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Short Communication

Variations in the carotenoid and anthocyanin contents of Korean cultural varieties and home-processed sweet potatoes

Hye Jin Kim [a,1], Woo Sung Park [a,1], Ji-Yeong Bae [a], So Young Kang [b], Min Hye Yang [c], Sanghyun Lee [d], Haeng-Soon Lee [e], Sang-Soo Kwak [e], Mi-Jeong Ahn [a,*]

[a] College of Pharmacy and Research Institute of Pharmaceutical Sciences, Gyeongsang National University, Jinju 660-701, Republic of Korea
[b] Department of Aqualife Medicine, Chonnam National University, Yeosu 550-749, Republic of Korea
[c] College of Pharmacy, Pusan National University, Busan 609-735, Republic of Korea
[d] Department of Integrative Plant Science, Chung-Ang University, Anseong 456-756, Republic of Korea
[e] Plant Systems Engineering Research Center, Korea Research Institute of Bioscience and Biotechnology (KRIBB), Daejeon 305-806, Republic of Korea

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ABSTRACT

The sweet potato is an important industrial crop and a source of food that contains useful dietary fiber and vitamins. Recently, orange- and purple-fleshed varieties have come under the spotlight due to their healthful components, carotenoids and anthocyanins, respectively. In this study, an HPLC-DAD method was applied to determine the carotenoid composition and content in nine Korean cultural varieties of sweet potato. Changes in carotenoid contents and composition were also observed during home-processing of an orange-fleshed cultivar with high carotenoid content (530 ± 60 μg/g of dry weight, DW as all-*trans*-β-carotene). A loss of the carotenoids was observed for all of the home-processing methods examined; the baked or boiled or steamed sweet potatoes had higher amounts of all-*trans*-β-carotene (246 ± 34, 253 ± 29 and 240 ± 21 μg/g DW, respectively) than pressure-cooked, sautéed and fried ones (194 ± 21, 201 ± 28 and 111 ± 19 μg/g DW, respectively). Interestingly, *cis*-isomer of the all-*trans*-β-carotene, 13Z-β-carotene was found in elevated amounts in all of the processed samples, particularly in baked, pressure-cooked and steamed sweet potatoes compared to control. Variations in anthocyanin content in the nine cultural varieties and home-processed sweet potatoes were also determined by an HPLC-DAD method.

1. Introduction

Carotenoids are synthesized by plants and some microorganisms, and most of them are liposoluble. They are responsible for the red, yellow, and orange colors, and act as photosynthesis aids and for the photoprotection of their hosts (Pfander, 1992; Demmig-Adams et al., 1996). Humans and animals are not able to synthesize carotenoids and need to acquire them by alimentation. Carotenoids are used in food and feed as colorants, flavorings, and nutritional supplements, being a source of provitamin A. The health benefits of carotenoids to humans and animals are becoming increasingly apparent. For example, there is evidence that these pigments may act as antioxidants and protect humans from serious disorders such as skin degeneration and aging, cardiovascular disease, certain types of cancer, and age-related diseases of the eye, such as macular degeneration or cataracts (Tapiero et al., 2004; Stahl and Sies, 2005; Rao and Rao, 2007).

Anthocyanins are polyphenolic water-soluble pigments and glycosides of polyhydroxy and polymethoxy derivatives of 2-phenylbenzopyrylium or flavylium salts. These compounds play a role in attracting animals in pollination and seed dispersal; they may also enhance plant resistance to insect attack, act as endogenous plant antioxidants and photoprotectors (Strack and

* Corresponding author. Tel.: +82 55 772 2425; fax: +82 55 772 2429.
E-mail address: amj5812@gnu.ac.kr (M.-J. Ahn).
[1] These authors contributed equally to this work.

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Wray, 1993; Delgado-Vargas et al., 2000). Evidence also suggests that this group of phytochemicals, besides being nontoxic and non-mutagenic, could exhibit multiple biological effects, such as antioxidant activity, anti-inflammatory action, inhibition of blood platelet aggregation, and antimicrobial activity, and could be used in the treatment of diabetic retinopathy and prevention of cholesterol-induced atherosclerosis (Luo et al., 2014; Pascual-Teresa et al., 2013; Zheng and Wang, 2003).

Sweet potato is the root of *Ipomoea batatas* (L.) Lam. (Convolvulaceae) and an important industrial crop and source of food that contains useful dietary fiber and vitamins (Kim et al., 2013). It has been widely consumed in Asia including China, Japan and Korea (Yamakawa and Yoshimoto, 2002). Recently, orange- and purple-fleshed varieties have come under attention owing to their healthful components, carotenoids and anthocyanins, respectively. As a food material, sweet potato is usually served after processing. Steaming and baking are the most popular and traditional home processing methods in Korea.

In this study, the major carotenoid and anthocyanin contents in sweet potato were determined for nine Korean cultural varieties including orange-fleshed sweet potato varieties (Juhwangmi and Sinhwangmi) and purple-fleshed varieties (Sinjami and Yeonjami). The stability of these natural pigments was also evaluated during several cooking process.

2. Materials and methods

2.1. Plant materials

Nine freshly harvested sweet potato cultural varieties were gifted from Bioenergy Crop Research Center, National Institute of Crop Science. The roots were from the same harvest batch, and harvested at 120 days after planting in Mooan, Jeonnam Province, June, 2013. The triplicate roots were washed and freeze-dried for carotenoid and anthocyanin analysis. All of the lyophilized samples were stored at −80 °C until the analysis was done, and outer layer was peeled before the analysis.

2.2. Home-processing methods

An orange-fleshed cultural variety, Sinhwangmi, and a purple-fleshed cultural variety, Sinjami, (average weight approximately 230 g) were used in this experiment. The root of the sweet potato was washed with tap water and dried at room temperature. Each triplicate root was peeled for frying and sautéing, and cooked by each home-processing method. All of the cooked samples were kept for 30 min at room temperature and then freeze-dried.

Baking. Samples (one root into three pieces) were baked for 20 min in an aluminum fan with a lid on a portable gas stove.

Boiling. Three chopped fresh roots (one root into six pieces) were boiled in a stainless steel pot with a lid for 15 min in 100 mL of natural mineral water.

Frying. Fresh sweet potato was chopped into 0.3 cm × 0.5 cm × 5 cm pieces and fried at 170 °C for 1 min in 300 mL of rice-bran oil.

Pressure-cooking. Sweet potato (one root into six pieces) was cooked at a medium heat for 10 min in a pressure cooker (Kitchen Sense) containing 100 mL of natural mineral water.

Sautéing. Sweet potato was chopped into 0.3 cm × 0.5 cm × 5 cm pieces and sautéed in a fry fan for 3 min with 5 mL of rice-bran oil with 1 g of salt.

Steaming. Three chopped fresh roots (one root into six pieces) were steamed on a perforated stainless steel insert with a tripod base in a stainless steel pot for 10 min with 50 mL of natural mineral water.

2.3. Carotenoid analysis

All extraction procedures were performed under subdued light to avoid degradation loss of the pigments. Two hundred and fifty milligram of the lyophilized samples were homogenized in a pre-chilled mortar and a pestle with 15 mL of acetone (0.01% butylated hydroxytoluene, BHT), sea sand, Na_2SO_4 and $NaHCO_3$. The solution was transferred to 15-mL conical tube and sonicated three times for 10 min. The extract was centrifuged at 5700 × *g*, 4 °C for 10 min (Eppendorf 5430R, Germany), and 5 mL of the supernatant was dried under a flow of N_2 gas and dissolved in 500 μL of a CH_2Cl_2 and acetone mixture (1:1, v/v). This sample solution was filtered through a 0.45 μm membrane filter (Whatman, PTFE, 13 mm) prior to HPLC analysis. For fried or sautéed materials, CH_2Cl_2 and acetone were used to extract the carotenoids.

Carotenoids were quantified using an external calibration method by the HPLC-DAD method described in our previous report (Kim et al., 2013). At this chromatographic condition, standard carotenoids gave peaks at the following t_R (min): 32.3 for β-cryptoxanthin, 35.8 for 13*Z*-β-carotene, 38.4 for all-*trans*-β-carotene and 39.6 for 9*Z*-β-carotene. Methanol, water and methyl *tert*-butyl ether used in the HPLC system were all of HPLC grade and the other chemicals were extra grade.

2.4. Anthocyanin analysis

Two hundred and fifty milligrams of the lyophilized samples were ground with sea sand and extracted three times by sonication for 10 each min with 15 mL of 1% HCl solution in methanol. The extract was centrifuged at 5700 × *g*, 4 °C for 10 min and the supernatant was filtered through a 0.45 μm membrane filter (Whatman, PTFE, 13 mm). For fried or sautéed materials, CH_2Cl_2 was used prior to the extraction procedure to remove the oily substance. The anthocyanins in samples were identified and quantified according to the previously reported method (Kim et al., 2012). The Agilent 1260 HPLC system (Agilent, Waldbronn, Germany) consisted of a temperature controlled autosampler, column oven, diode-array detector, and binary pump. The Chemstation software (Agilent, Avondale, CA, USA) was used to operate the HPLC-DAD system.

2.5. Colorimetric evaluation

The color attributes of transverse root sections were measured with a colorimeter (Konica Minolta CR-400, Osaka, Japan). Before testing, the colorimeter was calibrated using a Minolta standard white reflector plate. The color was measured at least three times, with a maximum of five, depending on the size of each root. The data were presented as L^* (lightness), a^* (redness), and b^* (yellowness) values from the Hunter color system. The obtained color attributes before and after baking were used to calculate ΔE, representing the total color differences between samples before and after baking as follows: $\Delta E = ((\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2)^{1/2}$ (Jing et al., 2012).

2.6. Antioxidant activity test with ABTS radical

ABTS radical was generated by the previously reported method (Re et al., 1999). The antioxidant activity of each anthocyanin extract was expressed as Trolox (Sigma, USA) equivalent antioxidant capacity (TEAC, μM).

2.7. Statistical analysis

All of the contents are expressed as the means ± standard deviations (SD) of triplicate determinations. The differences among

Table 1
Linear ranges and correlation coefficients of calibration curves.

Compounds	Range (μg/mL)	Slope (a)[a]	Intercept (b)[b]	Regression (r^2)	LOD (ng)
β-Cryptoxanthin (**1**)	0.03–12.5	141.9	7.6	0.9998	~10
13*Z*-β-Carotene (**2**)	0.03–12.5	219.5	−13.2	0.9996	~10
All-*trans*-β-carotene (**4**)	1.0–50	204.1	−32.8	0.9998	~10
9*Z*-β-Carotene (**5**)	0.03–12.5	134.1	−5.5	0.9968	~10

[a,b] Slope and intercept represent a and b in $Y = ax + b$ linear model. Y means peak area and x, concentration.

samples were statistically evaluated via one-way analysis of variance (ANOVA) with Microsoft Excel 2010 software. The values were evaluated at the 5% significance level using two-sided tests.

3. Results

3.1. Variations in carotenoids and anthocyanins in nine sweet potato cultivars

Calibration curves were constructed by analysis of a mixture containing four carotenoids at various concentration levels and plotting peak area against the concentration of each reference standard (Table 1). The curves showed good linearity, and the correlation coefficients were between 0.996 and 0.999 for all of the compounds over the following concentration ranges: 0.03–12.5 μg/mL for β-cryptoxanthin, 13*Z*-β-carotene and 9*Z*-β-carotene, and 1–50 μg/mL for all-*trans*-β-carotene. The recovery of four carotenoids was assessed by spiking samples with high and low concentrations of each reference compound, 5000 and 50 ng, respectively. The average recoveries were between 83.3% and 110% ($n = 3$). The limits of detection (LOD) were determined by serial dilution based on a signal-to-noise (S/N) ratio of 3:1 (Table 1). The peak purity was determined by the photodiode array detector and the corresponding computer software that allowed checking the singularity of each peak. In addition, the absorption spectrum of each peak was compared with the characteristic one by each standard compound.

Juhwangmi and Sinhwangmi showed the highest levels of total carotenoids, 665 and 500 μg/g dry weight (DW), respectively, and Daeyumi, Yeonhwangmi, Yulmi, Juhwangmi, Yeonjami, and Sinjami had less than 32 μg/g DW total carotenoid content in decreasing order. Carotenoids were not detected in Hayanmi (Table 2). The β-cryptoxanthin content in Sinhwangmi (21.2 μg/g DW) was higher than in Juhwangmi (11.3 μg/g DW). 13*Z*-β-Carotene and 9*Z*-β-carotene were only detected in three samples, Juhwangmi, Sinhwangmi and Yeonhwangmi with low values, from 3.1 to 13.0 μg/g DW.

For the anthocyanin content in the storage roots of the sweet potato, Sinjami with purple-fleshed had the highest level of anthocyanins, 7.14 mg/g DW, and another purple-fleshed cultivar, Yeonjami ranked second with a content of 2.98 mg/g DW (Table 3). Anthocyanins were not detected in the other samples. Peonidin 3-caffeoyl-*p*-hydroxybenzoyl-sophoroside-5-glucoside (**8**) and peonidin 3-caffeoyl sophoroside-5-glucoside (**6**) were two major anthocyanins in both samples. While peonidin 3-(6″-caffeoyl-6‴-feruloyl sophoroside)-5-glucoside (**9**) was the second major anthocyanin of Sinjami, this compound content was quite low in Yeonjami. Cyanidin 3-(6″,6‴-dicaffeoyl sophoroside)-5-glucoside (**4**) was not determined in Yeonjami.

3.2. Variations in carotenoid compositions during cooking

Several representative cooking methods were applied to determine the variation in carotenoid content during the processes. Although Juhwangmi had a higher total carotenoid content than Sinhwangmi, Sinhwangmi was chosen for this study because the circulation in Korea was higher for this cultivar than Juhwangmi. Fig. 1 summarizes the results from a series of experiments on the influence of home-processing conditions on the carotenoid content of sweet potatoes. The amounts of total carotenoids, all-*trans*-β-carotene (530 ± 60 μg/g DW) and β-cryptoxanthin were reduced after all of the types of cooking processes used in this study. Baked, boiled and steamed sweet potatoes showed higher amounts of total carotenoids (308 ± 39, 302 ± 33 and 309 ± 29 μg/g DW, respectively) and all-*trans*-β-carotene (246 ± 34, 253 ± 29 and 240 ± 21 μg/g DW, respectively) than pressure-cooked, sautéed and fried sweet potatoes (274 ± 28, 248 ± 36 and 167 ± 24 μg/g DW, respectively as total carotenoids, and 194 ± 21, 201 ± 28 and 111 ± 19 μg/g DW, respectively as all-*trans*-β-carotene). Interestingly, a *cis*-isomer of the all-*trans*-β-carotene, 13*Z*-β-carotene was found in elevated amounts in all processed samples, especially in baked, pressure-cooked and steamed ones (50.1–62.6 μg/g DW) compared with the control (11.6 ± 0.5 μg/g DW). The content of another isomer, 9*Z*-β-carotene significantly increased after pressure-cooking (14.5 ± 1.8 μg/g DW) and frying (13.9 ± 1.2 μg/g DW) compared to the other samples (7.4–10.5 μg/g DW). The loss of β-cryptoxanthin was 60.3–89.2% during all of the cooking process, which was greater than that of all-*trans*-β-carotene (Fig. 1B).

Table 2
Carotenoid contents in sweet potato cultivars of Korea ($n > 3$).[a]

Cultural varieties	Carotenoids (μg/g DW)				
	β-Cryptoxanthin	13*Z*-β-Carotene	All-*trans*-β-carotene	9*Z*-β-Carotene	Total
Sinjami	0.4 ± 0.0	ND[b]	2.8 ± 0.0	ND	3.2 ± 0.0
Yeonjami	0.7 ± 0.0	ND	3.0 ± 0.0	ND	3.7 ± 0.0
Juhwangmi	11.3 ± 1.4	13.0 ± 0.3	630 ± 15	10.3 ± 0.3	665 ± 17
Sinhwangmi	21.2 ± 0.4	11.6 ± 0.5	530 ± 60	7.4 ± 0.4	570 ± 62
Yeonhwangmi	2.0 ± 0.2	3.1 ± 0.0	14.9 ± 1.2	11.5 ± 0.2	31.5 ± 1.6
Jinhongmi	0.9 ± 0.1	ND	13.9 ± 0.5	ND	14.8 ± 0.7
Yulmi	1.7 ± 0.0	ND	12.5 ± 0.6	ND	14.4 ± 0.7
Daeyumi	1.9 ± 0.2	ND	28.5 ± 0.6	ND	30.4 ± 0.8
Hayanmi	ND	ND	ND	ND	ND

[a] Data are expressed as the mean (the average value of content for dry weight) and SD (the standard deviation value) of three independent experiments.
[b] ND, not detected.

Table 3
Anthocyanin contents and antioxidant activity of Korean sweet potato cultivars and home-processed sweet potatoes ($n > 3$).*

Anthocyanins	Yeonjami	Sinjami	Baking	Boiling	Pressure-cooking	Steaming	Sautéing	Frying
1	0.041 ± 0.004	0.109 ± 0.016[a]**	0.041 ± 0.096[b]	0.116 ± 0.007[a]	ND	ND	0.035 ± 0.008[b]	ND
2	0.211 ± 0.004	0.415 ± 0.045[a]	0.203 ± 0.021[b]	0.411 ± 0.007[a]	0.112 ± 0.010[d]	0.155 ± 0.005[c]	0.143 ± 1.3[b]	0.132 ± 0.013[b]
3	0.187 ± 0.010	0.332 ± 0.016[a]	0.222 ± 0.027[b]	0.252 ± 0.001[b]	0.039 ± 0.008[d]	0.123 ± 0.014[c]	0.047 ± 0.008[d]	0.042 ± 0.006[d]
4	ND	0.120 ± 0.008[a]	0.084 ± 0.013[a]	0.052 ± 0.001[c]	0.067 ± 0.004[c]	0.090 ± 0.005[b]	ND	ND
5	0.154 ± 0.016	0.349 ± 0.042[a]	0.378 ± 0.015[a]	0.187 ± 0.005[c]	0.283 ± 0.005[b]	0.404 ± 0.003[a]	0.060 ± 0.001[d]	0.052 ± 0.003[d]
6	0.843 ± 0.046	0.653 ± 0.073[a]	0.480 ± 0.026[a]	0.474 ± 0.003[a]	0.167 ± 0.002[b]	0.185 ± 0.017[b]	0.152 ± 0.027[b]	0.127 ± 0.020[b]
7	0.013 ± 0.001	0.246 ± 0.019[a]	0.276 ± 0.009[a]	0.113 ± 0.008[b]	0.175 ± 0.006[b]	0.228 ± 0.003[a]	0.029 ± 0.004[c]	0.024 ± 0.001[c]
8	1.25 ± 0.04	2.82 ± 0.11[a]	1.92 ± 0.03[b]	1.56 ± 0.01[c]	1.03 ± 0.03[e]	1.27 ± 0.02[d]	0.587 ± 0.018[f]	0.559 ± 0.003[f]
9	0.097 ± 0.004	1.19 ± 0.012[a]	1.13 ± 0.07[a]	0.531 ± 0.026[b]	0.486 ± 0.010[b]	0.581 ± 0.006[b]	0.204 ± 0.024[c]	0.185 ± 0.006[c]
Others	0.194 ± 0.012	0.904 ± 0.051[a]	0.574 ± 0.023[b]	0.471 ± 0.012[c]	0.201 ± 0.021[e]	0.321 ± 0.033[d]	0.099 ± 0.005[f]	0.085 ± 0.008[g]
Total	2.98 ± 0.10[b]	7.14 ± 0.28[a]	5.31 ± 0.06[b]	4.17 ± 0.01[c]	2.60 ± 0.03[f]	3.36 ± 0.06[d]	1.37 ± 0.09[g]	1.21 ± 0.04[g]
TEAC (μM)***	6.2 ± 0.3[b]	9.2 ± 0.9[a]	6.7 ± 0.7[b]	6.9 ± 0.4[b]	4.1 ± 0.5[c]	5.2 ± 0.7 [c]	2.5 ± 0.9[d]	2.8 ± 0.2[d]

1, peonidin 3-*p*-hydroxybenzoyl sophoroside-5-glucoside; **2**, cyanidin 3-(6″-feruloyl sophoroside)-5-glucoside; **3**, peonidin 3-(6″-feruloyl sophoroside)-5-glucoside; **4**, cyanidin 3-(6″,6‴-dicaffeoyl sophoroside)-5-glucoside; **5**, cyanidin 3-caffeoyl-*p*-hydroxybenzoyl-sophoroside-5-glucoside; **6**, peonidin 3-caffeoyl sophoroside-5-glucoside; **7**, cyanidin 3-(6″-caffeoyl-6‴feruloyl sophoroside)-5-glucoside; **8**, peonidin 3-caffeoyl-*p*-hydroxybenzoyl-sophoroside-5-glucoside; **9**, peonidin 3-(6″-caffeoyl-6‴-feruloyl sophoroside)-5-glucoside.

* Data are expressed as the mean (the average value of content for dry weight, μg/g DW) and SD (the standard deviation value) of three independent experiments.

** Different superscript letters in the same row indicate significant difference ($p < 0.05$) among samples.

*** Trolox equivalent antioxidant capacity (TEAC) was determined by ABTS assay.

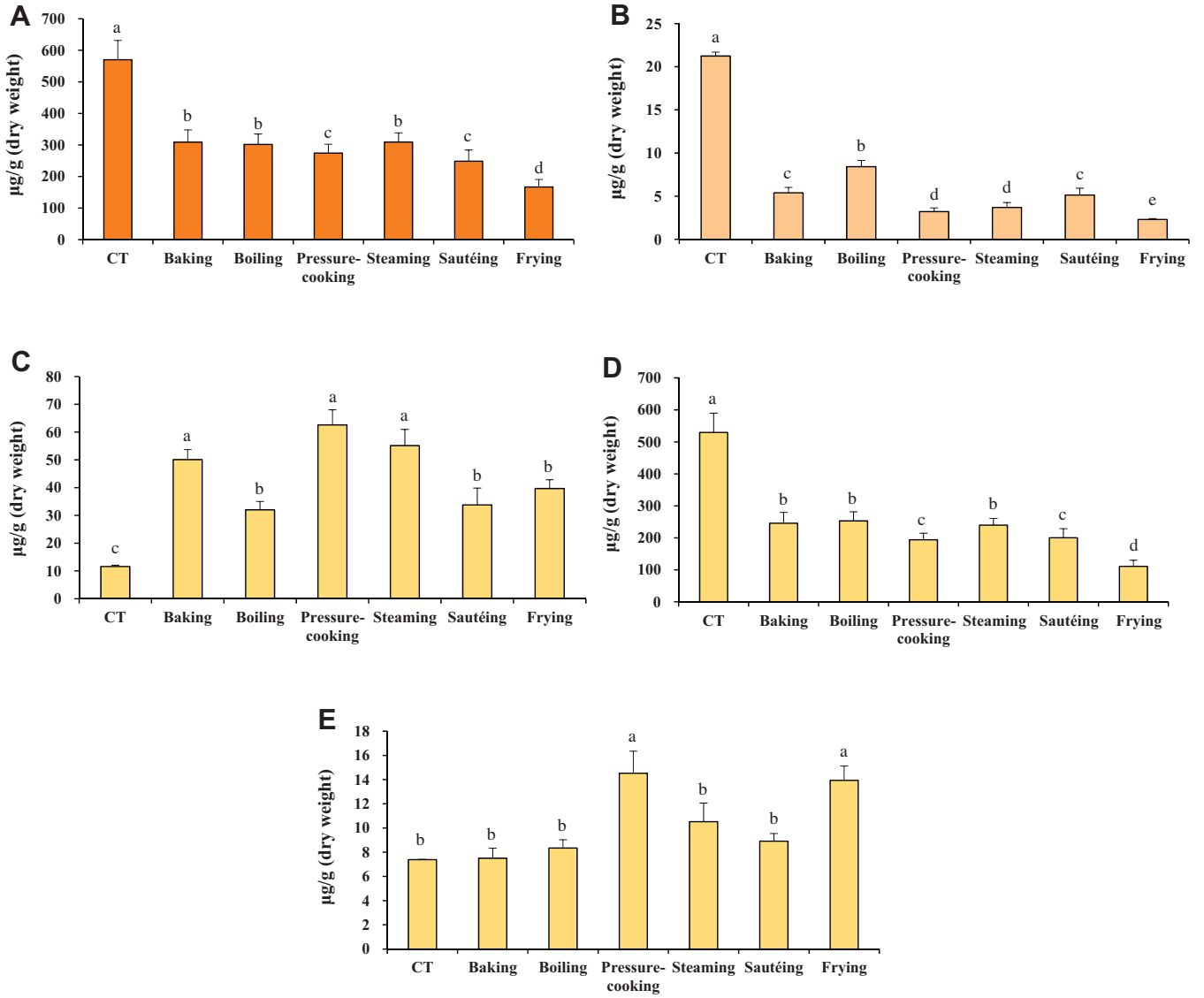

Fig. 1. Carotenoid stability in sweet potatoes during home-processing. (A–E) The amount of total carotenoids, β-cryptoxanthin, 13*Z*-β-carotene, all-*trans*-β-carotene and 9*Z*-β-carotene, respectively. The carotenoid contents are given as the means of three determinations of up to three different Sinhwangmi roots. Different letters indicate significant difference ($p < 0.05$) among samples.

3.3. Variations in anthocyanin compositions during cooking

The changes in anthocyanin content were observed during the home-processing of a purple-fleshed cultural variety, Sinjami, which had the highest anthocyanin content (7.14 ± 0.28 mg/g DW) of the varieties examined. The loss of total anthocyanins occurred during all of the home-processing methods. Baked, boiled and steamed sweet potatoes (5.31 ± 0.06, 4.17 ± 0.01 and 3.36 ± 0.06 mg/g DW, respectively) showed higher amounts of anthocyanins than pressure-cooked, sautéed and fried sweet potatoes (2.60 ± 0.03, 1.37 ± 0.09 and 1.21 ± 0.04 mg/g DW, respectively) (Table 3).

The content of **8**, most prominent major component in Shinjami, decreased after all of the processing with another anthocyanin, peonidin 3-(6″-feruloyl sophoroside)-5-glucoside (**3**). While baking process retained the contents of five other ingredients (**4**–**7** and **9**), the contents of **4**, **5** and **7** significantly decreased after boiling process. **1**, **2** and **6** anthocyanin contents remained after boiling process. The TEAC values of anthocyanin extract showed that the antioxidant activity was in accordance with the total anthocyanin content (Table 3).

3.4. Colorimetric evaluation of transverse section of nine sweet potato cultivars

For the Hunter color coordinates of the transverse sections of the nine Korean cultural varieties, the lowest L^* (lightness) and b^* (yellowness) values were obtained in two purple-fleshed cultivars, Sinjami and Yeonjami (Table 4). The two samples of orange-fleshed cultivars, Juhwangmi and Sinhwangmi displayed higher a^* (redness) values than the others. Sinjami, Yeonjami and Hayanmi presented lower b^* values than the others. A clear orange color was displayed in the cortex of Juhwangmi compared to the other parts. After baking, L^*, a^* and b^* values generally decreased for all of the nine cultural varieties, and the a^* value profoundly reduced than b^* value. The reduction values were approximately 20 and 17 for Sinjami and Sinhwangmi, respectively. Variations in the b^* value were low for the three yellowish white-fleshed cultivars, Yulmi, Daeyumi and Hayanmi. Interestingly, higher b^* value was found in Yulmi after baking. While the total color differences (ΔE) before and after baking were more than 25 in Sinhwangmi, Yeonhwangmi and Jinhongmi, the values were less than 20 in Yeonjami, Yulmi and Daeyumi (Table 4).

4. Discussion

Because of the high content of all-*trans*-β-carotene and the moderately low losses due to degradation and isomerization, the orange-fleshed sweet potato is regarded as a suitable food source of provitamin A (Bengtsson et al., 2008). Purple-fleshed sweet potatoes have high levels of anthocyanins, total phenolics and antioxidant activities, and have been utilized in health food markets as natural food colorants, juices and jams (Truong et al., 2010). In the past few years, various sweet potato cultivars with orange or deep purple flesh have been developed in Korea to meet these growing demands (Jeong et al., 2000; Lee et al., 2010).

High total carotenoids and all-*trans*-β-carotene contents were found in two orange-fleshed cultivars, Juhwangmi and Sinhwangmi, which had shown higher a^* (redness) and b^* (yellowness) values than the other varieties in the colorimetric evaluation of transverse sections. This result is consistent with previous studies that showed that all-*trans*-β-carotene is the major contributor to the provitamin A content of orange- and yellow-fleshed sweet potatoes, and the dark orange-fleshed sweet potato varieties had higher contents of all-*trans*-β-carotene than the yellow-fleshed varieties (Bengtsson et al., 2008; Kidmose et al., 2007). Meanwhile, Sinjami and Yeonjami, which had lower L^* and b^* values, and higher a^* values than other cultural varieties, had high anthocyanin contents. This result is in accordance with the fact that cyanidin-, peonidin- and pelargonidin-based anthocyanins are the major anthocyanins in the root of purple-fleshed sweet potatoes, and among them, cyanidin and peonidin contribute to the blue and red hues of the root (Truong et al., 2010; Lee et al., 2013).

The content of the *cis*-isomers of β-carotene constituted a minor proportion of the total β-carotene content (0–4%) except in Yeonhwangmi (Table 3). This is consistent with previous studies that reported *cis*-isomers of β-carotene contents between 0–5% of the total β-carotene content (Bengtsson et al., 2008; Kidmose et al., 2007; van Jaarsveld et al., 2006). Interestingly, Yeonhwangmi had a high proportion of 9*Z*-β-carotene to the total β-carotene content (39.0%). In contrast to the previous studies, β-cryptoxanthin was found in detectable amounts in eight Korean cultural varieties.

The overall decrease in L^*, a^* and b^* values after baking for all of the varieties could be related to carotenoid or anthocyanin loss because both of the natural pigments are labile to light, heat and oxygen. It has been reported that food processing and storage reduced carotenoid and anthocyanin contents in food materials and changed their chemical conformation (Lim et al., 2009; Bengtsson et al., 2008; Kidmose et al., 2007; Grace et al., 2014). Isomerization is also involved in the change of carotenoid composition. Isomerization of *trans*-carotenoid, which is the usual configuration of carotenoids in nature, to the *cis*-form is known to enhance solubility and decrease color intensity, melting point, and provitamin A activity (Rodriguez-Amaya, 2010). In this study, much more loss of total carotenoid and all-*trans*-β-carotene contents were detected during pressure cooking, sautéing and frying processes than baking, boiling and steaming. The largest loss occurred during the frying process. The 13*Z*-β-carotene content increased after all the home processing methods examined, particularly after baking and pressure-cooking and steaming (5- to 6-fold increase). Elevated contents of another isomer, 9*Z*-β-carotene, was detected in pressure-cooked and fried sweet potatoes, compared to the other samples.

These results were similar to those for the anthocyanin variations. The retention rate of total anthocyanins was also higher in baked, boiled and steamed samples than in pressure-cooked, sautéed and fried ones. Comparison of baking and boiling processing methods showed that retention of diacylated anthocyanins such as cyanidin 3-(6″,6‴-dicaffeoyl sophoroside)-5-glucoside (**4**), cyanidin 3-caffeoyl-*p*-hydroxybenzoyl-sophoroside-5-glucoside (**5**) and cyanidin 3-(6″-caffeoyl-6‴-feruloyl sophoroside)-5-glucoside (**7**) was higher in baking than boiling.

Table 4
Hunter values for transverse sections of nine cultural varieties of sweet potato before and after baking.

Cultural varieties	Before baking			After baking			ΔE
	L^*	a^*	b^*	L^*	a^*	b^*	
Sinjami	25.2	26.7	0.28	19.6	6.27	−1.69	21.2
Yeonjami	28.8	26.5	5.86	25.0	14.7	−4.32	16.1
Juhwangmi	69.2	27.0	47.8	52.5	15.2	44.5	20.6
Sinhwangmi	72.3	24.4	40.9	41.1	7.74	32.3	36.5
Yeonhwangmi	84.6	0.29	41.0	58.8	−5.71	37.0	26.8
Jinhongmi	84.5	−0.20	29.3	56.9	−6.99	25.4	28.7
Yulmi	87.0	−3.18	31.2	69.8	−5.85	34.1	17.6
Daeyumi	82.6	6.45	32.5	73.1	−3.73	30.9	14.0
Hayanmi	88.9	−1.21	13.9	66.2	−1.95	13.6	22.7

L^*, lightness; a^*, + red–green; b^*, + yellow–blue (CR-400, Minolta).

Monoacylated anthocyanins including peonidin 3-*p*-hydroxybenzoyl sophoroside-5-glucoside (**1**), cyanidin 3-(6″-feruloyl sophoroside)-5-glucoside (**2**) and peonidin 3-(6″-feruloyl sophoroside)-5-glucoside (**3**) were more stable in boiling than baking process. The most favorable cooking condition for total anthocyanin content was baking. In conclusion, baking, boiling and steaming home-processing methods are recommended to retain more carotenoids and anthocyanins after preparations. These methods are more popular than other processing methods in Korea.

Meanwhile, contrary to our previous study on carrots, among the six cooking methods, the greatest loss of total carotenoids and anthocyanins occurred during frying (Lim et al., 2009). The most dramatic isomerization of all-*trans*-β-carotene into 9*Z*-β-carotene also occurred through this cooking process. In fact, while significant water loss was not observed in the tap root of carrots during frying, a large amount of water loss was associated with the frying processing of sweet potato. This water loss could be related to the carotenoid and anthocyanin loss. The previous study reported that small amounts of carotenoids were lost during the frying process of sweet potatoes (Bengtsson et al., 2008). This discrepancy might have resulted from the fact that the sweet potato slice, a quarter of a root (from stem to root end) used in that study, was much bigger than the thin chips in this study. In that experimental condition, water loss would have occurred only on the surface of the sample. Another related research report found that the preparation of chips with a thickness of 0.2–0.3 cm by drying resulted in a significant reduction of carotenoid content compared to other processing methods (Kidmose et al., 2007).

Although carotenoid and anthocyanin loss occurred, the content in orange-fleshed and purple-fleshed sweet potato was still substantial. In future studies, large lumps or slices coated with flour should be considered for use in the frying process.

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References

Bengtsson, A., Namutebi, A., Larsson Alminger, M., Svanberg, U., 2008. Effects of various traditional processing methods on the all-*trans*-β-carotene content of orange-fleshed sweet potato. Journal of Food Composition and Analysis 21, 134–143.

Delgado-Vargas, F., Jiménez, A.R., Paredes-López, O., 2000. Natural pigments: carotenoids, anthocyanins, and betalains – characteristics, biosynthesis, processing, and stability. Critical Reviews in Food Science and Nutrition 40, 173–289.

Demmig-Adams, B., Gilmore, A.M., Adams, W.W., 1996. Carotenoids 3: in vivo functions of carotenoids in higher plants. Journal of the Federation of American Societies for Experimental Biology 10, 403–412.

Grace, M.H., Yousef, G.G., Gustafson, S.J., Truong, V.-D., Yencho, G.C., Lila, M.A., 2014. Phytochemical changes in phenolics, anthocyanins, ascorbic acid, and carotenoids associated with sweetpotato storage and impacts on bioactive properties. Food Chemistry 145, 717–724.

Jeong, B.C., Ahn, Y.S., Chung, M.N., Lee, J.S., Jeong, K.B., Oh, Y.B., Jeong, D.H., Cho, S.Y., Min, K.S., Lee, J.S., Kim, E.S., Kim, T.G., 2000. A new orange colored sweetpotato (*Ipomoea batatas* (L.) Lam.) cultivar, Sinhwangmi for the fresh and the processing. Korean Journal of Breeding Science 32, 93–94.

Jing, P., Zhao, S.-J., Ruan, S.-Y., Xie, Z.-H., Dong, Y., Yu, L., 2012. Anthocyanin and glucosinolate occurrences in the roots of Chinese red radish (*Raphanus sativus* L.), and their stability to heat and pH. Food Chemistry 133, 1569–1576.

Kidmose, U., Christensen, L.P., Agili, S.M., Thilsted, S.H., 2007. Effect of home preparation practices on the content of provitamin A carotenoids in coloured sweet potato varieties (*Ipomoea batatas* Lam.) from Kenya. Innovative Food Science & Emerging Technologies 8, 399–406.

Kim, H.W., Kim, J.B., Cho, S.M., Chung, M.N., Lee, Y.M., Chu, S.M., Che, J.H., Kim, S.N., Kim, S.Y., Cho, Y.S., Kim, J.H., Park, H.J., Lee, D.J., 2012. Anthocyanin changes in the Korean purple-fleshed sweet potato, Shinzami, as affected by steaming and baking. Food Chemistry 130, 966–972.

Kim, S.H., Kim, Y.-H., Ahn, Y.O., Ahn, M.-J., Jeong, J.C., Lee, H.-S., Kwak, S.-S., 2013. Down regulation of the lycopene ε-cyclase gene increases carotenoid synthesis via the β-branch-specific pathway and enhances salt-stress tolerance in sweetpotato transgenic calli. Physiologia Plantarum 147, 432–442.

Lee, J.-S., Ahn, Y.-S., Chung, N.-M., Kim, H.-S., Jeong, K.-H., Bang, J.-K., Song, Y.-S., Shim, H.-K., Han, S.-K., Suh, S.-J., 2010. A new purple sweetpotato cultivar for table use 'Yeonjami'. Korean Journal of Breeding Science 42, 679–683.

Lee, M.J., Park, J.S., Choi, D.S., Jung, M.Y., 2013. Characterization and quantitation of anthocyanins in purple-fleshed sweet potatoes cultivated in Korea by HPLC-DAD and HPLC-ESI-QTOF-MS/MS. Journal of Agricultural and Food Chemistry 61, 3148–3158.

Lim, C.J., Kim, H.Y., Lee, C.H., Kim, Y.G., Back, K.W., Bae, J.M., Lee, S.W., Ahn, M.-J., 2009. Variation in carotenoid composition in carrots during storage and cooking. Journal of Food Science and Nutrition 14, 240–245.

Luo, H., Lv, X.D., Wang, G.E., Li, Y.F., Kurihara, H., He, R.R., 2014. Anti-inflammatory effects of anthocyanins-rich extract from bilberry (*Vaccinium myrtillus* L.) on croton oil-induced ear edema and *Propionibacterium acnes* plus LPS-induced liver damage in mice. International Journal of Food Sciences and Nutrition 65, 594–601.

Pascual-Teresa, S., Sanchez-Ballesta, M.T., García-Viguera, C., 2013. Anthocyanins. In: Ramawat, K.G., Mérillon, J.M. (Eds.), Natural Products. Springer-Verlag, New York, pp. 1809–1819.

Pfander, H., 1992. Carotenoids: an overview. In: Packer, L. (Ed.), Methods in Enzymology, vol. 213. Academic Press, San Diego, pp. 3–13.

Rao, A.V., Rao, L.G., 2007. Carotenoids and human health. Pharmacological Research 55, 207–216.

Re, R., Pellegrini, N., Proteggente, A., Pannala, A., Yang, M., Rice-Evans, C., 1999. Antioxidant activity applying an improved ABTS radical cation decolorization assay. Free Radical Biology & Medicine 26, 1231–1237.

Rodriguez-Amaya, D.B., 2010. Quantitative analysis, *in vitro* assessment of bioavailability and antioxidant activity of food carotenoids—a review. Journal of Food Composition and Analysis 23, 726–740.

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

Strack, D., Wray, V., 1993. The anthocyanins. In: Harborne, J.B. (Ed.), The Flavonoids: Advances in Research Since 1986. Chapman & Hall, London, pp. 1–2.

Tapiero, H., Townsend, D.M., Tew, K.D., 2004. The role of carotenoids in the prevention of human pathologies. Biomedicine & Pharmacotherapy 58, 100–110.

Truong, V.-D., Deighton, N., Thompson, R.T., McFeeters, R.F., Dean, L.O., Pecota, K.V., Yencho, G.C., 2010. Characterization of anthocyanins and anthocyanidins in purple-fleshed sweetpotatoes by HPLC-DAD/ESI-MS/MS. Journal of Agricultural and Food Chemistry 58, 404–410.

van Jaarsveld, P.J., DeWet, M., Harmse, E., Nestel, P., Rodriguez-Amaya, D.B., 2006. Retention of β-carotene in boiled, mashed orange-fleshed sweet potato. Journal of Food Composition and Analysis 19, 321–329.

Yamakawa, O., Yoshimoto, M., 2002. Sweetpotato as food material with physiological functions. ISHS Acta Horticulturae 583, 179–185.

Zheng, W., Wang, S.Y., 2003. Oxygen radical absorbing capacity of phenolics in blueberries, cranberries, chokeberries, and lingonberries. Journal of Agricultural and Food Chemistry 51, 502–509.