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Yield potential and antioxidant activity of potatoes with coloured flesh

K. Pazderů[1], K. Hamouz[1], J. Lachman[2], P. Kasal[3]

[1]*Department of Crop Production, Faculty of Agrobiology, Food and Natural Resources, Czech University of Life Sciences Prague, Prague, Czech Republic*
[2]*Department of Chemistry, Faculty of Agrobiology, Food and Natural Resources, Czech University of Life Sciences Prague, Prague, Czech Republic*
[3]*Potato Research Institute, Havlíčkův Brod, Czech Republic*

ABSTRACT

In the experiment yield potential and antioxidant activity (AOA) of 13 potato cultivars with different flesh colour (purple (p); red (r); yellow (y) and white (w)) were evaluated at two localities with different environmental conditions in three years 2009–2011. Yield potential was evaluated at harvest time in physiological maturity of crop stand. The results confirm that total yield and yield of tubers > 40 mm of coloured potatoes cvs. Red Emmalie/r (68.98 t/ha), Blaue Elise/p (59.96 t/ha), Valfi/p (53.72 t/ha) were comparable with control cvs. Agria/y, Lady Balfour/w and Russet Burbank/w. Some cultivars with lower yield had share of tubers above 40 mm comparable with control cultivars (94.45% and 93.48% in case of cvs. Valfi/p and Blue Congo/p), respectively. Antioxidant activity was determined as ascorbic acid equivalent by ABTS (2,2´-azinobis (3-ethylbenzothiazoline-6-sulfonate) method. The lowest antioxidant activity was observed in the control cvs. Lady Balfour/w (ascorbic acid equivalent (AAE) 74.1 mg/kg fresh mattter (FM)), Agria/y (AAE 84.4 mg/kg FM) and Russet Burbank (AAE 93.9 mg/kg FM). In the group of cultivars with red flesh AOA was 3.2 to 5.1 times higher and in a group of purple-fleshed cultivars it was from 3.7 to 7.0 times higher.

Keywords: *Solanum tuberosum*; tuberous crop; anthocyanins; conventional cultivation; varieties of potatoes

Potatoes are an important food in the diet of mankind. Potatoes with coloured flesh may be encountered in many countries on all continents, but are grown only in small amounts. They were not interesting for consumers for a long time just because of their less attractive red (r) or purple (p) colour of the flesh. Currently gaining in importance in terms of health nutrition, they are increasingly sought and recommended as a healthier food (Lange et al. 2007, Hecht 2015). Potatoes can be a major source of natural antioxidants, which have a beneficial effect on human health (Brown 2005, Andre et al. 2014); in the flesh coloured potato, unlike yellow (y) and white (w) flesh potato, there are also significant quantities of anthocyanins with a high antioxidant activity (Kita et al. 2015), while the content of antinutritional glycoalkaloids in their tubers corresponds to other cultivars (Hamouz et al. 2014) and did not come close to the limit of 200 mg/kg fresh matter (FM), which indicate Zarzecka et al. (2015). Potato cultivars with coloured flesh may therefore be an interesting alternative to traditional cultivars, whose antioxidant activity is lower (Lachman et al. 2009). Although the antioxidant content in potato tubers colour is high, the main reason why these cultivars are not largely produced is their lesser attractiveness and fear of their low-yield potential. Recently, breeding these types of potatoes has expanded in the world, such as customer-interesting option with positive effects on health (Wegener et al. 2009, Vales et al. 2012). In the literature, however, there is no information about the yield potential of these cultivars.

The aim of this study was to determine the yield potential and antioxidant activity of tubers in ten

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potato cultivars with coloured flesh in comparison with high-yielding cultivars of European and world assortment (yellow flesh Dutch cv. Agria, white flesh cv. Lady Balfour from England and white flesh American cv. Russet Burbank). Furthermore, to determine to what extent they are influenced by genotype-mentioned characteristics of the cultivar, purple and red colour of the flesh and site conditions.

MATERIAL AND METHODS

Plant material. Potato tubers for evaluation of yield and chemical analysis were grown in 2009–2011 in exact field trials in the Czech Republic. Experiments with four replications were carried out in two localities with different altitude and climatic conditions (Table 1). In the locality Přerov nad Labem an experiment was made at the workplace of the Central Institute for Supervising and Testing in Agriculture (CISTA), Czech Republic, and on the site Valečov at the Experimental Station of the Potato Research Institute (PRI) Havlíčkův Brod. Basic characteristics of weather in the vegetation period in experimental years were presented at our previous article (Hamouz et al. 2014). The experiment included a total of 13 cultivars, including three with the traditional colour of flesh (one yellow and two white cultivars), six cultivars with purple flesh, and four cultivars of red-fleshed tubers. The source of seed tubers was first an import from abroad; second the Gene Bank of PRI. Conventional cultivation technologies (according to CISTA), which were uniform in both locations, were used.

Yield of tubers. Yield of tubers was determined at harvest time in physiological maturity of crop stand. Yield of tubers above 40 mm (marketable tubers) was determined after grading on sieve with 40 mm width of mesh.

Determination of antioxidant activity. Determination of the antioxidant activity (AOA) by 2,2'-azinobis (3-ethylbenzothiazoline-6-sulfonate (ABTS) assay: the indirect method described by Roginsky and Lissi (2005) was used, when a sample containing antioxidants reacts with a solution of stable synthetic radical, and meanwhile it is converted to a colourless product (ABTS assay). Absorbance was measured after the addition of a 100 μL sample to 1 mL of radical solution after 1 min; in a blank experiment 100 μL water was added. AOA was calculated as the decrease of absorbance by the equation:

$$\% \text{ inhibition ABTS} = [(A_0 - A_t)/A_0] \times 100$$

Calculated AOA was expressed as ascorbic acid according to the standard calibration curve (ascorbic acid, $R^2 = 0.9945$) made for given absorbance in t_0. Every sample was analysed 5 times. 54.8 mg ABTS were dissolved in 20 mL phosphate buffer (pH 7.0; 5 mmol) and activated to ABTS• + radical by addition of 1 g MnO_2 with occasional stirring and time of activation 20 min. (Pennycooke et al. 2005). Then the solution was centrifuged (5 min, 7000 g), filtered (45 μm) and diluted with phosphate buffer (pH = 7.4) to absorbance (t_0) A734 = 0.800 ± 0.02. Sample addition was 5 μL, time of reaction 20 min. Absorbance of the solution was measured at wavelength λ = 734 nm.

Statistical analysis. AOA values were calculated and expressed in mg of ascorbic acid equivalents (AAE). Obtained results were statistically evaluated by the ANOVA method of analysis of variance. Differences between mean values were evaluated by the Tukey's *HSD* (honestly significant difference) test in the SAS computer programme (SAS Institute, Cary, USA), version 9.1.3. at the level of significance $P = 0.05$.

RESULTS AND DISCUSSION

Antioxidant activity of tubers. The effect of cultivar and colour of the flesh: significant differences between cultivars can be seen in the antioxidant activity of tubers, and it is clear that cultivars with coloured flesh significantly exceed in this indicator yellow flesh and white flesh control cultivars

Table 1. Characterization of experimental locations

Locality	GPS coordinates	Altitude (m a.s.l.)	Average annual temperature (°C)	Annual sum of precipitation (mm)	Soil type	Soil texture
Přerov nad Labem	50°9'36.97''N, 14°49'30.08''E	178	8.8	352	Haplic Luvisol	sandy loamy
Valečov	49°38'39.28''N, 15°29'49,97''E	460	6.9	417	Acid Cambisol	sandy loamy

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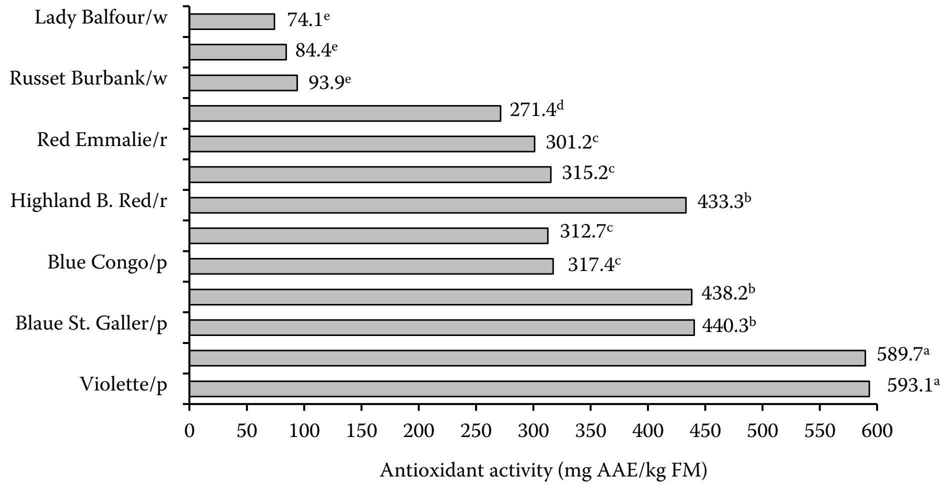

Figure 1. Antioxidant activity of cultivars; average of 2 localities and 3 years 2009–2011. Differences between means with the same letter are statistically non-significant at $P = 0.05$; Tukey *HSD* = 19.01. AAE – ascorbic acid equivalent; FM – fresh matter

(Figure 1). The lowest AOA three-year average values from both sites were achieved in white flesh cv. Lady Balfour (AAE 74.1 mg/kg FM), in yellow flesh cv. Agria (AAE 84.4 mg/kg FM) and in case of white flesh cv. Russet Burbank (AAE 93.9 mg/kg FM), while AAE of the group of cultivars with red pulp compared with the cv. Agria was detected 3.2 times (cv. Rosemarie) to 5.1 times (cv. Highland Burgundy Red) higher and in the case of group of cultivars with purple flesh even 3.7 times (cv. Valfi) to 7.0 times (cv. Violette) higher.

Differences of tuber AOA between cultivars with traditional colour of the flesh and with red and purple flesh we connect with the content of anthocyanin pigments, which are the important compounds with antioxidant activity in cultivars with coloured flesh, according to data in the literature. This is confirmed by Lachman et al. (2009), in the experiments with the 15 red- and purple-fleshed potato cultivars total anthocyanins content highly corresponded with antioxidant activity. A correlation between AOA and total anthocyanins ($R^2 = 0.659$) was found (Lachman et al. 2012). Whereas in potatoes with white or yellow flesh colour, prevalent contributors to AOA are chlorogenic acid, gallic acid, caffeic acid and catechin (Reddivari et al. 2007), in purple- and red-fleshed potatoes the major contributors of AOA are in particular anthocyanins. ORAC (oxygen radical absorbance capacity) and FRAP (fluorescence recovery after photobleaching) assays revealed that antioxidant levels in red- or purple-fleshed potatoes were 2 to 3 times higher than in white- or yellow-fleshed potatoes (Kosieradzka et al. 2004). Significant differences in AOA were detected also in the group of cultivars with coloured flesh, which corresponds to the published knowledge (Lachman et al. 2009, 2012).

Total yield, yield of marketable tubers > 40 mm, share of tubers > 40 mm. The analysis of variance (Table 2) shows a significant effect on yield traits in distinct locations, although the influence of cultivar and year was also significant. Affleck et al. (2008) show similar results that the influence of environment on yield is higher than that of cultivars, while the qualitative characteristics such as the number of tubers are more influenced by cultivar.

All evaluated yield parameters reached higher values at the Valečov site (56.76 t/ha for yield, 52.49 t/ha for marketable yield > 40 mm, 90.15% for share

Table 2. ANOVA analysis: effects of yield potential influencing factors

Factor[1]	Total yield			Yield of tubers > 40 mm			Share of tubers > 40 mm		
	mean square	*F*-test	*P*-value	mean square	*F*-test	*P*-value	mean square	*F*-test	*P*-value
Year	2165	75.3	< 0.0001	2766	108.1	< 0.0001	1061	99.4	< 0.0001
Locality	14181	493.2	< 0.0001	23321	911.6	< 0.0001	9409	881.3	< 0.0001
Cultivar	4347	151.2	< 0.0001	5195	203.1	< 0.0001	2296	215.1	< 0.0001
Error	29	–	–	26	–	–	11	–	–

[1]Model was counted with all interactions, only main factors are expressed in the Table 2

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Table 3. Influence of locality on yield of tuber size categories of potato (average of 13 cultivars and years 2009–2011)

Locality	Total yield (t/ha)	Yield of tubers > 40 mm (t/ha)	Share of tubers > 40 mm (%)
Přerov nad Labem	43.19[b]	35.05[b]	78.93[b]
Valečov	56.76[a]	52.49[a]	90.15[a]
HSD	1.16	1.10	0.71

Differences between means with the same letter are statistically non-significant at P = 0.05. *HSD* – honestly significant difference

of tubers > 40 mm) in comparison with the Přerov experimental site (Table 3). The reason for that were better environmental conditions for growing potatoes, higher sum of precipitation and lower average temperature, important for the formation of tubers (Govindakrishnan and Haverkort 2006). Generally, seasonal drought reduces the yield of marketable tubers more than the total yield of tubers (Stark et al. 2013).

Cultivar differences in yield, yield of tubers above 40 mm, and the share of tubers above 40 mm are shown in the Table 4. It can be stated that total yield of cultivars with coloured flesh evaluated in this experiment was lower in comparison with the control cvs. Agria/y, Lady Balfour/w and Russet Burbank/w (average yield 63.96 t/ha). The average yield of potatoes with red pulp was 51.90 t/ha, purple potatoes amounted to 44.00 t/ha.

However it is essential that there are coloured cultivars that have yield and other characteristics comparable with control cultivars (Rote Emma/r, 68.98 t/ha; Blaue Elise/p, 59.96 t/ha; Valfi/p, 53.72 t/ha) (Table 4). How Vales et al. (2012) declare, the main benefit (advantage) of cultivars with coloured flesh is their specialty. This and higher antioxidant activity conditioned by higher content of anthocyanins and other antioxidants are important properties for consumers (Wegener et al. 2009). High yields in some cultivars then demonstrate that these cultivars can be even interesting for large scale farming, and not only for small farmers or/and organic production sector. Lange and Kawchuk (2014) consider planting potatoes with coloured flesh with a higher content of antioxidants for the opportunity to diversify production and increase consumer interest for potatoes.

Table 4. Influence of cultivar on yield traits of potato; average of 2 localities and years 2009–2011

Cultivar/flesh colour	Total yield		Yield of tubers > 40 mm		Share of tubers > 40 mm	
	(t/ha)[1]	significance[2]	(t/ha)[1]	significance[2]	(%)[1]	significance[2]
Agria/y	65.26	bc	63.83	b	97.56	a
Lady Balfour/w	71.74	a	68.99	a	94.99	ab
Russet Burbank/w	54.90	de	53.32	c	96.99	a
Blaue Elise/p	59.96	cd	50.92	c	80.83	e
Blaue St. Galler/p	45.70	gh	41.06	de	89.55	c
Blue Congo/p	47.20	fg	44.25	d	93.48	b
Valfi/p	53.72	e	50.97	c	94.45	ab
Violette/p	28.50	j	21.11	h	70.02	g
Vitelotte/p	28.67	j	20.61	h	70.70	g
Herbie 26/r	45.67	gh	39.02	ef	82.98	de
Highland B. Red/r	41.82	hi	35.50	f	84.37	d
Rosemarie/r	51.12	ef	37.26	ef	71.68	g
Red Emmalie/r	68.98	ab	59.62	b	85.08	d
Average y and w	63.96	A	62.05	A	96.51	A
Average p	44.00	C	38.15	B	83.17	B
Average r	51.90	B	42.85	B	81.03	B

Cultivars: $HSD_{\text{total yield}}$ = 5.34; $HSD_{\text{yield of tubers > 40 mm}}$ = 5.03; $HSD_{\text{share of tubers > 40 mm}}$ = 3.25; colours: $HSD_{\text{total yield}}$ = 5.34; $HSD_{\text{yield of tubers > 40 mm}}$ = 5.61; $HSD_{\text{share of tubers > 40 mm}}$ = 3.71. [1]average of four replications; [2]differences between means with the same letter are statistically non-significant at P = 0.05; flesh colour: y – yellow; w – white; p – purple; r – red

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Some tested cultivars reached a lower yield compared with controls, but the share of tubers above 40 mm was comparable with control cultivars (94.45% and 93.48% in case of cvs. Valfi/p and Blue Congo/p). The relatively lower proportion of marketable tubers above 40 mm in cvs. Rosemarie/r (71.68%), Vitelotte/p (70.70%) and Violette/p (70.02%) was due to the high tuberization of these cultivars, although the size of the tubers for these special cultivars is not so important, for example cv. Purple Pelisse, newly bred cultivar in the USA has small tubers (91 g) (Vales et al. 2012). As was reported by Whitworth et al. (2014) also breeding of specialty coloured cultivars with small tubers for direct consumption is the new trend in the USA.

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Corresponding author:

Ing. Kateřina Pazderů, Ph.D., Česká zemědělská univerzita v Praze, Fakulta agrobiologie, potravinových a přírodních zdrojů, Katedra rostlinné výroby, Kamýcká 129, 165 21 Praha 6-Suchdol, Česká republika; e-mail: pazderu@af.czu.cz