

EVALUATION OF SUITABILITY OF *AMARANTHUS CAUDATUS* L.
AND *RICINUS COMMUNIS* L. IN PHYTOEXTRACTION
OF CADMIUM AND LEAD FROM CONTAMINATED SUBSTRATES

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Abstract: The phytoextraction is a process that uses living plants for cleaning up the heavy metals from contaminated soil. The cadmium and lead contamination of soils results from the application of sludge or urban composts, fertilizers, pesticides, motorization, metallurgy, and different technological processes. In industrial terrain the content of cadmium and lead in soils has increased in the recent years. This study was undertaken to evaluate the potential of *Amaranthus caudatus* L. 'Atropurpureus' and *Ricinus communis* L. 'Sanguineus Apache' for phytoextraction of cadmium and lead. Two species of ornamental plants, i.e. *Amaranthus caudatus* L. 'Atropurpureus' and *Ricinus communis* L. 'Sanguineus Apache', were planted in drainless containers in a substrate artificially polluted with cadmium and lead in order to evaluate their suitability for phytoremediation of soils or substrates contaminated with these metals. Cadmium was applied at increasing rates of 0, 1, 5 and 10 mg Cd·dm⁻³ in the form of cadmium sulfate 3CdSO₄·8H₂O, while lead was used at 0, 100, 500 and 1000 mg Pb·dm⁻³ in the form of lead acetate (CH₃COO)₂Pb·3H₂O. The applied doses of cadmium and lead in the experiment reflected different degrees of soil pollution. After five months of growth it was found that *Amaranthus caudatus* L. accumulated the biggest concentrations of cadmium and lead in leaves and the lowest concentrations in inflorescences. *Ricinus communis* L. accumulated the highest concentrations of cadmium in stems, while the lowest concentrations in inflorescences, whereas the biggest concentration of lead was accumulated in inflorescences and the least lead was accumulated in leaves. The biggest reduction of cadmium and lead concentrations after the completion of the experiment was found in substrates, in which *Amaranthus caudatus* L. was grown. The tested species of ornamental plants may be used in the phytoextraction of cadmium and lead from soils contaminated.

INTRODUCTION

The intensively developing civilization, next to numerous benefits, is also connected with contamination of the environment with heavy metals, including cadmium and lead [17, 21, 29]. The presence of these metals in polluted air, water and soil results in their uptake by plants, animal organisms and humans, causing many adverse effects. Soil contaminated with cadmium and lead becomes a source contaminating in turn all elements of the food chain. Thus for many years effective but cheap methods of purification of soil contaminated with heavy metals have been searched for. An increasing number of studies is being conducted worldwide on the dynamically developing field of bioremediation, such

as phytoremediation, in which living organisms, e.g. biopreparations from autochthonous bacteria and fungi [30] and plants [12], are used to purify the contaminated environment, including also soil. Plants accumulating very high concentrations of heavy metals in their organs, capable of growing under extremely adverse conditions, toxic for other species, are referred to as hyperaccumulators [13, 14, 16]. Many species of plants considered to be hyperaccumulators are known worldwide, while in the Polish climate there are few tested species potentially suitable for phytoremediation. In Poland in recent years studies have been conducted on the search for plants suitable for phytoremediation purposes [2, 3, 4, 7, 8, 9, 10, 11, 23, 26].

The above mentioned facts contributed to the decision to conduct studies, the aim of which was to determine whether the investigated species of ornamental plants, i.e. *Amaranthus caudatus* L. 'Atropurpureus' and *Ricinus communis* L. 'Sanguineus Apache' may be capable of cleaning substrate from cadmium and lead, what concentrations of these metals penetrate from the substrate to individual aboveground organs of the tested plants and which of the organs would accumulate the biggest concentrations of these metals. The effect of applied increasing rates of cadmium and lead on yielding of plants was also investigated, making it possible to determine the potential growth of these species of plants in a substrate with a respective pollution level.

MATERIAL AND METHODS

Pot experiments were conducted for two years in an unheated greenhouse at the Department of Horticultural Plant Nutrition, the Poznań University of Life Sciences, in which in a substrate artificially polluted separately with cadmium and separately with lead two ornamental plant species were grown, i.e. bent-root amaranth (*Amaranthus caudatus* L. 'Atropurpureus') and castor bean (*Ricinus communis* L. 'Sanguineus Apache').

The experiment was conducted in the spring-summer season (of each year of the study) in drainless pots of 6 dm³ for *Amaranthus caudatus* L. 'Atropurpureus' and of 10 dm³ for *Ricinus communis* L. 'Sanguineus Apache'. The vegetation experiment consisted of fourteen combinations, while each combination comprised ten replications. A replication consisted of one plant growing in the experimental pot. High-moor peat was the substrate, in which investigated species of ornamental plants were grown. The volume of 1 dm³ peat weighed 470 g. Concentrations of nutrients, pH (w H₂O) and EC (mS·cm⁻¹) in high-moor peat before and after liming (Table 1) were determined using the "Universal" method [25] in CH₃COOH solution at a concentration of 0.03 mol·dm⁻³: N – NH₄ and N – NO₃ by distillation [29], P – by colorimetry using the vanadium molybdenum method, K, Ca and Na – by flame photometry, Mg – by atomic absorption (FAAS), Cl and S – SO₄ – by nephelometry.

The other components (Fe, Mn, Cu, Zn) were determined in mg·dm⁻³ in the extract according to Lindsay by the flame FAAS technique. The reaction of the substrate expressed in pH was determined by potentiometry in H₂O (the substrate: water ratio of 1:2), while EC by conductometry in mS·cm⁻¹.

In order to provide pH within the range of 6.5–7.0 high-moor peat was limed. The dose of CaCO₃ at 7.5 g per 1 dm³ was established by preparing the neutralization curve. Macro- and microelements as well as heavy metals were added 14 days after peat liming. Nutrients were introduced in the form of 'Azofoska' multicomponent fertilizer at 3 g·dm⁻³

Table 1. The nutrient content ($\text{mg} \cdot \text{dm}^3$), $\text{pH}_{(\text{H}_2\text{O})}$ and $\text{EC}_{(\text{mS} \cdot \text{cm}^{-1})}$ in highmoor peat (before and after liming)

Nutrient	Highmoor peat (before liming)	Highmoor peat (after liming)
N-NH ₄	28	35
N-NO ₃	7	trace amountys
P	37	20
K	11	18
Ca	107	2045
Mg	21	164
S-SO ₄	10	25
Na	11	18
Cl	27	29
Fe	50.20	19.80
Zn	1.30	1.80
Cu	0.40	0.40
Mn	1.30	2.70
B	0.43	0.50
Mo	trace amountys	trace amountys
$\text{pH}_{(\text{H}_2\text{O})}$	3.86	6.41
$\text{EC}_{(\text{mS} \cdot \text{cm}^{-1})}$	0.16	0.49

substrate. The chemical composition of the 'Azofoska' multicomponent fertilizer was as follows (%): N 13.6, P₂O₅ 6.4, K₂O 19.1, MgO 4.5, Fe 0.17, Zn 0.045, Cu 0.18, Mn 0.27, B 0.045, Mo 0.090.

Cadmium was applied at increasing rates of 0, 1, 5 and 10 $\text{mg Cd} \cdot \text{dm}^{-3}$, separately for each pot in the form of cadmium sulfate $3\text{CdSO}_4 \cdot 8\text{H}_2\text{O}$, while lead was introduced at 0, 100, 500 and 1000 $\text{mg Pb} \cdot \text{dm}^{-3}$ in the form of lead acetate $(\text{CH}_3\text{COO})_2\text{Pb} \cdot 3\text{H}_2\text{O}$.

The applied doses of cadmium and lead in the experiment reflect different levels of pollution. Control substrates with no cadmium or lead addition ($0 \text{ mg} \cdot \text{dm}^{-3}$), the dose of 1 $\text{mg Cd} \cdot \text{dm}^{-3}$ and 100 $\text{mg Pb} \cdot \text{dm}^{-3}$ elevated content, 5 $\text{mg Cd} \cdot \text{dm}^{-3}$ and 500 $\text{mg Pb} \cdot \text{dm}^{-3}$ weak pollution, 10 $\text{mg Cd} \cdot \text{dm}^{-3}$ and 1000 $\text{mg Pb} \cdot \text{dm}^{-3}$ medium pollution.

Seeds of *Amaranthus caudatus* L. 'Atropurpureus' and *Ricinus communis* L. 'Sanguineus Apache' were sown in mid-April to boxes of $30 \times 48 \times 8$ (cm). They were sown to high-moor peat with an addition of the 'Azofoska' multicomponent fertilizer at $1.5 \text{ g} \cdot \text{dm}^{-3}$ substrate and $5 \text{ g CaCO}_3 \cdot \text{dm}^{-3}$ substrate. In early May seedlings of *Amaranthus caudatus* L. and *Ricinus communis* L. were planted at one plant per an experimental pot, filled earlier with the prepared substrate.

In the course of the experiment the plants were watered as required depending on ambient temperature. The analyzed plant species were eliminated at anthesis. The

procedure consisted in cutting down the aboveground parts of examined plants and their weighing. Leaves, stems and inflorescences were weighed separately.

Samples of plant material were collected (separately for inflorescences, leaves and stems) was predried in an extraction drier at a temperature of 105°C for 48 h. Such dried material was ground in a mixer. Next, it was transferred at 2.5 g to porcelain crucibles and mineralized in a LINN combustion furnace by Elektro Therm at a temperature of 450°C. Residue after mineralization was dissolved in 10% HCl (analytically pure) and transferred to flasks of 50 cm³. After mineralization the content of cadmium and lead was determined by atomic absorption spectroscopy FAAS using an AAS 3 Zeiss apparatus. The values determined in blank samples were subtracted from recorded heavy metal concentrations. Heavy metals were determined also in certified plant material of *Pseudevernia furfuracea*, certificate by the Institute for Reference Materials and Measurements in Belgium.

At the completion of the experiment substrate samples were collected from each pot and their concentrations of soluble cadmium and lead forms were determined in the extract according to Lindsay. This solution contained in 10 dm³: 50 g EDTA (ethylenediaminetetraacetic acid), 90 ml 25% NH₄OH basic solution, 40 g citric acid and 20 g Ca(CH₃COO)₂·2H₂O.

Recorded measurement results were analyzed statistically. Analyses comprised the two-way analysis of variance conducted separately for fresh weight of the aboveground part of plants for fresh weight of leaves, fresh weight of stems and fresh weight of inflorescences of the investigated species. Moreover, a one-way analysis of variance was performed for the concentrations of Cd and Pb in each of the analyzed plant organs in terms of each applied rate of the heavy metal. Statistical analyses were conducted using the Statobl program – a univariate analysis of variance for orthogonal factorial experiments, while differences between means were determined at the significance level $\alpha = 0.05$. In the conducted analyses the cadmium and lead concentration index was also calculated for the examined plant organs using the following formula:

$$C \text{ (metal concentration index)} = a : b$$

a – content in a plant growing in contaminated substrate

b – content in a plant growing in uncontaminated substrate

RESULTS AND DISCUSSION

When using higher plants to clean soil from heavy metals the tolerance of a given species to high metal concentrations affecting yielding is of great importance [19]. High concentrations of cadmium and lead generally result in a reduced yielding.

Jasiewicz and Antonkiewicz [22] when investigating the suitability of hemp in phytoremediation of areas polluted with heavy metals observed a reduction of yielding (depending on the object it ranged from 13 to 87%) in plants growing in soil polluted with metals already at the levels of Cd 1, Pb 15, Cu 10 and Zn 50 mg·kg⁻¹ d.m. soil.

In a study presented by Boratyński and Fabiszewski [6] hemp turned out to be a plant species resistant to excess heavy metals in the substrate. Gambuś [18] stated also that plants most tolerant to heavy metals included grasses and hemp, when he was growing them in soil to which he introduced jointly heavy metals at 8 mg Cd, 20 mg Cu, 16 mg Ni, 120 mg Pb and 80 mg Zn·kg⁻¹ d.m. soil.

The toxic effect of cadmium and lead on yields in *Virginia fanpetals* was stated by Antonkiewicz et al. [4] in their studies concerning heavy metal extraction using this plant species at 80 mg Cd·kg⁻¹ d.m. soil and 480 mg Pb·kg⁻¹ d.m. soil.

The toxic effect of increasing doses of cadmium (50–200 mg·kg⁻¹) on smaller quantity of total biomass *Ricinus communis* L. was observed [19].

The plant for phytoextraction applications should have high metal tolerance and high accumulation capacity in its aboveground organs [27].

The above mentioned studies investigated the effect of applied doses of heavy metals, corresponding to increasing degrees of soil contamination on fresh weight of individual aboveground parts of *Amaranthus caudatus* L. 'Atropurpureus' and *Ricinus communis* L. 'Sanguineus Apache' as well as total weight of aboveground parts of plants.

Fresh weight of leaves, stems, inflorescences and total weight of *Amaranthus caudatus* L. 'Atropurpureus'

When comparing the mean weight of tested organs and the total weight for *Amaranthus caudatus* L. 'Atropurpureus' plants growing on substrates contaminated with cadmium and plants grown on substrates contaminated with lead significant differences were found in the weight of stems and total weight for this species (Table 2). Plants growing in substrates polluted with cadmium were characterized by stem weight higher by 16.8% and total weight higher by 6.6%. Increasing doses of cadmium had a significant effect on growth for green matter of stems. The biggest weight was found in plants growing on

Table 2. Fresh weight (g·plant⁻¹) of leaves, stems, inflorescences and total weight of *Amaranthus retroflexus* L. 'Atropurpureus'

Metal	Dose of metal (Cd/Pb)				Mean
	0	1/100	5/500	10/1000	
Fresh weight of leaves					
Cd	221.9 a	199.7 a	203.9 a	180.0 a	201.4 a
Pb	221.9 a	202.7 a	200.7 a	185.5 a	202.7 a
Mean	221.9 b	201.2 ab	202.3 ab	182.8 a	
Fresh weight of stems					
Cd	191.7 a	226.9 c	237.9 c	262.5 d	229.8 b
Pb	191.7 a	190.2 a	210.4 b	194.4 a	196.7 a
Mean	191.7 a	208.6 b	224.1 c	228.4 c	
Fresh weight of inflorescences					
Cd	101.3 d	89.8 c	72.4 b	48.9 a	78.1 a
Pb	101.3 d	85.6 c	69.6 b	57.4 a	78.5 a
Mean	101.3 d	87.7 c	71.0 b	53.1 a	
Fresh weight of total weight					
Cd	515.0 b	516.4 b	514.2 b	491.4 ab	509.3 b
Pb	515.0 b	478.5 ab	480.7 ab	437.3 a	477.9 a
Mean	515.0 b	497.5 ab	497.5 ab	464.4 a	

the substrate, to which 10 mg Cd·dm⁻³ was introduced, while it was lowest in the case of substrate with no addition of this metal. Increasing doses of cadmium had a significant effect on fresh weight of inflorescences. However, an opposite dependence was observed than for stem weight. The highest weight of inflorescences was recorded for plants growing in the substrate uncontaminated with cadmium, while the lowest was found for the substrate with 10 mg Cd·dm⁻³. Increasing Cd doses did not have a significant effect on fresh weight of leaves or total weight of the aboveground parts of plants.

A significant effect of increasing doses of lead on fresh weight of individual organs was found for inflorescences, in which the highest weight was recorded in the substrate with no lead added, while the lowest in the substrate with 1000 mg Pb·dm⁻³. In the substrate with no lead addition the highest total weight of aboveground parts was also observed, while it was lowest in the substrate contaminated with the highest concentrations of lead. In the case of fresh weight of leaves no effect of increasing lead doses was found, while the biggest weight of stems was recorded in plants growing on the substrate, to which 500 mg Pb·dm⁻³ was introduced in comparison to plants growing on the other tested substrates, in which no significant variation was observed in terms of the weight of this organ.

Fresh weight of leaves, stems, inflorescences and total weight of Ricinus communis L. ‘Sanguineus Apache’

A higher mean weight of leaves, stems as well as total weight of plants were obtained in substrates polluted with cadmium in comparison to plants growing on substrates polluted

Table 3. Fresh weight (g·plant⁻¹) of leaves, stems, inflorescences and total weight of *Ricinus communis* L.

Metal	Dose of metal (Cd/Pb)				Mean
	0	1/100	5/500	10/1000	
Fresh weight of leaves					
Cd	302.9 a	372.6 d	369.5 cd	340.5 bc	346.4 b
Pb	302.9 a	312.7 ab	307.5 a	308.0 a	307.8 a
Mean	302.9 a	342.6 b	338.5 b	324.3 ab	
Fresh weight of stems					
Cd	260.2 c	243.8 bc	254.5 c	256.3 c	253.7 b
Pb	260.2 c	246.3 bc	218.5 ab	205.7 a	232.7 a
Mean	260.2 b	245.0 ab	236.5 a	231.0 a	
Fresh weight of inflorescences					
Cd	230.5 a	279.0 b	266.0 b	266.7 b	260.6 a
Pb	230.5 a	285.1 b	273.0 b	269.5 b	264.5 a
Mean	230.5 a	282.1 b	269.5 b	268.1 b	
Fresh weight of total weight					
Cd	793.6 a	895.5 c	890.0 c	863.5 bc	860.6 b
Pb	793.6 a	844.1 abc	799.1 ab	783.1 a	805.0 a
Mean	793.6 a	869.8 b	844.6 b	823.3 ab	

with lead (Table 3). In comparison to plants growing on a substrate uncontaminated with cadmium, in the other substrates greater weights of leaves, inflorescences and total weight of plants were observed. Only in the case of stems no significant effect of applied metal doses was found. Gangrong i Qingsheng [19] stated, that *Ricinus communis* L. is a plant moderately tolerant to Cd toxicity.

A significant effect of lead was recorded in terms of the weight of stems in *Ricinus communis*, for which it was highest in the substrate with no metal added and the substrate polluted with its smallest dose. No significant differences were found under the influence of this metal in terms of weight of leaves and total weight of aboveground parts. In all the substrates contaminated with lead a greater weight of inflorescences was observed in comparison to that of inflorescences in the case of plants growing on a substrate uncontaminated with lead.

Concentrations of cadmium and lead in aboveground organs of ornamental plants (in dry matter)

Figures 1 and 3 present results for concentrations of cadmium and lead in individual aboveground organs in the investigated species of ornamental plants. Within each of the applied metal doses a univariate statistical analysis was performed, comparing concentrations of individual metals in the tested organ between the two ornamental plant species.

In all the substrates to which cadmium was introduced a significantly higher content of this metal was found in leaves and stems of *Amaranthus caudatus* L. 'Atropurpureus'. This species was also characterized by a significantly higher content of Cd in inflorescences, but only in plants growing on the substrate, to which 5 and 10 mg Cd·dm⁻³ was introduced.

When comparing the content of cadmium in individual organs of *Amaranthus caudatus* L. 'Atropurpureus' its highest content was found in leaves, while it was lowest in inflorescences in plants growing on all the tested substrates. In leaves of *Amaranthus caudatus* L. 'Atropurpureus', in the substrate to which 10 mg Cd·dm⁻³ was introduced, the highest index of concentration for this metal was recorded (Fig. 2). The lowest index of cadmium concentration was found in inflorescences of *Amaranthus caudatus* L. 'Atropurpureus' growing on the substrate, to which 1 mg Cd·dm⁻³ was introduced.

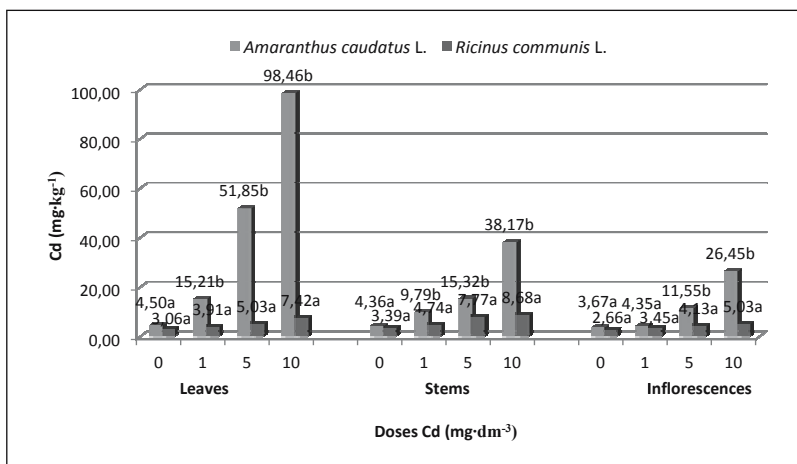


Fig. 1. Concentrations of cadmium in aboveground organs of ornamental plants (dry matter)

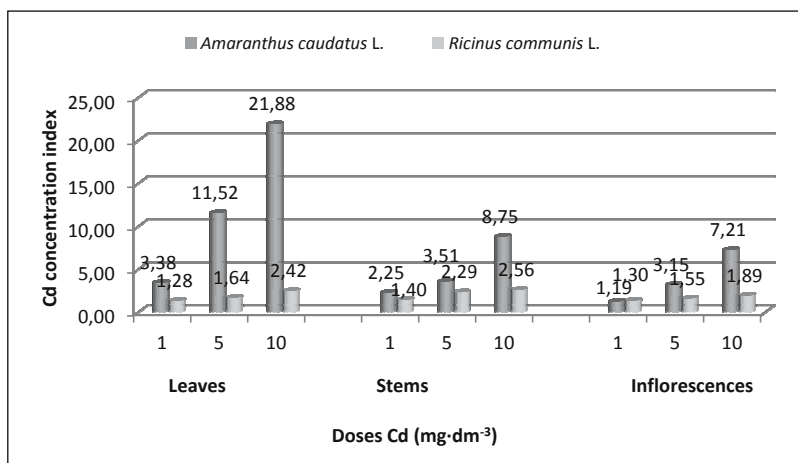


Fig. 2. Cadmium concentration index in aboveground organs of ornamental plants

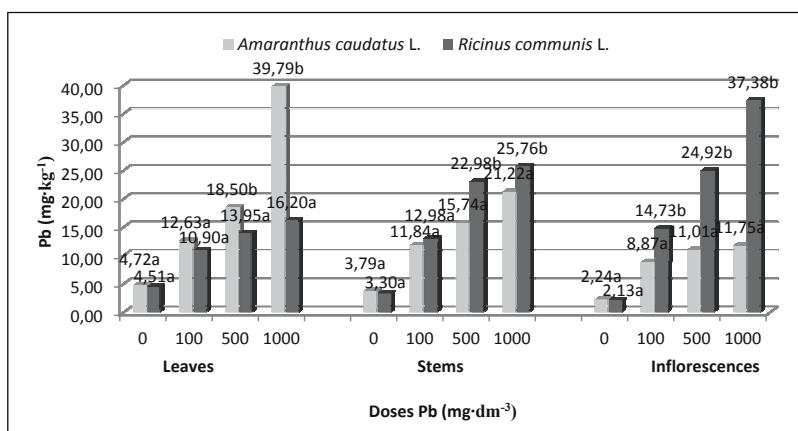


Fig. 3. Concentrations of lead in aboveground organs of ornamental plants (dry matter)

In *Ricinus communis* L. grown in the tested substrates the highest content of cadmium was found in stems, in which also the highest index of concentration was recorded for this metal. In turn, the lowest content was stated in inflorescences of plants growing on all the tested substrates. The highest index of cadmium concentration was recorded in stems of *Ricinus communis* L. growing on the substrate polluted with cadmium at 10 mg·dm⁻³, while it was the lowest in leaves of *Ricinus communis* L. growing on the substrate with 1 mg Cd·dm⁻³.

When comparing the content of lead in leaves of the investigated ornamental plant species a significantly greater difference was found in leaves of *Amaranthus caudatus* L. growing on the substrate, to which 500 and 1000 mg Pb·dm⁻³ was introduced (Fig. 3). In leaves of these two species growing on the substrate with no lead added and those with its

addition at $100 \text{ mg}\cdot\text{dm}^{-3}$, despite a greater content of this metal, no significant differences were observed. The biggest index of concentration in leaves was found in *Amaranthus caudatus* growing on the substrate with $1000 \text{ mg Pb}\cdot\text{dm}^{-3}$ (fig. 4).

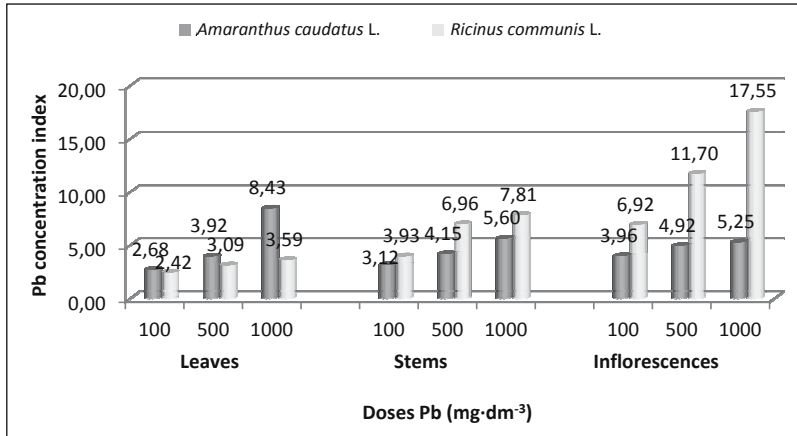


Fig. 4. Lead concentration index in aboveground organs of ornamental plants

A statistically higher lead content was found in stems of *Ricinus communis* L., which was grown on the substrate polluted with Pb at 500 and 1000 $\text{mg}\cdot\text{dm}^{-3}$ in comparison to stems of *Amaranthus caudatus* L. growing on those substrates. In turn, a greater content of lead in inflorescences was found in *Ricinus communis* L. growing on all the substrates, to which this metal was introduced.

When comparing individual aboveground organs in *Amaranthus retroflexus* L. the highest lead content was found in leaves, followed by stems, while the lowest in inflorescences. In *Ricinus communis* L. the highest concentrations of this metal were recorded in inflorescences, followed by stems, while the content was lowest in leaves. Bosiacki [9] and Bosiacki [11] when investigating the content of cadmium in individual organs of *Tagetes erecta* found the greatest concentrations of this metal in roots, leaves and shoots, while the content was lowest in inflorescences. A similar distribution of lead in individual organs of ornamental plants was reported by Bosiacki and Golcz [10].

The highest index of lead concentration was found for inflorescences of *Ricinus communis* L. growing on the substrate polluted with $1000 \text{ mg Pb}\cdot\text{dm}^{-3}$, while the lowest – in leaves of this species growing on the substrate with an addition of $100 \text{ mg Pb}\cdot\text{dm}^{-3}$.

Recorded results indicate that *Amaranthus retroflexus* L. is the species which accumulates higher concentrations of cadmium and lead substrates. The tested species of ornamental plants may be used in phytoextraction cadmium and lead of contaminated substrates.

Studies on the phytoremediation technique, using higher plants to purify soils from heavy metals have been conducted for many years. Chehregani et al. [15] proved that *Amaranthus retroflexus* L. could be used for the extraction of heavy metals from soils polluted.

Juśkiewicz-Swaczyna and Endler [23] when investigating bioaccumulation of heavy metals in organs of broom *Cytisus scoparius* stated that manganese and copper were accumulated in highest concentrations, in leaved stems and flowers, while in the lowest in fruits. As it was reported by Antonkiewicz and Jasiewicz [2], species capable of absorbing heavy metals and providing high yields include Jerusalem artichoke, maize, *Virginia fanpetals*, bent-root amaranth and hemp. They also stated species variation in terms of heavy metal uptake. The highest amounts of cadmium and zinc were removed by bent-root amaranth, those of lead and nickel – by *Virginia fanpetals*, whereas that of copper – by Jerusalem artichoke. Those authors when studying the suitability of maize *Zea mays* L. in phytoremediation of heavy metals stated that this species used zinc to the highest degree, while the lowest was found for lead [3].

The total amount of heavy metals fitoextracted from soil by plants is affected by factors such as plant biomass production, tolerance to higher concentrations and accumulation ability of used plant species [1, 5, 28].

Concentrations of cadmium and lead (soluble forms) in substrates at the completion of the experiment

When analyzing the content of cadmium in the substrates, in which ornamental plants were grown, it was found that its concentration in the substrate was increasing together with an increase in doses of this metal (fig. 5). After five months of growth it was shown that the highest concentrations of cadmium at the completion of the experiment were detected in the substrates, in which *Ricinus communis* L. was grown within all the applied doses of cadmium. The lowest concentrations of this metal were found in the substrates, in which *Amaranthus caudatus* L. was cultivated. The highest percentage losses of the metal were observed in the substrate polluted with cadmium at 10 mg·dm⁻³, in which *Amaranthus caudatus* L. was grown, where the loss of this metal at the completion of the experiment was 4.1 mg Cd·dm⁻³. The least amount of this metal was removed from the substrate with 5 mg Cd·dm⁻³, in which *Ricinus communis* L. was cultivated, as there the loss of cadmium in this substrate at the completion of the experiment amounted to 0.47 mg Cd·dm⁻³.

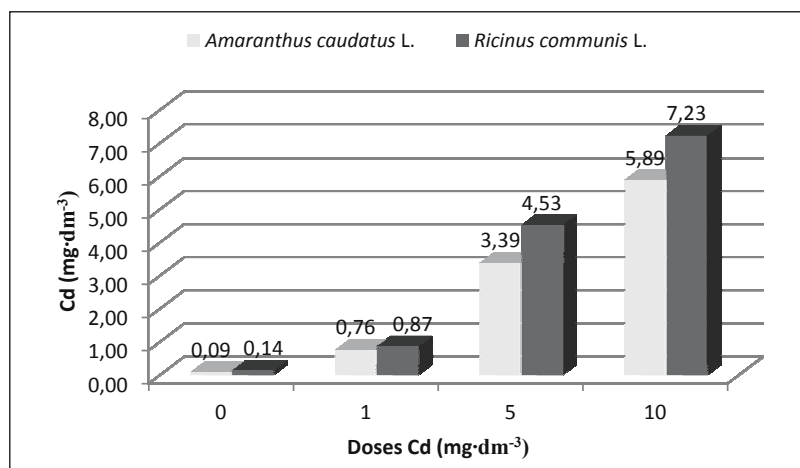


Fig. 5. Concentrations of cadmium (soluble forms) in substrates at the completion of the experiment

Similar trends were observed in the case of the substrates treated with increasing lead doses in which the analyzed plants were cultivated. Lead content increased together with an increase of metal doses introduced to the substrate (fig. 6). It was found that higher concentrations of lead at the completion of the experiments were found in the substrates, in which *Ricinus communis* L. was grown in comparison to the concentrations of this metal in the substrates, in which *Amaranthus caudatus* L. was grown. The highest reduction in the content of this metal ($64.3 \text{ mg Pb}\cdot\text{dm}^{-3}$) in relation to the introduced doses was found for the substrate with an addition of $100 \text{ mg Pb}\cdot\text{dm}^{-3}$, in which *Amaranthus caudatus* L. was cultivated. In turn, the lowest reduction of lead content ($232.8 \text{ mg Pb}\cdot\text{dm}^{-3}$) was recorded in the substrate, to which $500 \text{ mg Pb}\cdot\text{dm}^{-3}$ was introduced, used in the cultivation of *Ricinus communis* L.

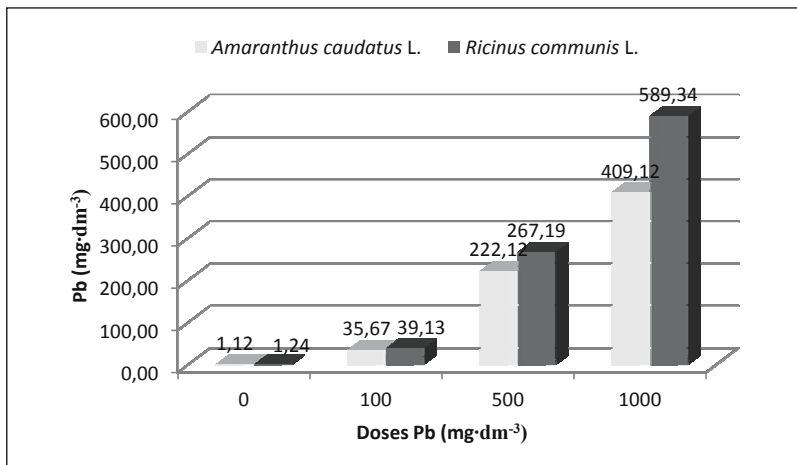


Fig. 6. Concentrations of lead (soluble forms) in substrates at the completion of the experiment

CONCLUSIONS

1. Increasing doses of cadmium had a significant effect on fresh weight of stems and inflorescences of *Amaranthus caudatus* L. 'Atropurpureus', while they did not have a significant effect on fresh weight of leaves and total weight. Lead doses had a significant effect on fresh weight of stems, inflorescences and total weight of *Amaranthus caudatus* L. 'Atropurpureus', while they did not influence significantly fresh weight of leaves.
2. Increasing doses of cadmium had a significant effect on fresh weight of leaves, inflorescences and total weight in *Ricinus communis* L. 'Sanguineus Apache', while they did not have a significant effect on fresh weight of stems. Doses of lead had a significant effect on fresh weight of stems and inflorescences in *Ricinus communis* L. 'Sanguineus Apache', whereas no significant effect was observed for fresh weight of leaves and total weight.
3. In *Amaranthus caudatus* L. 'Atropurpureus' the highest concentrations of cadmium and lead were accumulated in leaves, while the lowest were accumulated in inflorescences. In *Ricinus communis* L. 'Sanguineus Apache' the highest levels of cadmium were

- accumulated in stems, while the lowest in inflorescences, whereas the biggest concentrations of lead were accumulated in inflorescences and the lowest – in leaves.
4. Among studies varieties of ornamental plants *Amaranthus caudatus* L. ‘Atropurpureus’ characterized the highest content of cadmium in all the aboveground parts of plants while the highest content of lead was found only in leaves.
 5. The biggest reduction of cadmium and lead levels at the completion of the experiment was found in the substrates, in which *Amaranthus caudatus* L. ‘Atropurpureus’ was grown.
 6. The tested species of ornamental plants may be used in the phytoextraction of cadmium and lead from soils contaminated.

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OCENA PRZYDATNOŚCI *AMARANTHUS CAUDATUS* L. AND *RICINUS COMMUNIS* L. DO FITOEKSTRAKCJI KADMU I OŁOWIU

Fitoe ekstrakcja jest jedną z metod oczyszczania gleby z metali ciężkich przez wykorzystanie roślin. Zanieczyszczenie gleb kadmem i ołowiem spowodowane jest miejskimi ściekami, miejskimi kompostami, motoryzacją, nawożeniem, pestycydami, metalurgią i różnymi procesami technologicznymi. W glebach terenów przemysłowych w ostatnich latach obserwuje się zwiększanie zawartość kadmu i ołowiu. W podjętych badaniach oceniano potencjał *Amaranthus caudatus* L. i *Ricinus communis* L. do fitoekstrakcji kadmu i ołowiu. Dwa gatunki roślin ozdobnych: *Amaranthus caudatus* L. ‘Atropurpureus’ i *Ricinus communis* L. ‘Sanguineus Apache’ posadzono w pojemnikach bezodpływowych w podłożu sztucznie zanieczyszczonych kadmem i ołowiem w celu oceny ich przydatności do fitoremediacji gleb lub podłoży skażonych tymi metalami. Kadm zastosowano we wzrastających dawkach: 0, 1, 5, 10 mg Cd·dm⁻³, w postaci siarczynu kadmu 3CdSO₄·8H₂O, natomiast ołów w dawkach: 0, 100, 500, 1000 mg Pb·dm⁻³, w postaci octanu ołowiu (CH₃COO)₂Pb·3H₂O. Zastosowane dawki kadmu i ołowiu w doświadczeniu odzwierciedlają różny stopień zanieczyszczenia gleb. Po pięciu miesiącach wzrostu stwierdzono, że *Amaranthus caudatus* L. ‘Atropurpureus’ najwięcej kadmu i ołowiu akumulował w liściach a najmniej w kwiatostanach. *Ricinus communis* L. ‘Sanguineus Apache’ najwięcej kadmu akumulował w łodygach a najmniej w kwiatostanach, natomiast najwięcej ołowiu akumulował w kwiatostanach a najmniej w liściach. Największy ubytek kadmu i ołowiu po zakończeniu doświadczenia stwierdzono w podłożach, w których uprawiano *Amaranthus caudatus* L. ‘Atropurpureus’. Badane gatunki roślin ozdobnych mogą być wykorzystywane do fitoekstrakcji kadmu i ołowiu z gleb skażonych kadmem i ołowiem.