ECOLOGICAL CHEMISTRY AND ENGINEERING S

Vol. 17, No. 3 2010

Matúš PEŠKO[1*], Katarína KRÁĽOVÁ[1] and Elena MASAROVIČOVÁ[1]

RESPONSE OF *Hypericum perforatum* PLANTS TO SUPPLY OF CADMIUM COMPOUNDS CONTAINING DIFFERENT FORMS OF SELENIUM

WPŁYW RÓŻNYCH FORM SELENU NA AKUMULACJĘ ZWIĄZKÓW KADMU PRZEZ ROŚLINY *Hypericum perforatum*

Abstract: The effect of cadmium compounds containing selenium in different oxidation states such as Se(IV), Se(VI), and Se(–II) on production characteristics, shoot water content and chlorophyll content in the leaves as well as Cd and Se accumulation in plant organs of *Hypericum perforatum* plants was investigated. Complexes with nicotinamide (nia) of the type $Cd(NCX)_2(nia)_2$ where X = Se or S as well as $CdSO_4$ were used to compare the effect of Se and S on the above-mentioned parameters. The studied compounds applied at concentrations 12, 24 and 60 μmol · dm^{-3} reduced dry mass of plant organs. In general, water content of shoots as well as chlorophyll content in the leaves decreased with increasing the compound concentrations. Se speciation significantly affected accumulated amount of Cd and Se [mg · g^{-1} d.m.] in plant organs of *H. perforatum* plans what was reflected in the values of bioaccumulation factors (BAF), translocation factors (TF) as well as portion from the total metal amount accumulated by the plant occurring in the shoots. The comparison of the effect of $CdSO_4$ and $CdSeO_4$ as well as $Cd(NCS)_2(nia)_2$ and $Cd(NCSe)_2(nia)$ showed that exchange of S for Se in the NCX^- ligand led to decreased translocation of Cd into the shoots. The application of $CdSeO_4$ resulted in intensive translocation of Cd as well as Se into the shoots. Portion of Cd allocated in shoots related to the total Cd amount accumulated by the plant was about 20% for treatment with $CdSO_4$ and $Cd(NCS)_2(nia)_2$, about 12.8, 10 and 6% for treatment with $Cd(NCSe)_2(nia)_2$, $CdSeO_4$ and $CdSeO_3$. On the other hand, portion of Se allocated in shoots related to the total Se amount accumulated by *H. perforatum* plants achieved approx. 86, 48.6 and 45.9% after addition of $CdSeO_4$, $Cd(NCSe)_2(nia)_2$ and $CdSeO_3$.

Keywords: bioaccumulation, cadmium, chlorophyll, selenate(VI), selenate(IV), St. John's wort, water content

Introduction

Hypericum perforatum L. is a plant which has been traditionally used for many ethnopharmacological purposes, including treatment of mental disorders. Preclinical studies on the central nervous system activities of the plant extracts have exhibited that the extracts showed antidepressant, anxiolytic, sedative, nootropic, antischizophrenic, anticonvulsant

[1] Faculty of Natural Sciences, Comenius University, 842 15 Bratislava, Slovakia, tel. +421 2 60 296 340, fax +421 2 65 429 064
[*] Corresponding author: pesko@fns.uniba.sk

and analgesic activities. Several clinical data have confirmed the extracts or commercial preparations as effective as some standard antidepressants used for mild or moderate depression [1].

Metals have been investigated in different medicinal plant materials in order to establish their normal concentration range and consider their role in plants as part of human medicinal treatment. Metal monitoring as a pattern recognition method is a promising tool in the characterization and/or standardization of phytomedicines [2]. Since common St. John's wort (*Hypericum perforatum*) is particularly responsive to changes in climate, it could serve as indicator of biological responses to climate change [3].

Metal treatment can significantly change the chemical composition of secondary metabolites in *H. perforatum* plants and thereby seriously influence the quality, safety and efficacy of natural plant products produced by medicinal species. A treatment with 0.01 mmol $\cdot$ dm^{-3} Cr(VI) for seven days resulted in an increased production of protopseudohypericin (+ 135%), hypericin (+38%) and pseudohypericin (+ 5%). Treatment with 0.1 mmol $\cdot$ dm^{-3} Cr(VI) for two days also caused an increase of protopseudohypericin (+ 167%), hypericin (25%) and pseudohypericin (+5%) whereas after 7 d treatment massive increase of protopseudohypericin (+404%) and pseudohypericin (+379%) was observed but hypericin content was not be changed [4]. Murch et al [5] observed that *H. perforatum* seedlings grown in a sterile, controlled environment supplemented with 25 or 50 mmol $\cdot$ dm^{-3} nickel lost completely the capacity to produce or accumulate hyperforin and demonstrated a 15-20-fold decrease in the concentration of pseudohypericin and hypericin.

Masarovicova et al [6] found that stress-induced higher root respiration rate of the Cd-treated *H. perforatum* plants correlated with root growth inhibition accompanied with the lower value of root dry mass. Relatively high Cd uptake into the root required increased energy costs coming from root respiration. Previously it was confirmed that cadmium accumulation in plant organs of medicinal plant *Matricaria recutita* L. could be strongly affected by the presence of Se in different oxidation states [7, 8].

This paper is aimed to investigate the study of the effect of cadmium compounds containing Se in different oxidation states such as Se(IV), Se(VI), and Se(–II) on production characteristics, shoot water content and chlorophyll content in leaves as well as Cd and Se accumulation in plant organs of *Hypericum perforatum* plants. Complexes with nicotinamide (nia) of the type $Cd(NCX)_2(nia)_2$ where X = Se or S as well as $CdSO_4$ were used to compare the effect of Se and S on the above-mentioned parameters.

Material and methods

For experiments the following cadmium compounds were used: $(CdSO_4)_3(H_2O)_8$, $CdSeO_4$, $CdSeO_3$, $Cd(NCSe)_2(nia)_2$ and $Cd(NCS)_2(nia)_2$. $(CdSO_4)_3(H_2O)_8$ of analytical purity was purchased from Lachema (Brno, Czech Republic), the further compounds were prepared according to procedures described by Kralova et al [8, 9].

For cultivation of experimental plants seeds of *Hypericum perforatum* L. (Research Institute of Agroecology in Michalovce, Slovakia) were used. Six weeks old plants were cultivated in hydroponic solution at controlled conditions (photoperiod 16 h light/8 h dark; irradiation: 80 μmol $\cdot$ m^{-2} $\cdot$ s^{-1} PAR; mean air temperature: 28°C): control variant in Hoagland solution and metal variants containing studied compounds (12, 24 and 60 μmol $\cdot$ dm^{-3}, respectively) and the response of plants to metal treatment was evaluated 7 d after Cd application. Then dry mass of roots and shoots as well as shoot water content and chlorophyll concentration in the leaves were determined. Fresh and dry shoot mass (dried at 80°C to constant dry mass) was estimated in order to determine the shoot water content [100 - (dry mass x100/fresh mass)]. Chlorophyll concentration was estimated spectrophotometrically (Genesys 6, Thermo Scientific, U.S.A) after extraction into 80% acetone and calculated according to Lichtenthaler [10]. The results were evaluated by the multifactorial ANOVA algorithm ($p \le 0.05$) after verification of normality and homogeneity of the variance. The multiple comparisons of means were based on the method of Tukey contrast.

Cadmium and selenium concentrations in shoot dry mass were determined using the flame atomic absorption spectrometry (AAS) (Perkin Elmer 110, USA). Cadmium concentration was determined according to method described by Kralova et al [8]. Selenium concentrations were determined using hydride generation AAS. Prereduction of Se(VI) to Se(IV) was achieved by heating of 5 cm^3 aliquot of the digest in 6 $mol \cdot dm^{-3}$ HCl for 15 min at 90°C. Hydride generation was performed from the media of 6 $mol \cdot dm^{-3}$ HCl using solution of 10 $g \cdot dm^{-3}$ $NaBH_4$ in 10 $g \cdot dm^{-3}$ NaOH as the reductant.

Results and discussion

Production characteristics of *H. perforatum* plants treated with the studied compounds are presented in Table 1. The phytotoxicity of the highest concentration of studied compounds (60 $\mu mol \cdot dm^{-3}$) was manifested by desiccated leaves and leaf fall what was reflected in reduced shoot dry mass. The leaves of these experimental plants were yellow or brownish.

Table 1

Root and shoot length and dry mass of *Hypericum perforatum plants* treated with the studied compounds. Mean ± S.E., n = 6. Data followed by different letters are significantly different at the 0.05 probability level.
I - $CdSO_4$, *II* - $CdSeO_4$, *III* - $CdSeO_3$, *IV* - $Cd(NCS)_2(nia)_2$, *V* - $Cd(NCSe)_2(nia)_2$

Compound	Concn. [$\mu mol\ dm^{-3}$]	Root length [cm]	Shoot length [cm]	Root d.m. [mg]	Shoot d.m. [mg]
Control	0	18.7 ± 1.7^{ab}	19.7 ± 1.1^{abc}	65.3 ± 8.7^{a}	245.4 ± 52.7^{bcde}
I	12	17.5 ± 1.7^{ab}	22.0 ± 1.0^{abcd}	70.6 ± 13.5^{a}	259.5 ± 45.2^{cde}
	24	17.7 ± 0.9^{ab}	22.9 ± 1.6^{cd}	70.1 ± 8.9^{a}	218.3 ± 14.3^{bcde}
	60	19.7 ± 1.4^{ab}	21.2 ± 1.7^{abcd}	47.4 ± 3.0^{a}	158.5 ± 22.0^{abc}
II	12	17.2 ± 1.4^{a}	18.5 ± 2.1^{ab}	74.7 ± 11.0^{a}	234.4 ± 47.6^{bcde}
	24	19.1 ± 1.8^{ab}	21.8 ± 1.8^{abcd}	72.5 ± 14.7^{a}	174.8 ± 33.3^{abcd}
	60	19.2 ± 2.5^{ab}	17.9 ± 1.7^{abcd}	50.9 ± 6.2^{a}	100.7 ± 16.2^{a}
III	12	18.1 ± 0.8^{ab}	24.9 ± 1.4^{d}	79.2 ± 18.3^{a}	293.6 ± 49.5^{e}
	24	18.5 ± 1.5^{ab}	22.3 ± 2.0^{abcd}	72.1 ± 14.9^{a}	272.8 ± 59.8^{de}
	60	18.9 ± 2.0^{ab}	19.4 ± 1.3^{abc}	61.3 ± 11.9^{a}	187.4 ± 24.9^{abcde}
IV	12	21.8 ± 1.3^{b}	22.5 ± 1.1^{bcd}	77.9 ± 16.7^{a}	284.1 ± 41.1^{e}
	24	16.7 ± 1.0^{ab}	20.0 ± 1.1^{abc}	57.4 ± 9.9^{a}	228.9 ± 20.3^{bcde}
	60	19.2 ± 1.5^{ab}	20.6 ± 1.4^{abcd}	55.6 ± 6.9^{a}	234.4 ± 18.1^{bcde}
V	12	19.6 ± 2.2^{ab}	19.6 ± 2.1^{abc}	54.1 ± 6.0^{a}	199.3 ± 41.1^{abcde}
	24	17.1 ± 1.6^{a}	22.0 ± 1.2^{abcd}	52.8 ± 7.9^{a}	163.2 ± 20.3^{abc}
	60	18.5 ± 1.8^{ab}	21.6 ± 1.5^{abcd}	67.0 ± 17.0^{a}	150.3 ± 18.1^{ab}

Figure 1 presents results concerning dependence of total chlorophyll (Ch) content of leaves on the applied compound concentrations. Reduction of Chl content by $CdSO_4$ and $Cd(NCS)_2(nia)_2$ (compounds without Se) application was found to be lower than the effect of selenium containing compounds. The most toxic compound was found $Cd(NCSe)_2(nia)_2$. Cadmium was reported to affect chlorophyll biosynthesis and inhibit protochlorophyll reductase and aminolevulinic acid (ALA) synthesis [11]. According to Padmaja et al [12] the inhibitory effect of Se on Chl synthesis is not only by acting on constituent biosynthetic enzymes but also through lipoxygenase-mediated lipid peroxide levels and inhibition of antioxidant defence component. Moreover, cadmium also affects degradation of assimilation pigments [13]. Reduction of chlorophyll concentration in lettuce (*Lactuca sativa*) treated with H_2SeO_4 was observed by Xue et al [14] and also adult coffee plants leaves infiltrated with selenate(IV) showed significant decrease of photosynthetic pigments (chlorophylls, carotenoids and xanthophylls) [15]. Reduction of chlorophyll concentration after application of studied compounds was also confirmed previously in *M. recutita* plants [7].

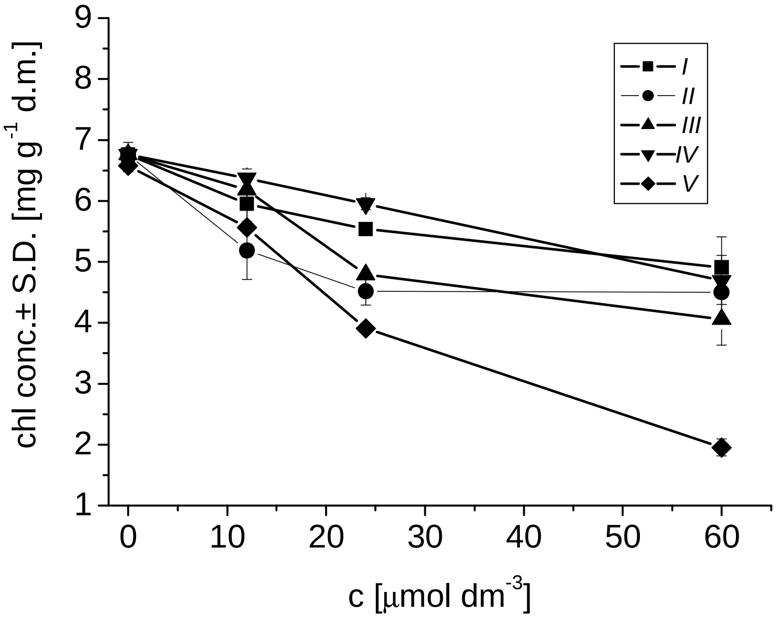

Fig. 1. Dependence of chlorophyll concentration in leaves of *H. perforatum* plants treated with the studied compounds. I - $CdSO_4$, II - $CdSeO_4$, III - $CdSeO_3$, IV - $Cd(NCS)_2(nia)_2$, V - $Cd(NCSe)_2(nia)_2$

Stronger loss of water (water stress induction) in shoots of *H. perforatum* plants was observed only for treatment with 60 $\mu mol \cdot dm^{-3}$ $Cd(NCSe)_2(nia)_2$, $CdSeO_4$ and $CdSO_4$ (Fig. 2). Toxic metals such as cadmium affect plasma membrane permeability what results in reduction of water content [16, 17].

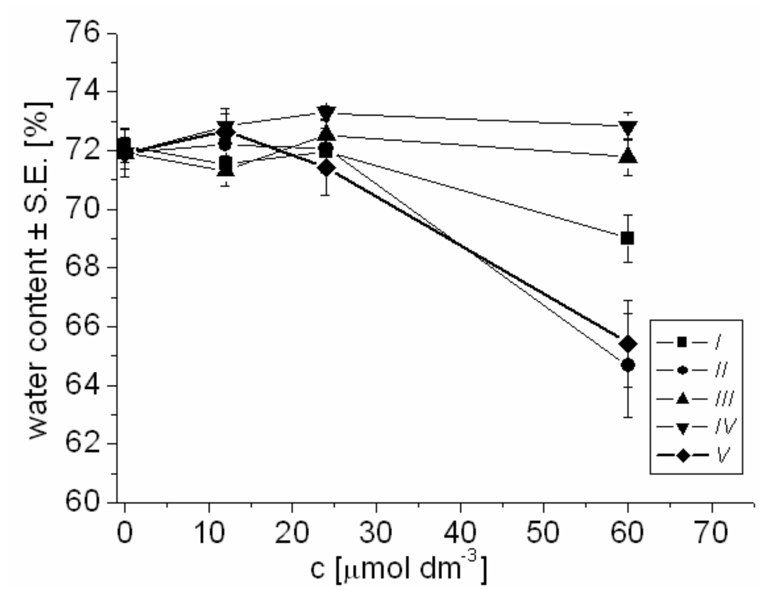

Fig. 2. Dependence of water content in shoots of *H. perforatum* plants treated with the studied

Cadmium and selenium concentration in roots and shoots *Hypericum perforatum* plants treated with the studied compounds and corresponding values of bioaccumulation (BAF) and translocations factors (TF) are summarized in Table 2. Bioaccumulation factors (BAF) express the ratio of the metal concentration in the biological material [μmol or μg · g^{-1} dry mass] to the metal concentration in external solution in [μmol or μg · dm^{-3}]. This parameter is important from the aspect that for phytotherapeutical use the aboveground parts of chamomile plants are of the interest.

The higher BAF values estimated for shoots reflect more effective mobility of the corresponding elements (Cd or Se) in the plants. The translocation factor TF corresponds to the ratio of accumulated Cd (or Se) amount in shoots and roots and thus it depends also on the actual dry mass of these plant organs (similarly as the portion from the total accumulated metal amount by the plant occurring in the shoots).

The dependence of accumulated Cd concentration in roots on the applied concentration of $CdSeO_4$, $CdSO_4$ and $Cd(NCS)_2(nia)_2$ showed linear increase, whereas for the treatment with $CdSO_4$ and $Cd(NCSe)_2(nia)_2$ at 60 μmol · dm^{-3} consecutive saturation of the roots with Cd was observed. The concentration of Se in roots and shoots of experimental plants increased linearly with the applied compound concentration. However, due to the treatment with the highest $Cd(NCSe)_2(nia)_2$ concentration saturation of the roots with Se was observed. The highest accumulated Cd concentration in both plant organs was obtained with $CdSO_4$ treatment. Substitution of sulphur with Se led to strong decrease of Cd concentration, mainly in shoots, indicating Cd-Se interference. It is necessary to stress that selenium and sulphur in plants share common metabolic pathways and these elements compete in biochemical processes affecting uptake, translocation, and assimilation pathways in plants [18].

Table 2

Cadmium and selenium concentration in roots and shoots of *Hypericum perforatum* plants treated with the studied compounds. *I* - $CdSO_4$, *II* - $CdSeO_4$, *III* - $CdSeO_3$, *IV* - $Cd(NCS)_2(nia)_2$, *V* - $Cd(NCSe)_2(nia)_2$ and corresponding values of bioaccumulation (BAF) and translocations factors (TF)

Comp.	c [µmol dm^{-3}]	Cd (Se) concn. [mg kg^{-1} d.m.] **BAF**				TF **% Cd (Se) in shoot**	
		Root		Shoot			
		Cd	Se	Cd	Se	Cd	Se
Control	0	31.8	7.0	2.5	4.6	-	-
I	12	2197 **1628.6**	-	126.5 **93.8**	-	0.212 **17.5**	-
	24	3811 **1412.5**	-	270.7 **100.3**	-	0.221 **18.1**	-
	60	6081 **901.6**	-	531.0 **78.7**	-	0.292 **22.6**	-
II	12	595 **441**	28.2 **29.8**	23.0 **17.1**	78.3 **82.6**	0.121 **10.8**	8.713 **89.7**
	24	1021 **378.4**	63.9 **33.7**	47.1 **17.5**	149.6 **78.9**	0.111 **10.0**	5.645 **85.0**
	60	2578 **382.2**	140.3 **29.6**	135.9 **20.2**	370.2 **78.1**	0.104 **9.4**	5.220 **83.9**
III	12	251 **185.7**	99.5 **105.0**	4.72 **3.5**	18.2 **19.2**	0.070 **6.5**	0.678 **40.4**
	24	491 **182.1**	178.2 **94.4**	7.5 **2.8**	37.8 **19.9**	0.058 **5.4**	0.803 **44.5**
	60	1337 **198.2**	319.0 **67.3**	27.8 **4.1**	116.8 **24.7**	0.064 **6.0**	1.119 **52.8**
IV	12	571 **423.3**	-	25.7 **19.1**	-	0.164 **14.1**	-
	24	997 **369.5**	-	65.1 **24.1**	-	0.260 **20.7**	-
	60	2010 **298.0**	-	172.8 **25.6**	-	0.362 **26.6**	-
V	12	723 **536.0**	192.4 **101.5**	31.1 **23.1**	109.6 **57.8**	0.158 **13.7**	0.558 **35.8**
	24	1263 **468.1**	262.9 **69.4**	62.8 **23.3**	212 **55.9**	0.154 **13.3**	0.519 **34.2**
	60	2400 **355.8**	329.3 **34.6**	138.5 **20.5**	398.2 **42.0**	0.129 **11.5**	0.372 **27.1**

Chizzola and Lukas [19] collected *Hypericum perforatum* plants and soil samples from many regions in Eastern Austria to study the variability in the Cd content. The higher Cd levels often with bioaccumulation factor > 1 were determined in plants growing in regions with somewhat lower soil pH and carbonate content than in other regions. High Cd concentrations have been found in the *H. perforatum* shoots in mining valley in NW Madrid (Spain) where soils affected by mining activities presented total Cd, Cu and Zn concentrations above toxic thresholds [20]. Germ et al [21] applied foliar spraying with selenium (10 mg · dm^{-3} Se in the form of sodium selenate(VI)) to *H. perforatum* plants. The concentration of Se in the organs of plants foliarly sprayed with Se ranged from 1000 ng · g^{-1} to 12 000 ng · g^{-1} whereas Se concentration in unsprayed plants was achieved only 20 ng · g^{-1} - 120 ng · g^{-1} what indicate that foliar application of Se fertiliser is feasible and effective in St. John's wort and results in Se-enriched nutritional supplements.

It is evident that accumulation of Cd in plant organs was strongly affected by Se oxidation state (Table 2). After selenate(VI) treatment Cd root concentration drops to a half in comparison with that obtained in the presence of selenate(VI), however this decrease was even significantly higher for Cd shoot concentration (approx by 80%). Cd root concentration after $Cd(NCSe)_2(nia)_2$ treatment was lower than that obtained after selenate(VI) addition (nevertheless higher than after selenate(IV) treatment) but shoot Cd concentration slightly exceeded that determined for selenate(VI) addition (Table 2). Substitution of Se with sulphur in $Cd(NCX)_2(nia)_2$ increased root Cd concentration approx by 24%, shoot Cd concentration was comparable (consequently, similar increase of Cd shoot concentration as in case of $CdSO_4$ in comparison to $CdSeO_4$ was not observed). With regards to application of individual studied compounds root Se content decreased in the following order: $CdSeO_3$ > $Cd(NCSe)_2(nia)_2$ > $CdSeO_4$, whereas for shoot Se concentration this sequence was opposite: $CdSeO_4$ > $Cd(NCSe)_2(nia)_2$ > $CdSeO_3$. This is in accordance with previous findings confirming higher mobility of selenate(VI) in the plants [7, 22]. However, the presence of selenium reduces the availability of metal ions (such as cadmium), blocking them in insoluble compounds. According to Shanker et al [22] the less mobile selenate(IV) after being reduced to selenide tends to form Cd–Se complex, which appears to be unavailable for the plants. On the other hand, the more mobile anion selenate(VI) is available for Cd–Se formation only after following a more complicated redox processes involving Se(VI) in SeO_4^{2-}, Se(IV) in SeO_3^{2-}, and Se(0) species.

In general it can be concluded that root to shoot translocation of Cd in *H. perforatum* plants was relatively low. Portion of Cd allocated in shoots related to the total Cd amount accumulated by the plant was about 20% for treatment with $CdSO_4$ and $Cd(NCS)_2(nia)_2$, about 12.8%, 10% and 6% for treatment with $Cd(NCSe)_2(nia)_2$, $CdSeO_4$ and $CdSeO_3$. On the other hand, portion of Se allocated in shoots related to the total Se amount accumulated by *H. perforatum* plants achieved approx 86%, 48.6% and 45.9% after addition of $CdSeO_4$, $Cd(NCSe)_2(nia)_2$ and $CdSeO_3$. For comparison portion of Cd allocated in shoots was 53.9% ($CdSeO_4$), 33.2% ($CdSeO_3$), 23.4% ($Cd(NCSe)_2(nia)_2$) and 42.5% ($Cd(NCS)_2(nia)_2$) for *Matricaria recutita*, cv. Goral [7], 61.8% ($CdSeO_4$), 42.9% ($CdSeO_3$), 36.2% ($Cd(NCSe)_2(nia)_2$) and 53.9% ($Cd(NCS)_2(nia)_2$) for *Brassica juncea* [23] as well as 38% ($CdSeO_4$) and 18% ($CdSeO_3$ and $Cd(NCSe)_2(nia)_2$) for *Pisum sativ*um plants [24]; portion of Se allocated in shoots reached 91.5% ($CdSeO_4$), 25.8% ($CdSeO_3$), 27.8% ($Cd(NCSe)_2(nia)_2$) for *M. recutita* [7], cv. Goral, 90.3% ($CdSeO_4$), 26.4% ($CdSeO_3$), 51.5% ($Cd(NCSe)_2(nia)_2$) for *B. juncea* [23] as well as 89% ($CdSeO_4$) and 18% ($CdSeO_3$ and $Cd(NCSe)_2(nia)_2$) for *Pisum sativum* plants [24].

The differences in the toxicity of both studied complexes could be also connected with diverse values of the corresponding stability constants related to NCS^- and $NCSe^-$ ligands. The overall stability constant (β_2) of the complex compound $Cd(NCS)_2$ is 602.56 ($\beta_2 = 10^{2.78}$), whereas β_2 estimated for $Cd(NCSe)_2$ is only 199.53 ($\beta_2 = 10^{2.3}$) indicating three times lower stability of the compound comprising $NCSe^-$ ligands [25]. Due to the release of NCS^- or $NCSe^-$ anions from the complex, not only cadmium but also these toxic anions could interact with suitable target groups of biomolecules.

Acknowledgements

This study was financially supported by Sanofi Aventis Pharma Slovakia. The authors thank Assoc. Prof. Iveta Ondrejkovičová from Faculty of Chemical and Food Technology, Slovak University of Technology in Bratislava for preparation of the studied compounds.

References

[1] Devrim O., Ozturk Y. and Ozkay U.D.: Turkiye Kinkleri Tip Bilimleri Dergisi., 2009, **29**, 708-715.
[2] Gomez M.R., Cerutti S., Olsina R.A., Silva M.F. and Martinez L.D.: J. Pharm. Biomed. Anal., 2004, **34**, 569-576
[3] Miller-Rushing A.J. and Primack R.B.: Ecology, 2008, **89**, 332-341.
[4] Tirillini B., Ricci A., Pintore G., Chessa M. and Singhinolfi S.: Fitoterapia, 2006, **77**, 147-170.
[5] Murch S.J., Haq K., Rupashinge H.P.V. and Saxena P.K.: Environ. Exp. Bot., 2003, **49**, 251-257.
[6] Masarovičová E., Kráľová K., Kummerová M. and Kmentová E.: Biologia, 2004, **59** (Suppl 13), 211-214.
[7] Lešíková J., Kráľová K., Masarovičová E., Kubová J. and Ondrejkovičová I.: Acta Horticult. (ISHS), 2007, **749**, 223-229.
[8] Kráľová K., Masarovičová E., Ondrejkovičová I. and Bujdoš M.: Chem. Pap., 2007, **61**, 171-175.
[9] Kráľová K., Masarovičová E., Lešíková J. and Ondrejkovičová I.: Chem. Pap., 2006, **60**, 149-153.
[10] Lichtenthaler H.K.: Methods Enzymol., 1987, **148**, 350-382.
[11] Stobart A.K., Griffiths W.T., Ameen-Bukhari I. and Sherwood R.P.: Physiol. Plant., 1985, **63**, 293-298.
[12] Padmaja K., Prasad D.D.K. and Prasad A.R.K.: Photosynthetica, 1990, **24**, 399-405.
[13] Somashekaraiah B., Padmaja K. and Prasad A.: Physiol. Plant., 1992, **85**, 85-89.
[14] Xue T.L., Hartikainen H. and Piironen V.: Plant & Soil., 2001, **237**, 55-61.
[15] Mazzafera P.: Plant & Soil., 1998, **201**, 189-196.
[16] Barceló J. and Poschenrieder C.: J. Plant Nutr., 1990, **13**, 1-37.
[17] Poschenrieder C., Gunse B. and Barceló J.: Plant Physiol., 1989, **90**, 1365-1371.
[18] Sors T.G., Ellis D. R. and Salt D.E.: Photosynth. Res., 2005, **86**, 373-389.
[19] Chizzola R. and Lukas B.: Water, Air, Soil Pollut., 2006, **170**, 331-343.
[20] Moreno-Jiménez E., Penalosa J.M., Manzano R., Carpena-Ruiz R.O., Gamarra R. and Esteban E.: J. Hazard. Mater., 2009, **162**, 854-859.
[21] Germ M., Stibilj V., Kreft S., Gaberscik A., Pajk F. and Kreft I.: Food Chem., 2009, **117**, 204-206.
[22] Shanker K., Mishra S., Srivastava S., Srivastava R., Dass S., Prakash S. and Srivastava M.M.: Bull. Environ. Contam. Toxicol., 1996, **56**, 419.
[23] Peško M., Kráľová K. and Masarovičová E.: Fresen. Environ. Bull., 2010, **19**, in press.
[24] Škopíková A., Kráľová K. and Masarovičová E.: Proc. ECOpole`08, 2008, **2**, 135-139.
[25] Valigura D., Gracza T., Mašlejová A., Papánková B., Šíma J. and Špirková K.: Chemical Tables, p. 189. Slovak University of Technology. Bratislava 2004 (in Slovak).

WPŁYW RÓŻNYCH FORM SELENU NA AKUMULACJĘ ZWIĄZKÓW KADMU PRZEZ ROŚLINY *Hypericum perforatum*

Abstrakt: Badano wpływ związków kadmu zawierających selen na różnym stopniu utlenienia m.in. Se(IV), Se(VI) i Se(-II) na charakterystyki produkcji, zawartość wody w pędach i zawartość chlorofilu w liściach, a także akumulację Cd i Se w organach roślin *Hypericum perforatum*. Do porównania wpływu Se i S na wyżej wymienione parametry wykorzystano kompleksy amidu kwasu nikotynowego (nia) $Cd(NCX)_2(nia)_2$, gdzie X = S lub Se, a także $CdSO_4$. Zastosowanie badanych związków o stężeniach 12, 24 i 60 µmol · dm^{-3} zmniejszało suchą masą organów roślin. Zazwyczaj zarówno zawartości wody w pędach, jak i zawartości chlorofilu w liściach malała wraz ze wzrostem stężenia związku. Specjacja Se miała znaczny wpływ na stężenie zaakumulowanych Cd i Se [mg · g^{-1} s.m.] w organach roślin *H. perforatum,* co znalazło swoje odzwierciedlenie w wartościach współczynników bioakumulacji (BAF), współczynników transferu (TF), a także w stężeniach zaakumulowanych przez roślinę metali. Porównanie wpływu $CdSO_4$ i $CdSeO_4$ oraz $Cd(NCS)_2(nia)_2$ i $Cd(NCSe)_2(nia)$ wykazało, że wymiana S na Se w ligandzie NCX^- prowadziła do zmniejszenia przenoszenia Cd do pędów. Zastosowanie $CdSeO_4$ spowodowało intensywne przenoszenie Cd oraz Se do pędów. Stężenie Cd w pędach w odniesieniu do całkowitego stężenia Cd zaakumulowanego w roślinie wynosiło ok. 20% w przypadku stosowania $CdSO_4$ i $Cd(NCS)_2(nia)_2$ oraz około 12,8, 10 i 6% w przypadku stosowania $Cd(NCSe)_2(nia)_2$, $CdSeO_4$ i $CdSeO_3$. Z drugiej strony, po dodaniu $CdSeO_4$, $Cd(NCSe)_2(nia)_2$ i $CdSeO_3$ stosunek stężeń Se w pędach do całkowitego stężenia Se zaakumulowanego przez rośliny *H. perforatum* osiągnął ok. 86, 48,6 i 45,9%.

Słowa kluczowe: bioakumulacja, kadm, chlorofil, selenian(IV), selenian(VI), ziele dziurawca, zawartość wody