini A. (2019). Reprint of: Growing healthy food under heavy metal pollution load: Overview and major challenges

Goro, A., Ferrini F., & Fini A. (2019). Reprint of: Growing healthy food under heavy metal pollution load: Overview and major challenges.
of tree based edible landscapes. Urban Forestry & Urban Greening, 126292. https://doi.org/10.1016/j.ufug.2019.02.009

Han, Y., Ni Z., Li S., Qu M., Tang F., Mo, R., Ye, C., & Liu, Y. (2018). Distribution, relationship, and risk assessment of toxic heavy metals in walnuts and growth soil. Environmental Science and Pollution Research, 25, 17434–17443. https://doi.org/10.1007/s11356-018-1896-3

Howsam, M., Jones K. C., & Ineson P. (2001). PAHs associated with the leaves of three deciduous tree species. II: Uptake during a growing season. Chemosphere, 44, 155–164. https://doi.org/10.1016/S0045-6535(00)00268-X

Hunt, K., Gold M., Reid W., & Warmund M. (2012). Growing Chinese chestnuts in Missouri. University of Missouri Center for Agroforestry.

Imeri, R., Kullaj E., & Millaku L. (2019). Distribution of heavy metals in apple tissues grown in the soils of industrial area. Journal of Ecological Engineering, 20, 57–66. https://doi.org/10.12911/22998993/99733

Jänská, M., Hajšlová J., Tomaniová M., Kocourek V., & Vávrová M. (2006). Polycyclic aromatic hydrocarbons in fruits and vegetables grown in the Czech Republic. Bulletin of Environmental Contamination and Toxicology, 77, 492–499. https://doi.org/10.1007/s00128-006-1091-y

Järup, L. (2003). Hazards of heavy metal contamination. British Medical Bulletin, 68, 167–182. https://doi.org/10.1093/bmbld/ dg032

Kalkisim, O., Ozdes D., Baltaci C., & Duran C. (2019). Assessment of heavy metal contents of mulberry samples (fruit, leaf, soil) grown in Gumushane Province. Erwerbs-Ostbau, 61, 85–96. https://doi.org/10.1007/s10341-018-0398-2

Kay, R. T., Arnold T. L., Cannon W. F., & Graham D. (2008). Concentrations of polycyclic aromatic hydrocarbons and inorganic constituents in ambient surface soils, Chicago, Illinois: 2001–2002. Soil and Sediment Contamination: An International Journal, 17, 221–236. https://doi.org/10.1080/15320380802006939

Khan, A., Khan S., Khan M. A., Qamar Z., & Waqas M. (2015). The uptake and bioaccumulation of heavy metals by food plants, their effects on plants nutrients, and associated health risk: a review. Environmental Science and Pollution Research, 22, 13772–13799. https://doi.org/10.1007/s11356-015-4881-0

Khanna, S., & Khanna P. (2011). Assessment of heavy metal contamination in different vegetables grown in and around urban areas. Research Journal of Environmental Toxicology, 5, 162–179. https://doi.org/10.3923/ rjet.2011.162.179

Korčak, R. F. (1989). Cadmium distribution in field-grown fruit trees. Journal of Environmental Quality, 18, 519–523. https://doi.org/10.2134/jeq1989.00472450001800040023

Kramer, M. G. (2014). Enhancing sustainable communities with green infrastructure. USEPA Office of Sustainable Communities. https://www.epa.gov/sites/production/files/2014-10/documents/ green-infrastructure.pdf

Krasny, M. E., & Tidball K. G. (2009). Applying a resilience systems framework to urban environmental education. Environmental Education Research, 15, 465–482. https://doi.org/10.1080/13504620903003290

Ksenofontova, T. I. (2014). Heavy metals accumulation pattern in berry crops of Lena river valley/Особенности содержания тяжелых металлов в ягодных культурах долины реки Лены. Aktualnye problemy gumanitarnykh i yeststvennykh nauk, (6–1), 77–79

Lee, T. I., Hsieh Y. S., Huang J. H., Huang L. J., Li J. S., Suy, M. C., & Wu, P. R. R. (2017). Spatial factors affecting patterns of edible land-
Murray, H., Thompson K., & Macfie S. M. (2009). Site- and species-specific patterns of metal bioavailability in edible plants. *Botany, 87*, 702–711. [https://doi.org/10.1139/B09-019](https://doi.org/10.1139/B09-019)

Nabulo, G., Young S. D., & Black C. R. (2010). Assessing risk to human health from tropical leafy vegetables grown on contaminated urban soils. *Science of The Total Environment, 408*, 5338–5351. [https://doi.org/10.1016/j.scitotenv.2010.06.034](https://doi.org/10.1016/j.scitotenv.2010.06.034)

National Research Council. (2009). *Urban stormwater management in the United States*. National Academies Press.

Paris, A., Ledournemouth, J. P., Poinot P., & Gaillard J. L. (2018). Polycyclic aromatic hydrocarbons in fruits and vegetables: Origin, analysis, and occurrence. *Environmental Pollution, 234*, 96–106. [https://doi.org/10.1016/j.envpol.2017.11.028](https://doi.org/10.1016/j.envpol.2017.11.028)

Park, H., Turner N., & Higgs E. (2018). Exploring the potential of food forestry to assist in ecological restoration in North America and beyond. *Restoration Ecology, 26*, 284–293. [https://doi.org/10.1111/rec.12576](https://doi.org/10.1111/rec.12576)

Peralta-Videa, J. R., Lopez M. L., Narayan M., Sause G., & Gardea-Torresdey J. (2009). The biochemistry of environmental heavy metal uptake by plants: Implications for the food chain. *The International Journal of Biochemistry & Cell Biology, 41*, 1665–1677. [https://doi.org/10.1016/j.biocel.2009.03.005](https://doi.org/10.1016/j.biocel.2009.03.005)

Phillips, D. H. (1999). Polycyclic aromatic hydrocarbons in the diet. *Mutation Research/Genetic Toxicology and Environmental Mutagenesis, 443*, 139–147. [https://doi.org/10.1016/S1383-5742(99)00016-2](https://doi.org/10.1016/S1383-5742(99)00016-2)

Pulford, I. (2003). Phytoremediation of heavy metal-contaminated land by trees—A review. *Environment International, 29*, 529–540. [https://doi.org/10.1016/S0160-4120(02)00152-6](https://doi.org/10.1016/S0160-4120(02)00152-6)

Roba, C., Roșu C., Pîștea I., Ozunu A., & Baciuc C. (2016). Heavy metal content in vegetables and fruits cultivated in Baia Mare mining area (Romania) and health risk assessment. *Environmental Science and Pollution Research, 23*, 6062–6073. [https://doi.org/10.1007/s11356-015-4799-6](https://doi.org/10.1007/s11356-015-4799-6)

Rockwood, D. L., Naidu C. V., Carter D. R., Rahman M., Spriggs T. A., Lin C., Alker G. R., Isebrands J. G., & Segrest S. A. (2004). Short-rotation woody crops and phytoremediation: Opportunities for agroforestry? *Agroforestry Systems, 61*, 51–63. [https://doi.org/10.1007/BFAGFO.0000028989.72186.e6](https://doi.org/10.1007/BFAGFO.0000028989.72186.e6)

Rojo Camargo, M. C., & Toledo M. C. F. (2003). Polycyclic aromatic hydrocarbons in Brazilian vegetables and fruits. *Food Control, 14*, 49–53. [https://doi.org/10.1016/S0956-7135(02)00052-X](https://doi.org/10.1016/S0956-7135(02)00052-X)

Rusanov, A. M., Savin E. Z., Nigmatyanova S. E., Nigmatyanov M. M., Grudinin D. A., & Stepanova M. A. (2011). Heavy metals content of apple fruits in urban environments/Содержание тяжелых металлов в плодах яблони в городских условиях. *Vestnik OGU, 1*, 148–151.

Salinas, R. O., González G. D., Bermúdez B. S., Udawatta R. P., & Schulz, R. C. (2009). Riparian and upland buffer practices. In H. E. Garrett (Ed.), *North American agroforestry: An integrated science and practice* (pp. 163–218, 2nd ed.). American Society of Agronomy. [https://doi.org/10.2134/2009.northamericanagroforestry2ed.c8](https://doi.org/10.2134/2009.northamericanagroforestry2ed.c8)

Shayler, H., McBride M., & Harrison E. (2009). Soil contaminants and best practices for healthy gardens. Cornell Waste Management Institute.

Shevchenko, A. A., & Doroshenko T. F. (2016). The heavy metal content in the fruits of apple trees in an urban environment/Содержание тяжелых металлов в плодах яблоки в городских условиях. *Vestnik Donbas National Academy of Civil Engineering and Architecture, 4*, 47–50.

Soceanu, A., Dobrinas S., Stanciu G., & Popescu V. (2014). Popycyclic aromatic hydrocarbons in vegetables grown in urban and rural areas. *Environmental Engineering and Management Journal, 13*, 2311–2315. [https://doi.org/10.30638/emej.2014.258](https://doi.org/10.30638/emej.2014.258)

Srogi, K. (2007). Monitoring of environmental exposure to polycyclic aromatic hydrocarbons: A review. *Environmental Chemistry Letters, 5*, 169–195. [https://doi.org/10.1007/s10311-007-0095-0](https://doi.org/10.1007/s10311-007-0095-0)

Staddon, C., Ward S., De Vito L., Zuniga-Teran A., Gerlak A. K., Schoeman Y., Hart A., & Booth G. (2018). Contributions of green infrastructure to enhancing urban resilience. *Environment Systems and Decisions, 38*, 330–338. [https://doi.org/10.1007/s10669-018-9702-9](https://doi.org/10.1007/s10669-018-9702-9)

Szolnoki, Zs, Farsang A., & Puskás I. (2013). Cumulative impacts of human activities on urban garden soils: Origin and accumulation of metals. *Environmental Pollution, 177*, 106–115. [https://doi.org/10.1016/j.envpol.2013.02.007](https://doi.org/10.1016/j.envpol.2013.02.007)

Tantzereva, I. G., Popov A. I., Chistokhin U. G., & Bolshakov V. V. (2006). Environmental and pharmacological study of certain medicinal plants of Kemerovo oblast/Эколого-фармакогностическое исследование некоторых лекарственных растений Кемеровской области. *Medititsa v Kuzbashe, 2*, 23–27.

Taylor, J. R., Lovell, S. T., Wortman, S. E., & Chan, M. (2017). Ecosystem services and tradeoffs in the home gardens of African American, Chinese-origin and Mexican-origin households in Chicago, IL. *Renewable Agriculture and Food Systems, 32*, 69–86.

Thakur, S., Singh L., Wahid Z. A., Siddiqui M. F., Attnaw S. M., & Fadhil Md Din, M. (2016). Plant-driven removal of heavy metals from soil: uptake, translocation, tolerance mechanism, challenges, and future perspectives. *Environmental Monitoring and Assessment, 188*, 206. [https://doi.org/10.1007/s10661-016-5211-9](https://doi.org/10.1007/s10661-016-5211-9)

Tošić, S., Alagić S., Dimitrijević M., Pavlović A., & Nujkić M. (2016). Plant-driven removal of heavy metals from soil by trees—A review. *Renewable Agriculture and Food Systems, 31*, 139–147. [https://doi.org/10.1017/S1356-01559700289.72186.e6](https://doi.org/10.1017/S1356-01559700289.72186.e6)

United Nations Economic Commission for Europe. (2020). *Air pollution, ecosystems and biodiversity*. [http://www.unece.org/environmental-policy/conventions/enrrapwelcome/cross-sectoral-linkages/air-pollution-ecosystems-and-biodiversity.html](http://www.unece.org/environmental-policy/conventions/enrrapwelcome/cross-sectoral-linkages/air-pollution-ecosystems-and-biodiversity.html)

USEPA. (2011a). *Chapter 16: Streambank and shoreline protection*. Engineering Field Handbook. [https://efofg.sc.egov.usda.gov/references/public/IA/Chapter-16_Streambank_and_Shoreline_Protection.pdf](https://efofg.sc.egov.usda.gov/references/public/IA/Chapter-16_Streambank_and_Shoreline_Protection.pdf)

USEPA. (2011a). *Land revitalization fact sheet—Improving urban soils*. [https://www.epa.gov/sites/production/files/2015-08/documents/fs_improving_urban_soils.pdf](https://www.epa.gov/sites/production/files/2015-08/documents/fs_improving_urban_soils.pdf)
USEPA. (2011b). *Evaluation of urban soils: Suitability for green infrastructure or urban agriculture*. EPA Publication No. 905R1103. USEPA.

USEPA. (2015). *Nonpoint source: Urban areas*. USEPA. https://www.epa.gov/nps/nonpoint-source-urban-areas

Vetrova, O. A., Kuznetsov M. N., Leonicheva E. V., Motyleva S. M., & Mertvishcheva M. E. (2014). Accumulation of heavy metals in the strawberry plants grown in conditions of anthropogenic pollution/Накопление тяжелых металлов в органах земляники садовой в условиях техногенного загрязнения. *Agricultural Biology, 5*, 113–119. 10.15389/agrobio.2014.5.113rus

von Hoffen, L. P., & Säumel I. (2014). Orchards for edible cities: Cadmium and lead content in nuts, berries, pome and stone fruits harvested within the inner city neighbourhoods in Berlin, Germany. *Ecotoxicology and Environmental Safety, 101*, 233–239. https://doi.org/10.1016/j.ecoenv.2013.11.023

Wang, Y. Q., Tao S., Jiao X. C., Coveney R. M., Wu S. P., & Xing, B. S. (2008). Polycyclic aromatic hydrocarbons in leaf cuticles and inner tissues of six species of trees in urban Beijing. *Environmental Pollution, 151*, 158–164. https://doi.org/10.1016/j.envpol.2007.02.005

Welsch, D. J. (1991). Riparian forest buffers—Function and design for protection and enhancement of water resources. USDA.

Wennrich, L., Popp P., & Zeibig M. (2002). Polycyclic aromatic hydrocarbon burden in fruit and vegetable species cultivated in allotments in an industrial area. *International Journal of Environmental Analytical Chemistry, 82*, 667–690. https://doi.org/10.1080/0306731021000075401

Widdowson, M. A., Shearer S., Andersen R. G., & Novak J. T. (2005). Remediation of polycyclic aromatic hydrocarbon compounds in groundwater using poplar trees. *Environmental Science and Technology, 39*, 1598–1605. https://doi.org/10.1021/es0491681

Wortman, S. E., & Lovell S. T. (2013). Environmental challenges threatening the growth of urban agriculture in the United States. *Journal of Environmental Quality, 42*, 1283–1294. https://doi.org/10.2134/jeq2013.01.0031

Wu, S., Zheng Y., Li X., Han Y., Qu M., Ni Z., Tang F., & Liu Y. (2019). Risk assessment and prediction for toxic heavy metals in chestnut and growth soil from China. *Journal of the Science of Food and Agriculture, 99*, 4114–4122. https://doi.org/10.1002/jsfa.9641

Yin, H., Tan Q., Chen Y., Lv G., & Hou X. (2011). Polycyclic aromatic hydrocarbons (PAHs) pollution recorded in annual rings of gingko (Gingko biloba L.): Determination of PAHs by GC/MS after accelerated solvent extraction. *Microchemical Journal, 97*, 138–143. https://doi.org/10.1016/j.microc.2010.08.008

Zhong, W., & Wang M. (2002). Some polycyclic aromatic hydrocarbons in vegetables from northern China. *Journal of Environmental Science and Health, Part A, 37*, 287–296. https://doi.org/10.1081/ESE-120002588

**SUPPORTING INFORMATION**

Additional supporting information may be found online in the Supporting Information section at the end of the article.

**How to cite this article:** Romanova O, Lovell S. Food safety considerations of urban agroforestry systems grown in contaminated environments. *Urban Agric Region Food Syst*. 2021;6:e20008. https://doi.org/10.1002/uar2.20008