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Accumulation of mineral elements in tuber periderm of potato cultivars differing in susceptibility to common scab

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Summary

Concentrations of Ca, P, K, Mg, Al, Fe, Mn, Cu and Zn were determined in healthy tuber peelings of cultivars less (Karin, Santé and Symfonia) and more (Agria, Désirée and Tomensa) susceptible to common scab when grown at two sites that differed in the level of scab incidence. The accumulation of some elements was significantly influenced by site, year, cultivar, maturity and the age of tuber periderm. At both sites, Ca and P in periderm tissue declined but Mg increased during the growing season. The Ca/P ratios in tuber periderm of all cultivars greatly decreased 83 days after planting. Concentrations of mineral elements measured at harvest may not reflect conditions present during the infection period, and consequently may not be related to scab incidence or severity.

Introduction

Common scab of potato is caused by *Streptomyces scabies* (Lambert & Loria, 1989). This disease does not decrease yields, but spoils the appearance and quality of tubers and this is important especially with potatoes grown for consumption. The disease can reduce the storage life and germination of potato seed tubers. Protection against common scab is mainly focused on soil amendments and breeding for genetic resistance. In their review of the effects of mineral elements applied to control scab, Keinath & Loria (1989) suggested that the concentration of nutrients in the potato periderm also should be measured to evaluate the effect of nutrient additions on the physiology of the host. Potato cultivars differ in the accumulation of nutrients from soil (Walworth & Muniz, 1993) and this can influence the content of minerals in particular plant organs. Literature data about the content of elements in potato periderm tissue are concerned with soil (Barnes & McAllister, 1971; Davis et al., 1976a), sources of calcium (Horsfall et al., 1954; Davis et al., 1976b; Lambert & Manzer, 1991), nitrogen, phosphorus, copper, iron, zinc, boron (Davis et al., 1976b), tuber size (Effmert, 1990), soil type (Simmons & Kelling, 1987) and in relation to plant diseases (McGuire & Kelman, 1986) including common scab (Davis et al., 1976a,b; Keinath & Loria, 1989). Data in each of these studies were for one cultivar only. The content of elements in potato periderm tissue has not been evaluated for two or more cultivars with different susceptibility to common scab cultivated at one experimental site. Although the reason for some of the above mentioned studies was to find the relationship between the content of elements and common scab, analysis of elements contained in tuber periderm tissue was done on samples harvested at the end of the vegetative period. Another investigation has shown that the accumulation of elements in potato tubers was determined primarily by the type and age of tissue and by the year and planting site (Míča & Vokál, 1988; Walworth & Muniz, 1993). We have not found any data in the literature that presents a relationship between the content of elements in tuber periderm tissue and the incidence of common scab, or that examined the accumulation of elements as a dynamic process. The objective of this study was to investigate the effect of soil conditions, year, cultivar and chronological tuber age on accumulation of elements in the tuber periderm tissue of potato cultivars differing in susceptibility to common scab.

Materials and methods

Plant material. The experiments were carried out using six cultivars of consumer potato (*Solanum tuberosum* L.): cv. Karin, Santé and Symfonia (less susceptible to common scab) and Agria, Désirée and Tomensa, (more susceptible) (Table 1). The cultivars varied in maturity period: early (110–120 days), semi-early (125–135 days) and semi-late (130–150 days).

Table 1. Common scab severity for six commercial potato cultivars grown on experimental sites differing by incidence of common scab.

Maturity	Cultivar	Experimental sites					
		České Budějovice			Vyklantice		
		1997	1998	Mean	1997	1998	Mean
Early	Karin	1.0	1.0	1.0	1.2	2.5	1.9
	Tomensa	1.0	1.2	1.1	3.5	4.1	3.8
Semi-early	Santé	1.0	1.3	1.1	3.3	4.6	4.0
	Agria	1.0	2.2	1.6	6.0	5.2	5.6
Semi-late	Symfonia	1.0	1.5	1.3	2.4	1.5	1.8
	Désirée	1.0	3.6	2.3	4.9	4.3	4.6

Experimental plots. Experimental plots were established on two sites, České Budějovice (Cb) and Vyklantice (Vy), both in South Bohemia, Czech Republic, in 1997 and 1998. The distance between the sites was about 100 km. The prevalent soil type on both sites was cambisol. Meteorological and soil characteristics of the experimental sites are shown in Table 2. Incidence of common scab was greater at Vy than at Cb (Table 1). Plots were planted by hand with whole tubers during the first week of May 1997 and the end of April 1998. Seed tubers were planted 30 cm apart in rows spaced 75 cm apart. The plots were 3 m long and 3 rows wide. The experiment on each site was designed as a Latin square with four replicates. Procedures recommended for cultivation, fertility and pest control in the Czech Republic were used. In both years tuber samples were collected 67, 83, 106 and 136 days after planting.

Table 2. Characteristics of the experimental sites.

	Experimental sites					
Characteristics	České Budějovice			Vyklantice		
Great soil group	cambisol			cambisol		
Average annual precipitation (mm)	620			696		
Average annual temperature (°C)	7.8			6.8		
Altitude (m)	380			620		
	1997	1998	Mean	1997	1998	Mean
pH/KCl	5.2	6.3	5.8	5.4	5.9	5.7
P(mg kg^{-1})	71	72	71.5	61	58	59.5
K(mg kg^{-1})	117	107	112	421	361	391
Mg(mg kg^{-1})	102	154	128	122	119	120
Ca(mg kg^{-1})	1440	1330	1385	1720	1550	1635
Ca/P	20.3	18.5	19.4	28.2	26.7	27.5
Al(mg kg^{-1})	1340	1787	1564	5510	6268	5889
Fe(mg kg^{-1})	3036	3755	3396	6234	7539	6887
Mn(mg kg^{-1})	262	288	275	661	689	675
Cu(mg kg^{-1})	8.8	12.5	10.7	7.7	7.0	7.35
Zn(mg kg^{-1})	19.7	15.4	17.6	30.7	31.4	31.1
% N	0.13	0.10	0.12	0.18	0.16	0.17
C_{ox} (%)	1.20	0.99	1.1	1.50	1.42	1.5
H^+(mmol kg^{-1})	46.0	23.0	35	76.0	51.0	64
CEC(mmol kg^{-1})[a]	110	90	100	240	190	215
Humus (%)	2.07	1.71	1.89	2.59	2.43	2.51

[a]CEC - cation exchange capacity

Scab evaluation. Severity of common scab was evaluated according to Wenzel & Demel (1967). Tubers were sorted into nine classes: 1, no scab; 2, 0.8% of the surface with scab lesions; 3, 2.8%; 4, 7.9%; 5, 18%; 6, 34%; 7, 55%; 8, 77%; 9, 100%. The results are expressed as means of four replicates at each experimental site. Each replicate consisted of 30 tubers chosen at random at the fourth sampling (136 days after planting).

Preparation of potato periderm tissue and analytical methods. Samples of potato peelings were obtained immediately after harvest. Ten medium-sized tubers were collected at random from the tubers harvested at each experimental site. Tubers were washed in distilled water, rinsed in 1% HCl solution for 2 minutes and then rinsed in distilled water again. The tubers were peeled with a standard potato peeler which produced a peel 1.5–2.0 mm thick containing periderm and several layers of cortical cells. Scabby periderm peeled from each tuber was collected separately from healthy periderm from the same tubers. The tissue was dried, ground and analysed for cations in a 1% HNO_3 solution with a SpectrAA 10 BQ device using atomic absorption spectrometry. The total phosphorus content was determined after mineralisation of the sample by perchloric acid (Sommers & Nelson, 1972). The total form of phosphorus in this solution was determined by means of ammonium molybdate and ascorbic acid (Murphy & Riley, 1962; Watanabe & Olsen, 1965).

Soil sampling and analytical methods. Soil samples were taken from the upper 15 cm layer (near the tubers) at the experimental sites during the first harvest of potatoes (after 67 days of growth). The sub-samples (10 partial samples from each site) were air-dried and sieved through 2 mm mesh. Soil pH and nutrients extractable with Mehlich II solution were determined using standard methods of the Czech Central Institute for Supervising and Testing in Agriculture (Zbíral, 1995). The contents of microelements in 2M HNO_3 extracts were determined by atomic absorption spectrometry with acetylene-nitrous oxide (Al) and acetylene-air flame (Mn, Fe, Cu, Zn).

Statistics. Statistical evaluation was made using Statistica Version 5. Four-way analysis of variance (ANOVA) was used to determine effects of different factors on the accumulation of elements in potato periderm.

Results and discussion

The experimental sites in České Budějovice (Cb) and Vyklantice (Vy) represent two extremes in the incidence of common scab on potato. Vyklantice was characterised by severe and regular occurrence, whereas Cb gave little or no common scab (Table 1). During the two years of this study, infection of cultivars susceptible and nearly resistant to common scab at the Cb site was 1 and 2.3, respectively, while at the Vy site it was 1.8 and 5.6, respectively. At both sites, resistant cultivars Karin, Santé and Symfonia were always less affected than cultivars susceptible to scab (cvs Agria, Désirée, Tomensa). The sites differed in most soil characteristics (Table 2). Except for P and Cu, values of all other elements measured (K, Ca, Al, Fe, Mn and Zn) were higher at Vy than at Cb. The Mg content and soil pH were similar at both sites. Both the incidence of common scab and the Ca content in the soil at Vy were higher than at Cb. This is in accordance with results of Horsfall et al. (1954) and Goto (1985) who found that severity of potato scab was positively correlated with the content of exchangeable calcium. Goto (1985) concluded that calcium content was a more reliable parameter than soil pH for evaluation the severity of potato scab. By contrast, Lambert & Manzer (1991) concluded that pH was a better predictor of scab incidence than the content of soil extractable calcium. It is fortuitous that the soil pH was very similar at both sites (5.7–5.8). Soil reaction is one of the factors which may influence the incidence of scab on potato tubers. Nevertheless, the experimental sites differed in the cation exchange capacity (CEC) which was significantly lower at the Cb site (100 mmol kg^{-1}) than at the Vy site (215 mmol kg^{-1}). CEC determines the supply of nutrients to plants from the soil. For example, CEC influences movement of calcium, and when the CEC value is low, movement of calcium in soil is limited (Simmons & Kelling, 1987). The importance of the CEC in soil to the incidence of common scab in potato has not been sufficiently investigated.

Differences in the concentration of elements were observed in peelings of potato tubers sampled 67, 83, 106 and 136 days after planting (Table 3). The contents of Ca and P at both sites significantly decreased during the vegetative period whereas the Mg concentration of all cultivars increased during the maturation period. It is evident that the site greatly influenced the accumulation of elements in tuber peelings. Concentrations of Al and Fe in the periderm of potato tubers grown at Cb significantly increased during the maturation period, whereas the concentration of these elements at Vy decreased slightly (Table 3).

Table 3. Statistical analysis of the dynamics of element contents in healthy periderm tuber tissue of potato cultivars differing in usceptibility to common scab.

	Experimental sites			
Element	České Budějovice		Vyklantice	
	Slope	P[a]	Slope	P[a]
Ca	-99.933	0.000045	-182.31	0.000095
P	-249.53	0.022	-259.07	0.000018
K	970.667	0.243	-429.95	0.551
Mg	84.2	0.000079	91.592	0.000049
Al	122.575	0.00045	-48.733	0.235
Fe	31.233	0.00059	-46.25	0.0642
Mn	1.262	0.598	-0.1958	0.943
Cu	0.446	0.121	-0.1883	0.335
Zn	2.596	0.217	-1.0824	0.131

[a]P = significance level. Null hypothesis is that there was no change in the content over time. If $P < 0.05$ the null hypothesis is rejected.

The concentration of calcium 136 days after planting was lower by 20–80% compared with the concentration in tubers harvested 67 days after planting (data not shown). Also the P content in tuber peelings decreased by 5–40%. Similarly Walworth & Muniz (1993) concluded that Ca and P in tubers declined during the growing season but they also reported a decrease in tuber Mg and K. However, their data were not for periderm but potato tissue nutrient concentrations. By contrast, we found that concentrations of Mg increased (5–35%) although K content in tuber periderm did not change. At the Cb site, the Fe content increased by 20–80% and Al increased by 10–200%.

In samples taken at the first harvest (67 days after planting), the average Ca/P ratios in tuber periderm of cultivars susceptible to common scab (Agria, Désirée, and Tomensa) were higher (0.15–0.62) than those which are nearly resistant to scab (Karin, Santé and Symfonia, 0.11–0.23). In all cultivars tested, the Ca/P ratio was significantly lower after 136 days of growth and the difference between the ratios of susceptible and resistant cultivars also decreased. A considerable decrease in Ca/P ratios (about 40–60%) was already observed 16 days after the first harvest (83 days after planting). A significant positive linear correlation ($r=0.6651$, $P=0.000535$) was observed between Ca/P ratios in tuber peelings and indices of scab severity.

Data in the literature, confirmed by our observations, show that during the maturation period the content of elements in tubers is influenced by many factors. The final content of elements evaluated during potato harvest does not correspond to the concentration of elements in younger tubers, when infection by *S. scabies* occurs and causes scabs on the tuber surface. It is generally agreed that the period of tuber initiation and expansion is critical for infection. As described by Lapwood (1973), young lenticels are the most susceptible and, based on this observation, it is possible to explain differences in results reported by Davis et al. (1976b) and Lambert & Manzer (1991). Davis et al. (1976b) showed that the calcium content in the peelings was highly correlated with scab, while Lambert & Manzer (1991) found that scab incidence was not correlated with Ca concentrations in healthy tuber periderm. With both, samples of potato peelings were collected after harvest. These authors and others (Davis et al., 1976a; Barnes & McAllister, 1971) did not consider the dynamics of element accumulation in tuber periderm tissue during the vegetative period and also when most scab infection occurred. At our sites, first scab lesions appeared 60–67 days after planting and in Table 4 we present a statistical evaluation of the effects of site, year, maturity and susceptibility to common scab on tubers harvested 67 days after planting. The influence of year (averaged over both experimental sites) was significant for accumulation of Ca, K, Al, Fe and Zn in tuber periderm. However, the accumulation of P, Mg, Mn and Cu was not dependent on the year of cultivation. The effect of site was also significant and at the Vy, cultivars accumulated more Mg, Al and Fe than at Cb and also the Ca/P ratio was higher. But the concentration of P and Cu in periderm was higher in potatoes harvested from Cb. There also were differences in accumulation of some of the elements (Ca, K, Mg) in cultivars with different maturities. Semi-early cultivars (SE) accumulated more Ca and Mg than early cultivars (E), but less K than semi-late cultivars (SL). Accumulation of other elements (P, Al, Fe, Mn, Cu, Zn) was not affected by cultivar maturity. Significant differences in accumulation of some elements were found between cultivars differing in susceptibility to common scab. In comparing the cvs Agria (susceptible) and Santé (resistant) (both SE), we found differing accumulations of Ca, Mn, Cu and Ca/P ratios. Similarly the content of P, Mn and the Ca/P ratio were different when we compared the cvs Désirée (susceptible) and Symfonia (resistant) (both SL). There were no statistically significant differences in element contents between Karin and Tomensa (E). Susceptible and nearly resistant cultivars (early, semi-early and semi-late) did not show any differences in the contents of K, Mg, Al, Fe and Zn in tuber periderm. The susceptible cvs (Agria, Désirée) had a higher Ca/P ratio and Mn concentration than resistant cvs (Santé, Symfonia) (Table 4).

Our observations showed that various factors including planting site, year, maturity, cultivar susceptibility, and type and age of tissue must be considered when evaluating relationships between concentrations of elements in tuber periderm tissue and common scab severity. The main conclusion of this study was that concentrations of Ca and P, which may influence the incidence of common scab, differ between the infection period and the harvest period.

Table 4. Statistical comparisons[a] of element contents in healthy tuber periderm tissue of potato cultivars.

Element	Source of variability								
	Year		Site		Maturity		Cultivar[b]		
	Effect	P	Effect	P	Effect	P	Effect	P	R vs. S
Ca	1997<1998	0.043002	--	--	E<SE	0.03902	SE	0.00516	R < S
P	--	--	Cb>Vy	0.000014	--	--	SL	0.024	R > S
Ca/P	--	--	Cb<Vy	0.007351	--	--	SE	0.047	R < S
							SL	0.02267	R < S
K	1997>1998	0.028101	--	--	SE<SL	0.00192	--	--	--
Mg	--	--	Cb<Vy	0.001944	E<SE	0.01316	--	--	--
Al	1997>1998	0.000021	Cb<Vy	0.025001	--	--	--	--	--
Fe	1997>1998	0.003612	Cb<Vy	0.000003	--	--	--	--	--
Mn	--	--	--	--	--	--	SE	0.049	R < S
							SL	0.048	R < S
Cu	--	--	Cb>Vy	0.01382	--	--	SE	0.049	R < S
Zn	1997>1998	0.002892	--	--	--	--	--	--	--

[a]Four way ANOVA with factors year, site, maturity, and cultivar. P=significance level.
[b]Experiments were with cultivars differing in susceptibility to common scab (R = resistant, S = susceptible) (Table 1).

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