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Carotenoids in potatoes – a short overview

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ABSTRACT

Carotenoids are one of major lipophilic constituents contributing to total antioxidant activity and provitamin content of potato, a major non-cereal staple food. The review briefly discusses health promoting properties of carotenoids and especially their contents and composition in different potato cultivars affected by flesh colour (white-, yellow-, purple- and red-fleshed) and the effect of selected factors on carotenoid total and individual levels, such as genotype, breeding, tuber development, heat processing – cooking, storage, effect of year, locality, etc. The aim of the recent research is obtaining potatoes with higher levels of beneficial carotenoids to improve one the most popular vegetables in the world.

Keywords: phytonutrients; *Solanum tuberosum*; xanthophylls; thermal processing and storage

Carotenoids are effective antioxidants with important health-promoting functions such as provitamin A activity, enhancement of the immune system and reduction of cardiovascular disease or cancer and help in the prevention of atherosclerosis (Bonierbale et al. 2009). The higher consumption of carotenoids can protect consumers and therefore considerable interest is currently being shown in the screening and development of food crops with increased concentrations of total and individual carotenoids (Stahl and Sies 2005). Potato is the fourth most important staple food crop after rice, wheat and maize, and it contains a wide range of phytochemicals, including phenolic compounds such as chlorogenic acid, anthocyanins in purple and red-coloured potatoes and carotenoids (Tierno et al. 2015, Lachman et al. 2016). Hence, potato tubers are considered an important source of bioactive compounds, which are highly desirable in diet (Ezekiel et al. 2013), although the concentrations of different phytochemicals are affected by cooking and other processes (Lachman et al. 2013). In particular, native potato germplasm can be considered a great source of variability for increased tuber nutritional value (Burgos et al. 2007, Fernandez-Orozco et al. 2013). The colour of potato tubers of conventional cultivars depends on carotenoid content and composition (Hejtmánková et al. 2013) and tuber yellow intensity is positively correlated with total carotenoid content. In the review main factors affecting carotenoid levels, such as genotype, climate and growing conditions, storage and cooking processes, are discussed.

Characteristics of carotenoids by their chemical composition. Carotenoids are an important group of natural organic pigments synthesized from plants that are naturally occurring in the chloroplasts and chromoplasts of photosynthetic organisms, such as plants and algae, and some fungi and bacteria (Valcarel et al. 2015). All share a tetraterpenoid structure of 40 carbon atoms, a long conjugated chain of double bonds in the centre of the molecule (chromophore) and near symmetry around the central double bond. They may be split into two classes, xanthophylls (which contain oxygen) and carotenes (which are purely hydrocarbons and contain no oxygen) (Rao and Rao 2007). Carotenoids serve two key roles in plants and algae: they absorb light energy for use in photosynthesis, and they protect chlorophyll from photodamage.

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Role and significance of carotenoids in human nutrition and their health benefits. Higher animals are incapable of biosynthesizing carotenoid, so these pigments are essentially indigested through the diet as precursors for retinol (vitamin A) biosynthesis. Provitamin A activity is the ability of carotenoids to form vitamin A (retinol and retinal) by the action of carotene dioxygenase. Any carotenoid containing at least one unmodified β-ionone ring may be cleaved to provide provitamin A activity. Thus, provitamin A active carotenoids include β-carotene, α-carotene, γ-carotene and β-cryptoxanthin. Although provitamin A activity is the major function of carotenoids, potent antioxidant activity of carotenoids through singlet oxygen quenching and deactivation of free radicals play important roles in the prevention of certain types of cancer, cardiovascular diseases, and macular degeneration (Müller et al. 2015). Apart from this, carotenoids play important roles in cellular and organelle function. β-Carotene inhibits inflammatory gene expression in lipopolysaccharide-stimulated macrophages with possible anti-obesity positive role (Williams et al. 2013). Generally, carotenoids are involved in embryonic development, gap junction communication, immune modulation, cell differentiation, anti-inflammation, bone metabolism, anti-angiogenesis, anti-proliferation, hematopoiesis, antioxidant activity, skin health, apoptosis and good vision (Saini et al. 2015).

Content of total and individual carotenoids in potato tubers. Recent findings suggest that carotenoid pool size is determined, at least in part, by the activity of carotenoid cleavage dioxygenases (Campbell et al. 2010). Higher levels of total carotenoids were found in the skin of tubers, with maxima values of 28 and 9 mg/kg dry weight (DW) in skin and flesh, respectively. Yellow-skinned or fleshed tetraploid cultivars also had higher contents than those with paler or white tissues, with no relationship found for other colours (Valcarel et al. 2015). Carotenoid concentrations in some diploid potatoes were reported up to 22 times higher than in white-fleshed potatoes (Haynes et al. 2011). The content of carotenoids is affected by cultivar and locality. Hamouz et al. (2016) reported that the content of total carotenoids in analysed cultivars ranged in 1.10–12.2 mg/kg DW and was influenced by genotype cultivar, locality and year. Breithaupt and Bamedi (2002) suggested that the total concentration of carotenoids in potatoes could be used as a tool to differentiate between white- or yellow-fleshed cultivars. Fernandez-Orozco et al. (2013) claimed that the total carotenoid contents for all cultivars ranged from 0.50–15.5 mg/kg DW, although most of the samples had less than 10.0 mg/kg DW, with an average value of about 4.35 mg/kg DW; however 50% of the RDA of vitamin A can be met by consuming 250 g of enriched genetically engineered potatoes.

The different types of xanthophylls show variable concentrations in various potato genotypes with lutein predominating and varying amounts of zeaxanthin, violaxanthin, and others reported. The main carotenoid was lutein in all cultivars (54–93%); furthermore violaxanthin, neoxanthin, zeaxanthin and β-carotene were identified in most of the analysed samples (Hejtmánková et al. 2013). The carotenoid analysis showed a similar qualitative composition for all potato cultivars, with the following substances being identified: all-*trans*-neoxanthin, 9'-*cis*-neoxanthin, all-*trans*-violaxanthin, 9-*cis*-violaxanthin, antheraxanthin, lutein-5,6-epoxide, all-*trans*-lutein, 9-*cis*-lutein, 13-*cis*-lutein, all-*trans*-β-cryptoxanthin and all-*trans*-β-carotene (Fernandez-Orozco et al. 2013). Two groups of pigments were assigned to partially (monoesters for dihydroxy-xanthophylls) and totally esterified carotenoids (monoesters of monohydroxy-xanthophylls and diesters for dihydroxy-xanthophylls). The lack of zeaxanthin in all samples should be remarked, in contrast to other studies which have reported that zeaxanthin is a major carotenoid in many potato cultivars (André et al. 2007a,b). Kotíková et al. (2016) reported that yellow cultivars showed a much higher average total carotenoid content (26.2 mg/kg DW) when compared to red/purple-fleshed potatoes (5.69 mg/kg DW). Yellow cultivars were dominated by antheraxanthin, whereas neoxanthin was the main carotenoid in red/purple cultivars.

Potato, which usually accumulates lutein and violaxanthin, was modified to accumulate zeaxanthin (Römer et al. 2002) in yellow-fleshed potato by transformation of neoxanthin epoxidase and it may also result in an increase in transcript for protein fibrillin evolved in carotenoid storage (DellaPenna and Pogson 2006). Metabolic engineering was recently applied to potato in order to increase the provitamin A content (Diretto et al. 2007), with a resulting increase of 20-fold and 3600-fold for total carotenoid and β-carotene content, respectively,

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in the biofortified 'golden potato'. Broad-sense heritability estimates were high for total carotenoid (0.81), lutein (0.77), zeaxanthin (0.73), and the lycopene beta-cyclase pathway carotenoids (0.73); moderate for neoxanthin (0.42); and low for violaxanthin (0.21) and antheraxanthin (0.13) (Haynes et al. 2011). Carotenoids and their contents reported in potato are summarized in Table 1.

Factors influencing carotenoid content in tubers

Flesh colour and genotype. Among raw tubers, the lowest lutein levels were in cultivars and advanced selections with white flesh. White and yellow-fleshed potatoes have similar compositions of carotenoids but the yellow colour is due to higher levels of certain xanthophylls (Perla et al. 2012). This is in agreement with findings of Brown (2005) who divided cultivars into white, yellow, and dark yellow categories on the basis of colour which corresponded to carotenoid levels 0.50 to 1.00, 1.50 to 2.50 and 5.00 to 7.00 mg/kg fresh weight (FW) grouping and the last category was assigned to dark yellow cultivars. White-fleshed cultivars have 0.50 to 1.00 mg carotenoids/kg FW, while moderately yellow-fleshed cultivars will generally possess from 1.00 to 3.50 mg carotenoids/kg FW. The more intensely yellow-fleshed genotypes, which may look orange, at the higher extremes are at levels above 10.0 mg/kg FW. The highest level was published as 26.0 mg/kg FW in diploid germplasm derived from South American Papa Amarilla cultivars (Brown et al. 2008). New yellowish-orange-fleshed potato cultivars such as Inca-no-hitomi with very high carotenoid contents (5.67 mg/kg FW) are now developed (Kobayashi et al. 2008). Cv. Agria (yellow flesh) reached 1.8 to 11.8 times higher levels of total carotenoids compared with cultivars of coloured flesh (Hamouz et al. 2016). Genotype significantly influenced the content and composition of individual carotenoids. As in cv. Agria, violaxanthin (41%) and lutein (55–78%) also dominated in all cultivars with coloured flesh. The relative content of β-carotene in cv. Agria represented 2% of total carotenoids, in cultivars with coloured flesh 5–12%.

The orange and yellow colour of the tuber flesh is due to zeaxanthin and lutein, respectively. Potato cultivars with white flesh contained less carotenoids as compared to cultivars with yellow or orange flesh. Total carotenoids content was reported in the range of 0.50–3.50 mg/kg FW and 8.00–20.0 mg/kg FW, respectively, in white- and yellow-fleshed potato cultivars (Brown et al. 2008). Researchers have been able to increase carotenoids content considerably using transgenic approaches. Ducreux et al. (2005) were able to increase tuber carotenoids content from 5.60–35.0 mg/kg DW (cv. Desirée) by overexpressing a bacterial phytoene synthase. They also observed large increase in the levels of individual carotenoids, β-carotene (more than 11 fold) and lutein (19 fold). Breithaupt and Bamedi (2002) investigated the carotenoid pattern of four yellow-fleshed and four white-fleshed German potato cultivars. The carotenoid pattern was dominated by violaxanthin, antheraxanthin, lutein, and zeaxanthin, which were present in different ratios, whereas neoxanthin, β-cryptoxanthin, and β-carotene were only minor constituents. Antheraxanthin was found to be the only carotenoid epoxide present in native extracts (Ezekiel et al. 2013). The total concentration of the four main carotenoids reached 1.75 mg/kg FW, whereas the sum of carotenoid esters accounted for 0.41–1.31 mg/kg FW. Generally, the levels of antheraxanthin were higher in those cultivars with greater total carotenoid contents, showing a trend similar to violaxanthin, which could be related to the violaxanthin cycle and to the lack of zeaxanthin in all samples (Fernandez-Orozco et al. 2013). Andean potatoes provide another rich and varied source of carotenoids. André et al. (2007a) reported a range of 3 to 36 mg/kg DW for total carotenoids among 74 Andean landraces. In another study, André et al. (2007b) screened 24 Andean cultivars and identified genotypes containing high concentration of lutein (1.12–17.7 mg/kg DW), zeaxanthin (18 mg/kg DW), and β-carotene (2 mg/kg DW). Burgos et al. (2009) analysed carotenoids content in tubers of 23 accessions of *S. phureja* and identified two accessions, with a very high concentration of zeaxanthin (12.9 mg/kg FW). Total and individual carotenoid concentrations were also estimated in *S. phureja* germplasm accessions by Bonierbale et al. (2009). These authors identified two cultivars with high zeaxanthin concentrations (above 10.0 mg/kg FW) and a group of accessions with relatively high β-carotene concentrations (above 0.1 mg/kg FW). The total carotenoid, antheraxanthin, violaxanthin, lutein, zeaxanthin and β-carotene concentrations ranged from 1.03–21.4 mg/kg

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Table 1. Carotenoids and their contents reported in potato tubers (mg/kg DW* or FW**)

Carotenoid	Content	Potato cultivars	References
Total carotenoids	28.0*	skin of tubers	Campbell et al. (2010)
	9.0*	flesh of tubers	
	1.10–12.2*	different cultivars	Hamouz et al. (2016)
	0.50–15.5*	different cultivars	Fernandez-Orozco et al. (2013)
	0.58–1.75**	yellow cultivars	Breithaupt et al. (2002)
	0.38–0.62**	white cultivars	
	26.2*/5.69*	yellow/red/purple	Kotíková et al. (2016)
	0.50–1.00**	white cultivars	Brown (2005)
	1.00–3.50**	yellow cultivars	
	8.0–20.0**	yellow-orange cvs.	
	26.0**	Papa Amarilla cvs.	Brown et al. (2008)
	5.67**	Inca-no-hitomi orange	Kobayashi et al. (2008)
	5.60–35.0*	transgen. Desirée	Ducreux et al. (2005)
	3.0–36.0*	Andean landraces	André et al. (2007a)
	1.03–21.4**	*S. phureja* accession	Bonierbale et al. (2009)
	2.57 ± 0.53*	Shetland Black	Burmeister et al. (2011)
	14.8 ± 2.22*	Red Laura	
	8.23 ± 2.98*	boiled M. Twilight	Tierno et al. (2015)
	1.51 ± 0.31*	boiled Shetl. Black	
Sum of carotenoid esters	0.41–1.31**	yellow and white	Breithaupt et al. (2002)
Individual carotenoids			
all-*trans*-Lutein	1.12–17.7**	Andean landraces	André et al. (2007b)
	0.55–1.89	*S. phureja* accession	Bonierbale et al. (2009)
	3.27–9.50*	raw tubers	Clevidence et al. (2005)
	3.89–9.50*	boiled tubers	
all-*trans*-Violaxanthin	trace–2.78**	*S. phureja* accession	Bonierbale et al. (2009)
all-*trans*-Antheraxantin	0.03–3.54**	*S. phureja* accession	Bonierbale et al. (2009)
all-*trans*-Zeaxanthin	18**	Andean landraces	André et al. (2007b)
	12.9**	*S. phureja*	Burgos et al. (2009)
	> 10.0**	*S. phureja*	Bonierbale et al. (2009)
	trace–12.9**	*S. phureja*	
	trace – 40*	accession raw/boiled tubers	Clevidence et al. (2005)
all-*trans*-β-Carotene	2**	Andean landraces	André et al. (2007b)
	> 0.1**	*S. phureja* accession	Bonierbale et al. (2009)
Lutein-5,6-epoxide	identified	commercial, bred, old and native cultivars	Fernandez-Orozco et al. (2013)
9-*cis*-Lutein	identified		
13-*cis*-Lutein	identified		
9-*cis*-Violaxanthin	+ 5,6-epoxide		
all-*trans*-Neoxanthin	+ 5,6-epoxide		
9´-*cis*-Neoxanthin	+ 5,6-epoxide		
Mutatoxanthin	identified		
Luteoxanthin	+ 5,6 epoxide		
Neochrome	identified		
all-*trans*-β-Cryptoxanthin	identified		

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FW, from 0.03–3.54 mg/kg FW, from trace to 2.78 mg/kg FW, from 0.55–1.89 mg/kg FW, from trace to 12.9 mg/kg FW, and from trace to 0.18 mg/kg FW, respectively. The native cultivars of South America with high levels of total carotenoids and high lipophilic ORAC are a unique germplasm source for introgression of these traits into specific potato cultivars outside the centre of origin (Brown et al. 2007). Burmeister et al. (2011) found that the main carotenoids in raw tubers of all *S. tuberosum* and *S. phureja* cultivars are 9-*cis*-violaxanthin, lutein and one unidentified carotenoid. Minor compound was identified as neoxanthin. Additionally, zeaxanthin and one further unidentified carotenoid could be found in cvs. Red Laura and Mayan Gold. No differences in the carotenoid composition between peel and parenchyma could be found. Total carotenoid content ranged from 2.57±0.53 mg/kg DW in cv. Shetland Black to 14.8±2.22 mg/kg DW in cv. Red Laura (calculated as β-carotene equivalents). Burgos et al. (2009) reported that significant and predominant amounts of zeaxanthin and antheraxanthin are found in deep yellow-fleshed potatoes while the carotenoid profile of yellow potatoes is composed of violaxanthin, antheraxanthin, lutein and zeaxanthin and that of cream fleshed potatoes of violaxanthin, lutein and β-carotene.

In the recent study, the carotenoid profile of sixty potato cultivars (commercial, bred, old and native cultivars) has been characterised in order to provide information to be used in selective breeding programmes directed to improve the nutritional value of this important staple food (Fernandez-Orozco et al. 2013). Cultivars were segregated into three groups according to the major pigment in the carotenoid profile: violaxanthin (especially those with higher carotenoid content), lutein, and neoxanthin. Other minor carotenoids were antheraxanthin, β-cryptoxanthin and β-carotene, while zeaxanthin was absent in all samples. The total carotenoid content ranged from 0.50–15.5 mg/kg DW, with an average value of about 4.35 mg/kg DW. Xanthophyll esters were present in most cultivars, mainly as diesterified forms, and a direct correlation was observed between the carotenoid content and the esterified fraction, suggesting that the esterification process facilitates the accumulation of these lipophilic compounds within the plastids.

Effect of year, locality and cultivation factors. Locality and year of higher average temperatures during the growing season produced higher total carotenoid contents in tubers (Hamouz et al. 2016). Kotíková et al. (2007) also confirmed that the year of cultivation had a significant effect on total carotenoids content.

Culinary treatment. Carotenoid content was observed to be lower in boiled as compared to raw potatoes, however, no significant difference in other methods of cooking was observed (Blessington et al. 2010). Isomerisation and oxidation reactions upon heating of carotenoids may cause small losses, which were later confirmed by Rautenbach et al. (2010) when they observed an average decrease of 9.7% in boiling sweetpotato for 12 min. In heat processed tubers, high amounts of carotenoids either changed from all-*trans* to 9-*cis* and 13-*cis*-isomeric form or were degraded. The comparative analysis of raw and boiled tubers showed high losses of carotenoids and carotenoid concentrations in boiled tubers were directly correlated with their corresponding concentration in the raw product (Tierno et al. 2015). The total pigment content was decreased by heat processing in all cultivars, 8.23–2.98 mg/kg DW could be found in cv. Mayan Twilight and 1.51–0.31 mg carotenoids/kg DW in cv. Shetland Black. Changes in concentrations due to boiling varied significantly among accessions. Boiling significantly reduced the violaxanthin and antheraxanthin concentration of all the accessions. However, the lutein and zeaxanthin concentrations of boiled tubers were not affected or were higher than the concentrations in raw tubers (Burgos et al. 2012). Boiled potatoes of deep yellow-fleshed cultivars are a significant source of zeaxanthin (above 5.00 mg per kg fresh weight basis).

A study that evaluated the effect of cooking on carotenoid concentration of three potato cultivars detected only lutein in the samples and reported that lutein concentration was not affected by cooking (Blessington et al. 2010). A more recent study, that analysed the carotenoid concentration of raw and boiled tubers of four potato cultivars with violaxanthin and lutein as the main carotenoids and zeaxanthin present in very low concentration, reported that heat processing transformed all-*trans* carotenoids to 9-*cis* and 13-*cis* isomeric forms or degraded them (Burmeister et al. 2011). Analysis of variance for the total carotenoids and violaxanthin, lutein and β-carotene concentrations revealed significant effects due to boiling accession interaction, which means that the effect of boiling on the concentration of these carotenoids

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varies among accessions (Burgos et al. 2012). The reduction of lutein and zeaxanthin concentration after cooking in some accessions can be easily explained by the fact that carotenoids are exposed to degradation during cooking. However, in some cases the lutein and zeaxanthin concentrations of a yellow-fleshed potato were higher following steaming and microwave cooking, suggesting that cooking altered the plant cell structure and liberated these compounds (Clevidence et al. 2005). Different types of cooking on vegetables concluded that steaming (3–5 min), microwaving (1.5–5 min) and boiling (9 min) had no effect on the lutein concentration and that in many cases carotenoids become more available after cooking due to the liberation of carotenoids from cell matrices. The lutein concentration of raw tubers ranged from 3.27–9.50 mg/kg DW and that of the boiled tubers from 3.89–9.50 mg/kg DW, with the intermediate yellow-fleshed accession showing the highest lutein concentration (above 8.00 mg/kg DW). However, this value is lower than the highest lutein concentration found by André et al. (2007a,b) (17.7 mg/kg DW) and Griffiths et al. (2007) (14.2 mg/kg DW). The zeaxanthin concentration ranged from trace levels to above 40.0 mg/kg DW, in both raw and boiled tubers, with the deep yellow-fleshed accession showing the highest concentrations. Regarding β-carotene, the two light yellow-fleshed accessions showed higher concentration in boiled than in raw tubers, and the intermediate yellow and deep yellow-fleshed accessions had reduced β-carotene concentrations after cooking. The β-carotene concentration of raw and boiled tubers ranged from 0 to above 1.20 mg/kg DW, in both raw and boiled tubers. André et al. (2007a,b) reported a β-carotene range of variation of 0.42–2.19 mg/kg DW. In purple-fleshed potatoes the boiling, steaming and baking treatments reduced the total carotenoid content by 20.2, 34.9 and 52.0%, respectively, whereas the microwaving, frying, air-frying and stir-frying treatments reduced the content by 66.3, 75.7, 72.0 and 76.2%, respectively (Tian et al. 2016a). Kotíková et al. (2016) reported that boiling decreased the total carotenoids by 92% compared to baking (by 88%) in yellow-, purple- or red-fleshed potatoes (Figure 1). Lutein was the most stable carotenoid against thermal processing (decreased by 24–43%) followed by β-carotene (decreased by 78–83%); other carotenoids were degraded nearly completely.

Generally, cooking will cause a decrease in the carotenoid content; boiling in water or frying in oil will diminish the carotenoids due to the thermal effect and the lipophilic properties of carotenoids (Tierno et al. 2015, Kotíková et al. 2016, Tian et al. 2016b). However, in some cases, during cooking protein-xanthophyll aggregates are dissociated allowing a detectible increase in carotenoids in cooked potatoes (Burmeister et al. 2011).

The bioaccessibility of main lutein and zeaxanthin in the 12 biofortified clones has been reported in the range from 53–160% and from 24–388%, respectively (André et al. 2015). The bioaccessibility of lutein and zeaxanthin in the yellow clones ranged from 76–82% for lutein and from 24–55% for zeaxanthin. Similarly Burgos et al. (2013) estimated that the bioaccessibility of lutein and zeaxanthin in yellow-fleshed potatoes ranged from 33–71% and from 51–71%, respectively. Interestingly, the gastrointestinal digestion process

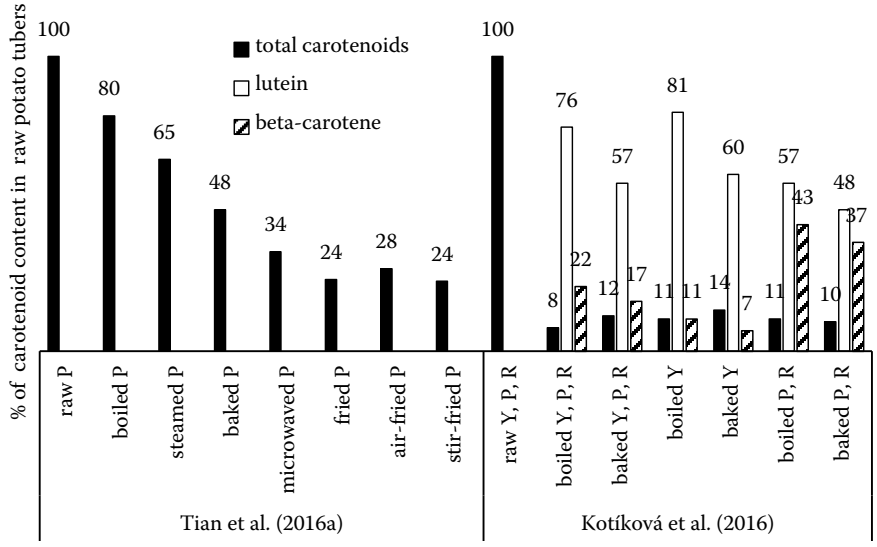

Figure 1. Average content of total carotenoids, lutein and β-carotene after cooking treatment of potato tubers (in % of their content in raw tubers; P – purple; Y – yellow; R – red)

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allowed a release of zeaxanthin from potato matrix of five clones to a greater extent than that observed in the respective boiled samples. The bioaccessibility of carotenoids (micellarization) is largely enhanced when dietary fat is consumed together with carotenoids. In addition, the concentrations in β-carotene are already low in boiled potatoes.

Carotenoids during tuber development and storage. Germplasms of *S. tuberosum* and *S. phureja* exhibit a wide (over 20-fold) variation in tuber carotenoid content. Morris et al. (2004) compared the levels of carotenoids during tuber development and storage in a high carotenoid-accumulating *S. phureja* accession with two *S. tuberosum* cultivars (Pentland Javelin and Desirée) that accumulate lower levels of tuber carotenoid. On a dry weight basis, total carotenoid levels were at a maximum early in tuber development. However, in the *S. phureja* accession, carotenoid levels remained at a high level throughout tuber development, whereas in the *S. tuberosum* accessions, carotenoid content decreased as dry weight increased. Following 9 months storage at 4°C the levels of zeaxanthin and antheraxanthin decreased, whereas the level of lutein increased; overall, however, there was only a small decrease in total carotenoid content. In non-stored potato tubers and in three storage conditions all storage treatments were higher in carotenoid content (expressed as lutein) in four cultivars and the interaction between genotype was significant for carotenoid content (Blessington et al. 2010).

REFERENCES

André C.M., Evers D., Ziebel J., Guignard C., Hausman J.-F., Bonierbale M., zum Felde T., Burgos G. (2015): In vitro bioaccessibility and bioavailability of iron from potatoes with varying vitamin C, carotenoid, and phenolic concentrations. Journal of Agricultural and Food Chemistry, 63: 9012–9021.

André C.M., Ghislain M., Bertin P., Oufir M., Herrera Mdel R., Hoffmann L., Hausman J.-F., Larondelle Y., Evers D. (2007a): Andean potato cultivars (*Solanum tuberosum* L.) as a source of antioxidant and mineral micronutrients. Journal of Agricultural and Food Chemistry, 55: 366–378.

André C.M., Oufir M., Guignard C., Hoffmann L., Hausman J.F., Evers D., Larondelle Y. (2007b): Antioxidant profiling of native Andean potato tubers (*Solanum tuberosum* L.) reveals cultivars with high levels of beta-carotene, alpha-tocopherol, chlorogenic acid, and petanin. Journal of Agricultural and Food Chemistry, 55: 10839–10849.

Blessington T., Nzaramba M.N., Scheuring D.C., Hale A.L., Reddivari L., Miller Jr. J.C. (2010): Cooking methods and storage treatments of potato: Effects on carotenoids, antioxidant activity, and phenolics. American Journal of Potato Research, 87: 479–491.

Bonierbale M., Grüneberg W., Amoros W., Burgos G., Salas E., Porras E., zum Felde T. (2009): Total and individual carotenoid profiles in *Solanum phureja* cultivated potatoes: II. Development and application of near-infrared reflectance spectroscopy (NIRS) calibrations for germplasm characterization. Journal of Food Composition and Analysis, 22: 509–516.

Breithaupt D.E., Bamedi A. (2002): Carotenoids and carotenoid esters in potatoes (*Solanum tuberosum* L.): New insights into an ancient vegetable. Journal of Agricultural and Food Chemistry, 50: 7175–7181.

Brown C.R. (2005): Antioxidants in potato. American Journal of Potato Research, 82: 163–172.

Brown C.R., Culley D., Yang C.-P., Durst R., Wrolstad R. (2005): Variation of anthocyanin and carotenoid contents and associated antioxidant values in potato breeding lines. Journal of the American Society for Horticultural Science, 130: 174–180.

Brown C.R., Durst R.W., Wrolstad R., De Jong W. (2008): Variability of phytonutrient content of potato in relation to growing location and cooking method. Potato Research, 51: 259–270.

Brown C.R., Culley D., Bonierbale M., Amoros W. (2007): Anthocyanin, carotenoid content, and antioxidant values in native South American potato cultivars. HortScience, 42: 1733–1736.

Burgos G., Amoros W., Morote M., Bonierbale M. (2007): Iron and zinc concentration of native Andean potato cultivars from a human nutrition perspective. Journal of the Science of Food and Agriculture, 87: 668–675.

Burgos G., Muñoa L., Sosa P., Bonierbale M., zum Felde T., Díaz C. (2013): In vitro bioaccessibility of lutein and zeaxanthin of yellow fleshed boiled potatoes. Plant Foods for Human Nutrition, 68: 385–390.

Burgos G., Amoros W., Salas E., Muñoa L., Sosa P., Díaz C., Bonierbale M. (2012): Carotenoid concentrations of native Andean potatoes as affected by cooking. Food Chemistry, 133: 1131–1137.

Burgos G., Salas E., Amoros W., Auqui M., Muñoa L., Kimura M., Bonierbale M. (2009): Total and individual carotenoid profiles in *Solanum phureja* of cultivated potatoes: I. concentrations and relationships as determined by spectrophotometry and HPLC. Journal of Food Composition and Analysis, 22: 503–508.

Burmeister A., Bondiek S., Apel L., Kűhne C., Hillebrand S., Fleischmann P. (2011): Comparison of carotenoid and anthocyanin profiles of raw and boiled *Solanum tuberosum* and *Solanum phureja* tubers. Journal of Food Composition and Analysis, 24: 865–872.

Campbell R., Ducreux L.J.M., Morris W.L., Morris J.A., Suttle J.C., Ramsay G., Bryan G.J., Hedley P.E., Taylor M.A. (2010): The metabolic and developmental roles of carotenoid cleavage dioxygenase 4 from potato (*Solanum tuberosum* L). Plant Physiology, 154: 656–664.

Clevidence B., Haynes K., Rao D., Novotny J. (2005): Effect of cooking method on xanthophyll content of yellow-fleshed potato. United States Japan Natural Resources Protein Panel, 34: 280–284.

doi: 10.17221/459/2016-PSE

DellaPenna D., Pogson B.J. (2006): Vitamin synthesis in plants: Tocopherols and carotenoids. Annual Review of Plant Biology, 57: 711–738.

Diretto G., Al-Babili S., Tavazza R., Papacchioli V., Beyer P., Giuilano G. (2007): Metabolic engineering of potato carotenoid content through tuber-specific overexpression of a bacterial mini-pathway. PLOS ONE, 2: e-350.

Ducreux L.J.M., Morris W.L., Hedley P.E., Shepherd T., Davies H.V., Millam S., Taylor M.A. (2005): Metabolic engineering of high carotenoid potato tubers containing enhanced levels of β-carotene and lutein. Journal of Experimental Botany, 56: 81–89.

Ezekiel R., Singh N., Sharma S., Kaur A. (2013): Beneficial phytochemicals in potato – A review. Food Research International, 50: 487–496.

Fernandez-Orozco R., Gallardo-Guerrero L., Hoirnero-Méndez D. (2013): Carotenoid profiling in tubers of different potato (*Solanum* sp) cultivars: Accumulation of carotenoids mediated by xanthophyll esterification. Food Chemistry, 141: 2864–2872.

Griffiths D.W., Dale M.F., Morris W.L., Ramsay G. (2007): Effects of season and postharvest storage on the carotenoid content of *Solanum phureja* potato tubers. Journal of Agricultural and Food Chemistry, 55: 379–385.

Hamouz K., Pazderů K., Lachman J., Čepl J., Kotíková Z. (2016): Effect of cultivar, flesh colour, locality and year on carotenoid content in potato tubers. Plant, Soil and Environment, 62: 86–91.

Haynes K.G., Clevidence B.A., Rao D., Vinyard B.T. (2011): Inheritance of carotenoid content in tetraploid × diploid potato crosses. Journal of the American Society for Horticultural Science, 136: 265–272.

Hejtmánková K., Kotíková Z., Hamouz K., Pivec V., Vacek J., Lachman J. (2013): Influence of flesh colour, year and growing area on carotenoid and anthocyanin content in potato tubers. Journal of Food Composition and Analysis, 32: 20–27.

Kobayashi A., Ohara-Takada A., Tsuda S., Matsuura-Endo Ch., Takada N., Umemura Y., Nakao T., Yoshida T., Hayashi K., Mori M. (2008): Breeding of potato variety 'Inca-no-hitomi' with a very high carotenoid content. Breeding Science, 58: 77–82.

Kotíková Z., Šulc M., Lachman J., Pivec V., Orsák M., Hamouz K. (2016): Carotenoid profile and retention in yellow-, purple- and red-fleshed potatoes after thermal processing. Food Chemistry, 197: 992–1001.

Kotíková Z., Hejtmánková A., Lachman J., Hamouz K., Trnková E., Dvořák P. (2007): Effect of selected factors on total carotenoid content in potato tubers (*Solanum tuberosum* L.). Plant, Soil and Environment, 53: 355–360.

Lachman J., Hamouz K., Musilová J., Hejtmánková K., Kotíková Z., Pazderů K., Domkářová J., Pivec V., Cimr J. (2013): Effect of peeling and three cooking methods on the content of selected phytochemicals in potato tubers with various colour of flesh. Food Chemistry, 138: 1189–1197.

Lachman J., Hamouz K., Orsák M. (2016): Colored potatoes. In: Singh J., Kaur L. (eds.): Advances in Potato Chemistry and Technology. 2nd Edition. Oxford, Academic Press Elsevier, 249–281.

Morris W.L., Ducreux L., Griffiths D.W., Stewart D., Davies H.V., Taylor M.A. (2004): Carotenogenesis during tuber development and storage in potato. Journal of Experimental Botany, 55: 975–982.

Müller L., Caris-Veyrat C., Lowe G., Böhm V. (2015): Lycopene and its antioxidant role in the prevention of cardiovasculasr diseases – A critical review. Critical Reviews in Food Science and Nutrition, 56: 1868–1879.

Perla V., Holm D.G., Jayanty S.S. (2012): Effects of cooking methods on polyphenols, pigments and antioxidant activity in potato tubers. LWT – Food Science and Technology, 45: 161–171.

Rao A.V., Rao L.G. (2007): Carotenoids in human health – Invited review. Pharmacological Research, 55: 207–216.

Rautenbach F., Faber M., Laurie S., Laurie R. (2010): Antioxidant capacity and antioxidant content in roots of 4 sweetpotato varieties. Journal of Food Science, 75: C400–C405.

Römer S., Lübeck J., Kauder F., Steiger S., Adomat C., Sandmann G. (2002): Genetic engineering of a zeaxanthin-rich potato by antisense inactivation and co-suppression of carotenoid epoxidation. Metabolic Engineering, 4: 263–272.

Saini R.K., Nile S.H., Park S.W. (2015): Carotenoids from fruits and vegetables: Chemistry, analysis, occurrence, bioavailability and biological activities. Food Research International, 76: 735–750.

Stahl W., Sies H. (2005): Bioactivity and protective effects of natural carotenoids. Biochimica et Biophysica Acta, 1740: 101–107.

Tian J.H., Chen J.C., Ye X.Q., Chen S.G. (2016a): Health benefits of the potato affected by domestic cooking: A review. Food Chemistry, 202: 165–175.

Tian J.H., Chen J.L., Lv F.Y., Chen S.G., Chen J.C., Liu D.H., Ye X.Q. (2016b): Domestic cooking methods affect the phytochemical composition and antioxidant activity of purple-fleshed potatoes. Food Chemistry, 197: 1264–1270.

Tierno R., Hornero-Méndez D., Gallardo-Guerrero L., López-Pardo R., Ruiz de Gallareta J.I. (2015): Effect of boiling on the total phenolic, anthocyanin and carotenoid concentrations of potato tubers from selected cultivars and introgressed breeding lines from native potato species. Journal of Food Composition and Analysis, 41: 58–65.

Valcarel J., Reilly K., Gaffney M., O'Brien N. (2015): Total carotenoids and L-ascorbic acid content in 60 varieties of potato (*Solanum tuberosum* L.) grown in Ireland. Potato Research, 58: 29–41.

Williams D.J., Edwards D., Hamernig I., Jian L., James A.P., Johnson S.K., Tapsell L.C. (2013): Vegetables containing phytochemicals with potential antiobesity properties: A review. Food Research International, 52: 323–333.

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