Heavy metals content in the *Fallopia* genus in Central European Cities – study from Wroclaw and Prague

Zawartość metali ciężkich w gatunkach z rodzaju *Fallopia* na obszarze miast środkowej Europy – badania z Wrocławia i Pragi

JUSTYNA SOŁTYSIAK, KATEŘINA BERCHOVÁ-BÍMOVÁ, MAREK VACH, TERESA BREJ

J. Sołtysiak, Wroclaw University of Environmental and Life Sciences, Department of Botany and Plan Ecology; e-mail: justyna.soltysiak@up.wroc.pl
K. Berchová –Bímová, Czech University of Life Sciences Prague, Department of Landscape Ecology; Institute of Botany, Czech Academy of Sciences, Průhonice; e-mail: katerina.berchova@ibot.cas.cz
M. Vach, Czech University of Life Sciences Prague, Department of Water Resources and Environmental Modelling; e-mail: vachm@knc.czu.cz
T. Brej, Wroclaw University of Environmental and Life Sciences, Department of Botany and Plan Ecology; e-mail: teresa.brej@up.wroc.pl

ABSTRACT: In this study highly invasive plant species from the *Fallopia* genus (*Fallopia japonica* and *Fallopia* ×*bohemica*) were investigated for their ability to accumulate heavy metals. Samples were collected from two large cities: Wroclaw and Prague. The content of Cr, Cd, Fe, Pb and Zn in soils covered by Knotweed taxa was determined. Afterwards, plant samples were collected from the places where the largest amounts of toxic metals were found. Rhizomes, roots and leaves of chosen samples of both *Fallopia* taxa have been treated separately, as different parts of the plant accumulate metals. The investigation has shown that in urban conditions Knotweed taxa spread on soils with higher than natural concentration of toxic metals. Only the chromium amount was similar to the normal range. In both species heavy metals were accumulated mainly in roots and rhizomes, but their concentration was significantly higher in *Fallopia japonica* underground parts than in the hybrid. There were no differences between species with metals content in the aboveground parts of the plant body. The results suggest that special attention should be paid to Cr. In all analyzed plants, high chromium content was found, while the Cr amount in soils samples was close to natural.

KEY WORDS: *Fallopia japonica*, *Fallopia* ×*bohemica*, heavy metals, urban areas

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Introduction

Increased heavy metals pollution is a consequence of human activity that affects all parts of the ecosystem. Flower plants have developed mechanisms resulting in avoidance or tolerance of heavy metals. The potential avoidance applies to the cellular and whole plant level. In general, the avoidance can be related to limited uptake of heavy metals from soil, sequestration of toxic metals from protoplasm or their elimination (Punz, Sieghardt 1993). Heavy metals tolerance builds up during genetic, physiological and ecological evolution on natural metalliferous areas (Ernst 2006). Evolution of metal tolerance is also possible in anthropogenic habitats. It follows within a shorter time depending on the metal levels and the selection pressure in the environment (Hall 2002).

Urban soils are often characterized by high concentrations of heavy metals that create difficult conditions for most plants growing there. Therefore, an adaptation to stress caused by heavy metals can facilitate plants invasion in anthropogenic areas. *Solidago canadensis* – an invasive plant species which spreads in soils contaminated by lead – presumably has this feature. Yang et al. (2007) compared the response of *Solidago canadensis* and two non-invasive species (*Festuca arundinacea* and *Kummerowia striata*) to soil polluted by lead. In *Solidago canadensis* roots Pb content was lower than in the roots of non-invasive species under corresponding Pb treatments. Furthermore, the above and belowground biomass as well as N and P uptake of invasive plants increased in comparison with those of non-invasive plants under elevated Pb soils. The authors concluded that the rapid growth of *Solidago canadensis* in Pb soils might be due to its ability to exclude or a reduce Pb uptake.

The *Fallopia* genus (*Fallopia japonica*, *Fallopia sachalinensis* and *Fallopia* × *bohemica*) are among the most invasive aliens in both Europea and North America. The phenomenon of Japanese Knotweed invasion is associated with various aspects. Firstly, species from the *Fallopia* genus have intensive rhizomatous growth and massive vegetative regeneration abilities (Brock et al. 1995; Bímová et al. 2003). Brock and Wade (1992) found that a new plant can be created from a rhizome segment about 0.7 g in weight (Brock et al. 1995). They are also able to regenerate from stems. Secondly, they show sexual reproduction by hybridization, which can bring new hybrids that are better suited to non-native regions (Bailey 2003; Bailey et al. 2007). Finally, the success of the *Fallopia* genus is connected with their easy development in various environmental conditions. They are able to grow in diverse soil types with various pH ranges and nutrient content (Beerling et al. 1994). Richards et al. (2008) reported Knotweed taxa from saline habitats, while Adachi (1996) described *Fallopia japonica* (var. *compacta*) as a perennial pioneer species in the volcanic wasteland on Mt. Fuji. Furthermore, seedlings from Fuji had a high vitality and a great ability to survive under extreme climate (Mariko et al. 1993). In Europe, Knotweed taxa show preferences for manmade habitats (Mandák et al. 2004). Members of the *Fallopia* genus are frequent components of urban ecosystems, where their range increases quickly. In particular, *Fallopia japonica* and its hybrid spread in soils with potential large concentrations of heavy metals. They are common along roads or motorways, dumps, deposits and alongside railway tracks. However, it has yet to be examined whether soils pollution by toxic metals interacts with their invasive abilities. The aim of this preliminary study was to find the differences in heavy metals uptake between different parts of plants and between two taxa from the genus (*F. japonica* var. *japonica* and *F. ×bohemica*). The results were used in the following studies (Sołtysiak, Berchová-Bímová, Brej – Response of *Fallopia* genus to heavy metal treatments, in prep.). *Fallopia* taxa metal uptake is frequently discussed in terms of using the species as soil cleaners.

The present paper shows the accumulation ability of heavy metals into different parts of the plant body and answers the question of the suitability of these plants for such purposes.

1. Methods

1.1. Species characteristics and sampling

In this investigation we focus on two highly invasive taxa from the *Fallopia* genus: *Fallopia japonica* (Houtt.) Ronse Decraene var. *japonica*, [syn.: *Polygonum cuspidatum* Sieb. et Zucc., *Reynoutria japonica* Houtt.] and *Fallopia ×bohemica* (Chartek et Chrtková) J. P. Bailey [syn.: *Polygonum × bohemicum* (Chartek et Chrtková) P. F. Zika et A. L. Jacobson, *Reynoutria ×bohemica* Chartek et Chrtková] – a hybrid between *Fallopia japonica* var. *japonica* and *Fallopia sachalinensis* (Bailey 2003). The first part of the investigation was to determine heavy metals content in soils which they cover. Thirty-six soil samples were collected from 16 locations (6 with *Fallopia japonica* and 10 with *Fallopia ×bohemica*) from Wroclaw and Prague. All samples were taken near the root zone from a depth of about 0–15 cm. The *Fallopia* genus contains several ploidy levels and different genetic variability within the taxa. *Fallopia japonica* is genetically uniform and can reproduce solely in a vegetative way. In Europe there is only one female clone of *Fallopia japonica* (Mandák et al. 2005). For this reason, soil samples were collected from under one *Fallopia japonica* clone of each locality. The hybrid samples were taken from under three different clumps. *Fallopia ×bohemica* is represented by different genotypes of both functional genders. It can reproduce in a vegetative way, but sexually reproduction is also occasionally present (Mandák et al. 2005).

1.2. Heavy metal content analysis

Samples were air-dried, dried until constant weight at 105°C, and digested in HNO_3. An atomic absorption spectroscopy (AAS) was used to determine Cd, Cr, Fe, Pb and Zn concentrations. Plants were then collected from two places in both cities where the largest amounts of toxic metals were found. Rhizomes with roots and leaves of *Fallopia japonica* and *Fallopia ×bohemica* were treated separately, as different parts of the plants accumulate metals (stems were not analyzed). Air-dried samples were dried to a constant weight (105°C), mineralized in HNO_3, and analyzed using the AAS method.

1.3. Data analysis

The differences between the taxa and under- and aboveground plant parts in heavy metal uptake were estimated using GLIM. The data was approximated by gamma distribution, because of the wide range of response variable values. The 1/x link function was used. The species (Japonica, Bohemica) and the plant parts (Above, Underground) were used as categorical predictors. The data was computed using Statistica® software.

2. Results

2.1. Soils

In soil samples collected from Wroclaw and Prague, higher than natural content of Cd, Fe, Pb and Zn was found. These results are illustrated in Table 1. Only chromium concentration was similar to normal. According to Allen (1989), the natural ranges of investigated metals are: 0.03–0.3 $\mu g \cdot g^{-1}$ ($mg \cdot kg^{-1}$) for Cd, 10–200 $\mu g \cdot g^{-1}$ for Cr, 2–20 $\mu g \cdot g^{-1}$ for Pb, 20–300 $\mu g \cdot g^{-1}$ for Zn and 50–1,000 $\mu g \cdot g^{-1}$ for Fe.

Table1. Content of heavy metals in soils [mg·kg^{-1}] collected from urban sites in Wroclaw and Prague

No.of sample	Sampling area	Cd	Cr	Fe	Pb	Zn
1	Roadside (Wrocław, Działkowa street)	0.05	2.5	740	12.8	10.5
2	Riverbank (Wrocław, Odra river)	0.27	2.8	920	7.0	38.2
3	Undeveloped area (Wrocław, Tramwajowa street)	0.28	8.6	2945	15.1	54.5
4	Roadside (Prague, Dejvická street)	0.69	32.7	41075	54.6	372.9
5	Lawn area (Prague, Kamýcká street)	0.27	30.8	38875	43.6	328.0
6	Roadside (Prague, Podbabská street)	0.16	31.7	35140	41.9	109.2
7	Roadside (Wrocław, Komandorska street)	1.39	16.8	9065	54.2	1006.0
8	Roadside (Wrocław, Komandorska street)	0.92	10.1	4655	29.0	1875.0
9	Roadside (Wrocław, Komandorska street)	0.80	2.0	1735	5.8	36.2
10	Undeveloped area (Wrocław, Orzechowa street)	0.38	3.8	2105	7.9	47.9
11	Undeveloped area (Wrocław, Orzechowa street)	0.30	5.1	1910	9.6	60.5
12	Undeveloped area (Wrocław, Orzechowa street)	0.28	7.2	3625	16.6	79.4
13	Car park (Wrocław, Robotnicza street)	0.19	9.1	4140	26.6	87.3
14	Car park (Wrocław, Robotnicza street)	0.21	8.1	3220	104.7	90.9
15	Car park (Wrocław, Robotnicza street)	0.72	15.5	6985	203.0	145.3
16	Riverbank (Wrocław, Odra river)	3.29	29.6	10625	29.2	733.0
17	Riverbank (Wrocław, Odra river)	1.25	14.2	9145	43.6	343.0
18	Riverbank (Wrocław, Odra river)	1.76	18.7	9529	64.4	431.0
19	Car park (Wrocław, Paczkowska street)	2.08	59.8	47745	110.8	2623.0
20	Car park (Wrocław, Paczkowska street)	1.36	32.7	22080	54.3	1354.0
21	Car park (Wrocław, Paczkowska street)	1.08	22.2	21530	50.2	1640.0
22	Park (Prague, near Konopiště Castle)	0.45	36.0	42640	39.7	76.2
23	Park (Prague, near Konopiště Castle)	0.31	33.7	43298	46.8	69.1
24	Park (Prague, near Konopiště Castle)	0.23	30.9	43895	46.2	59.8
25	Roadside (Prague, V Holešovičkách street)	2.34	42.4	41154	68.4	339.1
26	Roadside (Prague, V Holešovičkách street)	0.84	36.1	38521	65.1	320.3
27	Roadside (Prague, V Holešovičkách street)	0.70	32.0	35718	60.7	251.6
28	Roadside (Prague, V Holešovičkách street)	0.67	32.2	42331	62.0	278.2
29	Roadside (Prague, V Holešovičkách street)	0.13	31.0	36654	42.1	80.0
30	Roadside (Prague, V Holešovičkách street)	0.49	32.6	39738	48.7	220.9
31	Roadside (Československé armády, Hostivice)	0.67	32.2	42331	62.0	278.2
32	Roadside (Československé armády, Hostivice)	0.13	31.0	36654	42.1	80.0
33	Roadside (Československé armády, Hostivice)	0.49	32.6	39738	48.7	220.9
34	Roadside (Prague, Rozvadovská spojka street)	0.12	35.4	33763	32.9	59.9
35	Roadside (Prague, Rozvadovská spojka street)	0.07	30.2	34007	23.8	73.5
36	Roadside (Prague, Rozvadovská spojka street)	0.07	34.5	27197	26.2	54.7

Explanations: No. 1–6 – soils covered by *Fallopia japonica,* No. 7–36 – soils covered by *Fallopia ×bohemica*

2.2. Plants

Table 2. shows the content of Cd, Cr, Fe, Pb and Zn in different parts of *Fallopia japonica* and *Fallopia x bohemica*. In the majority of plant samples higher than natural metals content was found. Normal values for plants were accepted: 0, 01–0, 30 $\mu g \cdot g^{-1}$ ($mg \cdot kg^{-1}$) for Cd, 40–5000 $\mu g \cdot g^{-1}$ for Fe, 0,05–3,0 $\mu g \cdot g^{-1}$ for Pb and 15–100 $\mu g \cdot g^{-1}$ for Zn (Allen 1985). Statistically significant differences were found between above and underground parts of plants (W_{st}=11.30, d.f.=1, N=40, p=0.00078). In both species Cr, Cd, Fe Pb and Zn were accumulated mainly in roots and rhizomes, but the concentration of metals was significantly higher in underground parts of *Fallopia japonica* than in the hybrid. There were no differences between species with metals content in aboveground parts of the plant (Fig. 1).

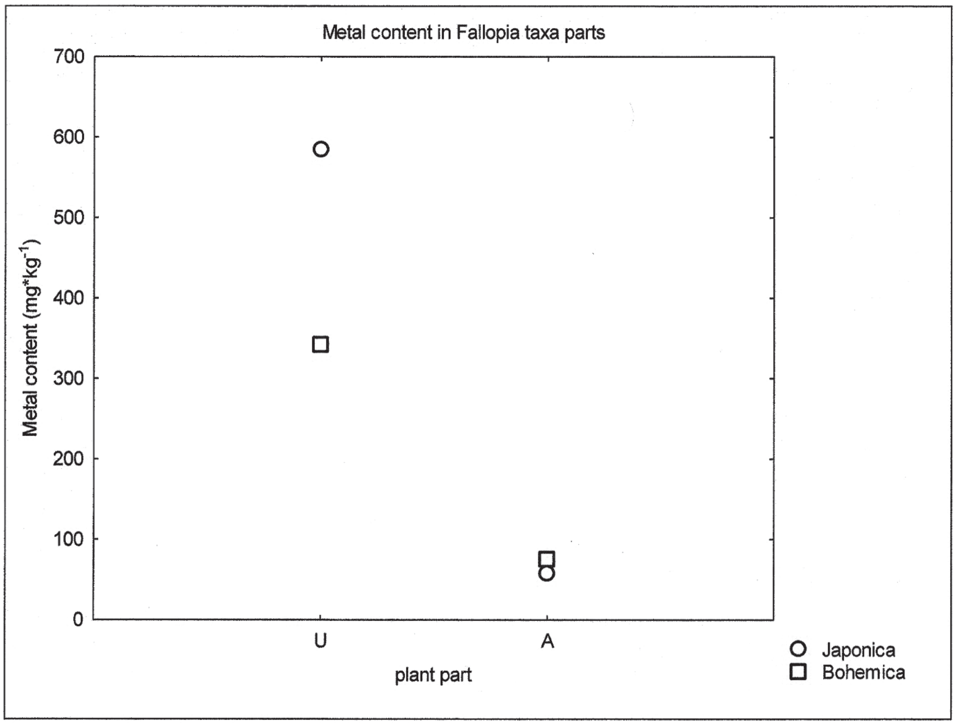

Fig.1 Differences between the taxa with heavy metals concentration in under and aboveground plant parts

Table 2. Content of heavy metals in plants from *Fallopia* genus [$mg \cdot kg^{-1}$] collected from Wroclaw and Prague

Species	Sampling area	Metal	Aboveground part of plants	Underground part of plants
Fallopia japonica	Wrocław, Tramwajowa street (No. 3)	Cd	6.69	11.51
		Cr	1.20	40.90
		Fe	224.50	3814.00
		Pb	5.00	27.35
		Zn	60.00	143.10
Fallopia japonica	Prague, Dejvice street (No. 4)	Cd	0.04	0.70
		Cr	0.62	10.00
		Fe	227.00	1421.40
		Pb	0.70	11.30
		Zn	44.30	357.00
Fallopia x bohemica	Wrocław, Paczkowska street (No.19)	Cd	2.22	19.67
		Cr	1.40	5.95
		Fe	235.50	913.50
		Pb	3.84	14.00
		Zn	53.90	279.80
Fallopia x bohemica	Prague, Holešovičkách street (No.25)	Cd	0.10	0.70
		Cr	1.00	21.60
		Fe	404.00	1896.80
		Pb	0.60	16.30
		Zn	48.80	246.30

3. Discussion

Japanese Knotweed was noted on metalliferous habitats in its native range of distribution. Nishizono et al. (1989) reported *Polygonum cuspidatum* (*Fallopia japonica*) from heavy metals (Cu, Zn and Cd) in polluted areas of Japan. The investigation has shown that in the urban conditions of Wroclaw and Prague Knotweed taxa spread on soils with higher than natural content of Cd, Fe, Pb and Zn. Therefore, even soils rich in heavy metals can be susceptible to invasion by the *Fallopia* genus.

Higher plants are characterized by various abilities to distribute and accumulate heavy metals. They can concentrate toxic metals in roots and restrict metal transfer into the aboveground parts (metal excluders), or they can gather heavy metals in aboveground parts, particularly in leaves (metal accumulators). Some species are heavy metal indicators and accumulate metals in shoots with the amount reflecting their content in soil (Punz, Sieghardt 1993; Memon at al. 2001). Heavy metals accumulation (Cu, Cd and Zn) by Japanese Knotweed in its native area was studied by Nishizono et al. (1989). Plants from metalliferous and non-metalliferous habitats were compared. In both cases about 90% of metals were accumulated in roots. Furthermore, Kubota et al. (1988) reported some Cu-binding proteins from the roots and rhizomes of *Polygonum cuspidatum* (*Fallopia japonica*), which are probably involved in metal tolerance. The amount of these compounds increased with increasing metal content in cytoplasm. In the presented study all metals were accumulated mainly in roots and rhizomes, which limited their transport into aboveground (more sensitive) parts of the plant.

An increased concentration of Cd, Fe, Pb and Zn in soil stimulated their increase in Knotweed taxa. Attention is paid to the relatively large amount of chromium in all plant samples, while the content of Cr in soils was similar to natural. The highest Cr level (40, 90 $mg \cdot kg^{-1}$ in the underground part and 1.20 $mg \cdot kg^{-1}$ in leaves) was measured in *Fallopia japonica* from Tramwajowa Street (No. 3). The chromium uptake and plant translocation is usually low. Allen (1989) reported the usual Cr concentration in plant material as 0.05–0.50 $\mu g \cdot g^{-1}$ ($mg \cdot kg^{-1}$). Kabata–Pendias and Pendias (1993) noted that chromium from 5.0–20.0 ppm ($mg \cdot kg^{-1}$) is harmful for most plants. Comparing other dates from the literature, the total chromium level may contain from 0.20–0.30 $mg \cdot kg^{-1}$ in *Citrus sinensis* to 10.20–14.80 $mg \cdot kg^{-1}$ in *Triticum spp.* (Samantaray at al. 1998). Qiu et al. 1999 reported that *Polygonum hydropiperoides* is a good Cr accumulator (Mei et al. 2002). Only a few species were classified as chromium hyperaccumulators, which accumulate high chromium quantity in their aboveground parts.

Toxic metals from contaminated soils can be removed by means of phytoextraction or phytoaccumulation without soil structure degradation (Ashraf et al. 2010). During this process heavy metals are absorbed and accumulated into the plant biomass. A plant useful as a soil cleaner should grow fast, accumulate metals and produce high biomass. Knotweed taxa metal uptake is discussed frequently in terms of using the species in a phytoremediation. For instance, Sukopp and Starfinger (1995) reported that *Reynoutria sachalinensis* (*Fallopia sachalinensis*) can accumulate heavy metals in leaves and stems and it has been proposed for the decontamination of soils polluted with heavy metals. The presented study shows the ability of heavy metals accumulation in *Fallopia japonica* and its hybrid. Nevertheless, there are two strong arguments against using Knotweed taxa as a soil cleaner. 1). Heavy metals should be accumulated into the aboveground parts of the plant that can be easily removed from the soil, while the investigated plants collected them in the roots and rhizomes. 2). Members of the *Fallopia* genus are highly invasive and even a small piece of rhizome can be a source of their invasion to new areas.

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Streszczenie

Celem powyższych badań była ocena akumulacji metali ciężkich: Cd, Cr, Fe, Pb i Zn przez inwazyjne gatunki z rodzaju *Fallopia* (*Fallopia japonica* i *Fallopia ×bohemica*). Materiał badawczy pobrano ze stanowisk rdestowców zlokalizowanych na terenie dwóch aglomeracji: Wrocławia i Pragi. Zawartość metali ciężkich określono w próbach glebowych, a następnie w nadziemnych i podziemnych częściach wybranych roślin. W analizowanych glebach wykazano wyższą w porównaniu z naturalną zawartość kadmu, żelaza, ołowiu i cynku oraz zbliżoną do naturalnej koncentrację chromu. Głównymi organami akumulującymi toksyczne pierwiastki były korzenie i kłącza rdestowców. Stężenie metali ciężkich w podziemnych organach *Fallopia japonica* było znacznie wyższe niż w *Fallopia ×bohemica*. Spośród badanych metali na szczególną uwagę zasługuje chrom. Pomimo iż, poziom Cr w materiale glebowym nie przekraczał zawartości naturalnej, rośliny zgromadziły znaczne jego ilości.