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Cross-adaptation of spring barley (*Hordeum vulgare* L.) to environmental stress induced by heavy metals

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The aim of this study was to investigate the possibilities of spring barley (cv. 'Aura DS') cross-adaptation to the impact of different (Cu, Zn, Cr, Ni, Cd and Pb) heavy metals. The most efficient cross-adaptation was detected after pretreatment with Cd and Ni. Pretreatment with Cd caused the most essential increase in tolerance to Cr and Ni, was the only stressor to whose impact spring barley was not more tolerant after pretreatment with Cd. After pretreatment by Ni, spring barley grew approximately 1.5 times better than not adapted ones, and only Cr was the metal to whose impact spring barley was not more tolerant after pretreatment with Ni. Cr and Pb, contrary to Cd and Ni, were detected to be the metals that almost did not stimulate cross-adaptation of spring barley to the other heavy metals and even adaptation to themselves. Cross-adaptive relations among the heavy metals were fou to be not always reciprocal. Cadmium was detected as a heavy metal with the most both-sided cross-adaptive relations with other metals and any reciprocal cross-adaptive relation were not detected for Cr and Pb.

Key words: spring barley, heavy metals, stress, pretreatment, cross-adaptation

INTRODUCTION

The growth and development of plants are controlled by a variety of external factors. Along with natural ones (extreme temperatures, water deficit or excess, high solar irradiance, deficit of nutrients, etc.), an increase in the anthropogenic pressure and first of all environmental pollution have resulted in the appearance of additional powerful external stress factors (acid rains, increased concentrations of ground level ozone, heavy metals, etc.) to which plants are not adapted evolutionarily (Larcher, 1995).

According to the general concept, stress is a very important plant reaction to the impact of different environmental factors. A stressor is usually considered as an external factor leading to a significant deviation from the optimal conditions (Dickinson, Murphy, 1998; Taiz, Zeiger, 2002; Alexieva at al., 2003). H. Selye, the pioneer of the concept of stress (1936), treated stress as a dynamic response of the whole organism to stress factors. Three main phases of stress were distinguished: alarm, resistance (adaptation) and exhaustion. Later, the fourth phase – regeneration (recovery) – was added, which was considered as a partial or full regeneration of a physiological function after the stress factor has been removed or reduced (Lichtenthaler, 1996). Following the ideas of H. Selye and other specialists in plant stress theory (Larcher, 1995; Godbold, 1998), in this paper stress will be treated as a response of plants to an external stress factor (stressor).

Adaptation of plants to environmental stressors is very important for plant growth, development and survival. In this context, adaptation is considered as relatively fast inheritable biochemical, physiological and / or morphological changes that improve plant resistance to the impact of a stress factor and allow to survive in the modified environment (Lichtenthaler, 1996; Dat et al., 1999). However, adaptation and increased resistance require additional energy and metabolites that are needed to restore homeostasis. Taking into account that the general amount of energy and nutrients accessible for plants are limited, reduction in growth and biomass formation is the most common currency paid to maintain the adaptation process. For this reason, it was presumed that adaptation to one stressor results in a reduced tolerance to another stressor, if the latter exceeds the limits of regeneration capacity and / or requires a different pathway of resistance (Larcher, 1995; Godbold, 1998).

However, adaptation to one stress factor can increase the tolerance of plants to other stressors, if they require similar physiological and/or morphological modifications. Such phenomenon is usually called cross-adaptation

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or cross-tolerance (Godbold, 1998; Dat et al., 1999; Alexieva et al., 2003; Streb et al., 2008). One of the first cases when the possibility of cross-adaptation was demonstrated was a survey of plant resistance to heavy metals in a smelter territory. Multiple plant resistance to different heavy metals was detected in this research. The plants growing in nickel / cupper-contaminated soils were found to be more resistant to lead and zinc despite the lack of elevated levels of these metals in the soil (Cox, Hutchinson, 1980). Similar conclusions were made on the basis of other investigations conducted in the environments polluted by different heavy metals (Watmough, Dickinson, 1996; Gonneli et al., 2001; Streb et al., 2008).

An increasing number of investigations shows that cross-adaptation is possible not only in the case of subsequent impact of different heavy metals and is a much more general event. Exposure of plants to moderate natural and anthropogenic stressors induces an increased resistance to different stress factors (Sabehat et al., 1998, Streb et al., 2008). For example, it salt stress was shown to increase cold tolerance (Ryu et al., 1995); heat stress protects against heavy metal toxicity (Bonha-Smith et al., 1987), water deficit increases resistance to ozone (Bender et al., 1991), UV-B radiation increase resistance to temperature extremes and some viruses (Yalpani et al., 1994; Alexieva, 2003), etc.

Although the possible general mechanisms of plant adaptation to different stressors are still poorly understood, cross-adaptation is often attributed to the fact that different stressors cause similar effects at the cellular level (Noctor, Foyer, 1998; Dat et al., 2000; Taiz, Zeiger, 2002). A lot of investigators support the idea that oxidative stress is caused by different natural and anthropogenic stress factors, including temperature extremes, water deficite, high light intensity, pathogens, mechanical damages, salt stress, ozone, heavy metals, noxious gases, UV radiation, acid rains, application of pesticides, etc. (Dat et al., 2000; Ivanov et al., 2003).

Heavy metals can cause an oxidative stress in two ways: they can take part in the formation of reactive oxygen species (ROS), such as superoxide ($O_2^{\bullet -}$), hydrogen peroxide (H_2O_2) and hydroxyl radical ($HO^{\bullet}$) or damage the antioxidative system and inhibit ROS removal or scavenging (Ercal et al., 2001; Prasad, 2004). Redox-active metals, such as copper, iron and, according to some authors, chromium, vanadium and cobalt, are involved in the formation of hydrogen peroxide and most toxic hydroxyl radical via Haber-Weiss and Fenton reactions (Okamoto et al., 2001; Valko et al., 2005; Sharma et al., 2008). Metals without redox capacity, such as cadmium, lead, mercury, nickel, zinc, cause a depletion of the antioxidant glutathione pool and antioxidative enzymes (catalases, superoxide dismutase, ascorbate peroxidase, etc.), thus increasing the amount of reactive oxygen species (Schutzendubel, Polle, 2001; Okamoto et al., 2001; Prasad, 2004).

Plants have developed antioxidative system based on enzymatic and non-enzymatic defense mechanisms, and the antioxidant pathway is considered as the most reliable way to determine cross-adaptation and cross-resistance (Noctor, Foyer, 1998; Dat et al., 2000). Recent investigations have driven attention to the possibilities of specific proteins inducing cross-adaptation to different stressors. Initially it was established that plants respond to heat shock by inducing the synthesis of polypeptides known as heat shock proteins (Sabehat et al., 1998; Gong et al., 2001). Other investigations have shown that synthesis of heat shock proteins is also induced by other stress factors, such as salinity, heavy metals, etc. and can result in cross-adaptation of plants to various stressors (Pareek et al., 1995). However, cross-adaptation is not a general occurrence, and its possibilities depend on plant species and the stage of ontogenesis, the type and strength of stress factors, etc. (Watmough, Dickinson, 1996; Alexieva, 2003; Zhang, Shu, 2006). Really, plant response to multiple stress factors is an extremely complicated process because several stressors may cause an impact on the same target as well as a single stressor may have multiple impacts on plants (Lutts, 2001). On the other hand, plants usually employ a number of different ways to deal with stress, using different mechanisms such as enzymatic or non-enzymatic detoxication, heat shock proteins, metallothioneins, phytochelatins, sequestration of metal ions, etc. (Sabehat et al., 1998; Noctor, Foyer, 1998; Dat et al., 2000). As noted by J. Zhang, W. S. Shu (2006), tolerance of plants to different stressors is more likely to involve an integrated network of multiple response processes than several isolated functions.

The aim of this study was to investigate the possibilities of spring barley (cv. 'Aura DS') cross-adaptation to the impact of different heavy metals.

MATERIALS AND METHODS

The Lithuanian cultivar 'Aura DS' of spring barley (*Hordeum vulgare* L.) was chosen as a research object because of its high sensitivity to the impact of heavy metals (Blažytė, 2005). Experiments were carried out in a vegetation room with the controlled environment: photoperiod 14 hours, average temperature 22 °C, relative humidity 65%. Light was provided by Philips MASTER Green Power CG T 600 W lamps with the light intensity at the level of plants 14000 Lx.

The plants, after seed sterilization and germination, were grown for five days in an aerated nutrient solution (0.4 mM $CaCl_2$, 0.65 mM KNO_3, 0.25 mM $MgCl_2 \cdot 6H_2O$, 0.01 mM $(NH_4)_2SO_4$, 0.04 mM NH_4NO_3 (Aniol, 1997; Ramaškevičienė et al., 2001) supplemented with different amounts of heavy metal salts; 24 germinated seeds were planted in each vegetation vessel, and three replicates were used for each treatment.

Six heavy metals – copper (Cu), zinc (Zn), chromium (Cr), nickel (Ni), lead (Pb) and cadmium (Cd) – were investigated in this study. Cu, Zn and Ni are considered to be essential and Cd, Pb and Cr non-essential metals for plant metabolism. Tak-

Table. **Effective heavy metal concentrations for 20% and 60% dry biomass reduction**

Heavy metal	EC20, µM	EC60, µM
Cu	1.9	13
Zn	5.8	364
Cr	0.5	130
Ni	0.9	15
Pb	2.7	683
Cd	0.4	11

ing into account that bivalent metals are considered as most toxic to plants (Kovacevic et al., 1999; Pandey, Sharma, 2002), the following salts were used for experiments: $CuSO_4 \cdot 5H_2O$; $CdSO_4 \cdot 8/3H_2O$; Pb SO_4; Ni $SO_4 \cdot 6H_2O$; $Cr_2(SO_4)_3 \cdot H_2O$; Zn $SO_4 \cdot 7H_2O$. Chromium sulfate is the only exception in this list, as Cr is trivalent in the study compound. Trivalent Cr is toxic to plants even at low concentrations and was reported to cause a severe oxidative damage to plant cells (Panda, Choudhury, 2005).

Cross-adaptation experiments were carried out in two stages. During the first stage, one group of plants were grown in a pure nutrient solution (reference treatment) and the other group of plants in a nutrient solution supplemented with relatively low concentrations of heavy metals (EC_{20} for dry biomass). The period of the main treatment was started at the second stage: barley seedlings were translocated to the nutrient solution supplemented with relatively high concentrations of heavy metals (EC_{60} for dry biomass). EC_{20} and EC_{60} had been determined during the previous experiments with the same cultivar of spring barley. Heavy metal concentrations used to reach 20% and 60% of growth inhibition are presented in Table. The pretreatment stage and the stage of the main treatment lasted 5 days each.

Biomass reduction is a key indicator which shows the impact of heavy metals. The relatively low (EC_{20} for dry biomass) growth inhibition means the metal concentration necessary to reach the 20% of growth inhibition as compared to reference treatment. The relatively strong (EC_{60} for dry biomass) growth inhibition means the metal concentration necessary to reach the 60% of growth inhibition as compared to reference treatment.

The biomass of plants after the first and the second stages of treatment was measured and the increment of biomass during the stage of the main treatment was assessed as a difference between the biomass after pretreatment stage and the biomass at the end of experiment. To determine dry weight, plants were dried in an electric oven at 70 °C for 24 hours.

The adaptation index (AI) for different combinations of heavy metals was calculated as a ratio of the increment of the dry biomass of pretreated plants to the increment of non-pretreated ones. STATISTICA 6 software was applied for the statistical analysis and presentation of data. Data on the meanvalues of the indicators with confidence limits (± SE) are presented in the figures.

RESULTS

Data on the increment of the dry biomass (roots and shoots) of spring barley during the main treatment with the heavy metals are presented in Fig. 1.

A couple of bars (white and grey) are dedicated to each metal. White bars represent the increment of dry biomass without pretreatment (reference treatment), i. e. when plants in the first stage of experiment were grown in pure nutrient solution, and grey bars represent the increment of dry biomass of pretreated plants, i. e. when plants in the first stage of experiment were grown in a nutrient solution supplemented with EC_{20} of the heavy metals (see Materials and Methods). The values are the means of plant dry biomass ± SE.

Three different patterns can be distinguished comparing the increment in dry biomass of pretreated and non-pretreated plants (Fig. 1.):

1. Pretreated plants grew up better than non-pretreated, and the biomass increment of pretreated plants during the period of the main treatment was significantly ($p < 0.05$) higher in the increment of non-pretreated ones. This case was considered as an indication of adaptation or cross-adaptation, i. e. plants after pretreatment became more tolerant to the impact of higher concentrations of the same or another heavy metal.
2. No statistically significant differences were found between the biomass increment of pretreated and non-pretreated plants ($p > 0.05$), i. e. no physiological adaptation was achieved in this case.
3. Pretreated plants grew up worse than non-pretreated ones ($p < 0.05$), and it is considered as an evidence of a reduced resistance of spring barley to heavy metal stress because of pretreatment with the same or another metal.

The adaptation index (AI) was calculated for a more evident comparison of the ability of the heavy metals studied to stimulate adaptation to the same or anoother metal (Fig. 2). The solid horizontal line in Fig. 2 presents cases when the increment of the dry biomass of pretreated plants equalled to the increment in the dry biomass of non-pretreated plants (AI = 1), i. e. no adaptive changes took place in the pretreatment period.

Cases of insignificant ($p > 0.05$) differences between biomass increment in pretreated and non-pretreated plants (A ~ 1) are represented by grey bars. Cases when biomass increment in pretreated plants was significantly ($p < 0.05$) higher than in non-pretreated ones (AI > 1) are represented by white bars. In the opposite cases, i. e. when the biomass increment in pretreated plants was significantly lower than in non-pretreated ones (AI < 1) are represented by black bars. A pretreatment metal is indicated on the top of each box, and abbreviations of metals used in the main treatment are presented below the bars (Fig. 2).

As one can see in Fig. 2, the most efficient cross-adaptation was achieved after pretreatment with Cd and Ni.

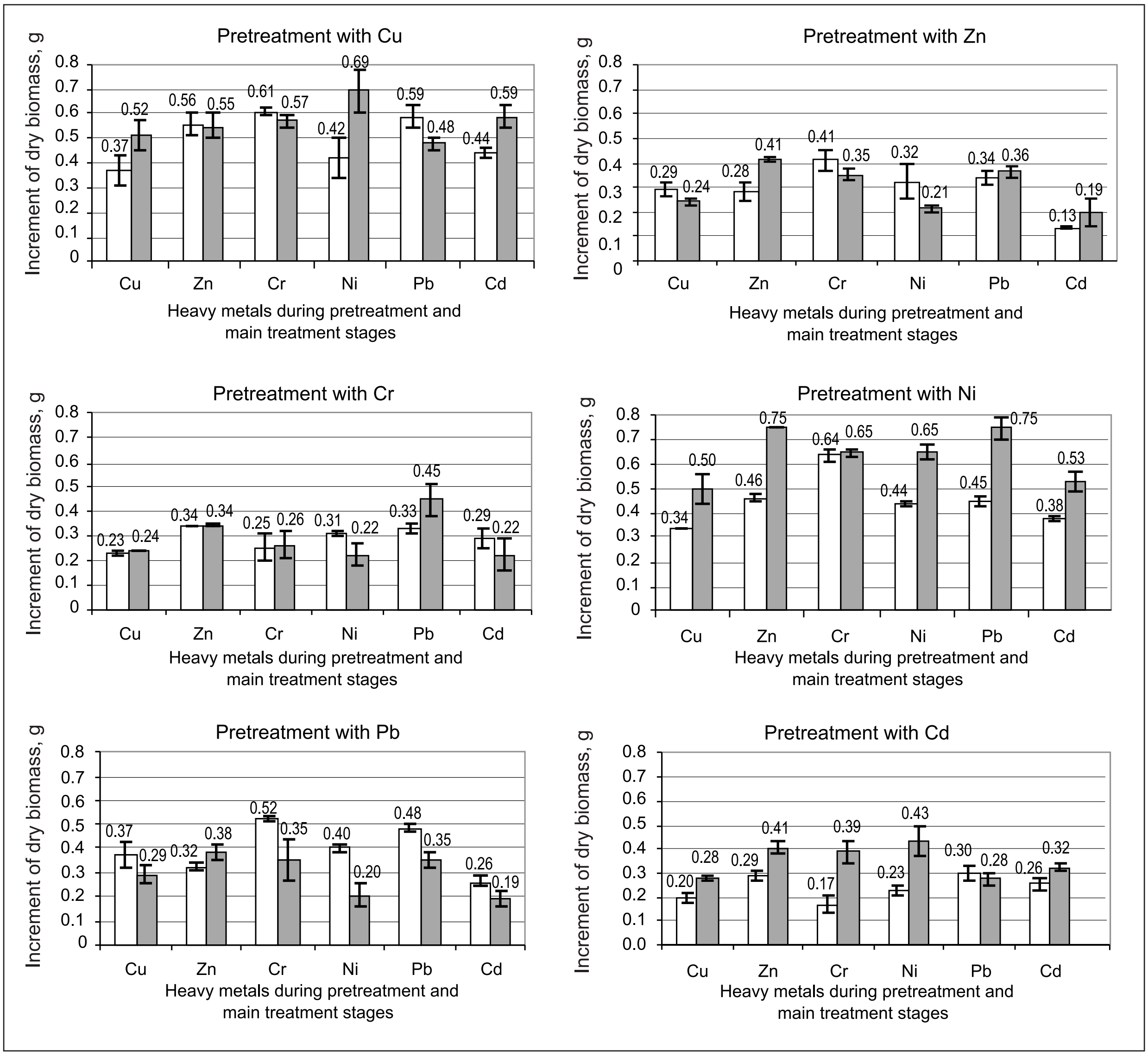

Fig. 1. Effect of pretreatment on the growth of spring barley under EC60 of different heavy metals (white bars – without pretreatment, grey bars – pretreated)

Pretreatment with Cd caused the most essential increase in tolerance to Cr (AI = 2.29) and Ni (AI = 1.87), and Pb was the only stressor to whose impact spring barley was not more tolerant after pretreatment with Cd (AI = 0.93). After pretreatment with Ni, the adaptation indexes for most of the study metals were rather similar, and plants adapted to Ni grew approximately 1.5 times better (AI varied from 1.39 in the case of Cd to 1.67 in the case of Pb) than not adapted ones. Cr was the only heavy metal to which impact spring barley was not more tolerant after pretreatment with Ni (AI = 1.02).

It is necessary to mention that cross-adaptation among heavy metals does not necessarily mean a mutual relationship. A scheme of cross-adaptive relations was created in order to summarize the results of our investigations (Fig. 3). An arrow between different heavy metals shows the direction of cross-adaptation. The exit of the arrow shows the metal applied in the pretreatment stage of the experiment, and the tip of the arrow indicates the metal applied during the main treatment.

Pretreatment with Cd resulted in a higher tolerance of spring barley to Cr, Cu, Zn and Ni, and vice versa – pretreatment with Cu, Zn and Ni resulted in a higher tolerance to the impact of Cd (Fig. 3). Accordingly, pretreatment with Ni increased the tolerance to Cu, Zn, Cd and Pb, but the tolerance to Ni was increased by pretreatment with only two of these metals – Cu and Cd. Pretreatment with Cu increased the tolerance to Ni and Cd and, vice versa, pretreatment with these heavy metals increased the tolerance to Cu. Pretreatment with Zn increased the tolerance only to Cd, but the tolerance to Zn was increased by three heavy metals – Cd, Ni and Pb. Pretreatment with Pb increased the tolerance only to Zn and two metals, Cr and Ni. And finally, pretreatment with Cr increased the tolerance only to Pb, and the tolerance to Cr was increased only by Cd.

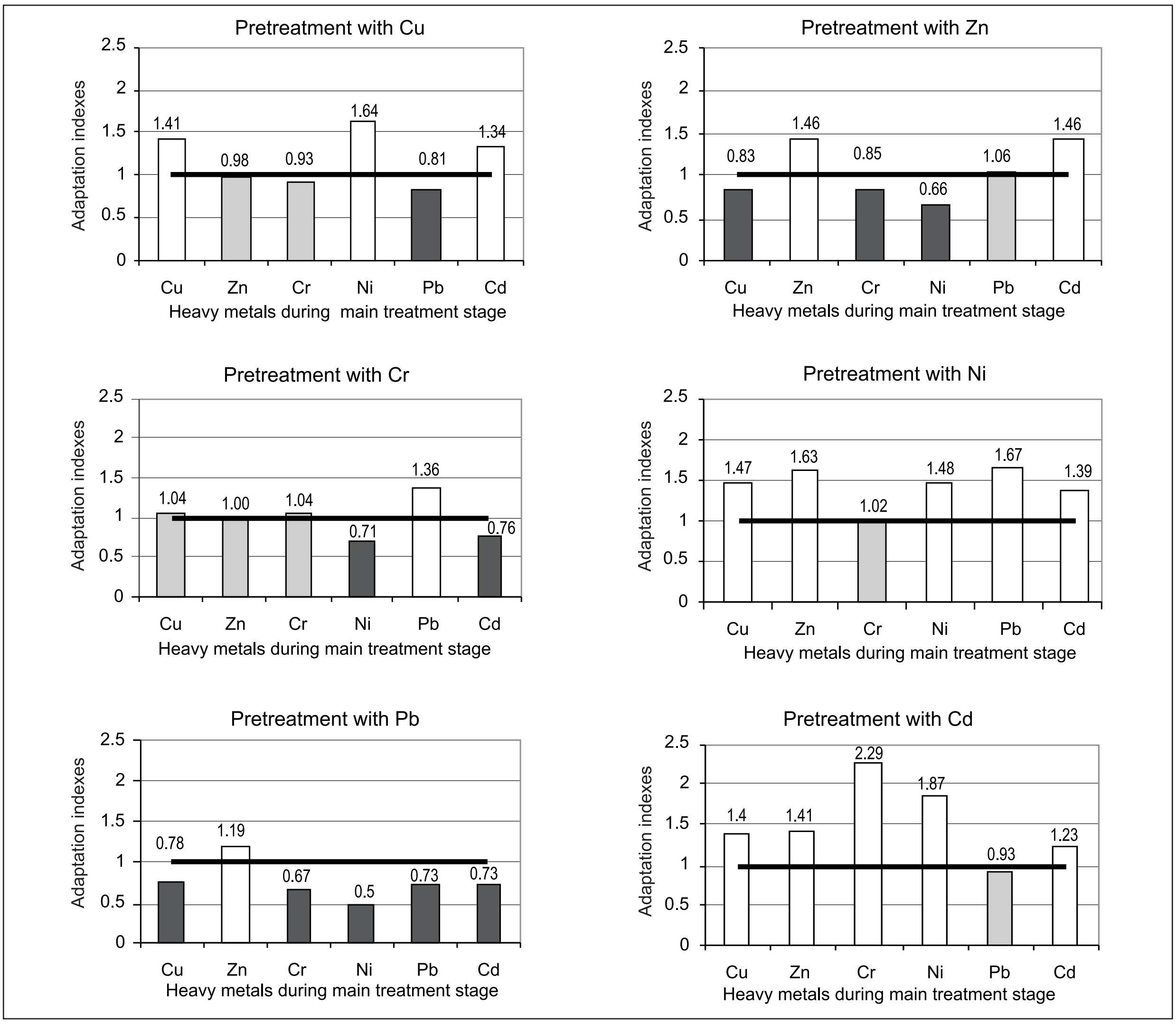

Fig. 2. Adaptation indexes (AI) for different combinations of heavy metals during pretreatment and the main treatment periods (grey bars – AI ~ 1; white bars – AI > 1; black bars – AI < 1)

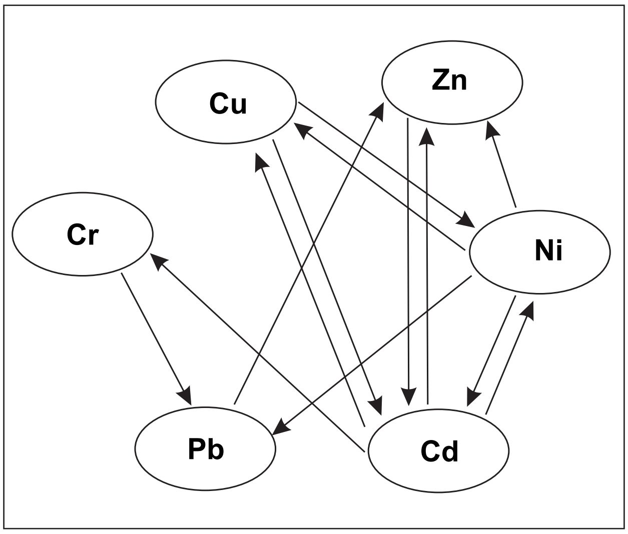

Fig. 3. Scheme of cross-adaptive relations among the study metals

DISCUSSION

The results of this investigation demonstrate that cross-tolerance among different heavy metals can be initiated by a short-term pretreatment with a moderate concentration of a particular heavy metal. However, metals differ in their ability to induce a plant's resistance to the same or other heavy metals. As is obvious from Figs. 2 and 3, Cd should be distinguished as a heavy metal with the highest number of interrelations with the other heavy metals. The ability of low Cd concentrations to enhance the tolerance of plants to the impact of not only different heavy metals but also of natural environmental stressors (extreme temperatures, UV-B radiation, etc.) was noted by different investigators (Verkleij, Prast, 1989; Malick, Rai, 1998; Zhang, Shu, 2006). This phenomenon is usually explained by the ability of divalent Cd ions to stimulate the biosynthesis of phytochelatins as metal-binding and antioxidative compounds. Phytochelatins are identified as sulfhydryl-rich non-protein peptides, and their main precursor is reduced glutathione. Phytochelatins form complexes with different heavy metals and detoxify them by sequestration in vacuoles; however, their biosynthesis is initiated mainly by divalent Cd ions (Clemens, 2001; Prasad, 2004; Almeida, 2007). Pretreatment with Cd enhanced tolerance to Cr, Ni, Zn and Cu. Pb was the only metal to which plants became not more tolerant after pretreatment with Cd. It is difficult to explain this phenomenon because of the lack of understanding the molecular mechanisms of tolerance to heavy metals. On the other hand, it is proposed that the main plant's resistance strategy to Pb is intensive accumulation of this heavy metal in roots, mainly based on the low mobility and big size of Pb ions. Cd differs from Pb in this respect, since a much smaller part of Cd ions is accumulated in roots. For this reason, tolerance to this metal could be based on some biochemical mechanisms acting in shoots (Kamel, 2008; Juknys et al., 2009). Thus, a possible reason why Cd did not stimulate tolerance to Pb may be related to different detoxification pathways of these heavy metals.

As already mentioned, pretreatment with Cd not only enhanced tolerance to Cu, Zn and Ni, but also increased the tolerance of spring barley to Cd. Cu, Zn and Ni are considered to be essential metals to plants. They are able to reduce the impact of toxic heavy metals by competing for their binding sites in cells, ameliorating plant's metabolism and antioxidative capacity (Mallick, Rai, 1998; Aravind, Prasad, 2005; Seregin, Kozhevnikova, 2006).

Pretreatment with Ni was effective in tolerance formation to Pb, Zn, Cd and Cu. Although Ni does not stimulate the biosynthesis of phytochelatins (Clemens, 2001; Salt et al., 2002; Seregin, Kozhevnikova, 2006), there may be other mechanisms of the hardening effect of Ni. In addition to its role as a micronutrient, an excess of Ni in plant environment triggers production of organic acids (citric, oxalic, some amino acids) which are able to bind heavy metal ions and transport them to vacuoles. This feature is rather often mentioned as a possible mechanism of Ni-induced cross-tolerance to other heavy metals (Prasad, 2004; Jocsak et al., 2005). On the other hand, Ni is an important component of metallocoenzymes which are able to assist in the enzymatic catalysis of specific reactions and to bind tightly divalent metal ions (Prasad, 2004). This property of Ni explains why in our study pretreatment with Ni stimulated cross-adaptation to all the heavy metals except chromium (Fig. 2).

The other essential metals, Cu and Zn, were less effective in cross-tolerance formation. Cu increased tolerance to Ni and Cd while Zn only to Cd. Concerning reciprocal adaptive relations between Zn and Cd, it is necessary to note that the biological role of these metals is very different. Zn is an essential micronutrient for plant growth and development, a cofactor of many enzymes, and plays an important role in the catalysis of photosynthesis, respiration, protein synthesis and other metabolic processes. Cd is considered as a non-essential and toxic element without any metabolic significance (Rout, Das, 2003; Aravind, Prasad, 2005). On the other hand, both Zn and Cd belong to the group II B of the Periodic Table and have some parallel physical and chemical properties allowing Cd and Zn to bind on the same target sites of biomolecules. This could be considered as the main reason for their cross-tolerance (Verkleij, Prast, 1989). However, there are no evidences of Zn effect on tolerance formation to heavy metals other than Cd.

Cu, in comparison with other micronutrients used in this research, has a very high oxidative capacity. Slight concentrations of Cu are necessary for antioxidative system activity, but higher amounts of Cu may disturb the redox homeostasis in the cell. Moreover, an excess of Cu ions directly initiates lipid peroxidation which results in dysfunctions of plasmic membranes (Blokhina et al., 2003). The disturbance of antioxidive balance and oxidative damage could determine a rather diverse impact of Cu on spring barley tolerance to the other heavy metals.

Cr and Pb, contrary to Cd and Ni, were detected to be the metals that almost did not stimulate spring barley cross-adaptation to the other heavy metals studied and even adaptation to itself. In the case of Cr pretreatment, Pb was the only metal to whose impact spring barley became more tolerant; after pretreatment with Pb, cross-adaptation was detected only to Zn (Fig. 2).

It should be noted that plant resistance to Cr is still poorely understood, and there is little information about the role of phytochelatins and metallothioneins in Cr detoxication. A presumption is made that metallothioneins rather than phytochelatins are responsible for binding Cr ions, and high transcription rates of these peptides were detected in Cr-tolerant species of plants (Panda, Choudhury, 2005). Moreover, trivalent Cr is considered to be a hard acceptor of electrons and, differently from other heavy metals, interacts strongly with oxygen ligands (Gardea-Torresdey et al., 2002). The different pathways of Cr toxicity and detoxication could be the reason for the weak cross-adaptation of Cr-pretreated plants.

Discussing the effect of pretreatment with Pb, it is necessary to note that Pb-pretreated plants became less resistant to the impact of the study metals (except Zn), including Pb itself (Fig. 2). As mentioned above, Pb is mainly immobilized in roots because of its low mobility and the big size of ions (Kamel, 2008; Juknys et al., 2009). Taking into account that phytochelatin is biosynthesized mainly in roots (Cobett, Goldsbrough, 2002; Inouhe, 2005), excessive accumulation of Pb in roots could inhibit phythochelatin production. Moreover, restricted synthesis of gluthatione, an important antioxidant and phytochelatin precursor, was noted after treatment with Pb (Sun et al., 2005). The decreased synthesis of phytochelatins and antioxidative capacity could be the reasons for a lower resistance of plants to most of the study heavy metals after pretreatment by Pb.

Considering that plants are usually exposed to multiple stressors, understanding of their interaction and possibilities of cross-adaptation can be used for assessing the consequences of environmental pollution to the growth and productivity of agricultural plants. Knowledge of interactions of heavy metals and of the possibilities of plants to aquire tolerance to the impact of different stressors can assist in developing the methods and technologies that are able to reduce environmental impact on plants. However, there is still a lack of understanding how plants adapt to multiple stressors. Studies concerning croos-adaptation among heavy metals are scanty. Our research could be characterized as a comprehensive study involving cross-adaptive interactions among six different heavy metals. On the other hand, a deeper insight into the biochemical mechanisms of tolerance formation are needed in future investigations.

CONCLUSIONS

1. The most efficient cross-adaptation was achieved after pretreatment with Cd and Ni. Pretreatment with Cd caused the most essential increase in tolerance to Cr (AI = 2.29) and Ni (AI = 1.87), and Pb was the only stressor to whose impact spring barley was not more tolerant after pretreatment with Cd (AI = 0.93). After pretreatment with Ni, adaptation indexes for most of the heavy metals studied were rather similar, and plants adapted to Ni grew up approximately 1,5 times better than not adapted ones. Only Cr was the metal to whose impact spring barley did not become more tolerant after pretreatment with Ni (AI = 1.02).

2. Cr and Pb, contrary to Cd and Ni, were detected to be the metals that almost did not stimulate cross-adaptation of spring barley to the other heavy metals and even adaptation to itself. In the case of Cr pretreatment, Pb was the only metal to whose impact spring barley became more tolerant (AI = 1.36), and after Pb pretreatment only cross-adaptation to Zn (AI = 1.19) was detected.

3. Cross-adaptive relations between heavy metals are not always reciprocal. Cd should be accepted as a heavy metal with the highest number of mutual relations with the other metals. Pretreatment with Cd resulted in an enhanced tolerance to Cu, Zn and Ni and pretreatment by the latter metals increased spring barley tolerance to Cd. In the case of Cu, reciprocal adaptive relations were characteristic with Ni and Cd, in the case of Ni with Cd and Cu, and in the case of Zn only with Cd. No reciprocal cross-adaptive relations were detected for Cr and Pb.

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VASARINIŲ MIEŽIŲ (*HORDEUM VULGARE* L.) KRYŽMINĖ ADAPTACIJA, ESANT SKIRTINGŲ SUNKIŲJŲ METALŲ SUKELTAM APLINKOS STRESUI

Santrauka

Šių tyrimų tikslas buvo nustatyti vasarinių miežių (*Hordeum vulgare* L. veislė 'Aura DS') kryžminės adaptacijos galimybes, esant skirtingų sunkiųjų metalų (Cu, Zn, Cr, Ni, Cd, Pb) poveikiui. Stipriausia kryžminė adaptacija pasireiškė, kai adaptacijos periodu buvo naudojami Cd ir Ni. Nustatyta, kad vasarinių mieži-ų tolerancija Cr ir Ni padidėjo adaptacijos periodu panaudojus Cd, tuo tarpu švinas buvo vienintelis stresorius, kuriam vasarinių miežių tolerancija nepadidėjo, nors adaptacijos periodu buvo veikiamas Cd. Vasariniai miežiai, kurie adaptacijos periodu buvo veikiami Ni, augo 1,5 karto geriau negu neadaptuoti. Vieninteliam Cr vasarinių miežių tolerancija nepadidėjo, adaptacijos periodu naudojant Ni. Nustatyta, kad Cr ir Pb, kitaip nei Cd ir Ni, beveik nestimuliavo vasarinių miežių kryžminės adaptacijos susiformavimo nagrinėtiems metalams. Vasarinių miežių, kurie adaptacijos periodu buvo paveikti mažų koncentracijų Cr ir Pb, didesnės tolerancijos šių metalų didelėms koncentracijoms nenustatyta.

Tyrimų rezultatai parodė, kad sunkiųjų metalų kryžminė adaptacija ne visada yra abipusė. Galima teigti, kad Cd sudarė daugiausiai abipusių kryžminės adaptacijos sąveikų su kitais sunkiaisiais metalais, ir nebuvo nustatyta nei vienos abipusės Cr ir Pb kryžminės sąveikos.

Raktažodžiai: vasariniai miežiai, sunkieji metalai, stresas, adaptacijos periodas, kryžminė adaptacija