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Effect of cadmium on mineral composition of rice grain

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ABSTRACT

The use of phosphate fertilizers plays a significant role in cadmium (Cd) accumulation in the soil. In this regards the purpose of our work was to study the effect of Cd on content of mineral elements in the grain of rice varieties. Plants were grown in pots filled with soil, containing 2 mmol/kg of $CdSO_4$. Cadmium was not found in rice grain. The content of mineral elements in grain of rice varieties is decreased in the following order (% of control) : Mg–Bakanaskyi (98) > Madina (93) > Chapsari (86%) > Barakat (84); Mn–Bakanaskyi (85) > Chapsari (72) > Madina (71) > Barakat (64); Fe– Madina (89) > Bakanaskyi (72) > Chapsari (57) > Barakat (48); Zn–Madina (93) > Bakanaskyi (87) = Chapsari (87) > Barakat (85); Cu–Chapsari (90) > Bakanaskyi (89) > Madina (83) > Barakat (73). Cadmium decreased the content of necessary mineral elements in rice grain. Content of Mg and Mn decreased in the least degree in Bakanaskyi cv; Fe and Zn content – in Madina variety; Cu content – in Chapsari cv. Under cadmium stress content of mineral elements decreased in the greatest degree in Barakat and Chapsari cvs.

Key words : Cadmium, copper, grain, iron, magnesium, manganese, rice, zinc

INTRODUCTION

Cadmium is a heavy metal, usually present in trace amounts in the soil. However, human activities and industrial agricultural practices increase the level of cadmium content in the soil. Overall use of fertilizer and pesticides can contain large amounts of the metal, which is a long time enters into the soil with fertilizers (Gimeno-Garcia *et al.,* 1996). Most Cd, contained in the soil, for plants is available because the soluble fraction is up to 35% of total (Andreu and Boluda, 1995). The use of phosphate fertilizers plays a significant role in the accumulation of Cd in soil. The degree of cadmium contamination of soil using

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phosphate fertilizers may reach 300 mg/kg (Grant *et al.,* 2010; Tirado and Allsopp, 2012; Singh and Maiti, 2016).

Cadmium is highly toxic and mobile. It is also noted the greater availability of Cd compared with other heavy metals such as Zn, Cu, Pb, which has a higher biological absorption coefficient (Lee *et al.,* 1998). Cadmium could accumulate during many years in human body, so the consumption of food containing this metal can induce chronic toxicity (Jackson and Alloway, 1992; FAO/ WHO, 1995). Cadmium is a calcium antagonist. Increased accumulation of cadmium in the human body causes Itai-Itai disease, which is expressed in reducing the calcium content in the bones, which causes them to soften. Entering through the food chain Cd causes a variety of diseases such as renal failure and osteomalacia.

Cadmium decreases productivity of crops, causes a violation of physiological and biochemical processes–decreases the content of photosynthetic pigments, the rate of photosynthesis, water use efficiency and mineral nutrition (Nazar *et al.,* 2012; Tóth *et al.,* 2012; Subhalakshmi *et al.*, 2018). Chelating agents such as phyto-siderophores promote the absorption of Cd (Liu *et al.,* 2008). Low diffusion coefficients of Cd in aqueous solution show that the absorption of Cd by roots depends on transpiration rate, indicating the importance of water management in the control of Cd uptake (Lux *et al.,* 2011). The content of cadmium in the xylem sap is directly correlated with the content of cadmium in the aerial parts and grain. The content of cadmium in the aerial organs and transpiration defined content in the grain of the Japanese rice varieties 'Habataki' (Zhao *et al.,* 2006). Cadmium is removed from the root to the aerial organs and accumulates through the stalks at the nodes. After 7 h of exposure, cadmium accumulates mainly in panicles than in leaf blades. This indicates that the nodes are an important place for redistribution cadmium coming from roots by transferring it from the xylem to the phloem. Cadmium from leaves mostly enters to the grain at maturity (Rodda *et al.,* 2011). Consequently, the amount of Cd accumulated depends on various factors such as the content in the soil, bioavailability, genetic characteristics of plants, as well as the nature of the soil, including rhizosphere (Huang *et al.,* 2011). At the consumption of rice with a high concentration of Cd (0.62 mg/kg) and rich in mineral elements such as Zn, Fe, Ca after two weeks Cd accumulated in less amounts in the kidneys and liver of rats in comparison with control options. Antagonistic effect of metals is also important in the accumulation of Cd by living organisms (Chaney *et al.,* 2001).

The World Health Organization (WHO, 1995) has set a maximum limit of Cd in food– 60-70 g per day, and the International Code for the food the commission has set a limit of 0.1 mg/kg for cereals and oilseeds are sold on international markets. Even in soils that are considered uncontaminated or slightly contaminated as a result of pollution by cadmium, coming from the fertilizer or the atmosphere, some crops like *durum* wheat, flax, sunflower and potatoes can accumulate Cd in quantities exceeding the current maximum level for consumption (Jackson and Alloway, 1992). In countries, where rice with relatively low mineral content is a staple food, there is a deficit of micronutrients. Cadmium contributes to the reduction of trace elements in crops. In this regard, the aim of our work was the study of the effect of cadmium on mineral elements content in the grain of rice varieties. Therefore, the original content of cadmium ions in the grain of rice varieties under study is of great interest.

MATERIALS AND METHODS

The objectives of this research were different varieties of rice (*Oryza sativa* L.) : Bakanaskyi, Madina, Barakat and Chapsari. The various varieties of rice were grown in soil culture in vessels filled with soil containing 2 mM $CdSO_4$.Control plants were grown in soil containing no cadmium. Plant samples (grain) 0.5 g were ground and were digested in mixture 5 ml HNO_3 and 0.5 ml HCl. Determination of mineral elements was performed by atomic absorption spectrophotometer (Perkin Elmer).

The data of experiments were analyzed statistically using two-way ANOVA with varieties and treatment as main effects for mineral content.

RESULTS AND DISCUSSION

The significance of minerals in the human body, animals and plants cannot be overestimated. The presence of minerals in food is vital to the metabolic processes. The lack of mineral elements and their imbalance in the soil and agricultural plants is the cause of different diseases. The acidity of the soil and seasonal factors, and the ionic composition of the soil influence the content of mineral elements in plants. Plants use these minerals, as structural components of carbohydrate and protein, organic molecules involved in metabolism. Therefore, the study had the effect of cadmium on mineral content in rice grain.

It studied mineral elements content, cadmium also, in grain of rice varieties grown in the presence of cadmium in soil. Cadmium was not found in grain of all studied rice varieties. However, in the presence of cadmium in soil, the content of mineral elements was reduced as compared to the control plants.

Magnesium is a part of the chlorophyll in plant cells. Magnesium is a cofactor for some enzymes, is an activator of phosphate-transporting enzymes as miokinase, diphosphopyridine nucleotide kinase and creatine kinase in human body. Magnesium is an important activator of pyruvate carboxylase, pyruvate oxydase. It is part of bones, teeth and affects the health of the digestive system and kidneys. Acute magnesium deficiency causes vasodilation, arrhythmia, irritability, depression and other adverse events (Murray *et al.*, 2000). Therefore, the magnesium content in staple foods like rice, is important for public health.

Rice varieties by content of Mg in grain in control variant are arranged in the following order (mg/kg) : Bakanaskyi (1480) > Chapsari (1403,7) > Madina (1363) > Barakat (1311) (Fig. 1).

Concentration of Mg in the presence of cadmium decreased as follows (mg/kg) : Bakanaskyi (1456) > Madina (1267) > Chapsari (1212) > Barakat (1105,45) .

According to the content of magnesium in the phase of full ripeness the greatest amount of Mg in control and in the presence of Cd in grain Bakanaskyi variety, but the differences between control variant and variant with cadmium were not significant (P > 0.05).

By reducing Mg content in the grain rice varieties in the following order (% of control) : Bakanaskyi (98) > Madina (93) > Chapsari (86%) > Barakat (84).

Manganese is a cofactor for many

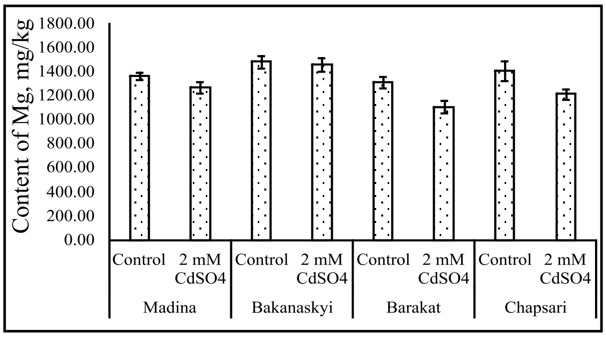

Fig. 1. Effect of cadmium on content of Mg in grain of rice varieties. Vertical bars represent ± SD of three replicates (n=3), differences between control variants and variants with cadmium were not significant.

enzymes, such as phoshohydrolases, decarboxylases and phosphotransferases (Murray *et al.*, 2000). It is included in the synthesis of glycoproteins, proteoglycans, and is a component of the mitochondrial superoxide dismutase. The fact that the manganese found in mitochondria indicates that it participates in the regulation of oxidative phosphorylation. All these facts are the evidence of the importance of manganese for living organisms.

In the phase of full ripeness, the manganese content in grain in the control variant was the highest in Madina cv. (Fig. 2), in the presence of Cd (2 mM) – in grain of Bakanaskyi cv; the lowest amount of Mn was found in control variant and in presence of Cd in Barakat variety.

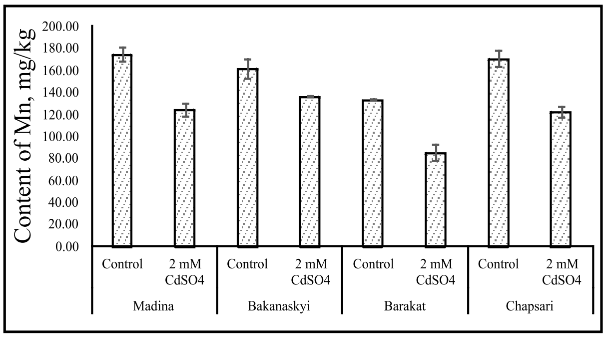

Fig. 2. Effect of cadmium on content of Mn in grain of rice varieties. Vertical bars represent ± SD of three replicates (n=3), P < 0.01 (between control variant and variant with cadmium).

According to Mn content in the phase of full maturity in control variant rice varieties can be arranged in the following order (mg/kg) : Madina (174, 20) > Chapsari (170,00) > Bakanaskyi (161,00) > Barakat (133,10). In variant with Cd (2 mM) rice varieties by Mn content are located as follows (mg/kg) :

Bakanaskyi (136,00) > Madina (123,70) > Chapsari (121,60) > Barakat (84,6) (P < 0.01).

The content of manganese (Mn) was reduced to the greatest extent in Barakat cv (36%), in the least degree in grain of Bakanaskyi variety (by 25%). Reduction of manganese grades can be arranged as follows (% of control): Bakanaskyi (85) > Chapsari (72) > Madina (71) > Barakat (64).

Iron deficiency is the most common eating disorder, breach of microelement composition of food around the world, including in Kazakhstan, making iron by far the most common nutrient deficient worldwide. If we use the number of patients with iron deficiency anemia as an indicator, it can be assumed that most pre-school children and pregnant women in developing countries, and at least 30-40% in industrialized countries suffer from iron deficiency (World of the United Nations. International Children's Emergency Fund/ United Nations University (WHO/UNICEF/ UNU, 2001). Iron is a part of the hemoglobin, which is involved in the transport of oxygen to the organs. Iron is an essential component of enzymes involved biological oxidation, cytochrome. It is a necessary component of succinate dehydrogenase, a cofactor for enzymes involved in the synthesis of neurotransmitters (Murray *et al.,* 2000). Iron deficiency in plants causes the suppression of electron transfer processes in the process of respiration and photosynthesis. Iron deficiency causes iron-deficiency anemia in humans. Thus, the content of this metal in food products is of great importance.

In the phase of full maturity in control variant and in the presence of Cd in soil Fe content was the highest in grain of Madina and Bakanaskyi varieties (Fig. 3) and lowest in Chapsari cv. In control variant rice varieties by iron content are arranged in the following order (mg/kg) : Madina (19.3) > Bakanas (17.2) > Barakat (15.7) > Chapsari (12.4); under cadmium stress (2 mM) (mg/kg) - Madina (17,1) > Bakanaskyi (12,4) > Barakat (7,46) > Chapsari (7,1) (P < 0.05).

In Madina variety, iron content decreased to a lesser extent (by 11%) in comparison with other varieties, while Barakat variety demonstrated the largest decline (52%) of iron content in grain.

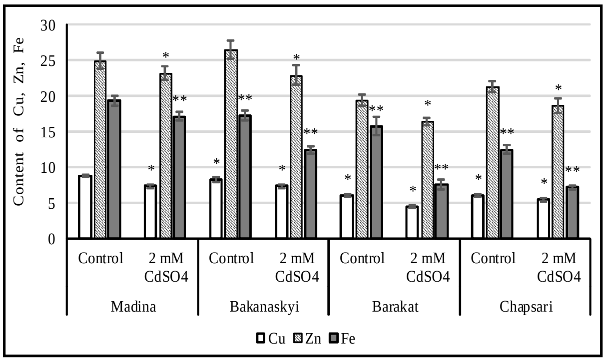

Fig. 3. Effect of cadmium on content of Cu, Fe and Zn in grain of rice varieties. Vertical bars represent ± SD of three replicates (n=3), * P< 0.05; **P<0.01 (between control variant and variant with cadmium).

The iron content in rice grain as compared to control varieties decreased in the following order (% of control) : Madina (89) > Bakanaskyi (72) > Chapsari (57) > Barakat (48).

Thus, in the phase of full ripeness iron content in the control variant and variant with cadmium in the lead was Madina variety.

Zinc is widely distributed in plant and animal tissues. It functions as a cofactor and is part of many enzymes, such as lactate dehydrogenase, alcohol dehydrogenase, glutamate dehydrogenase and RNA polymerase. Zn-containing enzymes were involved in metabolism and cell replication (Arinola, 2008). The primary role of zinc is in cell division, gene expression and metabolism of amino acids and nucleic acids. Bioavailability of vitamins A and E, also their metabolism depends on zinc status in cell. Zinc is essential for optimal function of insulin because it is part of the insulin (Soetan *et al.,* 2010). Zinc is an important component of protoplasm, as associated with enzymes, regulators of cellular metabolism. In plants, zinc is involved in the synthesis of chlorophyll, protects it from decay affects the assimilation of nitrogen by plants, activates enzymes in carbohydrate and energy metabolism, participates in the construction of a number of enzymes (some phosphatase) (Chernavskaya, 1989).

The zinc content in the phase of full ripeness in the control variant was the highest in grain of Bakanaskyi cv. the lowest - in Barakat cv. In the presence of cadmium in the soil, the highest content of Zn was found in grain of cv. Madina.

According to the content of zinc in grain in the phase of full ripeness in variant without Cd rice varieties are arranged in the following order (mg/kg) : Bakanaskyi (26,4) > Madina (24,92) > Chapsari (21,3) > Barakat (19,4).

Under cadmium stress by zinc content in grain rice varieties are located as follows (mg/kg) : Madina (23,2) > Bakanaskyi (22,9) > Chapsari (18,6) and Barakat (16,4) ($P < 0.01$).

The zinc content was also reduced in the presence of Cd (% of control) : Zn – Madina (93) > Bakanaskyi (87) = Chapsari (87) > Barakat (85).

Thus, Cd caused the decrease of Zn content in grain. In the presence of cadmium, it observed lowest degree of the decrease of Zn content in rice grain in Madina cv (by 6.8%). In grain of Chapsari and Bakanskyi cvs. zinc content reduced to the greatest extent as compared to other varieties.

It was found that the overexpression of genes from the family N ramp (natural resistance-associated macrophage protein) AtNramp1, AtNramp3 and AtNramp4 of transporters Zn, Mn, Fe, Co and Ni, increased the sensitivity of plants to cadmium (Ramesh *et al.,* 2004). It was found that iron carriers OsIRT1 and OsIRT2 (Nakanishi *et al.,* 2006) and zinc OsZIP1 (Ramesh *et al.,* 2004) may also serve as carriers of cadmium. Most of the cadmium accumulated in the grain is transported through the phloem (Tanaka *et al.,* 2007).

Application of NPK fertilizers increased Cd concentration in plants (Grant *et al.,* 2010). Zinc (Zn) in phosphorus fertilizers competes with Cd, which increases the Cd concentration in soil solution (Francois *et al.,* 2009). Zn also competes with Cd and reduces its absorption by plants (Grant *et al.,* 2010).

Copper is a part of enzymes such as cytochrome C oxidase, amine oxidase, catalase, peroxidase, ascorbic acid oxidase, cytochrome oxidase cytosolic superoxide dismutase, etc., and it plays an important role in iron absorption. Cu is an essential micronutrient for the circulatory and nervous systems in animal and human organisms (Tan *et al.,* 2006). It is necessary for bone growth and formation, formation of myelin sheath in the nervous system, makes the inclusion of iron in hemoglobin helps absorption of iron from the gastrointestinal tract (GIT) and a transmission iron from the tissues to the plasma (Chernavskaya, 1989). In plant cells, copper is part of the plastocyanin - electric transport component of the photosynthetic chain. It plays an important role in the life of organisms, enhances the oxidative processes and promotes the formation of chlorophyll (Tan *et al.,* 2006).

In control, variant copper content in grain was the highest in Madina cv. (Fig. 3). Under cadmium stress (2 mM) in grain of Bakanaskyi and Madina varieties it was found the highest concentration of copper.

Copper concentration in grain of rice varieties under cadmium stress is decreased in the following order : Control (mg/kg) : Madina (8.8) > Ba?anakyi (8.2) > Chapsari (6) = Barakat (6); 2 mM Cd (mg/kg) : Madina (7,3) = Bakanaskyi (7.3) > Chapsari (5.4) > Barakat (4.4).

In Barakat cv. content of copper (Cu) in the presence of cadmium in soil was reduced to a greater extent (17%) as compared to other varieties. In Chapsari cv., it was observed the smallest decline in the copper content in the presence of Cd (10%). According to the reduction of Cu content, the rice varieties are located as follows (% of control): Chapsari (90) > Bakanaskyi (89) > Madina (83) > Barakat (73).

Thus, copper content was highest in control variant and under copper stress in Madina and Bakanaskyi varieties, the least content of copper was found in Chapsari and Barakat varieties.

Thus, among the studied varieties, Madina and Bakanaskyi cvs. showed the most complete composition of the necessary minerals in the grain and in control and experimental variants. Grains of Madina variety in control variant contained the largest amounts of Mg, Fe and Cu, accumulated a significant amounts of Zn, and by the content of Mg it occupied an intermediate position. In the variant with cadmium, the amount of Zn, Fe and Cu in grain of Madina cv. was the highest as compared to other varieties.

CONCLUSION

The studied rice varieties differed on the content of mineral elements in grain in the presence of cadmium in the soil. In grains of the studied rice varieties in the presence of Cd was observed a significant decrease of accumulation of necessary elements of mineral nutrition. Cadmium in the least degree reduced the content of mineral elements in Madina and Bakanaskyi varieties, in the greatest degree– in cvs. Barakat and Chapsari. Content of Fe (up to 52%) and Mn (up to 36%) was decreased in the most degree. Content of Mg under cadmium stress did not change significantly in grain of rice varieties. The further research on molecular level is necessary to study the expression level of genes, responsible for transport of Cd and other mineral elements in rice varieties.

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REFERENCES

Andreu, V. and Boluda, J. R. (1995). Application of contamination indexes on different farming soils. *Bull. Environmen. Contam. and Toxicol.* **54** : 228-36.

Arinola, O. G. (2008). Essential trace elements and metal binding proteins in Nigerian consumers of alcoholic beverages. *Pak. J. Nutr.* **7** : 763-65.

Chaney, R. L., Reeves, P. G. and Angle, J. S. (2001). Rice plant nutritional and human nutritional characteristics role in human Cd toxicity. In : *Plant Nutrition.* Springer, Dordrecht. pp. 288-89.

Chernavskaya, H. M. (1989). Phyziologia rastitelnyh organismov i rol metallov (in Russian). Moskow, MGU, 156.

FAO/WHO (1995). Joint Committee on Food Additives and Contaminants.Position paper on cadmium (prepared by France). 27th Session. The Hague, The Netherlands. pp. 20-24.

François, M., Grant, C., Lambert, R. and Sauvé, S. (2009). Prediction of cadmium and zinc concentration in wheat grain from soils affected by the application of phosphate fertilizers varying in Cd concentration. *Nutrient Cycling in Agroecosystems* **83** : 125-33.

Gimeno-García, E., Andreu, V. and Boluda, R. (1996). Heavy metals incidence in the application of inorganic fertilizers and pesticides to rice farming soils. *Environ. Pollution* **92** : 19-25.

Grant, C. A., Monreal, M. A., Irvine, R. B., Mohr, R. M., McLaren, D. L. and Khakbazan, M. (2010). Preceding crop and phosphorus fertilization affect cadmium and zinc concentration of flaxseed under conventional and reduced tillage. *Plant and Soil* **333** : 337-50.

Huang, H., Yu, N., Wang, L., Gupta, D. K., He, Z., Wang, K. and Yang, X. E. (2011). The phytoremediation potential-of bioenergy crop *Ricinus communis* for DDTs and cadmium co-contaminated soil. *Bioresour. Technol.* **102** : 11034-38.

Jackson, A. P. and Alloway, B. J. (1992). The transfer of cadmium from agricultural soils to the human food chain. pp. 109-58. In : *Biogeochemistry of Trace Metals,* D. C. Adriano (ed.). Lewis Publishers, Boca Raton, FL., U. S. A.

Lee, J. S., Chon, H. T. and Kim, K. W. (1998). Migration and dispersion of trace elements in the rock-soil-plant system in areas underlain by black shales and slates of the Okchon Zone, Korea. *J. Geochem. Exploration* **65** : 61-78.

Liu, H., Zhang, J., Christie, P. and Zhang, F. (2008). Influence of iron plaque on uptake and accumulation of Cd by rice (*Oryza sativa* L.) seedlings grown in soil. *Sci. Total Environ.* **394** : 361-68.

Lux, A., Martinka, M., Vaculík, M. and White, P. J. (2011). Root responses to cadmium in the rhizosphere : A review. *J. Exptl. Bot.* **62** : 21-37.

Murray, R. K., Granner, D. K., Mayes, P. A. and Rodwell, V. W. (2000). *Harper's Biochemistry, 25th edn,* McGraw-Hill, Health Profession Division, USA.

Nakanishi, H., Ogawa, I., Ishimaru, Y., Mori, S. and Nishizawa, N. K. (2006). Iron deficiency enhances cadmium uptake and translocation mediated by the Fe2+ transporters $OsIRT_1$ and $OsIRT_2$ in rice. *Soil Sci. & Plant Nutr.* **52** : 464-69.

Nazar, R., Iqbal, N., Masood, A., Khan, M. I. R., Syeed, S. and Khan, N. A. (2012). Cadmium toxicity in plants and role of mineral nutrients in its alleviation. *Amer. J. Plant Sci.* **3** : 1476.

Ramesh, S. A., Choimes, S. and Schachtman, D. P. (2004). Over-expression of an Arabidopsis zinc transporter in *Hordeum vulgare* increases short-term zinc uptake after zinc deprivation and seed zinc content. *Plant Mole. Biol.* **54** : 373-85.

Rodda, M. S., Li, G. and Reid, R. J. (2011). The timing of grain Cd accumulation in rice plants : The relative importance of remobilisation within the plant and root Cd uptake post-flowering. *Plant and Soil* **347** : 105-14.

Singh, V. P. and Maiti, R. K. (2016). A review on factors affecting crop growth in rice (*Oryza sativa* L.). *Fmg. Mngmt.* **1** : 101-14.

Soetan, K. O., Olaiya, C. O. and Oyewole, O. E. (2010). The importance of mineral elements for humans, domestic animals and plants– A review. *African J. Food Sci.* **4** : 200-22.

Subhalakshmi, Shijagurumayum, Devi, G. A. S. and Singh, Ch. B. (2018). Grain guality evaluation of some aromatic rice varieties of Manipur, India. *Res. Crops* **19** : 169-81.

Tan, J. C., Burns, D. L. and Jones, H. R. (2006). Severe ataxia, myelopathy and peripheral neuropathy due to acquired copper deficiency in a patient with history of gastrectomy. *J. Parenteral and Enteral Nutri.* **30** : 446-50.

Tanaka, K., Fujimaki, S., Fujiwara, T., Yoneyama, T. and Hayashi, H. (2007). Quantitative estimation of the contribution of the phloem in cadmium transport to grains in rice plants (*Oryza sativa* L.). *Soil Sci. and Plant Nutr.* **53** : 72-77.

Tirado, R. and Allsopp, M. (2012). Phosphorus in agriculture : Problems and solutions. *Greenpeace Res. Laboratories Technical Report (Review)*, *2*.

Tóth, T., Zsiros, O., Kis, M., Garab, G. and Kovacs, L. (2012). Cadmium exerts its toxic effects on photosynthesis via a cascade mechanism in the cyanobacterium, Synechocystis PCC 6803. *Plant, Cell & Environ.* **35** : 2075-86.

Zhao, F. J., Jiang, R. F., Dunham, S. J. and McGrath, S. P. (2006). Cadmium uptake, translocation and tolerance in the hyperaccumulator *Arabidopsis halleri. New Phytologist* **172** : 646-54.

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