Site conditions and genotype influence polyphenol content in potatoes

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ABSTRACT: In the years 2005 and 2006 the effect of site conditions, yellow and purple fleshed varieties and mineral fertilization on the content of total polyphenols (TP) in potato tubers was investigated. In both years significantly the highest TP content (by 5.7 to 56.3% higher than in other localities) was determined at the Stachy locality; we ascribe it to apparently lower temperatures in the vegetation period at this locality of higher altitude. In the purple flesh Valfi variety TP content higher by 74 to 141% was recorded in average of both years, in comparison to yellow flesh varieties. In the group of eight yellow flesh varieties the highest TP content was recorded in the Ditta variety; it was higher by 38, 29 and 24% in comparison with Saturna, Agria and Asterix varieties. TP content was not significantly affected by fertilization with mineral fertilizers.

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

Attention of the world potato research is paid to polyphenolic compounds in potatoes because of three main reasons. Partly, it is for their accountability for undesirable colour changes of tuber flesh in raw and cooked potatoes; they are also examined with respect to their role in potato resistance against some diseases and pests; recently, their favourable healthy effects in human nutrition were reported (Friedman 1997).

Regarding healthy effects, polyphenols contained in foodstuffs could be classified as natural antioxidants; their potential nutritional and therapeutic effects are therefore a matter of interest. 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. Ascorbic acid and selenium possess strong antioxidant activity as well (Lachman, Hamouz 2005; Hlušek et al. 2005; Jůzl et al. 2007).

Potato tubers represent 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 depending on their flesh composition. Purple flesh potatoes contain anthocyanins (Fossen et al. 2003). They contain 69–350 mg anthocyanins/kg fresh matter or 55 to 171 mg/kg fresh matter; the amount depends on whether the tuber flesh is coloured totally or only partially (Brown et al. 2003). A positive correlation (Reyes et al. 2005) between antioxidant activity and the content of total polyphenols and anthocyanins was found, concluding that mainly these compounds play essential role in antioxidant capacity of potatoes. Currently, breeding experiments are performed with the aim to enhance the 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 affected mainly 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). The 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), ways and doses of fertilization (Kumar et al. 2004; Hajšlová et al. 2005) or ecological ways of cultivation (Hamouz et al. 2005).

The aim of this work was to obtain information about the effect of environmental and growing conditions on the content of total polyphenols in potato tubers. In our study we targeted the effect of sites with distinctively different conditions and the effect of fertilization. We also examined the effect of genotype of selected yellow and purple flesh varieties on the content of total polyphenols.

MATERIAL AND METHODS

In precise field trials in the years 2005 and 2006 at four localities in the Czech Republic with different altitudes yellow flesh potato varieties Impala, Karin, Ditta, Saturna were cultivated according to the principles of unique routine agricultural engineering; in addition, Agria, Asterix, Magda, Marabel (all yellow flesh) and a purple flesh Valfi variety were cultivated at the Lípa locality. All these varieties are registered in the EU countries. Characterization of individual sites (localities) is described in Table 1. As a forecrop, winter wheat was used; in the autumn mulch was ploughed under at the dose of 30 t per ha together with P and K fertilizers at doses related to nutrient reserves in the soil. In the spring, ⅔ of the total dose (120 kg N per ha) of nitrogen fertilizers (ammonium sulphate) were spread on the harrowed plot; the rest of dose was applied after emerging of growth (ammonium nitrate with calcium carbonate).

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

The second experiment was performed at 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 realized 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 tubers of individual variants were sampled and replicates of every experiment were used for laboratory analyses, which were performed at the Department of Chemistry of the Czech University of Life Sciences Prague. For the determination of the content of polyphenols the samples were frozen immediately after the harvest and then freeze-dried.

Analytical methods

Sample preparation. Potato tubers were freeze-dried in a freeze-drier Lyovac GT 2 (Leybold-Heraeus, Germany) and after freeze-drying and stabilization in a desiccator they were pulverized 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 fulfilled with 80% water ethanol to the mark, and finally 0.5 ml aliquots were pipetted for the determination.

Table 1. Characterization of experimental localities

Locality	Level above sea (m)	Average annual temperature (°C)	Annual sum of precipitation (mm)	Soil type	Soil texture
Přerov nad Labem	178	8.8	622	hL	sl, l
Praha-Suchdol	286	8.2	510	hL	l
Lípa	505	7.7	632	saC	sl
Stachy	860	6.3	755	eP	ls
Valečov	460	6.9	649	saC	sl, l

Soil type: hL – haplic Luvisol, saC – stagnic acid Cambisol, eP – entic Podzol, soil texture: sl – sandy loamy, ls – loamy sandy, l – loamy

Fig. 1. Effect of locality (site) on the content of total polyphenols
$HSD_{0.05}$ = 0.3373 (2005), $HSD_{0.05}$ = 0.4272 (2006), $HSD_{0.05}$ = 0.3831 (average 2005 to 2006); means (columns) with the same letter are not significantly different ($P \geq 0.05$)

Determination of total polyphenols (TP) with Folin-Ciocalteau reagent. A modified method using the Folin-Ciocalteau reagent was used. 0.5 ml of extract were pipetted into 50 ml volumetric flask and diluted with distilled water. Then 2.5 ml Folin-Ciocalteau reagent (PENTA, Czech Republic) were added, and after agitation 7.5 ml 20% sodium carbonate solution were added. After 2 hours standing at laboratory temperature absorbance was measured against blank at the wavelength λ = 765 nm on the spectrophotometer Helios Gamma (Thermo Electron Corporation, Great Britain). 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 the analysis of variance (ANOVA) and with more detailed evaluation by the 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 (Fig. 1). In both experimental years the highest TP content was determined at the Stachy locality. In the year 2005 the difference in comparison to other localities was 5.7 to 12.3%, in 2006 it

Table 2. Mean monthly temperatures (°C) and sum of precipitation in vegetation period in the years 2005 and 2006 at the experimental localities

Month	Stachy		Lípa		Přerov n. L.		Suchdol	
	temperature (°C)	precipitation (mm)	temperature (°C)	precipitation (mm)	temperature (°C)	precipitation (mm)	temperature (°C)	precipitation (mm)
2005								
IV	5.0	78	8.7	32	13.7	38	10.8	15
V	9.2	85	12.8	61	14.2	73	13.7	82
VI	12.6	95	15.9	33	18.3	67	17.5	84
VII	13.4	186	17.4	170	19.3	148	18.7	107
VIII	11.3	213	15.5	87	17.0	71	16.6	67
IX	10.5	112	7.9	53	15.7	31	15.6	69
IV–IX	10.3	769	13.0	436	16.4	428	15.5	424
2006								
IV	5.0	73	7.9	57	9.6	44	9.4	49
V	8.6	98	12.5	82	14.7	66	13.8	85
VI	13.3	44	17.2	87	18.4	111	18.2	88
VII	17.6	25	20.9	23	23.5	46	22.6	37
VIII	9.8	132	14.4	150	17.1	116	15.8	105
IX	12.6	29	15.1	10	17.1	11	15.4	7
IV–IX	11.2	401	14.7	408	16.7	395	15.9	371

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

Varieties	2005		2006		Average 2005–2006	
	g/kg DM	significant	g/kg DM	significant	g/kg DM	significant
Agria	3.07	c	4.07	abc	3.57	c
Asterix	3.80	bc	3.61	b	3.71	c
Impala	4.46	ab	4.56	ab	4.51	ab
Karin	4.78	a	4.22	abc	4.50	ab
Ditta	4.39	ab	4.83	a	4.61	a
Magda	3.85	bc	4.11	abc	3.98	abc
Marabel	3.81	bc	3.97	bc	3.89	bc
Saturna	3.04	c	3.62	b	3.33	c
Valfi	8.33	d	7.70	d	8.02	d
Average of varieties	4.39		4.52		4.46	

$HSD_{0.05}$ = 0.8228 (2005), $HSD_{0.05}$ = 0.8197 (2006), $HSD_{0.05}$ = 0.6725 (average 2005–2006); means with the same letter are not significantly different ($P \geq 0.05$)

was 48.7 to 56.3%. A reason of higher TP content at the Stachy locality is evidently related to markedly different climatic conditions of this site (Table 1), which were expressed in the level of mean temperatures and sum of precipitation in vegetation period of experimental years (Table 2). The Stachy locality is characterized by the highest altitude, the lowest average year temperature and the highest year sum of precipitation. In 2005 mean temperatures during the vegetation period were by 2.7 to 6.1°C lower and in the year 2006 by 3.5 to 5.5°C lower as compared to the other localities. Precipitation at the Stachy locality amounted to 176 % to 181% and to 98 % to 108% of values measured at the other localities in 2005 and 2006, respectively. The other three localities did not differ so distinctively in the levels of mean temperatures and sums of precipitation during the vegetation period and differences in TP content between them were not significant. We consider lower temperatures during vegetation period at 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

In both years purple flesh Valfi variety significantly differed from all eight yellow flesh varieties by significantly higher TP content (Table 3). In the year 2005, cv. Valfi showed TP content higher by 74.4% to 173.8%, in the year 2006 by 59.6% to 113.1%, and in average of both years by 74.0% to 140.6%.

There were also differences in TP content among the yellow flesh varieties. In average of both years the highest TP content was recorded in cultivars Ditta, Impala, Karin and Magda, where we found non-confirmative differences. The lowest TP content

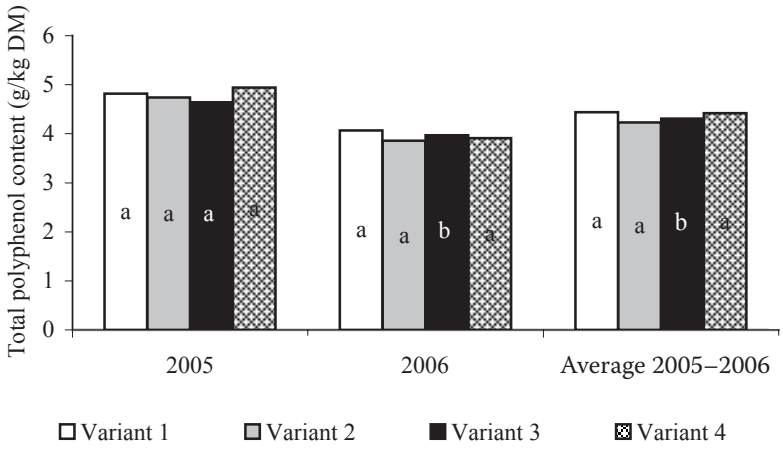

Fig. 2. Effect of the level of mineral fertilization (fertilization variants) on the content of total polyphenols (g/kg DM) at the Valečov locality
$HSD_{0.05}$ = 0.8913 (2005), $HSD_{0.05}$ = 0.3027 (2006), $HSD_{0.05}$ = 0.6193 (average 2005 to 2006); means (columns) with the same letter are not significantly different ($P \geq 0.05$)
Variant 1 without fertilization with 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

was found in cultivars Saturna, Agria and Asterix (by 38.1%, 28.9% and 24.3% lower in comparison with Ditta cultivar). These three varieties with the lowest TP content are designated largely for the production of fried products (chips – Asterix, Agria; crisps – Saturna). Saturna variety with the lowest TP content was topped by cultivars Impala (by 35.4%) and Karin (by 35.0%).

Lewis et al. (1998), in accordance with our results, found that purple or red flesh cultivars had the flavonoid concentration twice higher than white flesh cultivars, and 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 a range from 110 to 1,740 mg cyanidin-3-glucoside per kg fresh weight and from 760 to 1,810 mg chlorogenic acid per kg fresh weight, respectively. Contents of phenolics and anthocyanins were dependent on genotype. Also Pawelzik et al. (1999) and Friedman (1997) determined a significant effect of variety on TP content, which was confirmed by our recent results (Hamouz et al. 1999).

Effect of fertilization

Another significant factor influencing qualitative parameters of potatoes is the way of their cultivation and fertilization. For instance, conventional and ecological ways of cultivation cause differences in the content of ascorbic acid and chlorogenic acid (Hamouz et al. 1999; Hajšlová et al. 2005); their levels are higher in ecologically cultivated potatoes without use of industrial fertilizers. In our experiments in 2005, we observed a tendency of higher TP content with higher level of nitrogen fertilization (180 kg N/ha – Fig. 2) and on the other hand a tendency of decreased TP content with higher level of potassium and magnesium fertilization (166 kg K/ha and 60 kg Mg/ha). These results corresponded with conclusions of Kaldy and Lynch (1983); according to them the application of potassium fertilizers positively influences the content of phenolics and colour flesh changes. Some authors (Friedman 1997) report a relation of K fertilization to factors that influence TP content in lesser extent. Low 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 phenylammonia-lyase (PAL) activity (Cantos et al. 2002). Our experiments in 2006 did not confirm the trend of TP content decrease with increase of potassium dose; differences between variants were minimal and non-confirmative.

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Stanovištní podmínky a genotyp ovlivňují obsah polyfenolů v bramborách

ABSTRAKT: V letech 2005 a 2006 byl zkoumán vliv podmínek prostředí odrůd se žlutou a fialovou dužninou a minerálního hnojení na obsah celkových polyfenolů (CP) v hlízách brambor. Ze čtyř lokalit byl v obou letech zjištěn průkazně nejvyšší obsah CP (o 5,7 až 56,3 % vyšší proti ostatním lokalitám) na stanovišti Stachy, což přičítáme výrazně nižším teplotám ve vegetačním období v této lokalitě s vysokou nadmořskou výškou. U odrůdy Valfi s fialovou barvou dužniny byl zaznamenán v průměru obou let o 74 až 141 % vyšší obsah CP proti odrůdám se žlutou barvou dužniny. V rámci skupiny osmi odrůd se žlutou dužninou dosáhla nejvyššího obsahu CP odrůda Ditta, u níž byl zjištěn průkazně vyšší obsah CP proti odrůdám Saturna, Agria a Asterix (o 38, 29 a 24 %). Obsah CP nebyl prokazatelně ovlivněn hnojením minerálními hnojivy.

Klíčová slova: polyfenoly; brambory; odrůda; podmínky prostředí; hnojení

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