The impact of cooking procedures on antioxidant capacity of potatoes

RUDOLF ŠEVČÍK – ALEXEY KONDRASHOV – FRANTIŠEK KVASNIČKA – JOSEF VACEK – KAREL HAMOUZ – MICHAELA JIRUŠKOVÁ – MICHAL VOLDŘICH – HELENA ČÍŽKOVÁ

Summary

Recent studies have strongly supported the efficacy of diet rich in phytochemicals in reducing the risk of cardiovascular disorders, high cholesterol and cancer. Phytochemicals, such as plant polyphenols, vitamins and carotenoids, exert multiple beneficial effects due to their antioxidant properties. Being the most consumed vegetable of human daily food consumption, potato has attracted considerable interest as a potential source of dietary antioxidants. Current study includes a comparative analysis of antioxidant properties of yellow, red and blue potatoes typical for the Czech Republic, with the relation to their phenolic contents in fresh, cooked, cooked in steam, microwave-heated and fried potato samples. The objective was to find the relationship between the antioxidant capacity, total phenolics and potato variety in 12 samples of different potato cultivars. The impact of cooking procedures on antioxidant capacity of potatoes is also examined. Total antioxidant capacity in potato was determined using 2,2'-azino-bis(3-ethyl-benzothiazoline-6-sulphonate) (ABTS) assay and 2,2-diphenyl-1-picrylhydrazyl (DPPH) method. The total phenolic content was evaluated according to the Folin-Ciocalteau colorimetric assay and also by selective HPLC. Both antioxidant capacities and total phenolics were expressed as chlorogenic acid equivalents. The results demonstrate that antioxidant activities of potato correlate with phenolic contents in all samples. Red and blue varieties have significantly higher values of both phenolics and antioxidant contents compared to yellow potato.

Keywords

potato; polyphenols; antioxidant capacity; ABTS; DPPH

Epidemiological and experimental studies support the hypothesis that diets with high contents of plant foods are beneficial in the prevention of chronic diseases and cancer in humans, although the benefits for individuals may depend on their genetic profile [1–10].

Potato has attracted a considerable interest being one of the most consumed vegetables in Western populations. Recent findings suggested that potatoes could be an essential source of nutrients and biologically active compounds in human diet, the latter comprising. carotenoids, vitamin C and polyphenols, in particular anthocyanins and chlorogenic acid [11–14]. Studies by Brown [15, 16] revealed that potatoes may exert multiple antioxidative effects. Data from several studies implied that the antioxidant properties of potato polyphenols are related to both their scavenging effect (protection of low-density lipoprotein (LDL) and very-low-density lipoprotein (VLDL) from oxidation) and to their capacity to suppress inflammation [17, 18]. These properties are mainly related to anthocyanins that are contained in red and blue potato varieties. Potato polyphenols are reported to have potential antihypertensive activities and act as moderate angiotensin-converting enzyme (ACE) inhibitors [19]. Potato anthocyanins were also found to exert hepatoprotective effects by enhancing hepatic manganese superoxide dismutase (Mn-SOD), copper and zinc superoxide dismutase (Cu/Zn-SOD) and glutathione peroxidase (GSH-Px) mRNA expression in rats [20, 21].

Rudolf Ševčík, František Kvasnička, Michaela Jirušková, Michal Voldřich, Helena Čížková, Department of Food Preservation and Meat Technology, Faculty of Food and Biochemical Technology, Institute of Chemical Technology, Technická 3, CZ – 166 28 Prague, Czech Republic.

Alexey Kondrashov, Department of Medical Biochemistry, First Faculty of Medicine, Charles University, Kateřinská 32, CZ – 121 08 Prague, Czech Republic.

Josef Vacek, Potato Research Institute, Dobrovskeho 2366, CZ – 580 01 Havlickuv Brod, Czech Republic.

Karel Hamouz, Faculty of Agrobiology Food and Natural Resources, Czech University of Life Sciences, Kamýcká 129, CZ – 165 21 Prague 6 – Suchdol, Czech Republic.

Correspondence author:
Rudolf Ševčík, e-mail: rudolf.sevcik@vscht.cz

Tab. 1. Potato samples subjected to the study.

Sample number	Cultivar	Tuber flesh colour	Agricultural area
1	Agria	yellow	Havlíčkův Brod
2	Ditta	yellow	Havlíčkův Brod
3	Impala	yellow	Prague - Suchdol
4	Herbie 26	red	Havlíčkův Brod
5	Highland Burgundy Red	red	Prague - Suchdol
6	Salad Red	red	Havlíčkův Brod
7	Blue Congo	blue	Prague - Suchdol
8	Valfi	blue	Havlíčkův Brod
9	All Blue	blue	Havlíčkův Brod
10	Violette	blue	Prague - Suchdol
11	Blaue Hindelbank	blue	Prague - Suchdol
12	Blaue St. Galler	blue	Havlíčkův Brod

Anticarcinogenic properties of potato polyphenols have been reported in a recent study by REDIVARI et al. [22].

MATERIALS AND METHOD

Potatoes with differently coloured pulps (12 varieties) originated in two agricultural areas in the Czech Republic (Tab. 1). Potatoes were grown in conventional production technology at a planting distance of 30 × 75 cm, fertilized by 100 kg nitrogen and phosphorus, potassium according to soil supply prior to planting and late blight control. Tuber appearance was evaluated based on tuber size, shape and eye depth. Antioxidant capacity was determined by 2,2'-azino-bis(3-ethyl-benzothiazoline-6-sulphonate) (ABTS) assay using a commercial kit Randox TAS (radical ABTS; Randox Laboratories, Antrim, United Kingdom) and the 2,2-diphenyl-1-picrylhydrazyl (DPPH) method (see below). Total phenolics were determined by the Folin-Ciocalteau method. Chlorogenic acid was determined by selective HPLC (see below). Results were expressed as mg chlorogenic acid equivalents per gram.

Sample preparation

Free phenolic acids were determined in potato samples using the following procedures:

1. Raw potatoes were liquidized together with the peel. Then, 2 g of the liquidized potato sample were put into a 50 ml graduated glass flask and 40 ml of the extraction reagent, a methanol solution with 0.02% butylated hydroxytoluene (BHT), was added. The sample with the extraction reagent was treated in an ultrasonic bath for 15 min. Then, the sample flask was filled by the extraction reagent till the 50 ml mark, mixed and filtered through a paper filter, and subsequently through a membrane filter with the pore size of 0.45 μm.
2. Fresh potatoes were peeled, cut and liquidized using a blender. Further sample preparations were similar as described above. Potato peels were analysed in the same way.
3. The potato samples with a peel were boiled in water for 12 min. After cooking, samples with the peel were also liquidized. Similar cooking procedures (boiling in water) were implemented for the peeled samples and for the potato peel.
4. Potato samples with a peel were cooked by steaming for 30 min. Then, samples with the peel were liquidized. Further sample preparation was similar to the first case.
5. Potato with a peel was cooked in a microwave oven at 500 W for 5 min plus extra 2 min for readiness. Then the potatoes were liquidized together with the peel. Then the samples were treated as in the first case.
6. Potatoes with a peel were cut to 0.5 cm thick chips and fried in hot vegetable oil for 5 min. These French fries were removed from the oil bath, drained and were liquidized together with the peel. The rest of the sample preparation was similar to the first case.

Analytical Procedure

ABTS method

The Total Antioxidant Status (TAS) test was performed in accordance with the manufacturer's

instructions. The principle of the test is as follows: ABTS is incubated with a peroxidase (metmyoglobin) and H_2O_2 to produce the radical cation $ABTS^+$. This has a relatively stable blue-green colour, which is measured at 600 nm.

DPPH method

Free-radical-scavenging capacity of potato extracts was determined according to the previously reported procedure using DPPH [22]. The absorbance at 517 nm was measured against blank samples with methanol solution (80%).

TPC method

Total phenolic content (TPC) was determined using spectrophotometric assay on a Thermo Spectronic Genesys 20 UV-visible pectrophotometer (Thermo Fisher Scientific, Waltham, Massachusetts, USA) using Folin-Ciocalteau's reaction [22]. The absorbance was determined at 750 nm using chlorogenic acid as a standard. TPC was expressed as mg chlorogenic acid equivalents.

HPLC method

The content of chlorogenic acid (CGA) was determined using HPLC with a Dionex Summit Chromatograph consisting of a P680 pump, Ultimate 3000 Photodiode Array Detector and Autosampler ASI-100 driven by Chromeleon software (Dionex Corporation, Sunnyvale, California, USA). Separations were carried out on a 150 mm × 4.6 mm Eclipse XDB-C8 5 μm column (Agilent Technologies, Santa Clara, California, USA). Elution was carried out with two solvents: 5 mM KH_2PO_4 in methanol (A), KH_2PO_4 in demineralized water (B). The samples were eluted for 20 min at a flow rate of 1 ml·min^{-1}, with gradient. The column temperature was 20 °C and UV detection was performed at 325 nm.

Statistics

Data are presented as mean values ± standard deviation (SD; n = 3). The statistical significance was evaluated by Pearson's test, which is suitable for small numbers of samples, using GraphPad Prism version 4 software (GraphPad Software, San Diego, California, USA). The results are presented in the table of the correlation matrix.

RESULTS AND DISCUSSION

In this study of twelve potato cultivars with the yellow, red and blue flesh types, certain relationships between the antioxidant capacity, phenolics and the cooking procedures were observed. In order to find whether there is a relationship between the potato variety and total phenolics and the antioxidant capacity, the set of potato samples was divided into three clusters of yellow, red and blue flesh. The determination of phenolics in potato resulted in the finding that, among polyphenolic compounds present in potatoes, chlorogenic acid was contained in the highest amounts. Other phenolic substances, such as caffeic or protocaffeic acids, also occur in small numbers in potatoes. However, the amounts of these compounds are ten-fold lower compared to cholorogenic acid. This

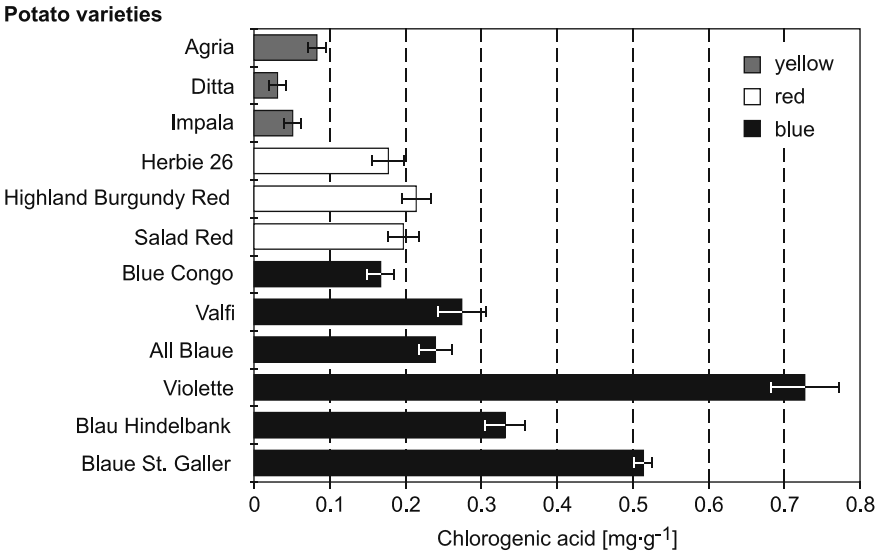

Fig. 1. Contents of chlorogenic acid in different potato varieties.
Data are expressed as mean ± SD (n = 3).

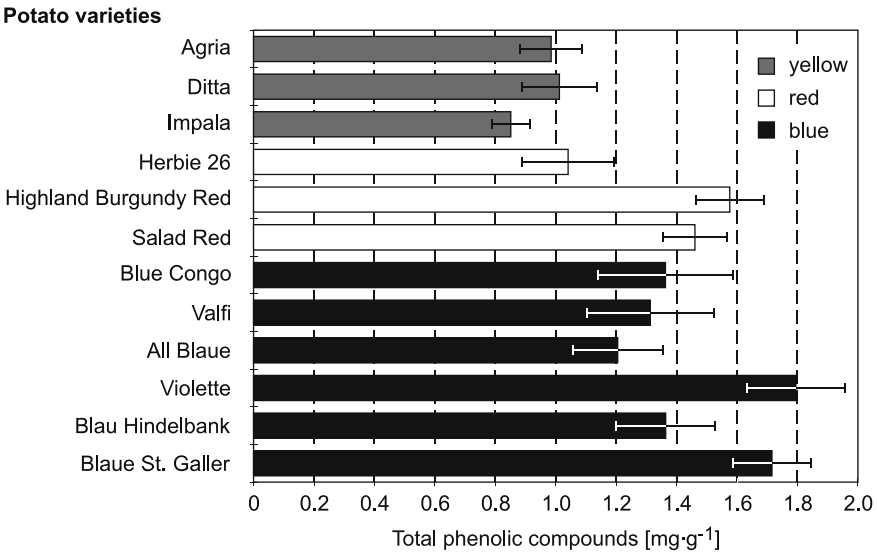

Fig. 2. Contents of total phenolic compounds in different potato varieties.
Data are expressed as mean ± SD (n = 3).

may be the reason for the fact that using HPLC, we have determined only cholorogenic acid. This result is consistent with the results published for potatoes by other investigators [11, 12, 15].

Chlorogenic acid contents were found to vary broadly in different potato cultivars. The lowest content was found in yellow potatoes: from 0.03 mg·g^{-1} to 0.08 mg·g^{-1}, compared to 0.18–0.21 mg·g^{-1} in red flesh varieties. The highest chlorogenic acid contents between 0.17 mg·g^{-1} and 0.73 mg·g^{-1} were detected in blue potato cultivars. These findings are in correspondence with the data in the literature, where chlorogenic acid content was three to four times higher in red and purple cultivars compared to yellow potato varieties [23, 24]. The contents of chlorogenic acid in different potato varieties is shown in Fig. 1.

The lowest content of total phenolic compounds (chlorogenic acid) was determined in potatoes with a yellow flesh. For the potatoes with a coloured (red and blue) flesh, the total phenolic contents were higher by 40% compared to yellow flesh varieties. Greater contents of total phenols in the varieties with a coloured flesh was associated with a high proportion of oenocyanin, which does not occur in potatoes with white or yellow-coloured flesh, as depicted in Fig. 2.

Phenolic contents of the examined potato samples appear to be associated with the antioxidant capacities, determined either by the ABTS assay or by the DPPH assay. In order to eliminate possible discrepancies, total antioxidant capacity was measured by two assays, ABTS and DPPH. Statistical analysis provided strong positive correlation (r = 0.93 and $p < 0.0001$) for the assays.

We have also found strong positive relationships between the total antioxidant capacity (TAC) and the phenolic content in all potato cultivars independently of the potato sample. The significance of these relationships is illustrate by the following statistical parameters: DPPH assay (r = 0.87, $p < 0.0002$) and ABTS assay (r = 0.71, $p < 0.0097$).

The results of statistical analysis and characteristics of all methods employed in this study are presented in Tab. 2.

Total antioxidant capacities measured by ABTS and DPPH assays were higher in red and blue potato varieties. These findings are presented in Fig. 3 and are consistent with the data in the literature [18, 23].

Interesting results were also obtained on the impact of different cooking procedures on the total antioxidant capacity in potato samples of Impla variety. Antioxidant capacity increased by

Tab. 2. The correlation matrix.

r	ABTS	DPPH	TPC	HPLC
ABTS	–	0.93	0.71	0.79
DPPH	0.93	–	0.87	0.91
TPC	0.71	0.87	–	0.84
HPLC	0.79	0.91	0.84	–

r – linear correlation coefficient, TPC – total phenolic content.

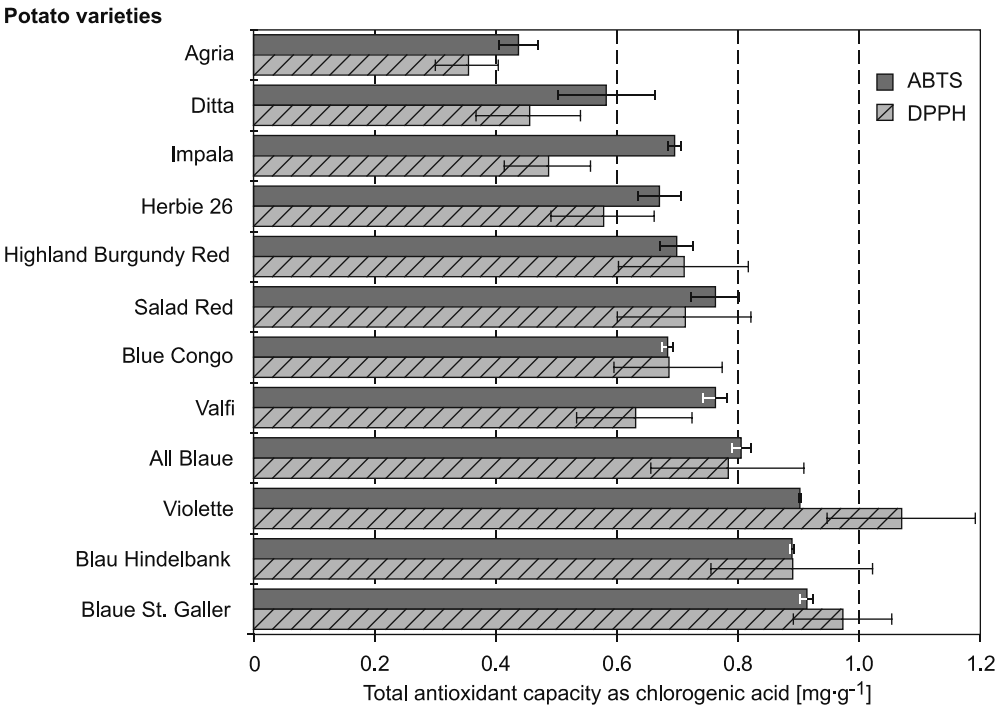

Fig. 3. The antioxidant capacity in different potato varieties measured by ABTS and DPPH assays.
Data are expressed as mean ± SD (n = 3).

30% for potatoes cooked in steam with the peel, compared to that of the raw tuber. When potatoes were boiled with the peel in water, no change was observed in the antioxidant capacity. All other adjustments lead to a decrease in the antioxidant capacity: when microwaved by 11%, peeled then cooked potatoes by 15%, and when fried in vegetable oil by 29% (Fig. 4). The potato variety Impala was selected to represent one of the most consumed potatoes in the Czech Republic.

In this study, simultaneous analysis of total phenolic content and total antioxidant capacity was determined in relation to potato variety and cooking procedures. The study extends the current

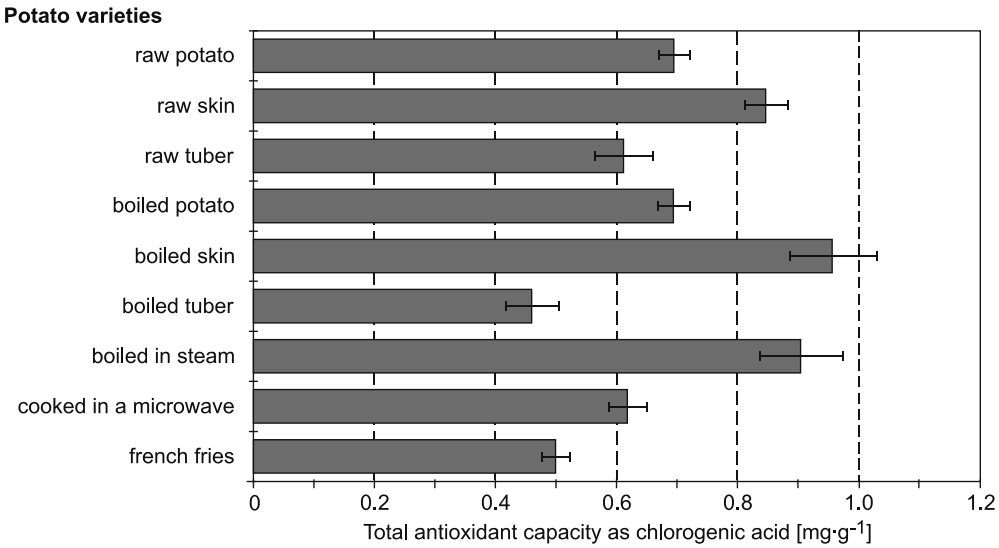

Fig. 4. Antioxidant capacity (ABTS assay) of Impala potato variety after using different cooking procedures.
Data are expressed as mean ± SD (n = 3).

knowledge by considering phenolic content and cooking procedures in relation to the total antioxidant capacity and potato variety. The results demonstrate that cooking procedures change the antioxidant capacity of potatoes.

CONCLUSION

On the basis of the results it can be concluded that potato varieties with a coloured flesh have up to four times higher antioxidant capacities compared to yellow varieties. Culinary processing, with the exception of peeling, causes augmentation of antioxidant capacities in all examined potatoes. Potato peel and the layer beneath it have higher antioxidant capacities compared to flesh (from 40% up to 400% increase, depending on the cooking method used). Cooking potatoes with in the peel seems to cause beneficial changes from the perspective of antioxidant capacity, however, this is only true if the cooked potatoes are consumed whole, together with the peel.

Acknowledgements

The study was supported by the Ministry of Education, Youth and Sports (Institutional research plans MSM6046137305, MSM0021620807), Czech Science Foundation (project GA525/06/0268) and by the Ministry of Agriculture (project QH92110).

REFERENCES

1. Kris-Etherton, P. M. – Hecker, K. D. – Bonanome, A. – Coval, S. M. – Binkoski, A. E. – Hilpert, K. F. – Griel, A. E. – Etherton, T. D.: Bioactive compounds in foods: Their role in the prevention of cardiovascular disease and cancer. The American Journal of Medicine, *113*, 2002, pp. 71S–88S.
2. Schröder, H.: Protective mechanisms of the Mediterranean diet in obesity and type 2 diabetes. The Journal of Nutritional Biochemistry, *18*, 2007, pp. 149–160.
3. Bazzano, L. A. – He, J. – Ogden, L. G. – Loria, C. M. – Vupputuri, S. – Myers, L. – Whelton, P. K.: Fruit and vegetable intake and risk of cardiovascular disease in US adults: the first national Health and Nutrition Examination Survey Epidemiologic Follow-up study. The American Journal of Clinical Nutrition, *76*, 2002, pp. 93–99.
4. Jenkins, D. J. A. – Kendall, C. W. C. – Marchie, A. – Jenkins A. L. – Augustin L. S. A. – Ludwig D. S. – Barnard, N. D. – Anderson, J. W.: Type 2 diabetes and the vegetarian diet. The American Journal of Clinical Nutrition, *78*, 2003, pp. 610–616.
5. Seifried, H. E. – Anderson, D. E. – Fisher, E. I. – Milner, J. A.: A review of the interaction among dietary antioxidants and reactive oxygen species. The Journal of Nutritional Biochemistry, *18*, 2007, pp. 567–579.
6. Kaliora, A. C. – Dedousis, G.: Natural antioxidant compounds in risk factors for CVD. Pharmacological Research, *56*, 2007, pp. 99–109.
7. He, F. J. – Nowson, C. A. – MacGregor, G. A.: Fruit and vegetable consumption and stroke: meta-analysis of cohort studies. The Lancet, *367*, 2006, pp. 320–326.
8. Wannamethee, S. G. – Lowe, G. – Rumley, A. – Bruckdorfer, R. – Whincup, K. R.: Association of vitamin C status, fruit and vegetable intakes, and markers of inflammation and hemostasis. American Journal of Clinical Nutrition, *83*, 2006, pp. 567S–574S.
9. Arts, I. C. – Hollman, P. C.: Polyphenols and disease risk in epidemiologic studies. American Journal of Clinical Nutrition, *81*, 2005, pp. 317S–325S.
10. Brat, P. – George, S. – Bellamy, A. – Du Chaffaut, L. – Scalbert, A. – Mennen, L. –Arnault, N. – Amiot, M. J.: Daily polyphenol intake in France from fruit and vegetables. The Journal of Nutrition, *136*, 2006, pp. 2368–2373.
11. Matilla, P. – Hellström, J.: Phenolic acids in potatoes, vegetables, and some of their products. Journal of Food Composition and Analysis, *20*, 2007, pp. 152–160.
12. Im, H. W. – Suh, B. M. – Lee, S. U. – Kozukue, N – Ohnisi-Kameyama, M. – Levin, C. E. – Friedman, M.: Analysis of phenolic compounds by high-performance liquid chromatography and liquid chromatography/mass spectrometry in potato plant flowers, leaves, stems, and tubers and in home-processed potatoes. Journal of Agricultural and Food Chemistry, *56*, 2008, pp. 3341–3349.
13. Shakya, R. – Navarre, D. A.: Rapid screening of ascorbic acid, glycoalkaloids, and phenolics in potato using high-performance liquid chromatography. Journal of Agricultural and Food Chemistry, *545,* 2008, pp. 5253–5260.
14. Chun, O. K. – Kim, D. C. – Smith, N. – Schroeder, D. – Han, J. T. – Lee, C. Y.: Daily consumption of phenolics and total antioxidant capacity from fruit and vegetables in the American diet. Journal of the Science of Food and Agriculture, *85*, 2005, pp. 1715–1724.
15. Brown, C. R.: Antioxidants in potato. American Journal of Potato Research, *82*, 2005, pp. 163–172
16. Brown, C. R.: Breeding for phytonutrient enhancement of potato. American Journal of Potato Research, *85*, 2008, pp. 298–307.
17. Stushnoff, C. – Holm, D. – Thompson, M. D. – Juany, W. – Thompson, H. J. – Wilson, P.: Antioxidant properties of cultivars and selections from the Colorado Potato Breeding Program. American Journal of Potato Research, *85*, 2008, pp. 267–276.
18. Han, K. H. – Sekikawa, M. – Shimada, K. – Hashimoto, M. – Hashimoto, N. – Noda, T. –Tanaka, H. – Fukushima, M.: Anthocyanin-rich purple potato flake extract has antioxidant capacity and improves antioxidant potential in rats. British

Journal of Nutrition, *96*, 2006, pp. 1125–1133.
19. Pihlanto, A. – Akkanen, S. – Korhonen, H. J.: ACE-inhibitory and antioxidant properties of potato (*Solanum tuberosum*). Food Chemistry, *109*, 2008, pp. 104–112.
20. Han, K. H. – Matsumoto, A. – Shimada, K. – Sekikawa, M. – Fukushima, M.: Effects of anthocyanin-rich purple potato flakes on antioxidant status in F344 rats fed a cholesterol-rich diet. British Journal of Nutrition, *98*, 2007, pp. 914–921.
21. Han, K. H. – Matsumoto, A. – Shimada, K. – Sekikawa, M. – Fukushima, M.: Anthocyanin-rich red potato flakes affect serum lipid peroxidation and hepatic SOD mRNA level in rats. Bioscience, Biotechnology and Biochemistry, *71*, 2007, pp. 1356–1359.
22. Reddivari, L. – Vanamala, J. – Chintharlapalli, S. – Safe, S. H. – Creighton Miller, J. Jr.: Anthocyanin fraction from potato extracts is cytotoxic to prostate cancer cells through activation of caspase-dependent and caspase-independent pathways. Carcinogenesis, *28*, 2007, pp. 2227–2235.
23. Reyes, L. F. – Miller, J. C. – Cisneros-Zevallos, L.: Antioxidant capacity, anthocyanins and total phenolics in purple and red-fleshed potato *(Solanum tuberosum* L.) genotypes. American Journal of Potato Research, *82*, 2005, pp. 271–277.
24. Al-Saikhan, M. S. – Howard, L. R. – Miller, J. C.: Antioxidant activity and total phenolics in different genotypes of potato (*Solanum tuberosum* L.). Journal of Food Science, *60*, 1995, pp. 341–343.

Received 23 November 2009; revised 9 December 2009; accepted 10 December 2009.