Effect of selected factors on total carotenoid content in potato tubers (*Solanum tuberosum* L.)

Z. Kotíková, A. Hejtmánková, J. Lachman, K. Hamouz, E. Trnková, P. Dvořák

Faculty of Agrobiology, Food and Natural Resources, Czech University of Life Sciences, Prague, Czech Republic

ABSTRACT

In the years 2004 and 2005 precise field trials were performed with the aim to evaluate the effect of variety, year of cultivation, N, P, K and Mg fertilization, and the cover with white propylene fibre Paegas-Agro UV 17 on the total carotenoid content (TC) in potato tubers. TC was determined by absorption UV-VIS spectrophotometry and obtained results were statistically evaluated (ANOVA and MANOVA variance analyses, Scheffe's test). Statistically significant differences ($P = 0.05$) in the ability of varieties to synthesize carotenoids were found (Karin, Agria and Marabel with high TC × Impala and Saturna with low TC) and also the year of cultivation significantly affected TC (5.8 mg/kg fw in 2004, 20.9 mg/kg fw in 2005). The effect of fertilization with N, P, K and Mg on TC in potatoes did not show any significant effect; however significant differences were observed among varieties. The effect of white polypropylene fibre in two early potato varieties (Adora and Impala) during three dates of harvest on TC in potato tubers was not significant. Contrariwise, statistically significant effects on TC were reported in the case of potato tubers maturity, year of cultivation and potato variety.

Keywords: potato; total carotenoids; year of cultivation; locality; variety; fertilization; white polypropylene fibre

Regarding the consumption amounts in human nutrition, potatoes are a significant source of energy (starch), proteins, minerals, vitamins and antioxidant active compounds.

Carotenoids are important for animals for their provitamin and antioxidant activity; in plant organisms they are involved in photosynthesis by excitation energy transfer, protection against harmful redundant irradiation and the formation of destructive singlet oxygen. Among all carotenoids circa fifty compounds (retinoids) show the activity of vitamin A. For provitamin activity of carotenoid precursors the presence of at least one unsubstituted β-ionone ring attached to the end of molecule is necessary. The most widespread and important provitamin A is β-carotene that is characterised by cyclization of β-ionone ring attached to both ends of carbon chain. Theoretically, by splitting of one molecule of β-carotene two molecules of vitamin A could be formed (Bauernfeind 1981). Considering this, the highest attention is devoted to the conversion of β-carotene to vitamin A (Bauernfeind 1981, Brubacher and Weiser 1985, Granguly and Sastry 1985). Carotenoids are one of the major constituents contributing to total antioxidant capacity of potato tubers (Figure 1). The antioxidant effect of carotenoids consists in their ability to neutralize free radicals by donor electron, without becoming active free radicals (Gross 1991, Mortensen et al. 1997). The ability of carotenoids to neutralize free radicals if affected both by the presence of polar functional groups (carbonyls and hydroxyls) attached to terminal ionone rings as well as to number of conjugated double bonds (Miller et al. 1996).

Recent studies prove that on the whole, the most effective carotenoid with free singlet oxygen scavenging effect is lycopene (Di Mascio et al.1989, Miller et al. 1996). According to Miller et al. (1996) and Woodall et al. (1997) carotenes with eleven conjugated double bonds are more active scavengers as compared with xanthophyls. The authors attribute

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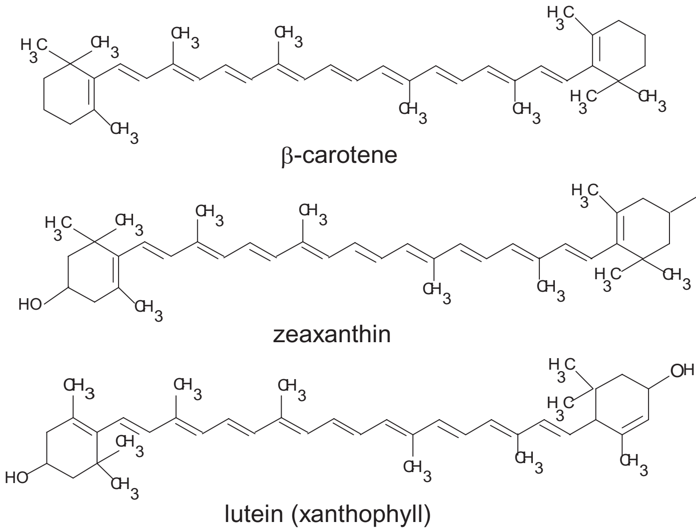

Figure 1. Major potato carotenoids

the low antioxidant efficiency to carotenoids with carbonyl functional groups at terminal rings having according to their opinion, substantial suppressing effect on free radical scavenging despite of longer chromophore with thirteen conjugated double bonds. On the other hand, Di Mascio et al. (1989) and Tinkler et al. (1994) consider dioxocarotenoids as very effective free radical scavengers. They ascribe the increase of their activity to an extensive system of conjugated double bonds.

Total carotenoid content (TC) in potato tubers ranges from 0.5 to 1 mg/kg fresh matter (fm) in white flesh potatoes and to 20 mg/kg in yellow potatoes. In potatoes with TC 0.35–7.95 mg/kg fm the oxygen radical absorption capacity (ORAC) ranges from 46 to 153 nmol α-tocopherol equivalents per kg fresh matter of tubers (Brown 2005).

Very important antioxidants contained in potato tubers are carotenoids lutein and zeaxanthin (42–66%), in lesser amounts β-carotene (1.1–3%). Brown (2005) determined lutein, zeaxanthin and violaxanthin as major potato carotenoids, while β-carotene and α-carotene were found only in trace amounts. Contrarily Duke (1992) in his database reports as major β-carotene (1 mg/kg) and its 5,6-monoepoxide. Müller (1997) evaluated TC in potato tubers as 4.5 mg/kg; TC consisted of violaxanthin (1.8 mg/kg), antheraxanthin (1.3 mg/kg), lutein (1.0 mg/kg), zeaxanthin (0.16 mg/kg), neoxanthin (0.14 mg/kg), β-carotene (0.05 mg/kg) and β-cryptoxanthin (0.03 mg/kg).

The aim of this study was to determine the effect of variety and year of cultivation, fertilization with N, P, K, Mg and use of polypropylene white fiber on TC in potato tubers.

MATERIAL AND METHODS

Characteristics of experimental localities and plant material

In precise field trials in the years 2004 and 2005 in two localities in the Czech Republic (Přerov nad Labem, Lípa) with different altitude, Impala (very early), Karin (early), Ditta (semi-early) and Saturna (late) varieties were cultivated in a unified way according to the standard agricultural engineering; moreover, in the Lípa locality Magda (very early), Marabel (early), Agria (semi-early), Asterix and Valfi (semi-late or late) varieties were cultivated. Basic characteristics of the localities are described in Table 1.

Forecrop used in these experiments was winter wheat, the autumn manure was ploughed under the dose 30 t/ha together with P and K fertilizers in the doses according to the reserve of nutrients in soil. In spring, nitrogen fertilizers were spread on the harrowed plot in two thirds from total dose 120 kg N/ha and the residue of the dose was applied after emerging of the vegetation. The plot was ploughed into 15–18 cm depth and drills were formed. Proper trials were based in four parallels in 75 × 30 cm spacing, area of parcel 3 m (4 rows) × 7.2 m. Preemergent herbicide Afalon 45 SC (linuron 450 g) at the dose 1.5 l/ha was applied before growing of bunches. Before the integration of vegetation one treatment with insecticide against Colorado potato beetle was performed as well as 5–7 treatments with fungicides against late blight according to the requirements in the localities.

Table 1. Characteristics of experimental localities

Locality	Level above sea (m)	Average annual temperature (°C)	Annual sum of precipitation (mm)	Soil type	Soil category
Přerov nad Labem	178	8.8	622	TBS	sl–l
Lípa	505	7.7	632	PGAC	sl
Valečov	460	6.9	649	PGAC	sl–l

Soil categories: TBS – typical brown soil, PGAC – pseudogleyic acid cambisol (brown gleysol); soil texture class groupings: sl – sandy loamy, l – loamy

The second trial was based in the Valečov locality (Table 1), where the influence of different fertilization levels with N, P, K and Mg nutrients was investigated. The trial was carried out with Ditta and Karin varieties, agricultural engineering was (in exception of inorganic fertilizers) the same as in the first experiment. Fertilization variants were as follows: variant 1: without fertilization with industry 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. Nitrogen was applied into soil in the form of urea, P in phosphate-magnesium fertilizer FOSMAG MK, K in the form of potassium chloride and Mg in magnesium fertilizer GRANOMAG.

After the harvest in the stage of physiological maturity the samples of tubers from parallels of every experiment were sampled for laboratory analyses, which were performed at the Department of Chemistry of the Czech University of Life Sciences, Prague.

In the third field trial in the locality Přerov nad Labem, two early varieties Adora and Impala were cultivated in a unified way according to the standard agricultural engineering. Two variants were compared – control cultivated on free trial plot and covered with white polypropylene fibre (Paegas-Agro UV 17).

Determination of carotenoids

Potato samples were prepared according to Lachman et al. (2003). Absorbance of acetone extracts was then measured in 1 cm cuvettes at λ = 444 nm against acetone (Spectronic Heλios γ spectrophotometer, Thermo Electron Corporation, GB) and total carotenoid content in mg/kg fw of sample was expressed as lutein equivalent from the equation:

$$(K + X)_L = \frac{A_{444} \cdot 25}{0.259} \cdot \frac{15}{m} \quad \text{(mg/kg fw)}$$

where: $(K + X)_L$ is total carotenoid content (carotenes and xanthophylls)
A_{444} is absorbance of acetone extract at λ = 444 nm
m is sample weight (g)

Statistic evaluation. The obtained results (mean values from three parallel determinations) were statistically evaluated by the ANOVA analysis of variance method, the Multivariate Design MANOVA (level of significance $P = 0.05$) and the Scheffe's test.

RESULTS AND DISCUSSION

Effect of variety

The effect of variety was investigated in both years in the Lípa locality; weather conditions (average temperature and precipitations) during the warm half-years (IV.–XI.) are recorded in the thermopluviograms (Figures 2 and 3) and evaluated according to the recommendations of World Meteorological Organization to describing meteorological or climatological conditions (Kožnarová and Klabzuba 2002). Average TC in 2004 was 5.8 mg/kg fw. The highest TC showed Agria variety (18.9 mg/kg fw), high TC was determined in tubers of Asterix (6.9 mg/kg fw) and Ditta (5.3 mg/kg) varieties. Average TC in 2005 was higher than in 2004 (20.9 mg/kg fw, Figure 4). The highest TC showed Marabel variety (46.6 mg/kg fw), a high ability of carotenoid biosynthesis showed also Agria, Karin, Magda and Asterix varieties. These varieties differed significantly from Ditta (7.6 mg/kg fw) and Valfi (1.5 mg/kg fw) varieties. Valfi variety with purple coloured tubers had a lower ability to carotenoid formation as compared with potato varieties with white or yellow tuber

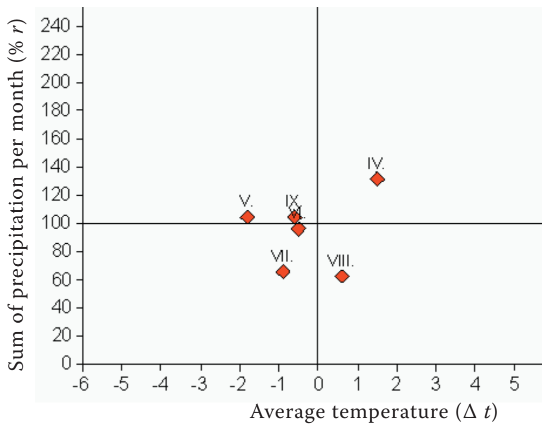

Figure 2. Precipitation and temperatures in a warm half-year 2004 (Central Institute for Supervising and Testing in Agriculture, Lípa)

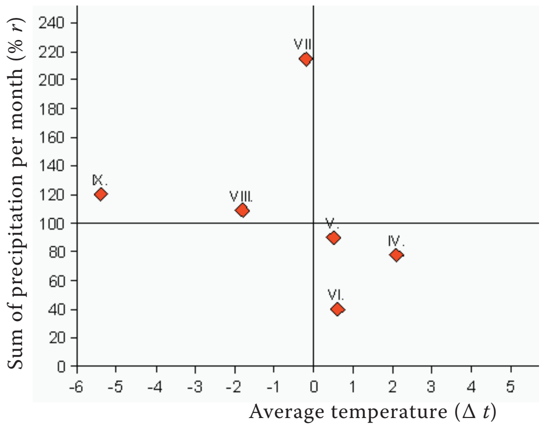

Figure 3. Precipitation and temperatures in a warm half-year 2005 (Central Institute for Supervising and Testing in Agriculture, Lípa)

flesh. In the average of both investigated years, relatively high TC was recorded in Agria variety and a low ability to synthesize carotenoids was typical for Impala and Saturna varieties.

The results of statistical evaluation confirmed statistically significant difference of varieties in their ability to accumulate carotenoids; the year of cultivation also highly affected TC. Differences in average values of Karin and Marabel in investigated years were very significant, only Ditta variety had relatively stable TC values.

Effect of N, P, K and Mg fertilization

In 2005 the effect of different fertilization variants on TC in Karin and Ditta varieties was evaluated. Whereas a statistically significant difference between the cultivated varieties was found (Figure 5), results of statistical evaluation did not confirm statistically significant differences between individual variants of fertilization. Karin showed higher TC (32.9 mg/kg fw) as compared to Ditta variety (21.8 mg/kg fw). From the obtained results we might assume that the carotenoid content was not statistically significantly related to the amounts and ratios of fertilizers used in the trials.

Effect of white polypropylene fibre on carotenoid content in tubers

In the field trials in 2004 the highest TC was determined in the second harvest date (Figure 6); in 2005 in potato tubers in the first harvest date (Figure 7). It is in accordance with the results obtained by Morris et al. (2004), who also estimated the highest carotenoid content at the beginning

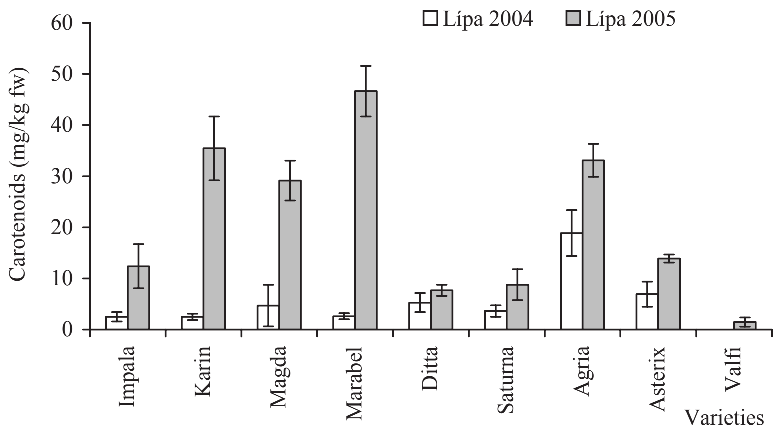

Figure 4. Effect of variety on total carotenoid content (mg/kg fresh weight) in the Lípa locality

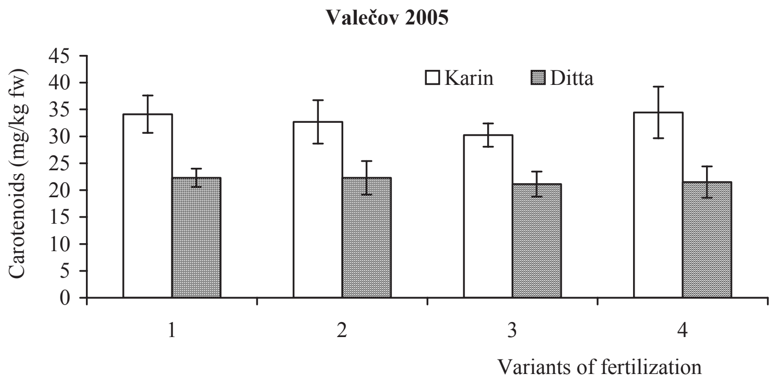

Figure 5. Effect of the level of mineral fertilization (fertilization variants) on the content of total carotenoids (mg/kg fresh weight) in the Valečov locality; vertical lines represent SD (4 replicates); variant 1 – without fertilization with mineral fertilizers (control); variant 2 – 100 kg N/ha, 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

of tubers development of both tested varieties. These results show that the carotenoid content is unambiguously dependent on physiological maturity of potato tubers. Carotenoid content decreases with the increase of dry matter during tuber development. Besides, in both investigated years a statistically significant effect of variety was determined. Adora variety possessed a higher ability to synthesize carotenoids (on average by 69% and 88% in 2004 and 2005, respectively) in

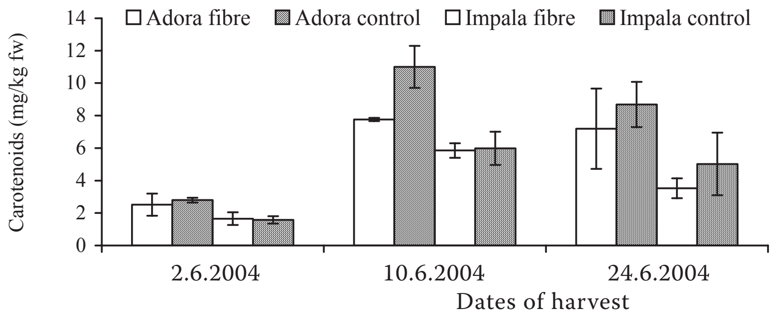

Figure 6. Effect of white polypropylene fibre on total carotenoids in potato tubers in the locality of Přerov nad Labem in 2004; vertical lines represent SD (4 replicates)

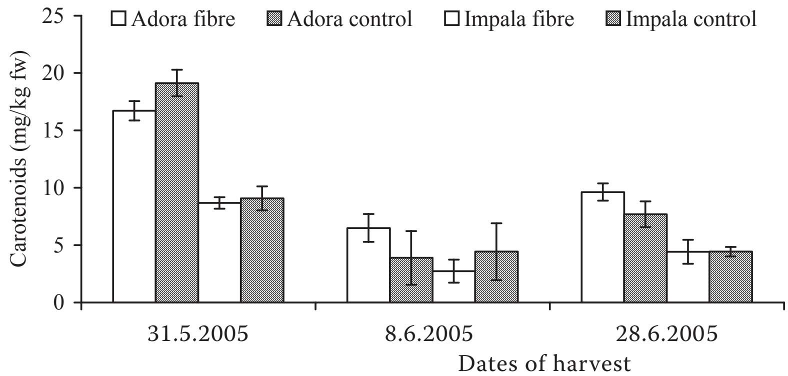

Figure 7. Effect of white polypropylene fibre on total carotenoids in potato tubers in the locality of Přerov nad Labem in 2005; vertical lines represent SD (4 replicates)

comparison with Impala variety. A statistically significant difference in TC was proved between the evaluated years as well. In all the compared variants higher TC values were statistically significantly higher in the year 2005 (in Adora variety by 59% and in Impala variety by 43% on average). In compliance with the results on the effect of white unwoven fibre on the content of carotenoids in early potatoes in the years 2000–2001 (Lachman et al. 2003), no statistically significant effect of white polypropylene fibre was found. Only a slight tendency to higher TC values in potatoes cultivated without cover in comparison with potatoes covered with white polyethylene fibre was observed. Adora variety in 2004 contained on average 5.82 mg/kg fw in covered variant vs. 7.50 mg/kg fw in uncovered variant, in Impala these values were 3.68 mg/kg fw and 4.20 mg/kg fw. A similar tendency was found in the year 2005 (Impala 5.27 mg/kg fw with covering vs. 5.98 mg/kg fw without covering). In 2005 TC in Adora almost did not differ (10.94 mg/kg in covered variants and 10.23 mg/kg fw in uncovered variants).

REFERENCES

Bauernfeind J.C. (1981): Carotenoids as Colorants and Vitamin A Precursors: Technological and Nutritional Applications. Academic Press, New York, USA.

Brown C. (2005): Antioxidants in potato. Am. J. Potato Res., *82*: 163–172.

Brubacher G.B., Weiser H. (1985): The vitamin A activity of beta-carotene. Int. J. Vit. Nutr. Res., *55*: 5–15.

Di Mascio P., Kaiser S., Sies H. (1989): Lycopene as the most efficient biological carotenoid singlet oxygen quencher. Arch. Biochem. Biophys., *274*: 532–538.

Duke J.A. (1992): Handbook of Phytochemical Constituents of GRAS Herbs and Other Economic Plants. CRC Press, Boca Raton, Florida.

Granguly J., Sastry P.S. (1985): Mechanism of conversion of beta-carotene into vitamin A – central cleavage versus random cleavage. World Rev. Nutr. Diet., *45*: 198–220.

Gross J. (1991): Pigments in Vegetables: Chlorophylls and Carotenoids. Van Nostrand, New York, USA.

Kožnarová V., Klabzuba J. (2002): Recommendation of World Meteorological Organization to describing meteorological or climatological conditions. Rostl. Výr., *48*: 190–192. (In Czech)

Lachman J., Hamouz K., Hejtmánková A., Dudjak J., Orsák M., Pivec V. (2003): Effect of white fleece on the selected quality parameters of early potato (*Solanum tuberosum* L.) tubers. Plant Soil Environ., *49*: 370–377.

Miller N.J., Sampson J., Candeias L.P., Bramley P.M., Rice-Evans C.A. (1996): Antioxidant activities of carotenes and xanthophylls. Febs Lett., *384*: 240–242.

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. J. Exp. Bot., *55*: 975–982.

Mortensen A., Skibsted L.H., Sampson J., Rice-Evans C., Everett S.A. (1997): Comparative mechanisms and rates of free radical scavenging by carotenoid antioxidants. Febs Lett., *418*: 91–97.

Müller H. (1997): Determination of the carotenoid content in selected vegetables and fruit by HPLC and photodiode array detection. Z. Lebensm. Unters. F. A, *204*: 88–94.

Tinkler J.H., Böhm F., Schalch W., Truscott T.G. (1994): Dietary carotenoids protect human cells from damage. J. Photoch. Photobio. B, *26*: 283–285.

Woodall A.A., Lee S.W., Weesie R.J., Jackson M.J., Britton G. (1997): Oxidation of carotenoids by free radicals: relationship between structure and reactivity. Biochim. Biophys. Acta, *1336*: 33–42.

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Corresponding author:

Prof. Ing. Jaromír Lachman, CSc., Česká zemědělská univerzita v Praze, Fakulta agrobiologie, potravinových a přírodních zdrojů, 165 21 Praha 6-Suchdol, Česká republika
phone: + 420 222 382 717, fax: + 420 234 381 840, e-mail: lachman@af.czu.cz