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EFFECT OF PRODUCTION SYSTEM AND POTATO VARIETIES ON THE CONTENT OF SELECTED ANTIOXIDANT COMPOUNDS IN TUBERS

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Abstract. The aim of the research was to determine the content of polyphenols and carotenoids in tubers of three potato varieties in an ecological and conventional production system and varied of precipitation during the vegetation period. The content of ingredients was determined by HPLC liquid chromatography. The main phenolic acid in the potato was chlorogenic acid, whose content ranges from 104 to 135 mg·100 g^{-1} fresh weight, but gallic and coumaric acid and flavonoids were present in small amounts. The dominant carotenoid in potato tubers was lutein, which content was five times higher (130.0 µg·100 g^{-1} fresh weight) than β-carotene (24.5 µg·100 g^{-1} fresh weight). The system of cultivation, variety and precipitation during the growing season on the tested compounds has been proven to be significant. Highly significant interaction of the production system with varieties in relation to gallic acid and total polyphenol content in tubers has been demonstrated. The organic production system increased the total polyphenol content by an average of 25% (43.7 mg·100 g^{-1} fresh tuber weight), and carotenoids by 13% (22.1 µg·100 g^{-1} fresh tuber weight) compared to the conventional system. Mid-early and mid-late varieties Legenda and Gustaw contained significantly more of these compounds than the early Viviana variety. Potatoes grown in a moderately moist growing season (2012) contained significantly more polyphenols and carotenoids in tubers than those grown in wet growing seasons (2011 and 2013).

Key words: carotenoids, polyphenols, potato, production system, variety

INTRODUCTION

There are several organic groups of bioactive compounds in potatoes. In addition to vitamins, these include polyphenols and carotenoids considered as valuable food ingredients due to their antioxidant effects [Brown 2005, Erigipt et al. 2014, Friedman and Levin 2009, Navarre et al. 2009, Valcarcel et al. 2015]. Polyphenols are a common term for several sub-groups of phenolic compounds such as phenolic acids, flavonoids, tannins and lignins that are naturally occurring in different parts of many plant species: flowers, fruits, seeds, leaves, roots, bark and wood elements. The most important sources of polyphenols are the parsley leaf (13.6) and root (3.1), chokeberry fruit (20.8), black currants (5.6) and cherries (4.6) g·kg^{-1} fresh weight [Dietrich et al. 2004, Gheribi 2011, Podsędek and Sosnowska 2007]. Potatoes with an average value of 1.6 g·kg^{-1} fresh weight are an important source of phenolic compounds, what has been confirmed

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by research around the world [Chun et al. 2005, Ezekiel et al. 2013, Müller 1997, Navarre et al. 2009, 2011] and in Poland [Rytel et al. 2014, Wierzbicka et al. 2015].

Carotenoids are fat-soluble molecules containing carbon chains, essential for the survival of plants and animals [Cuttriss et al. 2011, Ezekiel et al. 2013, Walter and Strack 2011]. They can be divided into orange carotenes and yellow xanthophylls, and among xanthophylls the dominant form is lutein. Vegetables with more than 10 mg of total carotenoids per 100 g edible portion are: kale (34.8), red paprika (30.4), parsley (25.7), spinach (17.3), carrots (15.9) and tomatoes (12.7) [Müller 1997]. According to Müller [1997] potatoes contain on average 0.45 mg carotenoids per 100 g^{-1} fresh weight, and in our research [Wierzbicka and Hallmann 2013] was 0.11 mg·100 g^{-1} fresh weight.

Growing consumer demand for organically grown products is associated with the belief of people that organic food is safer than conventional and has a higher nutritional value. Pawelzik and Möller [2014] proved that both conventional and organic system require improvement to increase the efficiency of nutrient utilization. For conventional system, precise fertilization and spraying schedules must be used. The organic system needs more effective organic fertilization, and biological protection measures.

The aim of this study was to determine the content of polyphenols and carotenoids in tubers of three potato cultivars cultivated in an organic and conventional production system and various humidity conditions in vegetation period.

MATERIALS AND METHODS

Field experiments were carried out in 2011–2013 at the Plant Breeding and Acclimatization Institute, Jadwisin division (52°45′ N, 21°63′ E) on light soil classified as farmed, such as tawny soils, grey brown soil type as well as rain-gley soil subtype [Marcinek et al. 2011]. There were studied three yellow-skinned potato varieties: mid-early Legenda with pale yellow flesh, mid-late Gustaw with creamy flesh and early Viviana with pale yellow flesh. The field experiment was set up in a split-plot randomized block design with three replicates. In organic and conventional system of production soil was characterised as acidic, with high phosphorus, average or low potassium and average and high magnesium content (Table 1). Potatoes were planting on

Table 1. The content of available form components in the soil (mg·kg^{-1}) and soil reaction (pH)

Year	pH in KCl	P	K	Mg
Organic system				
2011	5.3	70	53	60
2012	5.5	75	64	68
2013	5.4	72	62	65
Conventional system				
2011	5.0	67	89	50
2012	5.5	78	98	47
2013	5.3	74	95	40

the third decade of April and harvested on the third decade of September, after full of maturity. On each the field repetitions, one sample of 5 kg potatoes was taken for analysis. The analysis of the components were determined by liquid chromatography HPLC described by Hallmann et al. [2013].

Potato cultivation carried out in accordance with the principles of organic and conventional production. The crop rotation in organic production included following plant species: potato, oat with intercrop of field pea, yellow lupine with oat, winter rye with intercrop of serradella, buckwheat with intercrop of white mustard. The main source of nutrients for cultivation plants in organic system were: cattle manure in dose of 25 t·ha^{-1} applied before the potato cultivation and in dose of 12.5 t·ha^{-1} applied before the oat cultivation, straw and intercrop plants (field pea, white mustard, serradella). In the conventional cultivation system organic fertilizers were: rye straw with an intercrop of white mustard ploughed in autumn. Mineral fertilization of phosphorus and potassium were applied before the pre-winter plowing at a rate of 40 kg P·ha^{-1} and 110 kg K·ha^{-1}. Mineral nitrogen used at a rate of 100 kg N·ha^{-1} on spring before planting of tubers potato. Weeds were removed mechanically (organic production system) and chemically (one treatment immediately before the emergence and the second after the emergence of the potato plants) in conventional production system. During the growing season, protective measures against potato blight were carried out 3-5 times, and 2-3 times to prevent beetle infestations by used appropriates for system preparations.

Meteorological data such as: the air temperature and total rainfall from May to September of each year included in the Table 2. The mean air temperature was above the multiyear average in June and September of 2011, in July of 2012 and in May, June and August of 2013. The values of air temperature were lower in May and July of 2011, in June and August of 2012 and in September of 2013 year in compare to mean of multiyear. The average air temperature in individual years was close to the average for multiyear. The weather conditions in individual months of studied years differed more in relation to rainfall. The sum of precipitation during the vegetation period (V–IX) in study years was higher than the multiyear sum, especial in of 2011

Table 2. Temperature and rainfall during the potato growth period

Years	Month					Mean/Sum
	May	June	July	August	September	
Temperature (°C)						
2011	13.1	17.5	17.0	17.6	13.6	15.8
2012	13.8	15.6	19.5	17.4	12.9	15.8
2013	15.2	17.2	18.6	18.3	10.9	16.0
1967–2010	13.6	16.5	18.5	17.8	13.1	15.9
Rainfall (mm)						
2011	33.1	44.8	278.0	57.2	18.5	431.6
2012	52.4	96.6	92.2	87.2	26.9	355.3
2013	130.0	105.0	17.1	97.7	94.0	443.8
1967–2010	56.8	76.3	76.2	60.8	48.4	318.5

and 2013 years. Rainfall in 2011 and 2013 was characterized by higher volatility in individual months than in 2012 year. Low precipitation was observed in May, June and September of the year 2011, in July of the year 2013 and only in September in the 2012 year. Very high rainfall was stated in the July of the year 2011 and high in May, June, August and September in the year of 2013. On the base of sum of rainfall condition for growing potatoes determined as moderately humid in of 2012, and wet in of 2011 and of 2013 year.

All measured variables were statistically verified using the ANOVA variance analysis. To assess the differences between means, the Tukey test was used at $p<0.05$ and at $p<0.01$.

RESULTS AND DISCUSSION

Analysis of variance showed the significance of the cultivation system on all tested ingredients (Table 3). More bioactive compounds were found in potatoes grown using an organic system compared to conventional. The total amount of polyphenols (total phenolic acids and flavonoids) in tubers from the organic system was 176.6 and in the conventional 132.9 mg·100 g^{-1} FW and for carotenoids 165.0 and 142.9 µg·100 g^{-1} FW respectively (Table 4, 5 and 6). The organic production system resulted in an increase in total polyphenols content by an average of 43.7 mg·100 g^{-1} FW and 22.1 µg·100 g^{-1} FW in the case of carotenoids.

Table 3. The variance analysis of polyphenols and carotenoids in potato tubers

Specification	Variability source					
	A Production system	B Variety	C Year	AxB	AxC	BxC
Total polyphenols	**	**	**	**	**	n.s.
Total phenolic acid	**	**	**	*	**	n.s.
Chlorogenic acid	**	**	**	n.s.	**	n.s.
Gallic acid	**	n.s.	**	**	*	**
Coumaric acid	**	n.s.	**	n.s.	**	**
Flavonoids	**	**	n.s.	n.s.	n.s.	**
Quercetin-3-O-rutinoside	**	n.s.	*	*	*	*
Myrycetin	*	**	**	*	*	**
Kaempferol	**	*	**	n.s.	n.s.	*
Kaempferol-3-O-glucoside	**	**	**	n.s.	**	*
Total carotenoids	**	**	**	n.s.	**	n.s.
Lutein	**	**	**	n.s.	*	n.s.
β-carotene	**	*	**	*	n.s.	n.s.

*significant at $p < 0.05$, **highly significant at $p < 0.01$, n.s. – no significant difference

There is no consensus in the literature on whether organic food has more bioactive compounds than conventionally produced foods. Statistically higher levels of compound from organic production systems were demonstrated by many authors [Brandt et al. 2011, Faller and Fialho 2010, Gomiero et al. 2011, Hamouz et al. 1999]. Brandt et al. [2011] published that in organic produce the content of secondary metabolites is significantly (12%) higher than in corresponding conventionally produced fruits and vegetables. Faller and Fialho [2010] showed that organic fruits have higher polyphenols content than conventional ones, with values from 11.5 to 72.6%. Higher total polyphenols content in potatoes from organic growing system was shown by Hamouz et al. [1999]. Such result they related to the reaction of chemically non-treated plants against different stress factors (potato beetle feed-mark, infection with blight). Gomiero et al. [2011] reported that, organic agriculture appears to perform better than conventional farming, and provides also other important environmental advantages, such as halting the use of harmful chemicals and their spread in the environment. The other authors [Bourn and Prescott 2002, Dangour et al. 2009, Rosenthal and Jansky 2008, Søltoft et al. 2010] proved the higher nutritional value of conventionally grown food than produced organically. Bourn and Prescott [2002] reported on lack of strong evidence that organic and conventional foods differ in concentrations of various nutrients, but it is likely that organically grown foods are lower in pesticide residues. Dangour et al. [2009] did not notice differences based on the literature review in nutrient quality between organically and conventionally but admit that the small differences in nutrient content detected are biologically plausible and mostly relate to differences in production methods. According to Rosenthal and Jansky [2008] antioxidants levels were generally highest in potatoes grown in high-yielding production environments, and they increased during storage. Therefore, potatoes with high nutritional value, in terms of antioxidant activity, can be produced using conventional production and storage systems. Søltoft et al. [2010] on the basis of two-year field trials in three different geographical locations, no found statistically significant differences between conventional and organic agricultural systems for any of the analyzed polyphenols. Brandt et al. [2011] proved, a large variation among sub-groups of secondary metabolites, from a significantly higher (16%) content for defence-related compounds (polyphenols) to a no significant (2%) lower content for carotenoids in organic produce than in corresponding conventionally produced.

Statistical analyses of the study results showed the significance of the genotype on total polyphenols, phenolic acids, flavonoids and carotenoids (Table 3, 4, 5 and 6). The significantly large amounts of total polyphenols compounds were present in mid-early potatoes of variety Legenda (159.5) and mid-late of variety Gustaw (157.1) than in early potatoes of variety Viviana (147.1 mg·100 g^{-1} FW). Diversity in phenolic compounds content determined by the colour of the flesh, the origin of the variety and the maturity of the tubers was proved by many authors [Brown 2008, Ezekiel et al. 2013, Friedman and Levin 2009, Lewis et al. 1998, Navarre et al. 2011, Rytel et al. 2014]. In the current study, the average of polyphenols – 154.3 mg·100 g^{-1} FW (Table 4), was most similar to the average reported by others scientists, which was 160 mg·100 g^{-1} FW [Müller 1997, Navarre et al. 2009, 2011]. Navarre et al. [2009] found over a 15-fold difference in the amount of phenolic in different potato genotypes. Main phenolic acid in the potato was chlorogenic acid, whose content 119.0 mg·100 g^{-1} FW represent 77.1% of total polyphenols content in tubers. The remaining phenolic acids (gallic from 12.8 to 17.0 and coumaric from 4.7 to 14.9 mg·100 g^{-1} FW) and flavonoids (quercetin-3-O-rutinoside, myricetin, kaempferol, kaempferol-3-O-glucoside with an average content respectively of 5.7, 4.0, 1.8, 0.4 mg·100 g^{-1} FW) were in the minority (Table 4 and 5). They belong to the flavonol group, yellow or cream coloured dyes. According to other researchers [Ezekiel et al. 2013, Navarre et al. 2009, 2011,

Table 4. Content of polyphenols compounds in potato tubers (mg·100 g^{-1} FW)

Factors	Chlorogenic acid	Gallic acid	Coumaric acid	Total phenolic acids	Total flavonoids	Total polyphenols
Production system						
Organic	135.0 a	16.4 a	11.8 a	163.2 a	13.4 a	176.6 a
Conventional	104.0 b	13.9 b	4.7 b	122.6 b	10.3 b	132.9 b
Variety						
Gustaw	122.0 a	15.3 a	7.5 a	144.8 a	12.3 a	157.1 a
Legenda	124.0 a	15.2 a	7.5 a	146.7 a	12.8 a	159.5 a
Viviana	112.0 b	14.9 a	9.7 a	136.6 b	10.5 b	147.1 b
Year						
2011	124.0 a	12.8 b	9.5 b	146.3 b	11.2 a	157.5 b
2012	127.0 a	15.7 a	9.9 b	152.6 a	12.1 a	164.7 a
2013	107.0 b	17.0 a	14.9 a	138.9 b	12.3 a	151.2 b
Mean	119.0	15.1	8.3	142.4	11.9	154.3
Share (%)	77.1	9.8	5.4	92.3	7.7	100

Means with the same letter in a column do not differ significantly (at $p < 0.05$)

Rytel et al. 2014] chlorogenic acid and its isomers predominate in terms of phenolic acids and represent about 90% of total phenolic content in tubers, while other acids: coffee, coumaric, ferulic and synaptic are present in small amounts. Many authors [Brown 2008, Lewis et al. 1998, Navarre et al. 2011, Rytel et al. 2014] have shown that white and yellow fleshy varieties contain between two and three times fewer phenolic acids and flavonoids than red and violet fleshy varieties. According to Mulinacci et al. [2008], the content of phenolic components in the violet and red flesh of potatoes was similar (1018 mg·kg^{-1} FW) and in potatoes with white flesh, it was almost ten times less. It have also been shown that the skin of potato tubers contains more phenolic compounds than the flesh [Brown 2008, Lewis et al. 1998, Navarre 2009, Rytel et al. 2014, Valcarcel et al. 2015]. Lewis et al. [1998] determined that tuber flesh contained from 3 to 90 mg·100 g^{-1} FW chlorogenic acid and tuber skins showed much higher levels of this acid (100–400 mg·100 g^{-1} FW). Anthocyanins are important subspecies of flavonoids in red, blue and violet colours that are not present in potatoes with white, cream or yellow flesh. The flavonoids in our study have been within the range from 10.3 to 13.4 mg·100 g^{-1} (Table 4). Lewis et al. [1998] reported too that the amount of flavonoids in a potato was within the range from 2.0 to 3.0 mg·100 g^{-1} FW and the most important flavonoids were: catechin, kaempferol and naringenin.

Table 5. Content of flavonoids compounds in potato tubers (mg·100 g^{-1} FW)

Factors	Quercetin-3-O-rutinoside	Myricetin	Kaempferol	Kaempferol-3-O-glucoside	Total flavonoids
Production system					
Organic	6.6 a	4.3 a	2.0 a	0.5 a	13.4 a
Conventional	4.8 b	3.6 b	1.6 b	0.3 b	10.3 b
Variety					
Gustaw	5.9 a	4.1 a	1.8 ab	0.6 a	12.3 a
Legenda	5.4 a	5.1 a	1.9 a	0.3 b	12.8 a
Viviana	5.8 a	2.7 b	1.7 b	0.4 b	10.5 b
Year					
2011	5.4 b	2.3 c	2.7 a	0.8 a	11.2 a
2012	6.4 a	4.0 b	1.4 b	0.3 b	12.1 a
2013	5.2 b	5.7 a	1.2 b	0.2 b	12.3 a
Mean	5.7	4.0	1.8	0.4	11.9

Means with the same letter in a column do not differ significantly (at $p < 0.05$)

Table 6. Content of carotenoids compounds in potato tubers (μg·100 g^{-1} FW)

Factors	Lutein	β-carotene	Total carotenoids
Production system			
Organic	138.0 a	27.0 a	165.0 a
Conventional	121.0 b	21.9 b	142.9 b
Variety			
Legenda	134.0 a	26.3 a	160.3 a
Gustaw	132.0 a	24.2 ab	156.2 a
Viviana	123.0 b	22.8 b	145.8 b
Year			
2011	106.0 c	18.5 c	124.5 c
2012	149.0 a	32.2 b	181.2 a
2013	134.0 b	22.6 a	156.6 b
Mean	130.0	24.5	154.5
Share (%)	84.1	15.9	100.0

Means with the same letter in a column do not differ significantly (at $p < 0.05$)

Among the analyzed antioxidant compounds, potato tubers least contained carotenoids (Table 6). The largest amounts of carotenoids were present in the Legend mid-early variety (160.3), followed by mid-late variety Gustaw (156.2) and the lowest amounts in the early variety Viviana (145.8 μg·100 g^{-1} FW). Differences in carotenoids content among varieties determined by the colour of the flesh, the origin of the variety and tubers maturity was proved by others authors [Breithaupt and Bamedi 2002, Kotikova et al. 2007, Müller 1997]. Among carotenoids compounds the predominant one was lutein, which content was mean 130, and much lower β-carotene content of 24.5 μg·100g^{-1} FW. Similar results were received Breithaupt and Bamedi [2002] study in which carotenoids were dominated by among others lutein, and accounted for 175 μg·100 g^{-1} FW in total. The largest range in carotenoids content variability (50–1000) was presented by American author [Brown 2005, 2008], who stated that potatoes with white flesh contained from 50.0 to 100, yellow from 100 to 350, and orange from 350 to 1000 μg·100 g^{-1} FW.

Current work has shown that years of research have significantly differentiated the level of polyphenols (without flavonoids) and carotenoids (Table 4 and 6). The potatoes cultivated in a moderately wet conditions, contained significantly more polyphenols and carotenoids in tubers than cultivated in the wet conditions. In of 2011 year, in which month of July was very wet, there was significantly lower level of carotenoids than in two other years. A significant effect of the year on the antioxidant levels in tubers was observed by other authors [Kotikova et al. 2007, Rosenthal and Jansky 2008, Valcarcel et al. 2015]. Hamouz et al. [1999] reported that potatoes cultivated in warmer and drier regions in predominantly loam soils, produce lower amounts of polyphenol compounds than tubers cultivated in cooler and more humid regions with sandy loam soils.

CONCLUSIONS

1. Tubers potato grown in an organic system produced more about 25% of polyphenols and 13% of carotenoids than those grown in conventional system.
2. The main phenolic acid in the potato tubers was chlorogenic acid, while other acids: gallic and coumaric were presented in smaller amounts.
3. Among analyses carotenoid compounds the predominant one was lutein, five times higher than β-carotene.
4. Significantly more polyphenols and carotenoids were in the potato varieties of Legenda and Gustaw with a longer growing season, than in variety of Viviana with a shorter growing season.
5. Tubers harvested in a moderately humid vegetative season (year of 2012) contained more polyphenols and carotenoids than tubers harvested in wet vegetative season (years of 2011 and 2013).

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WPŁYW SYSTEMU PRODUKCJI I ODMIAN ZIEMNIAKA NA ZAWARTOŚĆ WYBRANYCH ZWIĄZKÓW ANTYOKSYDACYJNYCH W BULWACH

Synopsis. Celem badań było określenie zawartości polifenoli i karotenoidów w bulwach trzech odmian ziemniaków uprawianych w ekologicznym i konwencjonalnym systemie produkcji w warunkach zróżnicowanych opadów w okresie wegetacji roślin. Zawartość składników określono metodą chromatografii cieczowej HPLC. Głównym kwasem fenolowym w bulwach ziemniaka był kwas chlorogenowy, którego zawartość wynosiła od 104 do 135 mg·100 g^{-1} świeżej masy, a kwas galusowy i kumarowy oraz flawonoidy obecne były w niewielkich ilościach. Dominującym karotenoidem w bulwach ziemniaka była luteina, której zawartość była pięć razy większa (130 μg·100 g^{-1} świeżej masy) niż β-karotenu (24,5 μg·100 g^{-1} świeżej masy). Udowodniono istotny wpływ systemu uprawy, odmiany i opadów w okresie wegetacji na badane związki. Wykazano wysoce istotne współdziałanie systemu produkcji z odmianami w stosunku do kwasu galusowego oraz całkowitej zawartości polifenoli w bulwach. Ekologiczny system produkcji spowodował wzrost całkowitej zawartości polifenoli średnio o 25% (43,0 mg·100 g^{-1} świeżej masy bulw), a karotenoidów o 13% (22,0 μg·100 g^{-1} świeżej masy bulw) w porównaniu do systemu konwencjonalnego. Średnio wczesna odmiana Legenda i średnio późna odmiana Gustaw zawierały istotnie więcej tych związków niż wczesna odmiana Viviana. Ziemniaki uprawiane w umiarkowanie wilgotnym sezonie wegetacyjnym (2012 rok) zawierały istotnie więcej polifenoli i karotenoidów w bulwach, niż uprawiane w mokrych sezonach wegetacji (lata 2011 i 2013).

Słowa kluczowe: karotenoidy, polifenole, ziemniak, system produkcji, odmiana.

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