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Heavy metal contamination (Cu, Pb, and Cd) of washed and unwashed roadside blackberries (*Rubus fruticose* L.)

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Abstract

Foraging provides a multitude of individual, social, and environmental benefits. With green spaces decreasing in the United Kingdom, there is an opportunity for roadside verges to become valuable foraging resources; however, there is public concern over the safety of roadside forage. Human ingestion of heavy metal contaminants, such as copper (Cu), lead (Pb), and cadmium (Cd), originating from traffic activity, induces toxic effects in the body. Therefore, maximum Cu, Pb, and Cd guideline limits for human consumption in small fruits were established. However, studies of heavy metal concentrations in roadside forage and the effects of surface washing on concentrations are limited. This study examined Cu, Pb, and Cd in washed and unwashed wild blackberries (*Rubus fruticose* L.) along a main road in Kent, UK, and compares the values with maximum guideline limits. In all 44 samples, Cu, Pb and Cd concentrations were well below the maximum guideline limit or daily reference intake (RI) value. Cu and Pb concentrations were below the maximum daily intake in every sample if foragers eat one portion (80 g) of berries a day, but consuming a larger quantity of berries per day (e.g., 1 kg) could lead to an intake above the guideline limit for Cu (1 mg) and Pb (0.1 mg), but not Cd (0.03 mg). Washing did not significantly reduce the concentrations of Cu ($p = 0.174$) or Cd ($p = 0.752$) in blackberries, but did significantly reduce the Pb concentration ($p < 0.001$). However, Pb concentration was below maximum guideline limits for every sample regardless of washing treatment. Thus, wild blackberries collected from the roadside were suitable for human consumption, although the findings are not representative of all foraged berries or road networks. *Integr Environ Assess Manag* 2024;20:2107–2115. © 2024 The Author(s). *Integrated Environmental Assessment and Management* published by Wiley Periodicals LLC on behalf of Society of Environmental Toxicology & Chemistry (SETAC).

KEYWORDS: Food safety; Heavy metals; Toxicology; Urban foraging; Vehicle pollution

INTRODUCTION

The act of foraging (gathering wild foods for consumption) has long been a vital part of society (Hall, 2012). Despite its historical significance, foraging has become a recreational activity practiced by a growing number of individuals with access to secure food sources (Frazee et al., 2016; Hall, 2012). Foraging provides food production (O'Sullivan et al., 2017), influences an individual's mental well-being through a connection to nature (Keniger et al., 2013), and contributes to ecological sustainability by restoring potential sites (Morancho, 2003). In modern societies, the practice of foraging for resources in public spaces, along with the associated ecological and social importance (Table 1), has gone unrecognized by councils and developers (Shackleton et al., 2017).

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Foraging commonly occurs in urban and suburban locations (Gianotti & Hurley, 2016) because many wild edible plants are ubiquitous in these environments (Zimdahl, 2013). In these areas, foragers gather from a variety of sites such as private land, roadsides, and city parks (Gianotti & Hurley, 2016). Urban foraging can contribute significantly to the diets of some foragers (Synk et al., 2017). Berries are a primary crop for harvest, along with nuts and mushrooms (Gianotti & Hurley, 2016). One study noted that, of the various foraged foodstuffs, blackberries were a near-universally foraged product (Poe et al., 2013). Despite a recommendation by the accessible natural green space standard—developed to influence the quality, quantity, and distribution of green spaces in the UK—that residents of towns and cities should live no more than 300 m from a green space (Kazmierczak et al., 2010), only a third of people meet this recommendation (Barbosa et al., 2007). The maintenance of green spaces in urban settings can be influenced by the production of beneficial material and immaterial services (O'Sullivan et al., 2017), including those linked to foraging. Because more than 80% of people in England live in urbanized areas (Pateman, 2011) and the global urban population is expected to double by 2050 compared with 2010 estimates (Secretariat of the Convention on Biological Diversity, 2011), urban and peri-urban foraging practices are increasing in importance.

The introduction of recreational foraging develops an individual's first-hand knowledge of the local ecosystem (Jong & Varley, 2017). The connection between people and place enforces a sense of environmental responsibility, which is often then reflected in political identity, spurring regional and national conservation policies (Chipeniuk, 1998). Recently in Bristol, public opposition led to the rejection of a bylaw, which would have prevented fruit picking in local parks and green spaces (Bristol City Council, n.d., 2016). The sense of environmental ownership ensures the availability and public access to natural habitats (Hall, 2012). In densely developed areas with ever decreasing green spaces, there is considerable potential for roadside verges, which occupy nearly 1% of UK land surface (Underhill & Angold, 2000), to become key habitats through management. Typically, UK verges consist of regularly mown grassy vegetation; however, roadsides could support considerable diversity through altered mowing regimens and the sowing of wildflower seed mixes (O'Sullivan et al., 2017). Respondents to the Hjortenkrans survey suggested that there is public demand for roadside revegetation management schemes to increase local biodiversity (Hjortenkrans, 2008).

Neighborhood perception and approval are key components of the acceptance of proposed changes in verge management (O'Sullivan et al., 2017). Despite roadside verges being excellent sites for foraging, the transformation of verges into reserves may be dismissed by UK foraging communities who have expressed concerns over picking near busy roads and over the safety of verge produce (Fathen, 2023; Forestry and Land Scotland, 2019; Parry, 2020). Roadside vegetation can be contaminated by chemical pollutants generated by local traffic (Seiler, 2001). One of the main categories of pollutants are heavy metals (Forman & Alexander, 1998) from brake linings, tires, and exhaust fumes (Hjortenkrans, 2008). Through traffic activity and rainwater runoff, road surface dust containing heavy metals is disturbed and deposited on roadside soil and foliage (Figure 1; Seiler, 2001). The concentration of heavy metals in the soil will increase with proximity to the road (Akbar et al., 2006). Plants growing within the dispersal distance will be affected by dust surface contamination and the incorporation of heavy metals from the soil into their tissue via root system uptake (Clarke et al., 2015; Shahid et al., 2017; Figure 2), affecting the fruits and edible parts (Hamurcu et al., 2010).

Copper (Cu) is a micronutrient essential for growth and is commonly found in fruits (Zeiner & Cindrić, 2018). The daily reference intake (RI) of Cu for an average adult is 1 mg (European Commission Regulation 1169/2011; European Commission, 2011). Long-term ingestion of Cu above the daily RI induces noxious effects when the accumulation rate inside the body exceeds the discharge rate (Sardar et al., 2013; Shahid et al., 2017; Weeks et al., 2006). Low levels of heavy metal bioaccumulation can cause vomiting and diarrhea, and high levels can impede vital nutrients in the body, leading to malnutrition, cancer, and growth retardation (Sardar et al., 2013). Nonessential metals such as lead (Pb) and cadmium (Cd) are toxic at low levels and cause chronic damage to the human body (Hamurcu et al., 2010; Shahid et al., 2017). High Pb and Cd levels in food have been related to the etiology of cardiovascular, kidney, nervous, and bone disease, whereas chronic Pb poisoning can cause colic, constipation, and anemia (Sardar et al., 2013).

TABLE 1 Individual, social, and environmental benefits of green spaces in urban settings

Benefit	Description	Example
Individual	Positive physical and mental effects at an individual scale	Recreation and enjoyment (Morancho, 2003; Samways, 2007) Increased physical and psychological well-being, increased cognitive ability (Keniger et al., 2013) Even incidental interactions with nature (driving or walking past) have health benefits such as stress reduction (Keniger et al., 2013)
Social	Positive social effects at a community scale	Reduced health spending, reduced crime rate, social cohesion (Keniger et al., 2013) Access to green spaces increases local house prices (Morancho, 2003) Food supply and material goods (O'Sullivan et al., 2017) Support key goals of foragers around issues of food security and sovereignty (Poe et al., 2013)
Environmental	Positive environmental effects at a community or national scale	Children who are exposed to nature are more likely to support conservation initiatives as adults (Samways, 2007) Initiates strong public support that encourages governments to implement effective conservation schemes (Chipeniuk, 1998) Increase biodiversity, prevent soil erosion, carbon capture and storage, moderate temperature, maintain humidity, acoustic barrier between road and residential areas (Morancho, 2003) Phytoremediation—using hyperaccumulator plants to remove metal pollution from contaminated soils (Tangahu et al., 2011)

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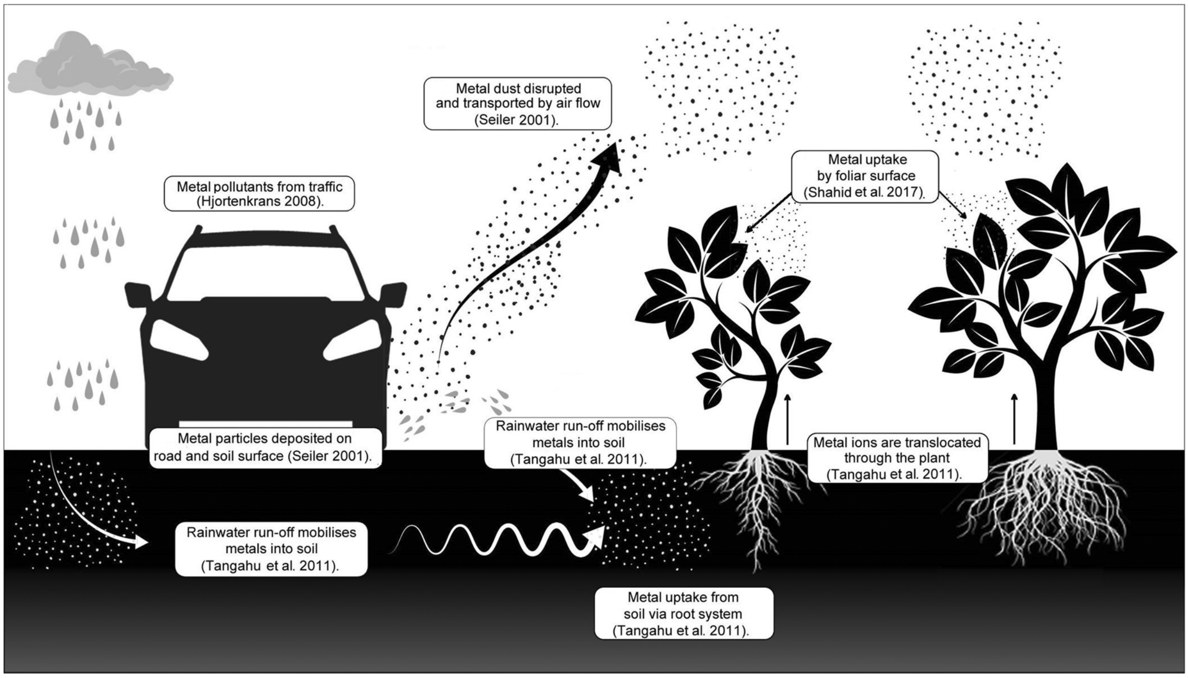

FIGURE 1 Deposition of heavy metals onto soil and foliage by traffic activity

The health effects associated with the long-term ingestion of contaminated fruits are difficult to predict because they depend on the concentration and bioavailability of the heavy metal (Islam et al., 2007) and the volume of fruit consumed by the individual (Sardar et al., 2013).

Due to the potential threat of long-term consumption, maximum limits have been established (Zeiner & Cindrić, 2018). According to the provisions of European Commission Regulation 2023/915 (European Commission, 2023), the maximum Pb concentration in berries and small fruit is

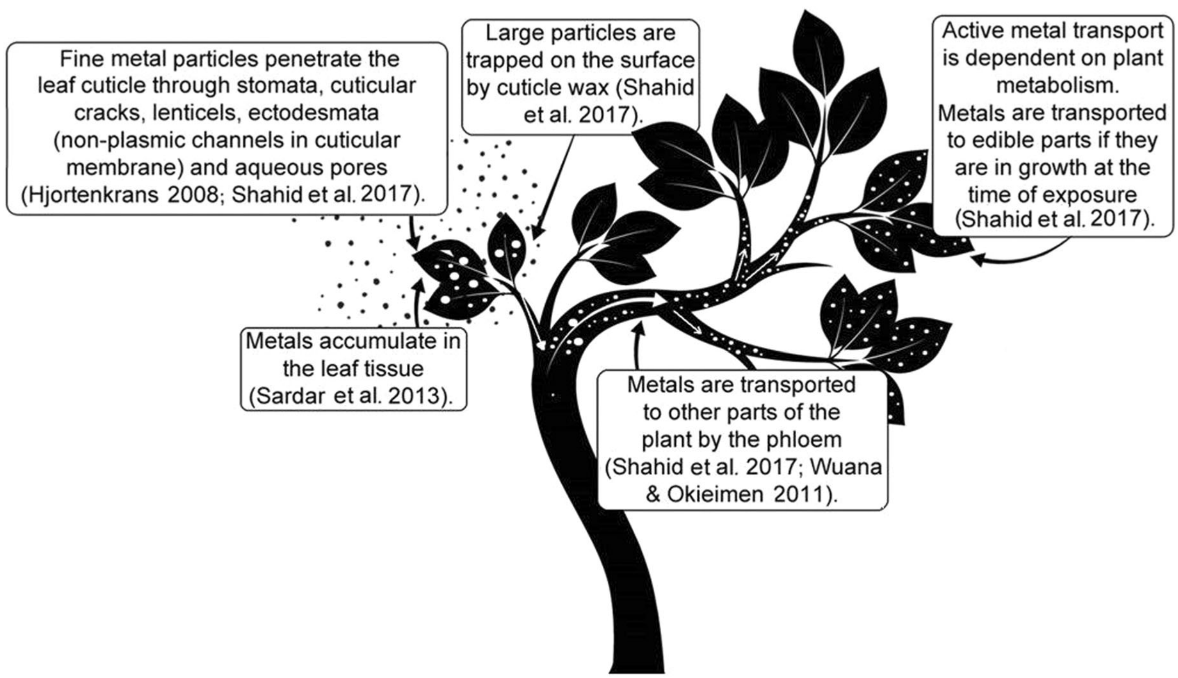

FIGURE 2 Heavy metal leaf penetration and translocation through plant

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0.020 mg/kg (wet weight), and the maximum Cd concentration in vegetables and fruit is 0.050 mg/kg (wet weight). Because of the popularity of consuming raw or unprocessed blackberries, it is necessary to quantify heavy metal content (Vlad et al., 2019) and the potential associated health risks (Shahid et al., 2017). In their study, Vlad et al. (2019) concluded that heavy metal concentrations ingested in a 100 g portion of fresh unwashed blackberries were above the referenced guideline values for adult consumption at 8.51 mg Pb, 0.74 mg Cd, and 5.71 mg Cu.

Surface washing can reduce metal contamination (Mohite et al., 2016). There is no method to completely remove heavy metal deposition because fine dust particles can penetrate the cuticle; however, larger particles trapped on the surface by cuticle wax may be removed by rinsing with water (Sardar et al., 2013; Shahid et al., 2017). Mohite et al. (2016) found that surface washing of leafy vegetables grown in heavily industrialized areas reduced Cu contamination to within the maximum limits, whereas Pb levels were reduced but remained above the limits. Swaileh et al. (2004) concluded that surface washing significantly reduced Pb concentrations in roadside vegetation to within guideline limits.

Foragers must be made aware of the specific risks associated with ingesting roadside vegetation and the effectiveness of surface washing in reducing pollutant concentrations. Because heavy metal accumulation rates are much lower in fruits than in roots, leaves, and flowers (Vlad et al., 2019), studies of heavy metal contamination of roadside soils and whole plants (Akbar et al., 2006; Hjortenkrans, 2008; Swaileh et al., 2004) may falsely represent concentrations in edible fruit. This may lead foragers to be unnecessarily hesitant about picking from roadside locations. This study aimed to quantify the Cu, Pb, and Cd concentrations of foraged roadside blackberries with respect to maximum limits for adult consumption and to determine the effects of surface washing on heavy metal concentration.

MATERIALS AND METHODS

Study area

Thanet Way (A229) is a major road in Kent managed by Kent Wildlife Trust and Kent Highway Services as part of the Kent & Medway Verge Project. This project has been in operation since 1999 and aims to identify, manage, and protect road verges with the intention of conserving threatened wildlife habitats (Kent Wildlife Trust, 2019). The project has seen the expansion of ancient woodland, heathland, and chalk grassland in the county and has reformed arable land through the collection and dispersal of seeds from successful verges (Kent Wildlife Trust, 2019). Thanet Way was selected for this case study because of the high volume of traffic, the proximity of forage to the road, and public accessibility to forage. If heavy metal concentrations in an area of high-density traffic are below the recommended guidelines, then it can be suggested that forage in locations with less traffic are also suitable for consumption. Forage that is easily accessible was chosen as a representative of what foragers are most likely to pick and consume.

Protocol

Blackberries were chosen because they are easily identifiable and accessible to novice foragers of all ages. They have long been a popular part of the British diet, with more than 100 wild British varieties, blooming from June to October (Lewis-Stempel, 2012). Blackberry (*Rubus fruticose* L.) samples were taken from plants found along a 500-m section of roadside verge at Thanet Way (A229) on 22 August 2019, starting at a busy roundabout and moving down the main road. In total, 44 samples were collected. The distance from the road varied along the 500 m section, with an average distance of 7.0 m, although the average distance from the road was greater at the roundabout (8.2 m) than at the main road (6.3 m). This section experiences both steady-speed driving on the main road and the more polluting transient driving modes (i.e., acceleration and deceleration) near the roundabout, previously described by Tong et al. (2000).

To be representative, individual fruits were selected only if they would be selected and eaten by local foragers. Fruits that were easily accessible, visibly healthy, ripe, and of a similar size were picked from low, middle, and high branches of all blackberry bushes and collected in polyethylene bags. All fruit was taken to the laboratory on the same day, where it was pooled and homogenized by hand before being split into two samples; one sample was placed in a sieve and rinsed thoroughly with tap water for 30 s while being constantly rotated, and the second sample was left untreated. Subsequently, each treatment was divided into 22 replicate samples per treatment. All samples were placed in foil trays and dried in a Carbolite Gero AX60 laboratory oven at 80 °C for three days. For sample preparation, the dried fruit material (with leaves and stalks removed) was ground in a blender for 5 min. Throughout the laboratory work, samples were handled as little as possible to avoid wiping away surface dust from the fruit, and the equipment was washed thoroughly between each use to prevent cross contamination.

Analysis for metal determination was performed on 0.250 g samples of blackberry from each of the 44 samples. These samples underwent microwave digestion using a Berghof Speedwave 4 Microwave Digester, with 6.0 mL nitric acid (65%) and 1.0 mL hydrogen peroxide (35%), based on the Berghof protocol for fruit (Berghof, n.d.). After cooling, the contents of each vessel were diluted to 50 mL using distilled water. For each sample, Pb, Cu, and Cd concentrations were determined using a PerkinElmer Optima 8000 ICP-OES. Results from blank samples were used to determine that the limit of detection (LOD) and limit of quantification (LOQ) were appropriate.

After analysis of digested dried blackberry samples, the data on Cu, Pb, and Cd (mg/kg) dry weight were converted to wet weight (mg/kg) by dividing by a wet/dry conversion factor of 4.62. This value was calculated by weighing fresh blackberry samples, placing them in foil trays, drying them in an oven at 200 °C for 2.5 h, reweighing, and then taking

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an average of the original weight of each sample divided by the final weight. Sample Cu, Pb, and Cd (mg/kg) wet weight were then converted into daily portions (mg/80 g wet weight) by dividing wet weight values by 12.5 (National Health Service, 2022).

Statistical analysis

After conducting Anderson–Darling normality tests on the data, two-sample *t*-tests for normally distributed data and Mann–Whitney tests for nonparametric data were performed on the values obtained from the study using Minitab for Windows (Minitab Inc., 2020). The aim of the statistical analysis was to determine whether the concentrations of metals in washed and unwashed samples differed significantly. Data for Cu and Pb concentrations followed normal distribution (p-value = 0.157 and p-value = 0.571, respectively). Cadmium concentrations did not follow normal distribution (p-value < 0.005); therefore, nonparametric tests were employed. For all statistical tests, the *p*-level was set at 0.05.

RESULTS

Effects of surface washing on Cu, Pb, and Cd concentrations

Although average concentrations of all three metals were lower for the washed samples than the unwashed berries (Table 2), there was no statistically significant difference for Cu ($p = 0.174$) or Cd (0.752). However, there was a statistically significant difference in Pb concentration ($p < 0.001$).

Cu, Pb, and Cd concentrations in relation to maximum RI values

The daily RI for Cu for an average adult is 1 mg (European Commission, 2011). In 95% of samples, Cu mg/kg wet weight exceeded this value. However, it is unlikely that an individual would consume 1 kg of wild blackberries daily. For the recommended daily portion size (80 g), Cu concentrations were well below the maximum daily intake in every sample.

The daily RI Pb concentration in small fruits is 0.1 mg/kg wet weight (European Commission, 2023). Lead mg/kg wet weight was greater than 0.1 mg/kg in 93% of samples. However, for the recommended blackberry portion size (80 g) for fruits and vegetables by the National Health Service (2022), the Pb concentration was under the guideline value in all samples. Although surface washing significantly reduced Pb concentration, it was not a necessity to reduce Pb in samples to below the maximum guideline values as all washed and unwashed samples were below this limit and therefore safe to consume.

The daily RI of Cd in small fruits is 0.030 mg/kg wet weight (European Commission, 2023). Cadmium mg/kg wet weight was lower than the guideline value in all samples; thus, Cd concentration in recommended blackberry portion size (80 g) remained below the RI value for all samples, regardless of washing treatment.

DISCUSSION

Effects of surface washing on Cu, Pb, and Cd concentrations

Surface washing did not significantly reduce the Cu and Cd concentrations in wild blackberries, suggesting that the source of Cu and Cd contamination is not strictly atmospheric deposition (Seiler, 2001). It is likely that roadside blackberry contamination is sourced mainly from foliar uptake of trace elements from atmospheric dust disturbed by vehicle activity and by root absorption of plants from soil contaminated by the leaching of atmospheric dust onto the soil surface (Li et al., 2007; Shahid et al., 2017). Because Cu and Cd are incorporated into plant tissue, surface washing may reduce heavy metal concentrations; however, no

TABLE 2 Average concentration of copper (Cu), lead (Pb), and cadmium (Cd) in unwashed and washed blackberries (±standard error), per kg dry weight, kg wet weight, and 80 g wet portion, and limit value

Element	Unit	Unwashed	Washed	Limit
Cu	mg/kg dry weight	7.742 ± 0.47	6.861 ± 0.43	1.000[a]
	mg/kg wet weight	1.676 ± 0.10	1.485 ± 0.09	
	mg/80 g wet portion	0.134 ± 0.01	0.119 ± 0.01	
Pb	mg/kg dry weight	2.210 ± 0.14	1.500 ± 0.12	0.020[b]
	mg/kg wet weight	0.478 ± 0.03	0.310 ± 0.03	
	mg/80 g wet portion	0.038 ± 0.00	0.025 ± 0.00	
Cd	mg/kg dry weight	0.009 ± 0.01	0.00 ± 0.00	0.050[b]
	mg/kg wet weight	0.0020 ± 0.00	0.0017 ± 0.00	
	mg/80 g wet portion	0.0002 ± 0.00	0 ± 0.00	

[a]Indicates the reference maximum daily intake as per European Commission Regulation 1169/2011.
[b]Indicates the maximum guideline limit as per European Commission Regulation No. 1881/2006.

treatment can fully remove dust deposition because fine particles can enter the leaf via the stomata and translocate throughout the plant (Sardar et al., 2013; Shahid et al., 2017). It is also possible that the surface washing method used in this study was inefficient at removing contaminants. Other studies rinsed the samples thoroughly several times with tap water followed by distilled water (Mohite et al., 2016) and washed thoroughly with deionized double-distilled water (Swaileh et al., 2004). Arguably, the treatment used in this study is more applicable to real-life situations because it is unlikely that foragers would rinse multiple times or own distilled water.

Surface washing significantly reduced Pb concentration in wild blackberries, suggesting that the main source of Pb contamination is atmospheric deposition of dust onto the fruit surface (Swaileh et al., 2004). However, since Pb concentration was below the guideline value for both washed and unwashed blackberries, washing blackberries was not a necessity to reduce the human health risks associated with ingestion. These results differ to those found in Mohite et al. (2016), where surface washing reduced Cu contamination of leafy vegetables to below the maximum guideline limit for human consumption, whereas the Pb concentration was above the maximum permissible limit in washed and unwashed samples. However, there is evidence that surface washing can significantly reduce Pb concentrations, to below the government-advised concentration for human consumption in some cases (Swaileh et al., 2004). This was not deemed necessary in this study since all three heavy metal contaminants were below the guideline values for an 80 g poriton regardless of washign treatment. However, it should also be noted for future studies (particularly those where washing might be required to reduce contaminants to safe levels) that the effectiveness of surface washing to remove contaminants is associated with not only how the berries have been washed but can also depend on the nature of the fruit surface, surface area, or the amount of contaminant initially present (Mohite et al., 2016).

Cu, Pb, and Cd concentrations in relation to maximum RI

Despite lower concentrations of mineral elements, excessive consumption of seemingly "safe" fruits could lead to toxic levels of metals in the body (Ekholm et al., 2007). Zeiner and Cindrić (2018) discuss whether, because of the high Pb levels in rose hip samples, intake should not exceed 100 g per week in adults. Despite low Pb levels in blueberry samples, negative health effects would be expected in cases of excessive consumption and that, for Cd concentration in blueberry samples to reach beyond the monthly recommended intake, an 80-kg adult would have to consume 700 kg of fresh blueberries in one month. To estimate the threat posed by ingestion of contaminated produce, the amount of forage an individual would realistically consume over a given period must be considered. One kilogram of fresh wild blackberries is under the RI concentration for Cd (0.03 mg/kg) but not for Cu (1 mg/kg) or Pb (0.02 mg/kg). Since it is unlikely that an individual would consume 1 kg of blackberries per day, it is unlikely that consumption of blackberries foraged from locations such as the one sampled in this study would be considered a risk to human health.

For the recommended 80 g portion size of fresh blackberries (National Health Service, 2022), the average Cu, Pb and Cd concentration was below the recommended guidelines. This is similar to findings from other studies (Llorent-Martínez et al., 2017; Ogundele et al., 2015).

Although this study did not find contamination of foraged blackberries, results presented in an analysis of wild blueberries, lingonberries, and rose hips growing in a supposedly unpolluted location in Croatia demonstrated that there were low Cd levels but high Pb levels, with Pb concentrations in blueberries ranging between 1.19 and 2.42 mg/kg dry weight (average of 1.99 mg/kg; Zeiner & Cindrić, 2018). Furthermore, in their study of contamination of roadside small fruits in Turkey, Hamurcu et al. (2010) reported Cu (0.27–0.05 mg/kg) and Pb (2.861.54 mg/kg) in samples, above the stated pollution level, yet Cd (0.16–0.06 mg/kg) did not reach the pollution level. This inconsistency in results examining contamination of wild fruits demonstrates a need for further studies of this kind.

Further considerations

This study may not be representative of all roadways. For example, metal concentrations may be particularly high near roundabouts due to an increase in traffic density and breaking activities that release metal contaminants, such as Cu, from brake linings (Hjortenkrans, 2008; Ogundele et al., 2015). The road condition may also influence roadside contamination. Ogundele et al. (2015) reported that paved roads with adequate drainage systems can reduce the spread of heavy metals to the surrounding soil. Therefore, areas with poorer drainage would likely allow contaminants to build up in the immediate environment. Finally, the distance from the road is a key factor in determining vehicle contamination. In this case, the concentrations of some contaminants in blackberries were below guideline values when foraged approximately 7 m from the road. However, since there are inconsistent findings in the literature, it could be suggested that foragers increase the distance from the road where they pick produce to be certain of its safety. Swaileh et al. (2004) found that roadside pollution did not extend farther than 20 m from the road's edge, whereas Hjortenkrans et al. (2008) demonstrated that some roadside contaminants can still be present at relatively high concentrations up to 45 m from the road. Similarly, Jaradat and Momani (1999) recorded contamination decreasing exponentially with distance from the road up, but with contamination still present up to 50 m away. Another study found a significant decrease in contamination in vegetation 45–50 m from the roadside compared with samples collected up to 5 m from the road (Khalid et al., 2018). Conversely, a study comparing soil contamination and plant toxicity up to 50 m from roads found that there was considerable pollution only up to 7 m from the road, and particularly strong plant toxicity was limited to the first 2 m (Nikolaeva et al., 2021). Thus, because research is

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needed to help foragers develop strategies to prevent risks from gathering urban wild foods (Poe et al., 2013), it is suggested that foragers increase the distance from the road near which they pick produce to at least 50 m from the roadside as a precaution, although this may not always be necessary (as with this study site). More research is needed to confirm an appropriate safe foraging distance on various roads. In addition to distance from the road, vehicle traffic volume affects contamination, and traffic counts or categories should be considered in assessments of roadside contamination because this can significantly affect contamination levels (Amato-Lourenco et al., 2020; Sáňka et al., 1995).

Sources other than vehicles will account for some contamination, but this will vary depending on the location studied. For example, metal contamination of road verges may also result from the application of fertilizers, pesticides, fungicides, and wastewater on neighboring land (Sardar et al., 2013; Hamurcu et al., 2010; Mohite et al., 2016; Wuana & Okieimen, 2011) that is then leached into the sample locations. The presence of heavy industry may also result in metal contamination of local vegetation, such as road verges (Wuana & Okieimen, 2011). However, in this study, the site was adjacent to commercial plots and fallow land—neither of these land uses are likely to have resulted in significant pollution, and these land uses have been the same for many years. Similarly, the ingestion of vegetables grown under contaminated conditions was the only exposure pathway considered in this study, in line with similar experiments (Murray et al., 2009). However, there is some health risk via pollution from other sources, namely the inhalation of airborne contaminants from vehicle traffic.

The pollution level may not be accurately represented by Pb, Cu, and Cd concentrations in wild blackberries. As well as being affected by climate, plant maturity, and soil characteristics, the pattern and rate of accumulation also varies between elements (Mohite et al., 2016; Ogundele et al., 2015). For example, Pb and Cd tend to accumulate in both the soil and leaves of roadside plants whereas Cu accumulates only in soils (Li et al., 2007). Because accumulation may be greater in soils than plants, quantifying the contamination of both plant material and soil can allow for a more detailed investigation of local pollution sources and contamination levels (Amato-Lourenco et al., 2020). Additionally, Swaileh et al. (2004) concluded that Pb and Cu concentrations in soils significantly increase with increasing traffic activity, whereas Cd concentration is not related to traffic pollution. Additionally, several additional metals and metalloids (i.e., Al, Mo, Ni, Se, Hg, V, Co, Zn, Cr, Fe, Ba, Sb, and Ti) are associated with contamination of roadsides from vehicles (Adamiec et al., 2016; Amato-Lourenco et al., 2020; Lough et al., 2005; Stark et al., 2019; Wiseman et al., 2015); therefore, these should also be considered in future studies.

Because plants take up and store nutrients from the soil differently, it is possible for the heavy metal concentrations found in certain fruits to falsely represent pollution levels in all forage from a single location (Akbar et al., 2006; Hjortenkrans, 2008). Ekholm et al. (2007) studied the mineral elements of 16 fruits and berries grown in Finland, with varying results. Raspberry (*Rubus idaeus*) samples contained, on average, a concentration of Cu (5 mg/100 g dry weight), which was above the RI guidelines. On the other hand, apple (*Malus* sp.) samples were considerably less polluted and contained a lower average Cu concentration (0.3 mg/100 g dry weight), well below the guideline values (Ekholm et al., 2007). Llorent-Martínez et al. (2017) concluded the mineral content of wild blackberries (*Rubus grandifolius*) was significantly different between two locations; no sample presented health risks through Cd, Cu, and Pb concentrations. Similarly, plants vary in their ability to accumulate metal or metalloid ions, both in aggregate and in specific structures such as berries (Murray et al., 2009). Therefore, the relative risk to humans from ingestion differs between plants.

CONCLUSION

The findings of this study have started a discussion of the safety of roadside forage in the UK. Due to the popularity of foraging and the many individual, social, and environmental benefits (Table 1), it is important for the public to feel confident about consuming roadside forage. From these results, there was no demonstrable health risk when foraging for blackberries along the roadside of a busy main road, although findings from other studies demonstrate that foragers may wish to pick blackberries at least 50 m from the roadside as a precaution. However, contamination will vary depending on several factors, including climate, soil characteristics, traffic density and breaking activity, road condition, distance from the road, presence of other sources of contamination, and the type of fruit or berry being picked. Although this will not significantly reduce the concentration of all contaminants, and not all fruits will have contaminants present above guideline limits or RI values, it is still recommended that foraged fruits or berries be washed thoroughly before consumption.

Further research is required to fully warn foragers of the potential health risks associated with foraging on different roadsides, under different environmental conditions, and for a wide range of commonly foraged foods. Because washing is the key method that foragers use to reduce contamination before consumption, more research is required to understand its effects (and potential benefits). This will allow consumers to make informed decisions about what and where to pick, as well as how often these foods are included in their diets.

AUTHOR CONTRIBUTION

Lauren K. Chamberlain: Conceptualization; data curation; formal analysis; investigation; methodology; validation; visualization; writing—original draft; writing—review and editing. **Hannah Scott**: Conceptualization; formal analysis; investigation; methodology; supervision; validation; writing—review and editing. **Naomi Beddoe**: Methodology; validation; visualization; writing—review and editing. **Naomi L. J. Rintoul-Hynes**: Conceptualization; data curation; formal analysis; funding acquisition; methodology; project administration; resources; supervision; validation; writing—review and editing.

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CONFLICT OF INTEREST

The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are openly available in ResearchGate at https://doi.org/10.13140/RG.2.2.18844.09606.

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