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EFFECT OF FOLIAR TREATMENT WITH SELENIUM AND COOKING ON THE NUTRITIONAL QUALITY OF POTATOES

WPŁYW NAWOŻENIA DOLISTNEGO SELENEM I GOTOWANIA NA JAKOŚĆ ŻYWIENIOWĄ ZIEMNIAKÓW

Abstract: In accurate small-plot experiments with potatoes we explored the effect of foliar applications of Se in the form of sodium selenate(IV) on tuber yields, the Se concentration in the tops and tubers of raw and boiled potatoes and in French fries, in the 'Karin' and 'Ditta' varieties. The experiments were established in Žabčice near Brno in 3 variants: (1) control; (2) 200 g Se $\cdot$ ha^{-1}; (3) 400 g Se $\cdot$ ha^{-1}. The mean total yields of tubers per ha were the highest in the control variant (19.99 Mg $\cdot$ ha^{-1}) but applications of selenium reduced the yields statistically insignificantly (to 16.79 and 18.39 Mg $\cdot$ ha^{-1}, respectively). The 'Ditta' variety produced higher yields. The average content of Se increased with the applied dose as compared with the control and equals: in the tops 0.255; 0.739 and 0.767 mg $\cdot$ kg^{-1} d.m., in raw tubers 0.214; 0.564 and 0.917 mg $\cdot$ kg^{-1} d.m., in boiled tubers 0.200; 0.523 and 0.915 mg $\cdot$ kg^{-1} d.m. and in French fries 0.223; 0.425 and 0.574 mg $\cdot$ kg^{-1} d.m. The content of Se decreased more markedly in French fries by heat processing. On the basis of the achieved results foliar nutrition appears to be a suitable and economically reasonable measure towards a targeted increase in the content of Se in potato tubers from the viewpoint of the positive effects of Se on the human organism.

Keywords: potatoes, selenium, foliar nutrition, yields, tops, tubers, French fries

Of late the importance of antioxidants in foodstuffs has been continuously growing since they improve the quality of the food and in this way protect human health. This group of substances also includes selenium. The source of selenium for the human organism is vegetables, fruit and agricultural produce [1] the predominant part being in the form of selenomethionine which is biologically more accessible for humans [2].

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In the human organism selenium is a component of biologically active proteins. Approximately 30 proteins with an enzyme activity have been confirmed of which the most important is glutation peroxidase which helps to protect lipoprotein membranes against the effect of hydroperoxides and other toxic compounds of oxygen [3]. Selenium is also a component of thioredoxin reductase which plays an important role in regeneration of the antioxidant system and is also a component of proteins partaking in the production of the thyroid hormone [4]. In these selenoproteins Se appears in the form of selenocysteine amino acid [5]. Selenium plays a part in the prevention of cardiovascular diseases and cancer. Se deficiency gives rise to a number of health problems related to the immune system, virus infections, male reproduction organs, thyroid gland, asthma and various inflammations [6].

To a large extent the content of Se in plants is based on its concentration in the soil; most soils contain between 0.01 to 0.2 mg Se · kg^{-1} [7] in the various oxidation degrees – selenide (Se^{2-}), selenate(IV)* (SeO_3^{2-}) and selenate(VI) (SeO_4^{2-}) [8]. The water-soluble fraction of Se in the soil is taken up by plants and the plants prefer selenates(VI) to selenates(IV). Apart from that the plant can take up Se in the form of amino acids such as selenomethionine [4, 9]. Soil pH affects Se uptake and as it decreases the uptake of selenate(IV) and selenate(VI) is considerably restricted [10].

Since potatoes (*Solanum tuberosum* L.) are consumed on a regular basis, they are seen as a suitable crop for exploring Se supplementation thus increasing its content in the population. The Recommended Dietary Allowance (RDA) of Se for adult males and females is 0.055 mg · day^{-1} [11]. According to the German and Austrian Nutrition Society and the Swiss Nutrition Association a daily dose of 0.03–0.07 mg Se · day^{-1} is sufficient for an adult female and male [12]. However in most EU countries the daily intake of Se is below the RDA level [13] and according to Dietary Reference Intakes (DRI) [11] the acceptable upper limit of Se intake for adults is 0.4 mg · day^{-1}.

Tubers of selected potato varieties grown in the Czech Republik were analysed and their content of selenium was seen as insufficient [14]. The Se concentration in potato tubers can be elevated by foliar applications of Se, in this way contributing to the solution of the problem of Se deficiency in human nutrition as the studies of many researches confirmed [2, 3, 15–19].

The objective of the present experiment was to explore the effect of foliar Se applications on yields of potato tubers and on the content of Se in the tops and in variously treated tubers – raw, boiled and in French fries.

Material and methods

Foliar applications of selenium were applied in a small-plot trial established on experimental plots of the School Farm of the Mendel University of Agriculture and Forestry Žabčice in Brno (altitude 179 m a.s.l.). Table 1 shows the agrochemical characteristics of the soil prior to the establishment of the experiment.

* Formerly known as selenite.

The soil was leached in Mehlich's III solution (CH_3COOH, NH_4NO_3, NH_4F, HNO_3 and EDTA). Phosphorus was determined by colorimetry and K, Ca and Mg using the AAS method. The available Se portion was extracted with a 2 mol · dm^{-3} HNO_3 solution and then AAS-determined.

Table 1

Results of analyses of a medium heavy soil (acc. to Mehlich III method)

Nutrient	Content [mg · kg^{-1}]	Supply
Phosphorus	87.5	good
Potassium	204.8	good
Magnesium	383.6	very high
Calcium	3 399.2	high
Selenium	0.11	—
pH/$CaCl_2$	6.07	mildly acid

Two potato varieties, the early 'Karin' and semi-early 'Ditta', were used in the experiment and two levels of foliar selenium application in the form of sodium selenate(IV) were tested. The experiment was established in four replications. The pattern of the experiment was as follows:

1. unfertilised control,
2. 200 g Se · ha^{-1} on the 48^{th} day of vegetation,
3. 400 g Se · ha^{-1} split
   – 1^{st} dose 200 g · ha^{-1} applied on the 48^{th} day of vegetation,
   – 2^{nd} dose 200 g · ha^{-1} applied on the 55^{th} day of vegetation.

The potatoes were planted on 3 April 2007. Selenium was applied at the beginning of bud setting, ie at the beginning of tuber formation. During vegetation the plot was kept free of weeds and treated with pesticides against the Colorado potato beetle (*Leptinotarsa decemlineata*) and late blight (*Phytophtora infestans*).

The dry spring weather (April) influenced the time of harvest. The 'Karin' variety was harvested on the 99^{th} day of vegetation on 2 July 2007 and 'Ditta' on the 106^{th} day of vegetation on 9 July 2007. Planning the harvest dates was based on the highest demand of these varieties on the Czech market. At harvest the tops and tubers were sampled and the hectare tuber yields were determined. The tops and tubers were rinsed in water; the tubers were then peeled and prepared for the respective method of processing – dried, raw, boiled and French fries. All parts of the potatoes were dried at 60 ^{o}C, then homogenised and prepared for analysis.

The samples were mineralised by decomposition of the samples in a mixture of HNO_3 and H_2O_2 in the MILESTONE MLS 1200 MEGA microwave. After transforming into the defined volume the sample was analysed on the UNICAM 939 "SOLAR" atomic absorption spectrophotometer using the method of hydride production by means of the "vapour system" UNICAM VP 90. The results were statistically processed using the STATISTICA 8 programme and method of multifactorial ANOVA followed by Tukeye's test at a 95 % level of significance.

Results and discussion

Table 2 shows the results of yields. It was discovered statistically significant differences between the varieties; the total yields of the 'Ditta' variety were higher than 'Karin' in all the three variants.

Table 2

The effect of selenium application on tuber yields

Variant	Karin		Ditta	
	[Mg · ha^{-1}]	[%]	[Mg · ha^{-1}]	[%]
1	16.03^{a}	100.0	23.95^{b}	100.0
2	11.17^{c}	69.7	21.20^{b}	88.5
3	15.22^{ac}	94.9	19.89^{ab}	83.0

* The same letters indicate insignificant differences among variants and varieties ($p < 0.05$).

No statistically significant difference was detected among the variants of the 'Ditta' variety, although the yields decreased with the increasing dose of Se. The highest yields, ie 23.95 Mg · ha^{-1}, were achieved in the control variant not fertilised with Se (Table 2).

The yields of variant 2 of the 'Karin' variety decreased statistically significantly compared with variant 1. With the highest dose of selenium in variant 3 the differences compared with the other two variants were insignificant. The results are in compliance with those of Jůzl et al [15] who also achieved the highest yields with the Se-unfertilised control variant of the potato variety 'Ditta' (25.9 Mg · ha^{-1}) as compared with 'Karin' (22.3 Mg · ha^{-1}). However, Jůzl et al [15] in their experiments applied Se in doses of 12, 24, 48 and 72 kg Se · ha^{-1} into the soil in the form of Na_2SeO_3. With increasing Se doses the tuber yields decreased and between the varieties the yields differed. On the other hand Turakainen et al [19] achieved statistically significantly lower tuber yields in the control variant not fertilised with Se; however they applied only 0.075 and 0.3 mg Se · kg^{-1} of soil in the form of Na_2SeO_4. These low doses of Se into the soil and another form of Se (Na_2SeO_4) probably caused the increasing of yield of potatoes.

The Se content in raw tubers of the 'Karin' variety (Table 3) increased with the applied dose of 0.2; 0.474 and 1.025 mg · kg^{-1} d.m.; the difference was statistically significant only between variant 3 and variants 1 and 2. The tendency in the selenium content of the 'Ditta' variety was similar (0.227; 0.654 and 0.809 mg · kg^{-1} d.m.). The difference was statistically significant only between variants 1 and 3. No differences were detected between the varieties. Poggi et al [2] achieved similar results; with foliar applications of 50 and 150 g Se · ha^{-1} they saw a linear increase in its content in the potato tubers. Likewise Jůzl et al [16] reported that even after a foliar application of only 100 g · ha^{-1} the Se concentration in tubers increased as much as 2.81 times when compared with controls not fertilised with selenium.

Table 3

The effect of applications of selenium on its content in raw tubers

Variant	Karin		Ditta	
	[mg · kg^{-1} d.m.]	[%]	[mg · kg^{-1} d.m.]	[%]
1	0.200^{a}	100.0	0.227^{ab}	100.0
2	0.474^{abc}	237.0	0.654^{bcd}	288.1
3	1.025^{d}	512.5	0.809^{cd}	356.4

The Se content in boiled tubers of both varieties (Table 4) was seen to increase (0.2; 0.494 and 0.841 mg Se · kg^{-1} d.m. in 'Karin' and 0.2; 0.552 and 0.989 mg Se · kg^{-1} d.m. in 'Ditta'). In both varieties the differences among the variants were statistically in significant. The differences between the varieties in the case of the individual variants were statistically not significant. The effect of heat treatment of the tubers by boiling on the content of selenium was insignificant. Average concentrations of Se in boiled tubers of the respective variants were comparable with the Se concentration in raw tubers (Tables 3 and 4).

Table 4

The effect of applications of selenium on its content in boiled tubers

Variant	Karin		Ditta	
	[mg · kg^{-1} d.m.]	[%]	[mg · kg^{-1} d.m.]	[%]
1	0.200^{a}	100.0	0.200^{a}	100.0
2	0.494^{b}	247.0	0.552^{b}	276.0
3	0.841^{c}	420.5	0.989^{c}	494.5

The Se content in French fries (Table 5) of the variety 'Karin' also increased with increasing Se doses (0.249; 0.421 and 0.814 mg Se · kg^{-1} d.m.); between variant 1 and 2 there was no statistically significant difference. The Se content in tubers of variant 3 was significantly higher than in the other variants. The Se content in French fries of the variety 'Ditta' was similar (0.2; 0.428 and 0.333 mg Se · kg^{-1} d.m.) and a statistically significant difference was detected only between variants 1 and 2.

Table 5

The effect of applications of selenium on its content in French fries

Variant	Se content in French fries			
	Karin		Ditta	
	[mg · kg^{-1} d.m.]	[%]	[mg · kg^{-1} d.m.]	[%]
1	0.249^{ab}	100.0	0.200^{b}	100.0
2	0.421^{a}	169.1	0.428^{a}	214.0
3	0.814^{c}	326.9	0.333^{ab}	166.5

Frying reduced the content of Se compared with raw tubers. This reduction was significant in variant 3 of the variety ‘Ditta’; among varieties this difference was insignificant. Jůzl et al [15] reached the same conclusions saying that the Se content in boiled potatoes decreased by 15 % and in French fries by 22 % in an experiment where doses of 12, 24, 48, 72 kg Se · ha^{-1} were applied. The same authors [18] monitored similar results in an experiment with soil (12 and 24 kg Se · ha^{-1}) and foliar (200 and 400 g Se · ha^{-1}) applications; after heat treatment the Se content in potato tubers decreased. Frying reduced the Se content more than boiling.

The Se content in tops (Table 6) of the ‘Karin’ variety also increased with the applied dose (0.237; 0.695 and 1.013 mg Se · kg^{-1} d.m.); the difference between variant 1 and 3 was statistically significant.

Table 6

The effect of applications of selenium on its content in tops (ppm in dry matter)

Variant	Karin		Ditta	
	[mg · kg^{-1} d.m.]	[%]	[mg · kg^{-1} d.m.]	[%]
1	0.237^{a}	100	0.272^{a}	100
2	0.695^{ab}	293.2	0.782^{ab}	287.5
3	1.013^{b}	427.4	0.518^{ab}	190.4

No difference was discovered among the variants of the ‘Ditta’ variety. Between the varieties no significant differences were discovered either. The Se content in the tops was comparable with the Se content in tubers. On the other hand Jůzl et al [18] discovered that after foliar application of 400 g Se · ha^{-1} the content of Se in the aboveground parts of potato was 3 times higher than in the tubers. The same authors [17] also pointed out that after soil application of selenium in doses ranging between 12 and 72 kg · ha^{-1} the tubers contained half the amount of Se than the potato tops.

Conclusions

The results imply that the application of Se did not increase yields and that with an increasing dose of foliar selenium its content in the potato tubers and in tops increased. Heat treatment of tubers by boiling did not change the content of selenium, but in French fries it reduced the content of Se. These differences in contents of Se in boiled tubers and French fries were probably caused by different processing temperatures (boiling 100 ^{o}C and frying 190 ^{o}C). Foliar applications of 200 and 400 g Se · ha^{-1} are seen as an effective way to increase the nutritional quality of potatoes.

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WPŁYW NAWOŻENIA DOLISTNEGO SELENEM I GOTOWANIA NA JAKOŚĆ ŻYWIENIOWĄ ZIEMNIAKÓW

Abstrakt: W ścisłym doświadczeniu mikropoletkowym badano wpływ nawożenia dolistnego selenu w formie selenianu(IV) sodu na plony bulw ziemniaków odmian 'Karin' i 'Ditta', zawartość Se w łętach i bulwach ziemniaków surowych i gotowanych oraz we frytkach. Doświadczenia założono w Žabčicach koło Brna w 3 wariantach: (1) kontrola; (2) 200 g Se · ha^{-1}; (3) 400 g Se · ha^{-1}. Największe średnie plony bulw uzyskano w obiekcie kontrolnym (19,99 Mg · ha^{-1}), a stosowanie selenu zmniejszało statystycznie nieznacząco plony (odpowiednio o 16,79 i 18,39 Mg · ha^{-1}). Odmiana 'Ditta' wytwarzała większe plony. Średnia zawartość Se zwiększała się wraz z zastosowaną dawką Se w porównaniu z obiektem kontrolnym i wynosiła w łętach 0,255; 0,739 i 0,767 mg · kg^{-1} s.m., w bulwach surowych 0,214; 0,564 i 0,917 mg · kg^{-1} s.m., w gotowanych bulwach 0,200; 0,523 i 0,915 mg · kg^{-1} s.m. i we frytkach 0,223; 0,425 i 0,574 mg · kg^{-1} s.m. Zawartość Se zmniejszała się wyraźniej we frytkach w wyniku obróbki termicznej. Na podstawie uzyskanych wyników można stwierdzić, że nawożenie dolistne wydaje się być odpowiednim i ekonomicznie uzasadnionym sposobem w kierunku osiągnięcia większej zawartości Se w bulwach ziemniaków z punktu widzenia pozytywnego wpływu Se na organizm ludzki.

Słowa kluczowe: ziemniaki, selen, nawożenie dolistne, plony, łęty, bulwy, frytki