The effect of site conditions, variety and fertilization on the content of polyphenols in potato tubers

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ABSTRACT

In precise field trials in the CR in the years 2004 and 2005 the effect of site conditions, yellow- and purple-fleshed varieties and fertilization on the content of total polyphenols (TP) in potato tubers was investigated. Comparing four localities, significantly highest TP content (by 5.7 to 13.4% higher than in other localities) was determined in the locality Stachy in both years, which we ascribe to apparently lower temperatures in the vegetation period in this locality of high altitude. In comparison to yellow flesh varieties, in the case of purple flesh Valfi variety TP content higher by 52 to 153% was recorded as the average of both years. As for the group of eight yellow flesh varieties, Karin variety had the highest TP content and showed a significant increase in comparison to Agria, Saturna and Asterix varieties by 67, 60 and 37%, respectively. TP content was not demonstrably affected by fertilization with mineral fertilizers, but we recorded a tendency to lesser TP content (by 3 to 9.9%) in the variant with higher potassium and magnesium fertilization (166 kg K/ha and 60 kg Mg/ha).

Keywords: polyphenol; potato; variety; environmental condition; fertilization

High attention of the world potato research is devoted to polyphenolic compounds in potatoes because of three main reasons; their influence on undesirable colour changes of tuber flesh in raw and cooked potatoes; further examination of their role in potato resistance against some diseases and pests; and in recent time mainly their favourable healthy effects in human nutrition (Friedman 1997).

Regarding healthy effects, polyphenols contained in food stuffs could be classified as natural antioxidants, which attract interest due to their potential nutritional and therapeutic effects. According to their chemical structure antioxidants could be classified into polyphenols (flavonoids, anthocyanins, phenolcarboxylic acids and coumarins), carotenoids (carotenes – precursors of vitamin A and xanthophyls) and tocopherols. Also ascorbic acid and selenium possess a strong antioxidant activity (Hlušek et al. 2005, Lachman and Hamouz 2005).

Potato tubers are a significant source of antioxidants in human nutrition (Al-Saikhan et al. 1995). According to Brown (2005) potatoes should be considered as vegetables that may have a high antioxidant capacity dependent on their flesh composition. Purple flesh potatoes contain anthocyanins (Fossen et al. 2003); they have their tuber flesh coloured totally or only partially and they contain 69–350 mg anthocyanins/kg fresh matter or 55–171 mg/kg fresh matter, respectively (Brown et al. 2003). A positive correlation (Reyes et al. 2005) between the antioxidant activity and the content of total polyphenols and anthocyanins was found concluding that mainly these compounds play an essential role in antioxidant capacity of potatoes. Currently breeding experiments are performed with the aim to enhance antioxidant activity of potatoes by an increase of the content of phenolic compounds and carotenoids as the main constituents contributing to their antioxidant activity (Brown 2005).

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Content of polyphenols is especially affected by variety, year of cultivation, stress factors (mechanical damage of tubers, attack of pathogens or action of light on tubers) and by cooking treatment. In a lesser extent the effect of locality, potassium fertilization, storage temperature, γ-irradiation and other factors could be involved, but there is only a little demonstrable empirical evidence in the literature references (Friedman 1997). Content of total polyphenolic compounds and anthocyanins is dissimilar at different stages of tuber maturity; it is affected by different environmental conditions, e.g. longer days and lower temperatures (Reyes et al. 2004), way and doses of fertilization (Kumar et al. 2004, Hajšlová et al. 2005) or ecological way of cultivation (Hamouz et al. 2005).

The aim of this work was to obtain knowledge about the effect of natural and growing conditions on the content of total polyphenols in the potato tubers. Particularly, we targeted the effect of sites with distinctively different conditions and the effect of fertilization. We also investigated the effect of genotype of selected yellow- and purple-fleshed varieties on the content of total polyphenols.

MATERIAL AND METHODS

In precise field trials in the years 2004 and 2005 in four localities of the Czech Republic with different altitudes, potato varieties Impala, Karin, Ditta, Saturna, and in the Lípa locality also yellow flesh varieties Agria, Asterix, Magda, Marabel and a purple flesh variety Valfi, were cultivated according to principles of unique routine agricultural engineering. All these varieties are registered in the EU countries. Characterization of individual sites (localities) is described in Table 1. As a fore crop winter wheat was used; in the autumn mulch was ploughed under at the dose of 30 t/ha together with P and K fertilizers at doses related to nutrient reserves in the soil. In the spring 2/3 of total dose 120 kg N/ha of nitrogen fertilizers (ammonium sulphate) were spread on the harrowed plot, and the rest of the dose was applied after emerging of growth (ammonium nitrate with calcium carbonate).

Experiments were performed in four replications in plantation spacing 0.75 × 0.30 m, plot area 3 m (4 lines) × 7.2 m.

The second experiment was performed in the Valečov locality (Table 1), where the effect of different levels of fertilizers with N, P, K and Mg nutrients on the content of total polyphenols was investigated. The experiment was realised with two varieties – Ditta and Karin, agrotechnical engineering was the same as in the first experiment. Nutrient doses per ha in individual variants were as follows: variant 1. without application of mineral fertilizers; variant 2. 100 kg N/ha, 44 kg P/ha, 108 kg K/ha, 30 kg Mg/ha; variant 3. 100 kg N/ha, 44 kg P/ha, 166 kg K/ha, 60 kg Mg/ha; variant 4. 180 kg N/ha, 44 kg P/ha, 108 kg K/ha, 30 kg Mg/ha.

After the harvest in physiological maturity potato tubers from individual variants and replicates of every experiment were sampled for laboratory analyses that were performed at the Department of Chemistry of the Czech University of Agriculture in Prague. For the determination of the content of polyphenols the samples were frozen and then freeze-dried immediately after the harvest.

Analytical methods

Freeze-drying. Potato tubers were freeze-dried in a freeze-drier Lyovac GT 2 (Leybold-Heraeus, Germany) and after the freeze-drying and stabi-

Table 1. Characterization of experimental localities

Locality	Above sea level (m)	Average annual temperature (°C)	Annual sum of precipitation (mm)	Soil type	Soil category
Přerov nad Labem	178	8,8	622	TBS	sl, l
Praha-Suchdol	286	8.2	510	TBS	l
Lípa	505	7.7	632	PGAC	sl
Stachy	860	6.3	755	BPS	ls
Valečov	460	6.9	649	PGAC	sl, l

Soil categories: TBS – typical brown soil, PGAC – pseudogleyic acid cambisol (brown gleysol), BPS – cryptopodzol (brown podzolic soil); soil texture class groupings: sl – sandy loamy, ls – loamy sandy, l – loamy lization in a desiccator they were pulverised in a laboratory grinder and then extracted with 80% water ethanol for 24 hours (15 min in ultrasonic bath and 1 h in a laboratory shaker). Sample weight was about 10 g. Obtained extracts were quantitatively transferred into 100 ml volumetric flasks and filled with 80% water-ethanol to the mark, and finally 0.5 ml aliquots were pipetted for the determination.

Determination of total polyphenols (TP) with Folin-Ciocalteau reagent. A modified method using Folin-Ciocalteau reagent was used. 0.5 ml of sample was pipetted into 50 ml volumetric flask and diluted with distilled water. Then 2.5 ml Folin-Ciocalteau reagent (PENTA, the Czech Republic) and after agitation 7.5 ml 20% sodium carbonate solution was added. After 2 hours standing at laboratory temperature absorbance at wave length λ = 765 nm on the spectrophotometer Heλios γ (Spectronic Unicam, Great Britain) was measured against blank. Results were expressed as gallic acid equivalents (in g/kg dry matter, gallic acid Merck, Germany). Mean values were obtained from three parallel determinations.

Statistical evaluation. Results were statistically evaluated by variance analysis method (ANOVA) and with a more detailed evaluation by Fisher test in statistical program SAS (version 8.02) at the level of significance $P = 0.05$.

RESULTS AND DISCUSSION

Effect of site

Different site conditions significantly affected TP content in tubers (Figure 1). In both experimental years the highest TP content was determined in the Stachy locality. In the year 2004 difference in comparison to other localities was 11.2–13.4%, in the year 2005 5.7–12.3%. The reason of higher TP content in the Stachy locality is evidently related to markedly different climatic conditions of this site (Table 1), which are expressed in the level of mean temperatures and sum of precipitation in vegetation period of experimental years (Table 2). Locality Stachy, in comparison to the other localities, is characterized by the highest altitude, the lowest average year temperature and the highest year sum of precipitation. In the year 2004 mean temperatures during the vegetation period were by 3.5–6°C lower and in the year 2005 by 2.7–6.1°C lower in the Stachy locality as compared to other localities. Precipitation on Stachy locality amounted in the year 2004 153–193% and in the year 2005 176–181% of values measured on other localities. Other three localities did not differ so distinctively in the levels of mean temperatures and sum of precipitation during the vegetation period and differences in TP content between them were

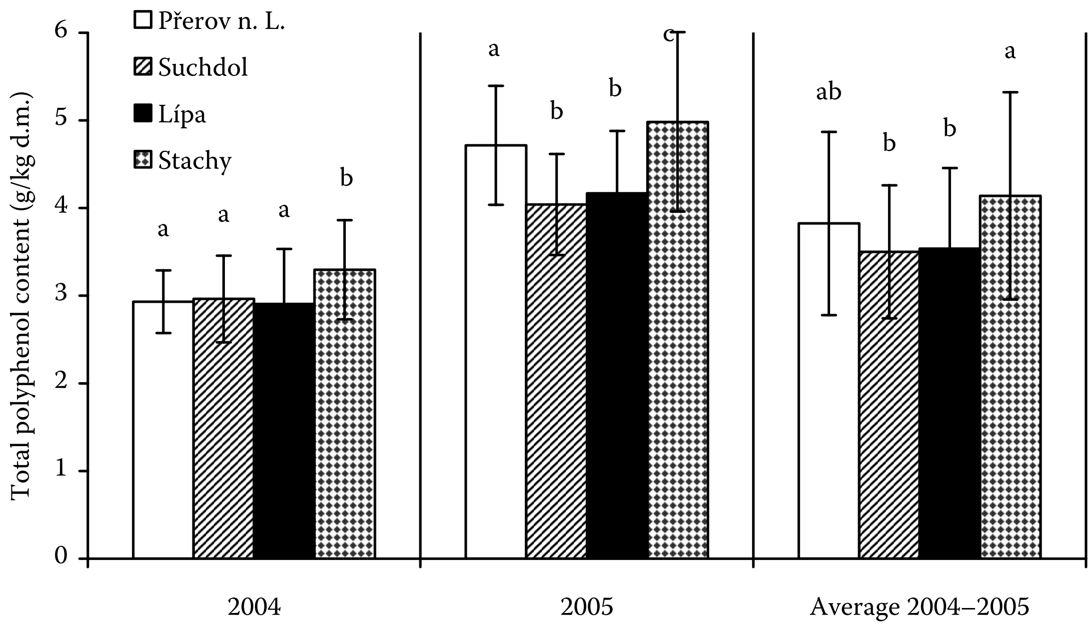

Figure 1. Effect of locality (site) on the content of total polyphenols; vertical lines represent SD (4 replicates), means with the same letter are not significantly different ($P \geq 0.05$)

Table 2. Mean monthly temperatures (°C) and sum of precipitation (mm) in the vegetation period in the years 2004 and 2005 in the experimental localities

	Stachy		Lípa		Přerov nad Labem		Praha-Suchdol	
	°C	mm	°C	mm	°C	mm	°C	mm
2004								
April	4.9	71	8.1	54	10.5	25	10.1	0
May	6.8	106	10.5	71	13.4	33	12.1	24
June	11.1	142	14.8	80	17.2	86	16.4	104
July	12.6	79	16.7	52	19.4	53	17.8	52
August	14.2	56	17.9	50	20.1	51	19.4	66
September	9.7	85	12.3	46	14.5	31	14.9	37
April–September	9.9	539	13.4	353	15.9	279	15.1	283
2005								
April	5.0	78	8.7	32	13.7	38	10.8	15
May	9.2	85	12.8	61	14.2	73	13.7	82
June	12.6	95	15.9	33	18.3	67	17.5	84
July	13.4	186	17.4	170	19.3	148	18.7	107
August	11.3	213	15.5	87	17.0	71	16.6	67
September	10.5	112	7.9	53	15.7	31	15.6	69
April–September	10.3	769	13.0	436	16.4	428	15.5	424

non significant. We consider lower temperatures during vegetation period in the Stachy locality as the main reason of higher TP content.

Higher TP content in regions with relatively cool and humid climate corresponds with our recent results (Hamouz et al. 1999). Also Reyes et al. (2004) confirmed that longer days and cooler temperatures in Colorado favoured about 2.5- and 1.4-times higher anthocyanin and total phenolic content than in Texas-grown tubers.

Effect of variety

Purple flesh Valfi variety differed significantly in both years from all eight yellow flesh varieties by a significantly higher TP content (Table 3). In the year 2004 cv. Valfi showed higher TP content by 22.8–125.9% in comparison to yellow flesh varieties, in the year 2005 by 74.4–173.8%, in average of both years by 52.7–153.4%.

In the grouping of yellow flesh varieties some varieties differed in TP content as well. In this grouping in both years the highest TP content was determined in Karin variety, which contained in average of both years higher TP content in comparison to Agria, Saturna and Asterix varieties by 66.7%, 59.8% and 37.1%, respectively. All these three varieties with the lowest TP content are designated largely for the production of fried products (chips – Asterix, Agria or crisps – Saturna). Further Saturna variety was demonstrably exceeded in TP content by cv. Impala (by 45.4%) and Magda (by 37.4%) and cv. Agria with the lowest TP content was significantly exceeded by Impala (by 51.8%), Magda (by 43.4%) and Marabel (by 40.3%) varieties.

Lewis et al. (1998) in agreement with our results found that purple- or red-fleshed cultivars had the flavonoid concentration twice higher than white-fleshed cultivars and had three to four times higher the concentration of phenolic acids. Reyes et al. (2005) estimated the anthocyanin and total phenolic concentrations of different purple and red flesh potato genotypes in the range from 110 to 1740 mg cyanidin-3-glucoside per kg fresh weight and from 760 to 1810 mg chlorogenic acid per kg fresh weight, respectively. Contents of phenolics and anthocyanins depended on genotype. Also Pawelzik et al. (1999) and Friedman (1997) deter-

Table 3. Effect of variety on the content of total polyphenols in the Lípa locality

Varieties	2004		2005		Average 2004–2005	
	g/kg d.m.	significance	g/kg d.m.	significance	g/kg d.m.	significance
Agria	1.99	a	3.07	a	2.54	a
Asterix	2.37	ab	3.80	b	3.08	abc
Impala	3.23	c	4.46	c	3.85	cd
Karin	3.68	d	4.78	c	4.23	d
Ditta	2.46	b	4.39	c	3.43	abcd
Magda	3.42	cd	3.85	b	3.64	cd
Marabel	3.30	cd	3.81	b	3.56	bcd
Saturna	2.25	ab	3.04	a	2.65	ab
Valfi	4.51	e	8.33	d	6.42	e
Average of varieties	3.07		4.39		3.73	

$LSD_{0.05}$ = 0.3783 (2004), $LSD_{0.05}$ = 0.5018 (2005), $LSD_{0.05}$ = 0.9392 (average 2004–2005); means with the same letter are not significantly different ($P \geq 0.05$)

Table 4. Effect of the level of mineral fertilization (fertilization variants) on the content of total polyphenols (g/kg d.m.) in the Valečov locality

Fertilization variant*	Variety	Total polyphenols (g/kg d.m.)	Average of fertilization variant	(%) (variant 2 = 100%)
1	Karin	3.598	3.158	96.5
	Ditta	2.717		
2	Karin	3.623	3.272	100.0
	Ditta	2.922		
3	Karin	3.137	2.947	90.1
	Ditta	2.756		
4	Karin	3.136	3.045	93.1
	Ditta	2.954		

$LSD_{0.05}$ = 0.4869 (fertilization variant); *variant 1. without application of mineral fertilizers, variant 2. 100 kg N/ha, 44 kg P/ha, 108 kg K/ha, 30 kg Mg/ha, variant 3. 100 kg N/ha, 44 kg P/ha, 166 kg K/ha, 60 kg Mg/ha, variant 4. 180 kg N/ha, 44 kg P/ha, 108 kg K/ha, 30 kg Mg/ha

mined a significant effect of variety on TP content, which has already been confirmed by our recent results (Hamouz et al. 1999).

Effect of fertilization

Significant factor influencing qualitative parameters of potatoes is the way of their cultivation and fertilization. E.g. conventional and ecological way of cultivation cause differences in the content of ascorbic acid and chlorogenic acid (Hamouz et al. 1999, Hajšlová et al. 2005), whereas their levels are higher in ecologically cultivated potatoes without use of industrial fertilizers. In our experiments differences of TP contents between four experimental variants ranged between 3.0–9.9%, but they were not statistically significant (Table 4). The highest

TP content was determined in the variant No. 2 with common N, P, K and Mg nutrient doses. The most apparent tendency to TP decrease was found in the variant No. 3 with higher K and Mg doses in comparison to other variants. This result corresponds with conclusions of Kaldy and Lynch (1983); according to them the application of potassium fertilizers positively affected the content of phenolics and colour flesh changes. Some authors (Friedman 1997) suggest that K fertilization is one of the factors that influence TP content in a lesser extent. A lesser content of polyphenols in potato tubers cultivated with higher surplus of potassium could contribute to lesser enzymatic browning, even if the main factor influencing browning is mainly phenylammonia-lyase (PAL) activity (Cantos et al. 2002).

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