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PHYTOEXTRACTION OF NICKEL BY SELECTED ORNAMENTAL PLANTS

FITOEKSTRAKCJA NIKLU PRZEZ WYBRANE GATUNKI ROŚLIN OZDOBNYCH

Abstract: In the pot experiment the effect of increasing doses of Ni (the control, 25, 50, 75, 150, 300 mg · dm^{-3} substrate) on the content of this metal in individual organs of aboveground parts was investigated in three selected species of ornamental plants: Aztec marigold (*Tagetes erecta* L.), sunflower (*Helianthus annus* L.) and love-lies-bleeding (*Amaranthus caudatus* L.). A significant effect of increasing Ni doses on the content of this metal was found in individual organs of selected species. In *Tagetes erecta* L. and *Amaranthus caudatus* L. the highest amounts of nickel were accumulated in leaves, while in sunflower growing in the substrate, to which nickel was introduced at 25, 50, 75 and 150 mg·dm^{-3}, the highest amounts of this metal were accumulated in inflorescences. Among the analyzed species of ornamental plants growing in the substrate with no addition of this metal and in the substrate with an addition of 25 and 50 mg Ni · dm^{-3} the highest nickel uptake was observed in *Tagetes erecta* L. plants. For the substrate with an addition of 75, 150 and 300 mg Ni · dm^{-3} the biggest nickel accumulation was recorded in *Amaranthus caudatus* L.

Keywords: nickel, ornamental plant, phytoextraction, phytoremediation, *Tagetes erecta* L., *Helianthus annus* L., *Amaranthus caudatus* L.

Introduction

Intensive development of the civilization has been accompanied by the contamination of the environment with heavy metals, including nickel. Large amounts of nickel are transferred to the environment by combustion of liquid fuels, petroleum products and other fossil fuels as well as extensive applications of this metal in the metallurgical industry (*eg* anticorrosive coats) and as a catalyst in organic syntheses [1], which indicates that urbanized areas are at a particular risk of elevated nickel emissions. In Poland plants capable of phytoremediation of heavy metals are searched for, as they may decontaminate the environment in our moderate climate. As it was reported by [2], most species suitable for phytoremediation purposes belong to the families *Brasicaceae* and *Fabaceae*. When analyzing the urban landscape we may observe increasing efforts to enhance the aesthetics and appearance of green areas, providing applications for such ornamental plant species,

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which may improve the structure and reduce contamination of soils in the city. Additional factors determining the selection of species for urban plantings should include a given plant's capacity to survive and function normally in the environment seriously contaminated with heavy metals and phytoextraction capacity, *ie* the accumulation of large amounts of metals in the aboveground parts. Studies on plants capable of decontaminating urban soils from heavy metals were conducted *eg* by [3-9].

Attractiveness of the technology using ornamental plants for the remediation of contaminated environments was an incentive for the investigations conducted within this study. Analyses were conducted on three commonly used species of ornamental plants growing on soils contaminated with different levels of nickel. The aim of these analyses was to determine which of the cultivated species accumulated the biggest amounts of this metal and what amounts of nickel penetrate from the soil to individual organs of aboveground parts of tested plants.

Material and methods

The pot experiment was conducted in an unheated greenhouse at the Department of Horticultural Plant Nutrition, the Poznan University of Life Sciences, the Marcelin Experimental Station. Three species of ornamental plants, *ie* Aztec marigold (*Tagetes erecta* L. 'Hawaii'), sunflower (*Helianthus annus* L. 'Pacino') and love-lies-bleeding (*Amaranthus caudatus* L. 'Atropurpureus'), were planted to a substrate artificially contaminated with nickel (nickel sulfate). The vegetation experiment was run in drainless containers, for love-lies-bleeding and sunflower of 6 dm^3 in capacity, while for marigold of 2 dm^3.

Table 1

The nutrient content [$mg \cdot dm^3$], pH (in H_2O) and EC [$mS \cdot cm^{-1}$] in highmoor peat (before and after liming)

Nutrient	Highmoor peat (before liming)	Highmoor peat (after liming)
$N\text{-}NH_4$	28	35
$N\text{-}NO_3$	7	trace amountys
P	37	20
K	11	18
Ca	107	2045
Mg	21	164
$S\text{-}SO_4$	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
pH	3.86	6.41
EC	0.16	0.49

The substrate in which all the three ornamental plant species were grown was highmoor peat by Hartmann (sphagnum peat, milled, fractionated, of acid reaction, pH 3.86). This peat is characterized by high water capacity, at the same time retaining a springy structure. The weight of 1 dm^3 peat was 470 grams. In order to obtain an optimal pH for these ornamental plants, ranging from 6.0 to 6.5, highmoor peat was limed. The dose of $CaCO_3$ of 6.5 g per 1 dm^3 was established on the basis of a neutralization curve. The nutrient content, $pH_{(H2O)}$ and EC [$mS \cdot cm^{-1}$] in highmoor peat before and after liming were determined using the universal method (Table 1).

At 14 days after liming macro- and micronutrients were added in the form of 'Azofoska', a multicomponent fertilizer (Table 2), at 2 g per 1 dm^3 substrate and nickel was introduced to the substrate in the form of nickel sulfate (chemically pure salt). Six increasing doses of nickel corresponded to the following contamination levels: 0 (control) - natural content, 25 $mg \cdot dm^{-3}$ - elevated content, 50 $mg \cdot dm^{-3}$ - weak contamination, 75 $mg \cdot dm^{-3}$ - medium contamination, 150 $mg \cdot dm^{-3}$ - strong contamination, and 300 $mg \cdot dm^{-3}$ - very strong contamination.

Table 2

The content of components in multicomponent fertilizer 'Azofoska'

Nutrient	Percentage contents
N	13.6
P_2O_5	6.4
K_2O	19.1
MgO	4.5
Fe	0.17
Zn	0.045
Cu	0.18
Mn	0.27
B	0.045
Mo	0.090

Seeds of *Helianthus annus* L. were sown on 16 April directly to the substrate with one seed per container. At the beginning of May previously prepared seedlings of *Tagetes erecta* L. and *Amaranthus caudatus* L. were planted at one plant per container. In the course of the experiment plants were watered as needed, depending on ambient temperature. Once a week all plants were watered with tap water to constant weight. Plants were collected at anthesis. In the collected plant material moisture content was determined (separately for every organ) in order to determine dry matter content. Before collection of the plant material intensity of leaf colouring was determined using an N-tester and it was expressed in non-standardized units, *ie* SPAD (*The Signaling Pathway Database*).

At the completion of the experiment substrate samples were collected and their contents of soluble nickel forms were determined in the extract according to Lindsay. This solution contained in 10 dm^3: 50 g EDTA (*ethylenediaminetetraacetic acid*), 90 cm^3 25% NH_4OH basic solution, 40 g citric acid and 20 g $Ca(CH_3COO)_2 \cdot 2H_2O$. Moreover, samples of plant material were collected (separately for inflorescences, leaves and stems) and later mineralized. Dry mineralization of plant material was run at a temperature of 450ºC in a Linn Elektro Therm combustion furnace. Produced ash was dissolved in 10% HCl (analytically pure). After mineralization the content of nickel was determined by *atomic absorption spectroscopy* AAS using an AAS 3 Zeiss apparatus. The values determined in blank samples were subtracted from recorded heavy metal contents.

Obtained results concerning nickel contents were subjected to one-way analysis of variance, for each substrate and each organ separately. Statistical analyses were performed in the STAT software at the significance level $\alpha = 0.05$.

Results and discussion

Nickel content in individual organs of analyzed plant species

Under normal conditions the content of nickel in plants most typically ranges from 0.1 to 5 ppm Ni in dry matter [10].

Toxic concentration of nickel in plants is highly varied, depending on the degree of sensitivity or resistance of plants, ranging from 10 to 100 ppm. The degree of harmfulness of nickel depends on its chemical form. Many plants exhibit resistance and ability to accumulate nickel in large amounts, over X000 ppm, thanks to which they may be used as indicators of biogeochemical progression [11].

The concentration of 100 mg Ni $\cdot$ kg^{-1} dry matter in plants indicates its excessive accumulation in the soil and phytotoxic action [12].

If nickel level in the soil is elevated, the transfer of this metal to fruits decreases in favour of apical parts [13].

The content of nickel in individual organs of *Tagetes erecta* L. increased with an increase of nickel content in the substrate (Figs 1-3). Among the analyzed organs of *Tagetes erecta* L. the highest nickel content was recorded in leaves of plants growing in all contaminated substrates and in the substrate with no addition of this metal. As it was reported by Litynski and Jurkowska [10], the distribution of nickel in plants is not uniform, with its highest amounts being found in leaves. Similar results were reported by Chatterjee and Dube [14], who found the highest nickel contents in leaves. Accumulation of nickel in individual parts of plants depended on the concentration of nickel and physical properties of soil. In turn, in a study by Fargasova [15] it was shown that nickel content was uniform in whole seedlings of *Sinapsis alba* L.

In the conducted investigations in *Tagetes erecta* L. growing in the substrate with an addition of 25, 50 and 75 mg Ni $\cdot$ dm^{-3} and in the control the stems were the organs accumulating the smallest amounts of nickel (Fig. 3). In turn, in case of the substrate, to which 150 and 300 mg Ni $\cdot$ dm^{-3} were added, the smallest amounts of Ni were recorded in inflorescences (Fig. 1). Bosiacki [5], when investigating cadmium content in individual organs of this plant observed the highest levels of this metal in roots, leaves and shoots, while they were the lowest in inflorescences. A similar distribution of lead in individual organs of ornamental plants was reported by Bosiacki and Golcz [6].

In *Helianthus annus* L. it was found that it was inflorescences, which accumulated the biggest amounts of nickel, in case of substrates to which 25, 50, 75 and 150 mg Ni $\cdot$ dm^{-3} were introduced (Fig. 1). In the substrate highly contaminated with nickel (300 mg Ni $\cdot$ dm^{-3}) the highest content of this metal was recorded in leaves (Fig. 2), while the lowest - in inflorescences (Fig. 1). In the substrate contaminated with nickel at 25, 50 and 75 mg $\cdot$ dm^{-3}, the lowest content of this metal was observed in leaves of *Helianthus annus* L. (Fig. 2), while in the substrate with an addition of 150 mg Ni $\cdot$ dm^{-3} the lowest amounts were found in stems (Fig. 3).

In their studies on the suitability of *Helianthus annus* L. for phytoremediation Prasad and Freitas [16] showed that *Helianthus annus* L. accumulates many toxic metals.

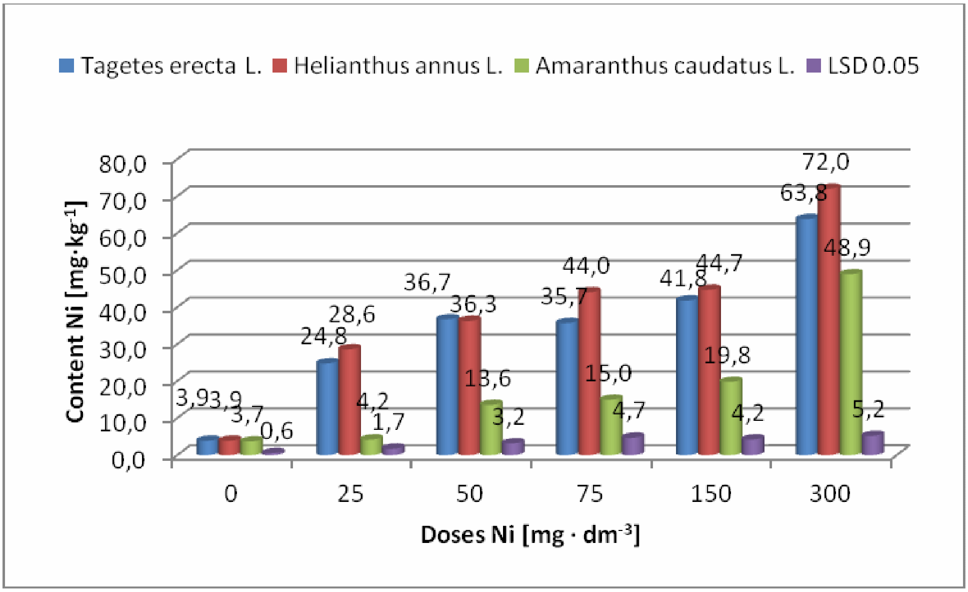

Fig. 1. Content of nickel [mg · kg^{-1} d.m.] in the inflorescences of the selected ornamental plants

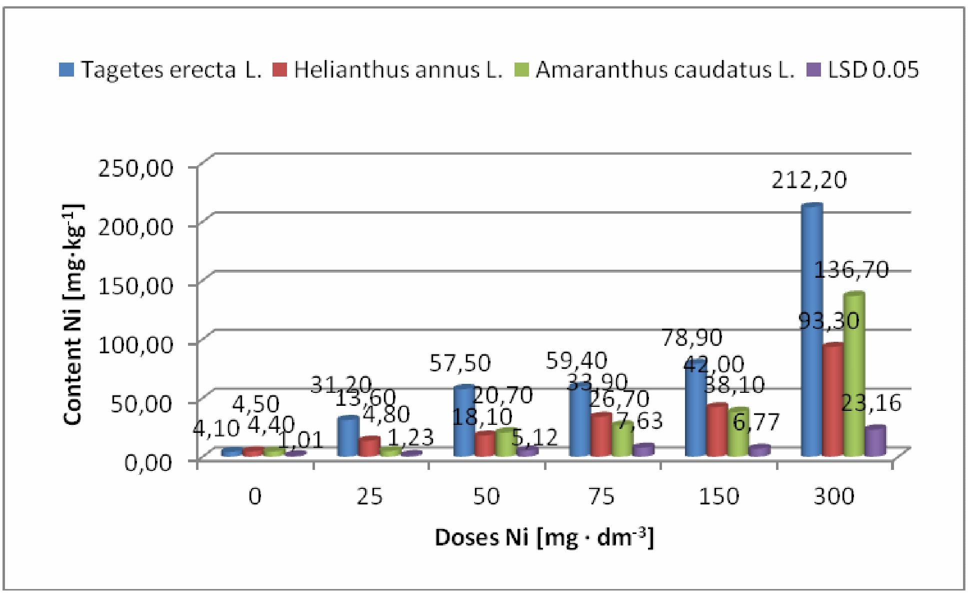

Fig. 2. Content of nickel [mg · kg^{-1} d.m.] in the leaves of the selected ornamental plants

Love-lies-bleeding (*Amaranthus caudatus* L.), similarly as Aztec marigold (*Tagetes erecta* L.), accumulated the highest amounts of nickel in leaves (Fig. 2). Inflorescences and stems accumulated much less of this heavy metal, particularly in the last two combinations with the highest dose of nickel (Figs. 1 and 3). In the substrate to which 25, 50 and 150 mg Ni · dm^{-3} were introduced as well as the control, the lowest content of nickel was found for stems of *Amaranthus caudatus* L. (Fig. 3), while in the substrate with a dose of 75 and 300 mg Ni · dm^{-3} the lowest amounts of this metal were recorded in inflorescences (Fig. 1).

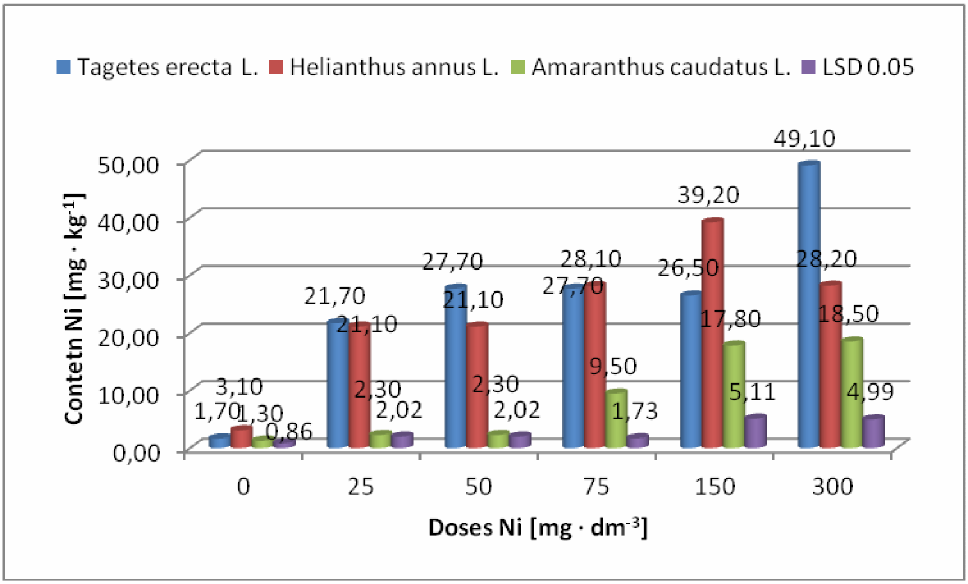

Fig. 3. Content of nickel [mg · kg^{-1} d.m.] in the stems of the selected ornamental plants

When comparing the content of nickel in inflorescences of the analyzed species the highest nickel content was observed in *Helianthus annus* L. and *Tagetes erecta* L. The smallest content of nickel was found in inflorescences of *Amaranthus caudatus* L.

The highest amounts of nickel were accumulated in leaves of *Tagetes erecta* L. (Fig. 2). The other species accumulated much lower amounts of nickel in comparison with *Tagetes erecta* L.

When comparing the content of nickel in stems of individual species, its highest content was observed in *Tagetes erecta* L. and *Helianthus annus* L. growing in the substrate, to which this metal was introduced (Fig. 3). The lowest content of Ni was observed in stems of *Amaranthus caudatus* L. Stems of *Amaranthus caudatus* L. accumulated smaller amounts of nickel than the species mentioned earlier.

Baker and Chesnin [17] reported that the concentration of 10 mg · kg^{-1} d.m. in plants indicates an excessive accumulation of this metal in the soil. However, certain plants may exhibit tolerance to its high concentration and accumulate it in large amounts [18]. Such a high accumulation of metals is facilitated by different mechanisms of tolerance, *eg* binding in cell walls, chelation and detoxication by cell organic compounds (organic acids, phytochelatines), deposition in metabolically inactive organelles (vacuoles) or in external trichomal tissues [19].

Assuming nickel contents in individual organs of analyzed species of ornamental plants growing in the substrate with no nickel addition as 100%, the percentage increase in the amount of this metal in these organs was calculated for plants growing in contaminated substrates (Table 3).

Table 3

The percentage increase in the content of nickel in individual organs of species of ornamental plants, depending on the dose of nickel

Species	**Doses Ni [mg·dm^{-3}]**					
	0	**25**	**50**	**75**	**150**	**300**
Inflorescences						
Tagetes erecta L.	100%	535.9	841.0	815.4	971.8	1535.9
Helianthus annus L.		633.3	830.8	1028.2	1046.2	1746.2
Amaranthus caudatus L.		13.5	267.6	305.4	435.1	1221.6
Leaves						
Tagetes erecta L.	100%	661.0	1302.4	1348.8	1824.4	5075.6
Helianthus annus L.		202.2	302.2	653.3	833.3	1973.3
Amaranthus caudatus L.		9.1	370.5	506.8	765.9	3006.8
Stems						
Tagetes erecta L.	100%	1176.5	1529.4	1458.8	2788.2	5382.4
Helianthus annus L.		580.6	806.5	1164.5	809.7	2854.8
Amaranthus caudatus L.		76.9	630.8	1269.2	1323.1	4207.7

Except for plants growing in the substrate, to which 50 mg Ni·dm^{-3} were introduced, the highest percentage increase in nickel content in inflorescences was found in *Helianthus annus* L. The smallest increase in the content of nickel in inflorescences was observed for *Amaranthus caudatus* L. The highest increase in the content of this metal in leaves and stems was recorded for *Tagetes erecta* L. When comparing the percentage increase in the content of nickel in individual organs the highest increase was found in stems of the analyzed plant species.

Nickel concentration index

In the conducted invetigations the index of nickel concnetration was calculated for the analyzed organs of plants

$$C = a / b$$

where: *a* - content in plants growing in contaminated substrate, *b* - content in plants growing in non-contaminated substrate.

In *Tagetes erecta* L. the highest nickel concentration index in the analyzed organs was found for stems of plants (Fig. 4). The lowest nickel concentration index in *Tagetes erecta* L. was recorded for inflorescences.

In *Helianthus annus* L., in the substrate, to which 25 and 50 Ni mg·dm^{-3} were introduced, the highest nickel concentration index was found for inflorescences, while the lowest - for leaves (Fig. 5). In the substrate contaminated with nickel at 75 mg·dm^{-3} the highest index of the concentration of this metal was recorded for stems of plants, while the lowest - for leaves. In the substrate contaminated with nickel at 300 mg·dm^{-3} the highest Ni concentration index was found for stems of plants, the lowest for inflorescences, while in the substrate with 150 mg Ni·dm^{-3} an opposite dependence was observed.

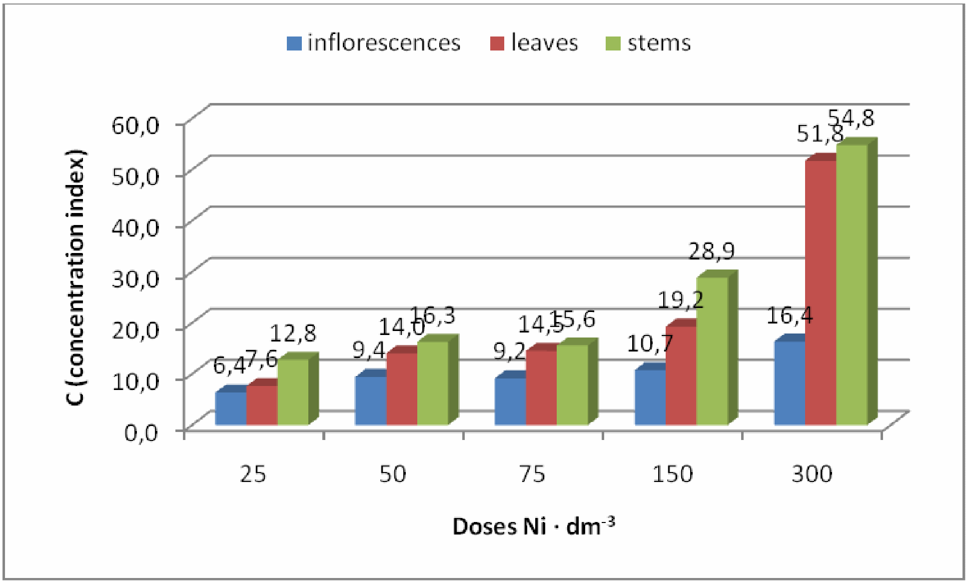

Fig. 4. Nickel concentration index in the analyzed organs of *Tagetes erecta* L.

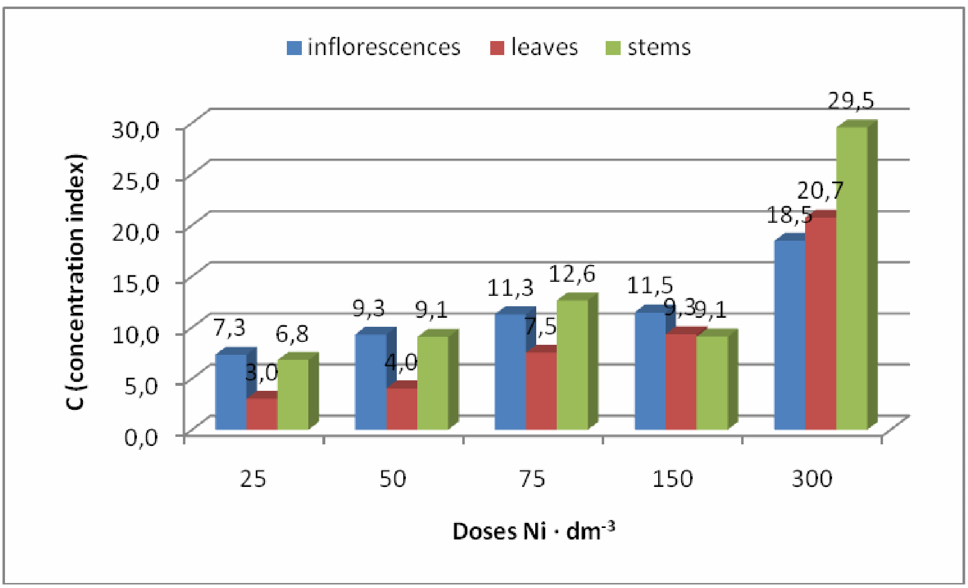

Fig. 5. Nickel concentration index in the analyzed organs of *Helianthus annus* L.

In *Amaranthus caudatus* L. in all substrates contaminated with nickel the highest nickel concentration index was recorded for stems, while the lowest - for inflorescences (Fig. 6).

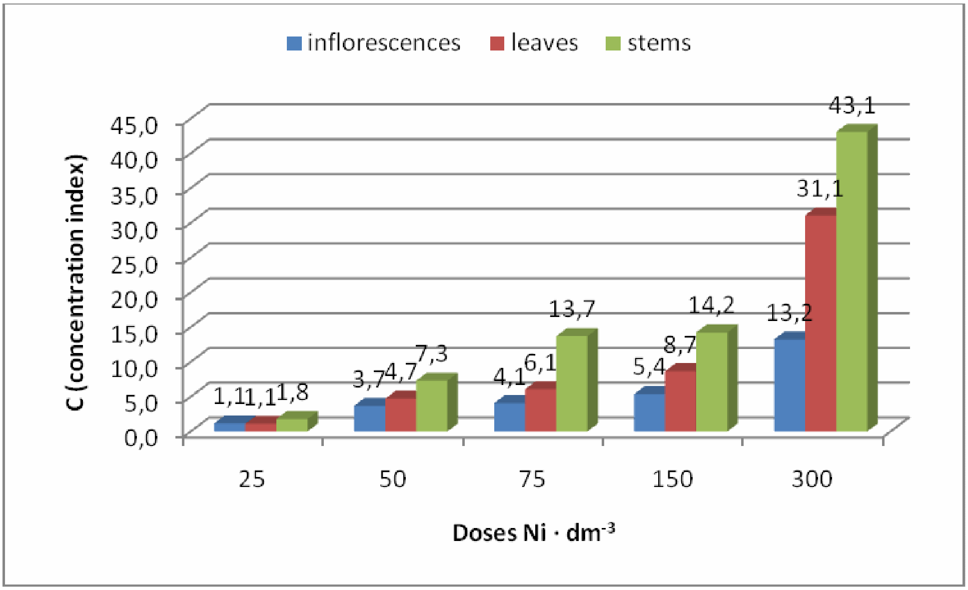

Fig. 6. Nickel concentration index in the analyzed organs of *Amaranthus caudatus* L.

Nickel uptake by aboveground parts of analyzed species of ornamental plants

Dry matter of *Tagetes erecta* L. was lower in the substrates, to which nickel was introduced, in relation to the matter obtained in the substrate with no addition of this metal (Fig. 7). Increasing doses of nickel introduced to the substrate were accompanied by an increase in the uptake of this metal by *Tagetes erecta* L. The highest uptake of nickel was observed in plants growing in the substrate with an addition of 300 mg Ni · dm^{-3}.

Similar dependencies were recorded in a study by Fargasova [15], where with an increase in the concentration of sewage sludge containing chromium and nickel dry matter content in roots was observed to decrease in seedlings of *Sinapsis alba* L., while dry matter of shoots for most applied concentrations remained unchanged or increased. The percentage uptake of nickel from sewage sludge in roots and shoots was almost 10.2 to 15.8%. In a study by Gospodarek [20] on the effects of nickel contamination of soil it was shown that in soil contaminated with nickel after 2-year culture the highest seed yield was obtained, in soil contaminated three years earlier the seed yield remained identical to that in the combination with soil contaminated in the same year. With time on soil contaminated with nickel an increase was observed for germinability of seeds damaged by *Bruchus rufimanus* Boh., as well as an improvement in traits of the obtained seedlings.

The lowest dry matter was found in *Helianthus annus* L. for the substrate, to which 300 mg Ni · dm^{-3} were introduced. The highest dry matter content was recorded for the substrate with a dose of 25 mg Ni · dm^{-3}. When analyzing mean nickel uptake by this species it was found that the uptake of this metal increased with an increase in nickel doses. The highest nickel uptake was found for plants growing in the substrate with an addition of 300 mg Ni · dm^{-3}.

Bigger dry matter content in *Amaranthus caudatus* L. in comparison to the control was observed in the substrates, to which nickel was added at 150 and 300 mg Ni · dm^{-3}. The highest dry matter of plants was recorded in the substrate with an addition of 150 mg Ni · dm^{-3}. In the other substrates, to which nickel was introduced, a smaller yield of dry matter was obtained in *Amaranthus caudatus* L. in comparison to the yield produced in the substrate with no addition of this metal. Similarly as in the previous species, nickel uptake increased with an increase in the doses of this metal introduced to the substrate. This species produced the highest yields of dry matter in comparison to the other analyzed species of ornamental plants.

The influence of these doses of nickel on the height, diameter, fresh total mass and fresh masses of individual organs of plants was presented in the publication of Bosiacki and Wojciechowska [21].

Among the analyzed ornamental plant species growing in the substrate with no addition of the metal and in the substrate with an addition of 25 and 50 mg Ni · dm^{-3} the highest uptake of nickel was observed for *Tagetes erecta* L. plants. In the substrate with an addition of 75, 150 and 300 mg Ni · dm^{-3} the highest nickel uptake was found in *Amaranthus caudatus* L. Bosiacki [5] in his study conducted on cadmium phytoextraction from substrates stated that the highest uptake of this metal was found for *Tagetes erecta* L. Bosiacki and Golcz [6] in their investigations stated that *Tagetes erecta* L. was characterized by the highest lead uptake.

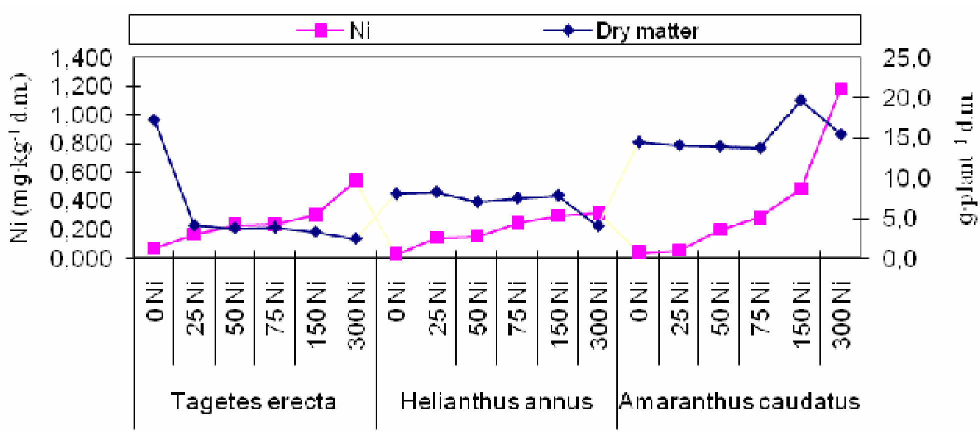

Fig. 7. The dry matter of analyzed species of ornamental plants and nickel uptake by aboveground parts of these plants

Content of nickel in substrates after the completion of the experiment

With an increase of nickel doses its concentration in the substrate increased as well (Fig. 8). It was found that the highest amounts of nickel after the completion of the experiment were detected in the substrates, on which *Amaranthus caudatus* L. was grown for all the applied nickel doses. The lowest amount of this metal was found in the substrates, in which *Tagetes erecta* L. was grown. The highest percentage reduction of this metal was observed for the substrate with an addition of 300 mg Ni · dm^{-3}, in which *Tagetes erecta* L.

was grown, where the reduction of nickel after the completion of the experiment was 33.9%. Staunton et al [22] showed that the release of organic anions and modification of soil pH by roots in the rhizosphere may considerably reduce the binding of nickel in the substrate and enhance its bioavailability and thus - uptake by plants. In a study by Salta et al [23] it was shown that plant roots may affect the solubility of heavy metals by acidification of the soil medium with protons released from roots.

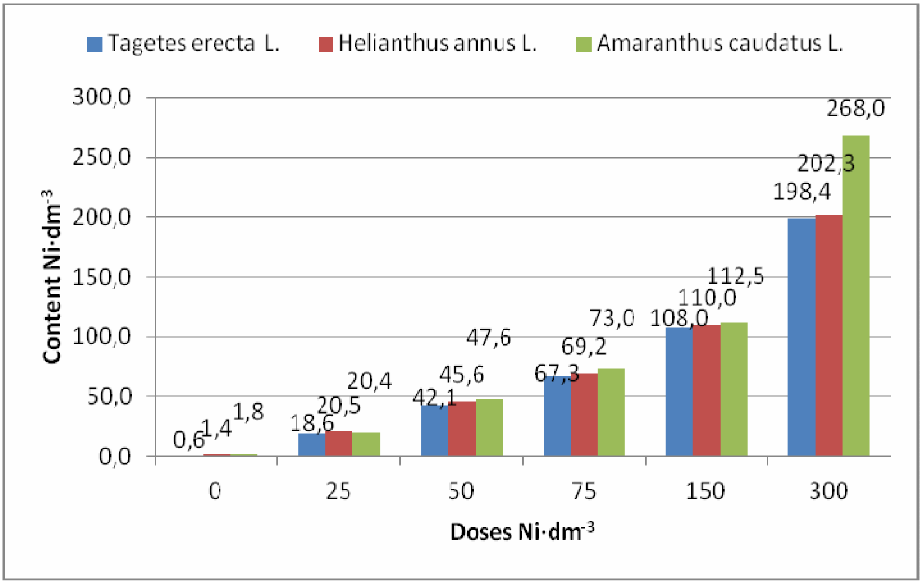

Fig. 8. The content of nickel in substrates [mg · dm^{-3}] after the completion of the experiment

Intensity of colouring of blades of fresh leaves in analyzed ornamental plant species

Nickel is frequently found in combination with porphyry compounds and chlorophyll, in which it substitutes other metals, eg Fe and Mg [24], at excessive concentrations (10÷100 mg · kg^{-1}) it excludes iron from metabolism in plants, leading to the development of chlorosis and necrosis. The harmful effect of nickel may be reduced by an addition of magnesium to soil [25].

Kukier and Chaney [26] in their study on grasses showed that the intensity of chlorosis was directly proportional to the reduction of yields, which means that the measurement of chlorophyll reflects the toxic effects and nutrient deficits.

The highest intensity of leaf colouring in *Tagetes erecta* L. was found in the control combination (Fig. 9). Such a reaction may suggest that in the control iron was not displaced from chlorophyll, while in leaves of plants growing in substrates, to which nickel was introduced, where a lower intensity of colouring was found, this metal may replace iron. The lowest intensity of leaf colouring was observed in plants growing in the substrates with an addition of 50 and 150 mg Ni · dm^{-3} in relation to the intensity of leaf colouring in plants growing in the substrate with no nickel added.

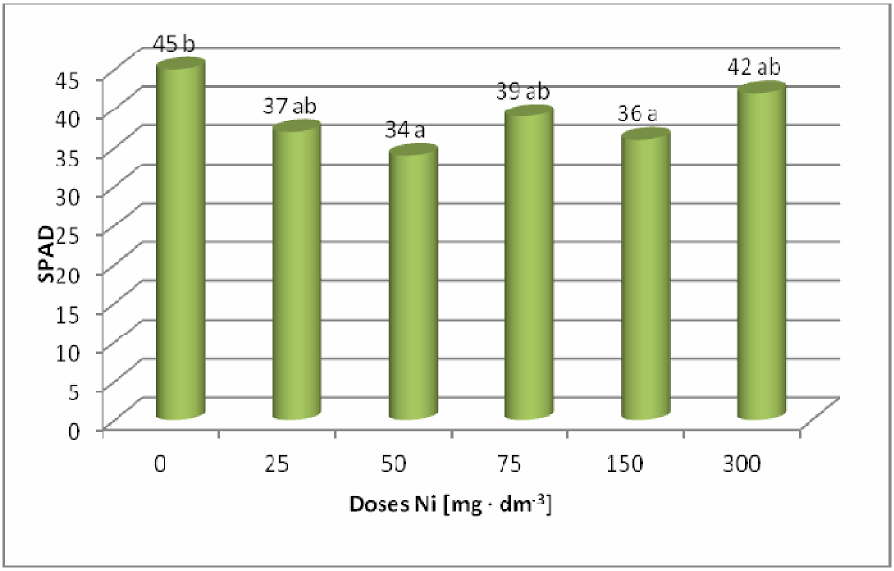

Fig. 9. Intensity of colouring of blades of fresh leaves in *Tagetes erecta* L.

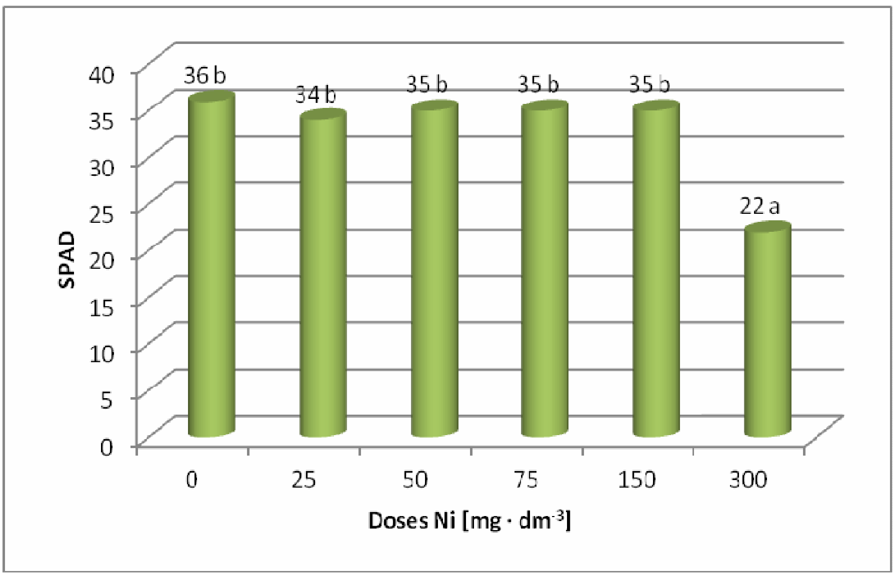

Fig. 10. Intensity of colouring of blades of fresh leaves in *Helianthus annus* L.

Intensity of leaf colouring in *Helianthus annus* L. was similar in all combinations except for the substrate, to which 300 mg Ni · dm^{-3} were introduced, where the lowest content of chlorophyll was observed (Fig. 10).

The highest intensity of leaf blade colouring in *Amaranthus caudatus* L. was found in plants growing in substrates with an addition of 150 and 300 mg Ni · dm^{-3}, while the lowest in leaves of plants growing in substrates with an addition of 25 and 75 mg Ni · dm^{-3} (Fig. 11).

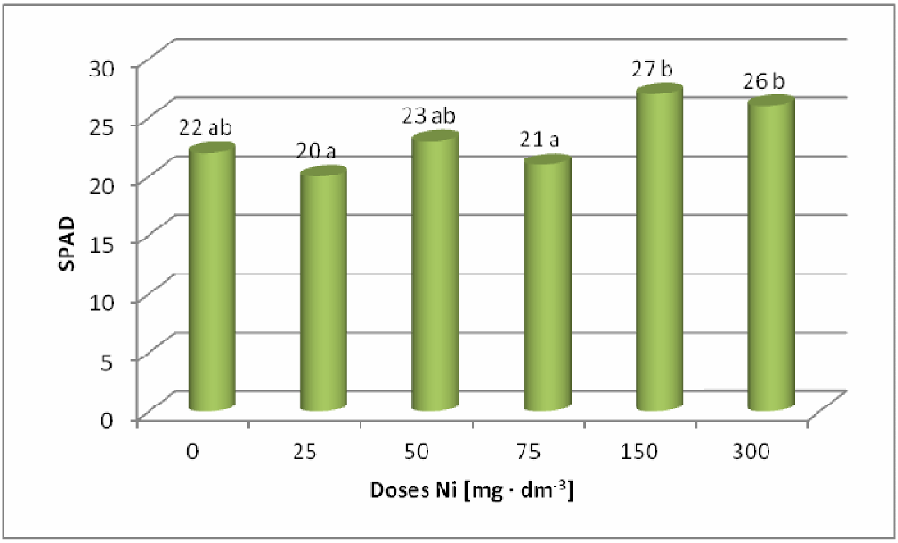

Fig. 11. Intensity of colouring of blades of fresh leaves *Amaranthus caudatus* L.

Conclusions

1. Content of nickel in plants was dependent on the concentration of this metal in the substrate. The content of this heavy metal in plants increased with an increase in its dose in the substrate.
2. *Tagetes erecta* L. 'Hawaii' and *Amaranthus caudatus* L. 'Atropurpureus' accumulated the highest amounts of nickel in leaves, while *Helianthus annus* L. growing in the substrate, to which nickel was introduced at 25, 50, 75 and 150 mg · dm^{-3}, accumulated the highest amounts of this metal in inflorescences.
3. In inflorescences the highest content of nickel was recorded in *Helianthus annus* L. 'Pacino' and *Tagetes erecta* L. 'Hawaii'. The smallest content of nickel was observed in inflorescences of *Amaranthus caudatus* L. 'Atropurpureus'.
4. In stems of individual species the highest nickel content was observed in *Tagetes erecta* L. 'Hawaii' and *Helianthus annus* L. 'Pacino' growing in substrates, to which this metal was introduced. The lowest Ni content was recorded in stems of *Amaranthus caudatus* L. 'Atropurpureus'.
5. After the completion of the experiment the biggest amounts of nickel were reported in substrates, in which *Amaranthus caudatus* L. 'Atropurpureus' was grown, for all the applied nickel doses. The lowest amounts of this metal were observed in substrates, in which *Tagetes erecta* L. 'Hawaii' was grown.
6. Among all the analyzed species of ornamental plants, growing in the substrates with no addition of the metal and in the substrates with an addition of 25 and 50 mg Ni · dm^{-3}, the highest nickel uptake was found for *Tagetes erecta* L. 'Hawaii' plants. In the

substrates with an addition of 75, 150 and 300 mg Ni · dm^{-3} the biggest nickel uptake was observed for *Amaranthus caudatus* L. 'Atropurpureus'.

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FITOEKSTRAKCJA NIKLU
PRZEZ WYBRANE GATUNKI ROŚLIN OZDOBNYCH

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Abstrakt: W doświadczeniu wazonowym badano wpływ rosnących dawek Ni (kontrola, 25, 50, 75, 150, 300 mg · dm^{-3} podłoża) na zawartość tego metalu w poszczególnych organach części nadziemnych trzech wybranych gatunków roślin ozdobnych: aksamitka wyniosła (*Tagetes erecta* L.), słonecznik ogrodowy (*Helianthus annus* L.), szarłat zwisły (*Amaranthus caudatus* L.). Stwierdzono istotny wpływ rosnących dawek Ni na zawartości tego metalu w poszczególnych organach wybranych gatunków. *Tagetes erecta* L. i *Amaranthus caudatus* L. najwięcej niklu akumulowały w liściach, natomiast słonecznik ogrodowy rosnący w podłożu, do którego wprowadzono nikiel w ilości 25, 50, 75 i 150 mg·dm^{-3}, najwięcej tego metalu akumulował w kwiatostanach. Spośród badanych gatunków roślin ozdobnych rosnących w podłożu bez dodatku metalu oraz w podłożu z dodatkiem 25 i 50 mg Ni · dm^{-3} największym pobraniem niklu charakteryzowały się rośliny *Tagetes erecta* L. W podłożu z dodatkiem 75, 150 i 300 mg Ni · dm^{-3} największe pobranie niklu stwierdzono u *Amaranthus caudatus* L.

Słowa kluczowe: nikiel, rośliny ozdobne, fitoekstrakcja, fitoremediacja, *Tagetes erecta* L., *Helianthus annus* L., *Amaranthus caudatus* L.