J. Elementol. 2008, 13(4): 513-519

EFFECT OF SELENIUM ON SELECTED MACRONUTRIENTS IN MAIZE PLANTS

Barbara Hawrylak-Nowak

Chair of Physiology
University of Life Sciences in Lublin

Abstract

Selenium is an essential element for humans, animals and some species of microorganisms. In higher plants, however, the role of selenium is still unclear. Because selenium enrichment may influence the nutrient balance of plants, a study was done to test the effects of selenite-Se ($Na_2SeO_3 \cdot 5H_2O$) on selected macronutrients content in maize (*Zea mays* L. var. *saccharata* Kcke. cv. Złota Karłowa) seedlings. Plants were grown in Hoagland I nutrient solution (pH 6,2) amended with selenite at 0 (control), 5, 25, 50 and 100 $\mu mol \cdot dm^{-3}$ for 14 days. The dry weight of the shoots was then analyzed for phosphorus (P), potassium (K), calcium (Ca) and magnesium (Mg) content. Phosphorus and calcium content increased, while potassium content decreased with increasing selenium treatments. No significant differences were found for magnesium level. Plant growth was affected by excessive selenium concentration. At low concentration (5 $\mu mol \cdot dm^{-3}$), selenium tended to stimulate the plant growth and the root elongation but at higher concentrations (50 and 100 $\mu mol \cdot dm^{-3}$) the dry mass accumulation and root tolerance index severely decreased.

The study revealed that disturbances of growth and reduction of plant's biomass at the presence of high selenium concentrations in the nutrient solution may have resulted from the disturbance of mineral balance of plants, namely accumulation of large amounts of calcium and phosphorus in shoot tissues.

Key words: selenium, maize, chemical composition.

WPŁYW SELENU NA ZAWARTOŚĆ WYBRANYCH MAKROELEMENTÓW W ROŚLINACH KUKURYDZY

Abstrakt

Selen jest pierwiastkiem niezbędnym dla ludzi, zwierząt oraz niektórych mikroorganizmów, jednak jego rola w roślinach wyższych nie jest w pełni poznana. Ponieważ wzbogacenie podłoża w selen może wpływać na równowagę mineralną roślin, przeprowadzono ba-

dr Barbara Hawrylak-Nowak, Chair of Plant Physiology, University of Life Sciences in Lublin, Akademicka 15, 20-950 Lublin, Poland, phone: (081) 4456879, e-mail: bhawrylak@yahoo.com

dania dotyczące wpływu selenu w formie seleninu ($Na_2SeO_3 \cdot 5H_2O$) na zawartość wybranych makroelementów w siewkach kukurydzy (*Zea mays* L. var. *saccharata* Kcke. cv. Złota Karłowa). Rośliny rosły przez 14 dni w pożywce Hoaglanda I (pH 6,2) wzbogaconej w selen, który stosowano w następujących stężeniach: 0 (kontrola), 5, 25, 50 i 100 $\mu mol \cdot dm^{-3}$. Po tym czasie w suchej masie organów nadziemnych analizowano zawartość fosforu (P), magnezu (Mg), potasu (K) i wapnia (Ca). Stwierdzono, że wraz ze wzrostem stężenia selenu w pożywce, w organach nadziemnych roślin wzrastała zawartość fosforu i wapnia, malała zaś zawartość potasu. Nie wykazano istotnych różnic w zawartości magnezu. Wprowadzenie do podłoża selenu wpływało również na wzrost roślin. Stwierdzono, że selen w niskim stężeniu (5 $\mu mol \cdot dm^{-3}$) stymulował wzrost siewek oraz elongację systemu korzeniowego, ale w jego wyższych stężeniach tego pierwiastka (50 i 100 $\mu mol \cdot dm^{-3}$) akumulacja biomasy oraz indeks tolerancji korzenia drastycznie malały. Z przeprowadzonych badań wynika, że zaburzenia wzrostu oraz redukcja biomasy roślin w obecności wysokich stężeń selenu w podłożu może być związana z zakłóceniem równowagi mineralnej roślin, a zwłaszcza z gromadzeniem w tkankach pędów znacznej ilości wapnia i fosforu.

Słowa kluczowe: selen, kukurydza, skład chemiczny.

INTRODUCTION

Selenium – an element chemically similar to sulfur – is a micronutrient essential for people, animals and some microorganisms. Traces of selenium play a principal role in cellular metabolism, namely in anti-oxidation reactions. However, selenium has quite a narrow spectrum of physiological action because its deficiency as well as excess exert negative effects on functions of an organism (Sembratowicz, Grela 1997).

Although all plants are able to take up and metabolize selenium, the assumption about its necessity for higher plants has not been fully confirmed yet. Plants differ in their ability to accumulate selenium in tissues, therefore they were divided into species capable of active and specific selenium accumulation (selenium accumulators) and those which cannot accumulate selenium (Adriano 1986).

Accumulation of high selenium amounts in tissues of plants that have no capability of its accumulation, inducing toxicity of the element, is strictly associated with non-specific incorporation of selenocytein and selenomethionin into proteins instead of cystein and methionin, respectively. It was found that the bond formed between selenium atoms in selenocystein is longer, weaker and more labile than disulfide binding, which may have influence on slight changes in the third-order structure of proteins and evoke disturbances of catalytic functions of enzymes (Mazzafera 1998, Terry et al. 2000). Replacing cystein by selenocystein in proteins may also disturb formation of disulfide bridges. Furthermore, selenium has a negative effect on protein synthesis because selenomethionin appearing instead of methionin probably impairs formation of peptide binding (Terry et al. 2000).

It is suggested that interaction with general minerals is one of more important factors due to which trace elements affect the plant's metabolism. Presence of heavy metals may induce deficiency of macronutrients and micronutrients necessary for a proper course of principal life processes (Baranowska-Morek 2003). Interaction between selenium and a given element depends on quantitative proportions and it may also cause synergistic effects (Pyrzyńska 2000). Selenium – like heavy metals – can modify uptake and accumulation of minerals which are important for metabolism (Kopsell et al. 2000, Pazurkiewicz-Kocot et al. 2003). Moreover, positive influence of selenium on changes in the activity and permeability of the cellular membrane has been found, and this may be one of the earliest symptoms of the influence of selenium on plants (Kinraide 2003).

The present experiments were aimed at evaluating the influence of selenium on plant growth and content of selected macronutrients (P, K, Mg, Ca) in maize seedlings growing at the presence of varied sodium selenate concentrations.

MATERIALS AND METHODS

The experiments were carried out in water cultures and their purpose was to investigate the influence of selenium on contents of selected macronutrients in maize plants (*Zea mays* L. var. *saccharata* Kcke. cv. Złota Karłowa). Seeds obtained from the Seed Center in Lublin were placed on wet filter paper 1 cm from the upper edge, covered with a wet filter band and rolled up. The tubes thus prepared were placed vertically in beakers filled with distilled water and left for 7 days at 25°C. Afterwards, healthy and well-developed seedlings were placed in glass jars of 1 dm^3 capacity (two in each jar) filled with 1.5-fold concentrated Hoagland I nutrient solution (pH 6.2). After 3 days, selenium in the form of sodium selenate ($Na_2SeO_3 \cdot 5H_2O$) was introduced at following concentrations: 0 (control), 5, 25, 50, or 100 $\mu mol \cdot dm^{-3}$. The maize plants grew in an air-conditioned plant growth room under controlled photon density stream within the photosynthetically active range of 270 $\mu mol \cdot m^{-2}$ s^{-1} at a photoperiod of 14/10 h and temperature 25/20°C (day/night).

After 14 days, the index of tolerance (IT), which defines the increase of root length of experimental plants expressed as per cent relative to control, was determined (Mc Neilly 1994). Also dry matter of roots and shoots was determined. Dry plant material was subjected to chemical analyses for determination of the content of the following macronutrients in aerial plant organs: phosphorus by vanadium-molybdate colorimetry; magnesium by colorimetry using titanium yellow; potassium and calcium by the AAS technique (Nowosielski 1974). The experiment was performed in three time-independent repetitions. In all the experiments, the least small difference (LSD) between the means was calculated using Tukey's test. Differences at $P = 0.05$ were considered as statistically significant.

RESULTS AND DISCUSSION

Due to chemical similarity of selenium to sulfur, most of the references deal with interaction between these two elements. It was found that plants take up, transport and metabolize sulfur and selenium using similar mechanisms. It is a common opinion that both anions are transported by sulfur carriers in cellular membranes, therefore the presence of sulfur may affect selenium accumulation and vice versa (TERRY et al. 2000, ELLIS and SALT 2003). However, selenium influence on other than sulfur macronutrients is a subject of only small number of studies and their results are not always univocal.

The current experiment revealed that introduction of selenium into the medium significantly interacted with the chemical composition of aerial parts of maize plants (Table 1). Phosphorus and calcium in dry matter manifested an increasing tendency along with an increase in the selenium concentration in the nutrient solution. Amounts of phosphorus slightly increased at the presence of 5 and 25 µmol Se·dm^{-3}; however, the differences were not statistically significant. Selenium introduced into the medium at the levels of 50 and 100 µmol·dm^{-3} caused about a 4-5-fold increase of phosphorus content in dry matter in relation to the control. Similar dependence was found for calcium. Its content in shoots was much elevated at the presence of 50 and 100 µmol Se·dm^{-3}, exceeding by about 5-6-fold the control value. WU and HUANG (1992), in their experiments on selenium affecting accumula-

Table 1

Influence of selenium on some macronutrients content in maize shoots (mean of tree replications)

Selenium concentration in nutrient solution (µmol·dm^{-3})	(% d. w.)			
	Ca	K	Mg	P
0 (control)	0.280^{a}	3.705^{b}	0.275	0.375^{a}
5	0.340^{a}	4.210b^{c}	0.290	0.430^{a}
25	0.305^{a}	4.550^{c}	0.295	0.505^{a}
50	1.615^{b}	3.400^{ab}	0.340	1.835^{b}
100	1.340^{b}	2.830^{a}	0.340	1.450^{b}
LSD $_{0.05}$	0.413	0.831	n.s.	0.546

Means in each column followed by the same letter are not significantly different.

tion of macro- and micronutrients in fescue and clover, recorded similar dependencies regarding calcium concentrations, while contrary results were achieved for phosphorus. In experiments conducted by KOPSELL et al. (2000), selenium did not have any effect on calcium accumulation; instead it caused a decline in phosphorus in cabbage plants. SINGH and MALHOTRA (1976) as well as MIKKELSEN et al. (1989) observed increased phosphorus content in plants cultivated at the presence of selenium.

Our analysis of potassium content revealed that at the presence of 25 μmol $Se \cdot dm^{-3}$, the level of this macronutrient increased by 23%, while after adding 100 μmol $Se \cdot dm^{-3}$ into the nutrient solution, its content decreased by 24% as compared to the control. Other selenium rates did not exert significant influence on potassium contents in aerial parts of maize plants. Positive effects of selenium in the form of selenite on potassium accumulation were also observed by PAZURKIEWICZ-KOCOT et al. (2003), who found that the content of potassium in maize leaves significantly increased when introducing 10 μmol $Se \cdot dm^{-3}$ into the medium, but a contrary dependence was recorded in roots. KOPSELL et al. (2000) revealed that the potassium level in cabbage leaves increased linearly along as the selenium concentration in the medium rose.

Our analysis of the influence of various selenium concentrations on magnesium accumulation indicated that the content of the latter did not differ considerably as compared to the control plants. ARVY et al. (1995) achieved similar results when analyzing effects of selenium in forms of selenate and selenite on ionic balance of suspended cultures of *Catharanthus roseus* L.

Influence of selenium on plants largely depends on its chemical form and its concentration in nutrient solution. Our own studies revealed a stimulating effect of selenium at the concentration of 5 $\mu mol \cdot dm^{-3}$ on plant growth (Table 2). Dry matter of the maize roots and aerial organs exceeded the control by 79% and 62%, respectively, at the presence of 5 $\mu mol \cdot dm^{-3}$ selenium. Also slight stimulation of root system elongation was observed under these conditions (IT = 110%). Selenium concentrations above 25 $\mu mol \cdot dm^{-3}$ resulted in a dramatic biomass decrease, which resulted mainly from less developed aerial organs (Table 2). After introducing selenium into the medium at the rate of 100 $\mu mol \cdot dm^{-3}$, root dry matter was lower by 56%, and that of aerial parts by 78% in relation to the control. The two highest selenium concentrations caused reduction of root growth potential. The IT of roots reached only 68% and 57% of the control values at the presence of 50 and 100 μmol $Se \cdot dm^{-3}$, respectively.

The results achieved by HARTIKAINEN et al. (2000) also confirm the fact that selenium interaction with plants depends on its concentration. At lower rates, selenium stimulated growth of ryegrass seedlings, while at high doses it acted as pro-oxidant reducing yields and inducing metabolic disturbances. Later experiments by XUE et al. (2001) on lettuce seedlings confirmed positive influence of low selenium concentrations on yielding of the species;

Table 2

Influence of selenium on dry weight and IT of maize plants
(mean of tree replications)

Selenium concentration in nutrient solution (μmol · dm^{-3})	Dry weight (g per jar)		Roots IT
	roots	shoots	
0 (control)	0.831^b	2.899^c	100.0^a
5	1.485^c	4.686^d	110.2^a
25	0.792^b	2.389^c	91.45^a
50	0.469^a	1.184^b	67.67^b
100	0.367^a	0.649^a	56.73^b
$LSD_{0.05}$	0.160	0.471	18.64

Means in each column followed by the same letter are not significantly different.

however, the effect depended on plant's development stage. Phytotoxicity of high selenium levels is associated mainly with non-specific replacement of sulfur amino acids by their selenium analogues (Terry et al. 2000). Moreover, this effect may result from disturbances in mineral balance, which is indicated by analysis of chemical composition of maize shoots performed in the present experiment. It was found that the largest differences in the content of the macronutrients we determined, as compared to control plants, were closely connected with a considerable decrease in the dry matter of seedlings and reduction of root growth potential (Tables 1, 2).

CONCLUSIONS

1. Contents of macronutrients in aerial parts of maize depended on a selenium concentration in the nutrient solution. Selenium at concentrations of 50 and 100 μmol · dm^{-3} caused a significant increase in phosphorus and calcium. Potassium significantly increased at the presence of 25 μmol Se · dm^{-3}, while decreasing under the influence of 100 μmol Se · dm^{-3}. Presence of selenium in the medium did not have significant influence on magnesium.

2. Selenium at 5 μmol · dm^{-3} concentration stimulated maize seedling growth, while rates 50 and 100 μmol · dm^{-3} dramatically reduced dry matter of plants and inhibited the root system elongation.

REFERENCES

ADRIANO D.C. 1986. *Trace elements in the terrestrial environment*. Springer-Verlag New York Inc.

ARVY M.P., THIERSAULT M., DOIREAU P. 1995. *Relationships between selenium, micronutrients, carbohydrates, and alkaloid accumulation in Catharanthus roseus cells*. J. Plant Nutr., 18(8): 1535-1546.

BARANOWSKA-MOREK A. 2003. *Roślinne mechanizmy tolerancji na toksyczne działanie metali ciężkich*. Kosmos, 52: 283-298.

ELLIS D.R., SALT D.E. 2003. *Plants, selenium and human health*. Curr. Opin. Plant Biol., 6: 273-279.

HARTIKAINEN H., XUE T., PIIRONEN V. 2000. *Selenium as an anti-oxidant and pro-oxidant in ryegrass*. Plant Soil, 225: 193-200.

KINRAIDE T.B. 2003. *The controlling influence of cell-surface electrical potential on the uptake and toxicity of selenate (SO_4^{2-})*. Physiol. Plant., 117: 64-71.

KOPSELL D.A., RANDLE W.M., MILLS H.A. 2000. *Nutrient accumulation in leaf tissue of rapid--cycling Brassica oleracea responds to increasing sodium selenate concentrations*. J. Plant Nutr., 23(7): 927-935.

MAZZAFERA P. 1998. *Growth and biochemical alterations in coffee due to selenite toxicity*. Plant Soil, 102: 189-196.

MC NEILLY T. 1994. *Metal toxicity*, In: *Soil mineral stresses. Approaches to crop improvement*. YEO A.R., FLOWERS T.J. (eds.): Springer – Verlag Berlin Heidelberg.

MIKKELSEN R.L., PAGE A.L., BINGHAM F.T. 1989. *Factors affecting selenium accumulation by agricultural crops*, In: *Selenium in agriculture and the environment*. JACOBS L.W. (eds.) Am. Soc. of Agronomy, Madison, WI.

NOWOSIELSKI O. 1974. *Metody oznaczania potrzeb nawożenia*. PWRiL, Warszawa.

PAZURKIEWICZ-KOCOT K., GALAS W., KITA A. 2003. *The effect of selenium on the accumulation of some metals in Zea mays L. plants treated with indole-3-acetic acid*. Cell. Moll. Biol. Lett., 8: 97-103.

PYRZYŃSKA K. 2000. *Związki selenu w środowisku naturalnym*. Wiad. Chem., 54: 140-150.

SEMBRATOWICZ I., GRELA E. 1997. *Selen w żywieniu zwierząt*. Post. Nauk Rol., 1(97): 97-106.

SINGH M., MALHOTRA P.K. 1976. *Selenium availability in berseem (Trifolium alexandrium) as affected by selenium and phosphorus application*. Plant Soil, 44: 261-266.

TERRY N., ZAYED M., DE SOUZA M.P., TARUN A.S. 2000. *Selenium in higher plants*. Ann. Rev. Plant Physiol. Plant Mol. Biol., 51: 401-432.

WU L., HUANG Z-Z. 1992. *Selenium assimilation and nutrient element uptake in white clover and tall fescue under the influence of sulphate concentration and selenium tolerance of the plants*. J. Exp. Bot., 43(4): 549-555.

XUE T., HARTIKAINEN H., PIIRONEN V. 2001. *Antioxidative and growth-promoting effect of selenium in senescing lettuce*. Plant Soil, 237: 55-61.