Effects of cooking methods on the β -carotene levels of selected plant food materials

Jung-Ah Shin, Yoonji Heo, Mimi Seo, Youngmin Choi¹, and Ki-Teak Lee*

Department of Food Science and Technology, Chungnam National University, Daejeon 34134, Korea

¹Functional Food & Nutrition, Dept. Agro-food Resource, National Academy of Agricultural Science, Rural Development Administration, Jeonju, Jeonbuk 54875, Korea

Received January 23, 2016
Revised April 16, 2016
Accepted May 2, 2016
Published online August 31, 2016

*Corresponding Author
Tel: +82-42-821-6729
Fax: +82-42-821-8785
E-mail: ktleee@cnu.ac.kr

pISSN 1226-7708
eISSN 2092-6456

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Abstract In the present study, the β -carotene contents of 14 plant food materials prepared by boiling, steaming, or baking or when they are raw were analyzed and compared. After boiling three pulse species, namely, peas, kidney beans, and dried mung beans, β -carotene contents of peas and kidney beans increased significantly, whereas that of mung beans (dried material) decreased. True retention factors of β -carotene contents in the cooked kidney beans, peas, and mung beans after boiling were 174.2, 128.3, and 91.8%, respectively. After steaming, the β -carotene content of regular millets significantly decreased but that of taros increased, in which the true retention factors were observed with β -carotene contents of 72.4% in the steamed regular millets and 160.9% in the steamed taros. Moreover, β -carotene contents in yellow-fleshed sweet potato (raw: 896.2 $\mu\text{g}/100\text{ g}$) decreased by baking (786.4 $\mu\text{g}/100\text{ g}$) and steaming (steaming: 553.1 $\mu\text{g}/100\text{ g}$). These results suggest that β -carotene contents in the selected plant food materials markedly depend on the cooking method and plant food materials classification.

Keywords: β -carotene, cooking method, true retention, plant food materials

Introduction

β -Carotene is the compound responsible for the yellow and orange colors in various vegetables and is one of the important fat-soluble carotenoids. Moreover, it contains conjugated double bonds and can exist in plant bodies as carotenoid-protein complexes (1). In particular, β -carotene is a minor food component that is known to protect cell membranes and enhance visual, generative, and immune functions (2). Among the carotenoids existing in nature, some of them such as β -carotene, α -carotene, and β -cryptoxanthin are converted into vitamin A by intestinal mucosa (3). The Food and Agricultural Organization and World Health Organization have proposed the activity of vitamin A to be quantified in retinol equivalents (RE) or μg (4). This is a way to show the activity of vitamin A considering the absorption rate of β -carotene consumed as foods. The ratio of conversion of β -carotene into vitamin A and the nutritional conversion can be shown as 1 RE = 1 μg retinol = 6 μg β -carotene (5).

In general, vegetables are diversely cooked at home, using different cooking methods. However, loss of nutrient in cooked vegetables can occur as mentioned by previous works (6,7). For example, all-*trans*- β -carotene, which has 100% provitamin A activity, can be changed to *cis*- β -carotene by isomerization or partially destroyed by thermal degradation after cooking (6). In Korea, certain

vegetables including potatoes are generally boiled before intake, while pumpkin and taro are commonly steamed. Baking and steaming are the usual cooking methods for sweet potatoes. Therefore, changes of nutritional values in various vegetables are expected by different cooking methods.

Typically, the content of β -carotene in vegetables has been determined by high-performance liquid chromatography (HPLC) for reasons of accuracy, reproducibility, and stability (8-11). The United States Department of Agriculture (USDA) maintains a food nutritive component database and uses retention factors to assess the levels of nutritive components in prepared foods. However, in Korea, limited data are available on the content of nutritional components in cooked vegetables. Thus, studies are needed to evaluate the degree of nutrient retention in cooked vegetables after cooking them using different methods.

This study was performed to provide the degree of β -carotene retention for establishing Korean Standard Food Composition Database by Rural Development Administration, in which frequently consumed plant food materials and their cooking methods were selected. Therefore, β -carotene levels in raw and differently cooked plant food materials were compared, from which the bioavailability of β -carotene might be evaluated depending on the different cooking methods.

In this study, 15 plant food materials were selected and their β -carotene contents were compared after boiling, steaming, and baking and when they were raw. To validate the accuracy and precision of the β -carotene analysis method used, recovery percentages (%) were calculated by analyzing a certified reference material (CRM) with certified and reference concentration value for β -carotene. Based on the current data obtained, the retention of β -carotene after cooking can be reorganized.

Materials and Methods

Chemicals and standards Normal grade solvents were used for the extraction of β -carotene in food samples. HPLC-grade solvents used for HPLC analysis were purchased from Fisher Scientific (Pittsburg, PA, USA). β -Carotene standard (Wako: 032-17991, 95.0%, HPLC assay) for the quantification curve was from Wako Pure Chemical Industries, Ltd. (Osaka, Japan).

Plant food materials for cooking treatments Three legume families (kidney beans, dried mung beans, and peas), chestnuts affiliated to nut and seed products, and four varieties of potatoes (purpled-flesh potatoes, yellowed-flesh potatoes, *Daegi* potatoes, and *Sumi* potatoes) were boiled at respective suitable condition. Pumpkin, regular millets (dried), taros, and perilla leaves were steamed and their β -carotene content analyzed. Two kinds of sweet potatoes (white-fleshed and yellow-fleshed) were treated by baking and steaming process, respectively. These raw and cooked materials were illustrated in Table 1. After cooking treatment of vegetables, their β -carotene contents were compared. The selected plant food materials were purchased randomly at local grocery stores in Seoul and Gyeonggi metropolitan area of South Korea. To increase generalizability of our samples, each type of food materials was purchased from at least three different stores.

Cooking treatment Respective plant food materials were treated by each cooking method commonly used in Korea. Cooking condition for all cooking treatments was adapted according to suitable palatability of each food materials. Cooking methods used were boiling, steaming, and baking as follows. All cooking were performed at Dept. Agro-food Resource, National Academy of Agricultural Science, Rural Development Administration.

Boiling Different cooking time was applied according to the types of food materials, i.e., legumes (kidney beans, dried mung beans, and peas), potatoes (purpled-flesh potatoes, yellowed-flesh potatoes, *Daegi* potatoes, and *Sumi* potatoes), and the chestnuts. The legume materials were boiled with a lot of water (10 times than samples) for 5–60 min. The boiled legume materials were rinsed with cold distilled water and drained using a colander to remove the excess water. In potatoes, enough water was added to cover the

potatoes to half of sample volume. They were boiled for 25–40 min at 100°C, then rinsed with cold distilled water, and finally drained off using a colander.

For the different samples, 1 kg of each was weighed separately. In five separate stainless-steel pots, 10 L of water was transferred and heated with lids on. Preliminary experiments were conducted to determine the boiling time (data not shown). After the water started to boil (100°C), the samples were transferred to the pot and boiled for the time periods shown in Table 1 depending on food matrix. The boiled samples were placed on a stainless steel sieve to remove water and were allowed to stand for 10 min and then reweighed to calculate cooking yields.

Steaming Steaming of samples (1 kg) was conducted in a domestic stainless steamer. Distilled water was taken to boiling temperature prior to the addition of the samples. When steam started to emerge from the pot, the samples were placed on a perforated plate above the boiling water. Steaming was performed for 10 to 70 min depending on sample matrix. The steamed samples were cooled for 15 min under atmospheric pressure and reweighed. In the case of sweet potatoes, the skin of sweet potatoes was removed.

Baking For the baking process, 1 kg of each sweet potato was weighed separately and the samples were positioned on the center of the rack in a preheated (200°C for 10 min) conventional gas oven. Samples were baked at 200°C for the first 20 min and then 140°C for a further 10 min. The samples were removed from the oven and placed on a stainless steel sieve to cool down temperature before reweighing.

Soon after being reweighed, all samples were quickly deep-frozen in liquid nitrogen to minimize the nutritional loss in grinding samples and then homogenized using a Robot Coupe Blixer (Robot Coupe USA, Jackson, MS, USA). Each sample was stored at a low temperature of 70°C prior to the β -carotene analysis.

Saponification and extraction for analysis of β -carotene Various plant food materials to analyze the content of β -carotene were pretreated by direct saponification method using an alkali solution, and then, β -carotene was extracted by organic solvents according to a previous study (12). Three grams of sample were placed in an extracting tube and 10 mL of ethanol containing pyrogallol (6%, w/v) as an antioxidant was also added. Then, the extracting tube was fully agitated and flushed with nitrogen gas for 1 min. After sonication for 10 min, 8 mL of 60% potassium hydroxide in water was added into the extracting tube and then homogenized vigorously using a vortex mixer for 1 min. Again, the mixture was flushed by nitrogen gas and finally then connected to an air condenser. For saponification of samples, it was reacted for 1 h in a shaking water bath (BS-21; Lab companion, Ramsey, MN, USA) set at 100 rpm and 75°C. The saponified samples were cooled sufficiently. Twenty milliliters of 2% sodium chloride solution and 15 mL of extraction solvent (*n*-hexane:

Table 1. Raw and cooked food materials with different cooking method

Food materials	Cooking method	Cooking time (min)	Raw		
			Whole	Edible part	Cooked
Kidney beans (cooked without bean pod)	boiled	6
Mung beans (dried)	boiled	60	-
Chestnuts (just from husk)	boiled	30
Peas (cooked with bean pod)	boiled	5
Potato, purpled flesh	boiled	35
Potato, yellowed flesh	boiled	35
Potato, Daeji	boiled	40
Potato, Sumi	boiled	35
Pumpkin, mature	steamed	30
Regular millet, polished grain (dried)	steamed	70	-
Taro	steamed	30
Perilla leaves	steamed	10	-

Table 1. Continued

Food materials	Cooking method	Cooking time (min)	Raw		
			Whole	Edible part	Cooked
Sweet potato, white-fleshed	steamed	35
Sweet potato, white-fleshed, baked		140°C (20 min), 200°C (20 min)	-	-
Sweet potato, yellow-fleshed	steamed	25
Sweet potato, yellow-fleshed, baked		140°C (20 min), 200°C (10 min)	-	-

ethyl acetate=85:15, v/v) with 0.01% BHT were added into an extracting tube. After vortexing the tube, the upper solvent was passed through sodium sulfate column to remove moisture and then combined into a 50-mL volumetric flask. This procedure was performed three times for the extraction of β -carotene. Ten milliliters of the combined extracts were evaporated under nitrogen gas and then dissolved in 1 mL of chloroform to make an appropriate concentration. After homogenizing by a vortex mixer, the mixture was filtered through a 0.5- μ m syringe filter (PTFE, DISMIC-13JP; Toyo Roshi Kaisha, Ltd., Tokyo, Japan). The whole volume was transferred to a HPLC vial for quantification of β -carotene. All samples were performed in duplicates.

HPLC analysis for identification of β -carotene The content of β -carotene was analyzed with HPLC (SP930D; Younglin, Anyang, Korea) using a Nova Pak[®] C18 4 μ m (3.9 $\times$ 150 mm i.d., Waters, Milford, MA, USA) column as previously described by Shin *et al.* (13). The injection volume was 20 μ L and β -carotene was eluted at a constant flow of 1 mL/min. The wavelength of UV-Vis detector for β -carotene was 450 nm. The gradient elution was performed using A solvent of a mixture of acetonitrile : methanol : dichloromethane (70:10:30, by volume) and B solvent of a mixture of acetonitrile : methanol : dichloromethane (75:20:5, by volume) as following this gradient. Gradients started with 100% B for 3.5 min, then decreased to 0% B over the next 18.5 min, were held for 6.5 min, followed by a rapid increase to 100% B in 1.5 min, and were finally held of 10 min. Identification of peak of β -carotene in the HPLC chromatogram of sample extracts was performed by a comparison to retention time of the eluted standard. During the analysis, all the operations were performed under subdued light condition to protect the content of β -carotene (12).

External standard curve for the quantification of β -carotene was

presented in Table 2. The content of β -carotene in food was expressed as microgram β -carotene per 100 g of vegetables using the equation: $Y = 196.23 \times 116.39 (R^2 = 0.9986)$, where Y is the peak area of β -carotene (mV) and X is the concentration (μ g/mL) of β -carotene standard (12). Repeatability and reproducibility of this analytical method were secured using CRM. Quality control (QC) chart was prepared periodically by analyzing the commercial milk powder (In-house control material) together with samples delivered weekly.

Analysis of CRM and data evaluation CRM BCR[®]-485 (mixed plant food materials) was utilized to assess the accuracy and precision of this analytical method for β -carotene quantification in several plant food materials. Analytical value of β -carotene to the assigned value of CRM was presented as recovery%. z-Score was used for the evaluation of CRM analysis. Limit of detection (LOD) and of quantification (LOQ) are determined on the basis of reversed-phase HPLC analytical method of β -carotene. LOD is the lowest analyte concentration in a sample that can be detected, corresponding to the analyte concentration for which the signal-to-noise ratio is equal to 3.3. LOQ is the lowest analyte concentration in a sample that can be quantified, corresponding to the analyte concentration for which the signal-to-noise ratio is equal to 10 (14). The analytical value between LOD and LOQ is presented as trace and below LOD is expressed as ND (not detected). All analytical data were presented with standard deviation and relative standard deviation.

Variation percentage of β -carotene and true retention factor The variation percentage (%) of β -carotene and weight in samples were calculated on the basis of the difference between raw and cooked samples. True retention factor (%TR) of β -carotene was calculated according to Murphy *et al.* (15) as following:

$$\%TR = (Nc \times Wc) / (Nr \times Wr) \times 100,$$

where Nc = nutrient content per weight of cooked food, Wc = weight of cooked food, Nr = nutrient content per weight of raw food, and Wr = weight of food before cooking. Therefore, TR% is defined as the proportion of the remaining nutrient in the cooked food in comparison with the originally present nutrient in the raw food (15,16). Weight yield factor (%) was calculated with weight change after cooking based on before cooking as following formula:

$$\begin{aligned} &\text{Weight yield factor (\%)} \\ &= (\text{weight of sample after cooking} / \text{weight of raw sample}) \times 100 \end{aligned}$$

Statistical analysis All vegetables were analyzed in duplicates and expressed as means, standard deviation, and relative standard deviation. Results were subjected to the analysis of variation (ANOVA) using SAS software (Statistic Analysis System ver 9.2, SAS Institute Inc., Cary, NC, USA). Statistical significance was set at a 95% confidence level ($p < 0.05$). Means for all experiments were compared using Student's t-test or Duncan multiple-range test.

Results and Discussion

Certified Reference Material Analysis by HPLC To verify the analysis methods used for securing reliable data on β-carotene contents in foods before and after cooking, the β-carotene content of mixed vegetables (BCR[®]-485), which are a certified reference material, was measured (Table 2). The assigned β-carotene level of the certified reference material was 2,560 μg/100 g. Moreover, according to our HPLC results, its β-carotene content was 2,544 μg/100 g with a RSD of 2.1% and an accuracy of 99.4%. The z-score was 0.1. In general, the permissible level of accuracy of an analytical value is a recovery rate in the range of 90-110%. z-Score closer to zero indicate that analytical values are closer to the certified value, and z-score is considered satisfactory if it is within two units of zero. Therefore, the analytical value of the β-carotene content of CRM as determined using our technique was satisfactory.

β-Carotene contents of raw and boiled samples Table 3 compares the β-carotene contents of raw and boiled samples, i.e., three legumes (kidney beans, mung beans, and peas), chestnuts belonging to nut and seed products, and four species of root and tuber crops [yellow-fleshed potatoes, purple-fleshed potatoes, *Daeji* potatoes (*Solanum tuberosum* L. cv. *Dejima*), and *Sumi* potatoes (superior potatoes)]. The β-carotene contents of raw peas, dried mung beans, and raw kidney beans were 382.8, 243.5, and 52.6 μg/100 g respectively (Table 3). Peas, mung beans, and kidney beans were boiled for 5, 60, and 6 min, respectively. Dried mung beans were treated for a longer boiling time than the other legumes. After boiling, β-carotene contents of peas and kidney beans significantly increased to 463.2 and 90.3 μg/100 g, respectively ($p < 0.05$), whereas the β-carotene content of mung

Table 2. Calibration curve, limit of detection, limit of quantification, and analytical value

β-Carotene calibration	
Concentration range (μg/mL)	0.1-40
Calibration curve	$Y = 196.23X - 116.39$
Coefficient of correlation (R^2)	0.9986
Limit of detection (LOD, μg/mL)	0.03
Limit of quantification (LOQ, μg/mL)	0.09
Total β-carotene	
Certified reference material number	BCR [®] -485
Food matrix	Mixed vegetables
Certified value (μg/100 g)	2,560±120
Analytical value (μg/100 g)	2,544±54.1
Accuracy (%)	99.4
CV (%) ¹⁾	2.1
z-Score ²⁾	0.1

Values are mean±standard deviation.

¹⁾CV (%): percentage coefficient of variation

²⁾z-Score=(the participant's analytical value the assigned value)/the standard deviation of the assigned value

beans significantly decreased to 111.5 μg/100 g ($p < 0.05$). According to the USDA Agricultural Research Service (ARS) National Nutrient Database, β-carotene contents in samples of peas (green, raw) and mung beans (mature seeds, raw) are 449 and 68 μg/100 g, respectively (4), and the β-carotene contents of cooked peas (green, cooked, boiled, drained, without salt) and mung beans (mature seeds, cooked, boiled, without salt) are 470 and 19 μg/100 g, respectively (4). These values showed tendencies similar to those observed in the present study. In general, pulses comprise hard and dense tissues. When heated, the peptide chain structures of proteins, their main components, are denatured (17); thereafter, the resulting loosened tissues facilitate extraction and increase β-carotene extraction rates. In general, β-carotene in green vegetables exists as a form of carotenoid-protein complexes (i.e., carotenoprotein), resulting in the decrease of digestion and absorption rate (1). Thus, bioavailability of β-carotene can be improved by the softening of fibrous tissues and the destruction of carotenoprotein through cooking (1).

Species-specific changes in β-carotene contents after cooking are considered because of the fact that the components of pulses differ among species and their moisture content. However, the β-carotene content of raw chestnuts slightly decreased from 28.6 to 20.2 μg/100 g after boiling without a significant difference (Table 3, $p > 0.05$).

From the four species of root and tuber crops (yellow-fleshed potatoes: 35 min, purple-fleshed potatoes: 35 min, *Daeji* potatoes: 40 min, and *Sumi* potatoes: 35 min), their β-carotene contents after appropriate boiling time were determined (Table 3). No β-carotene was detected in the four species when raw, which agrees with the food composition table of the Rural Development Administration (18). Conversely, after boiling, small amounts of β-carotene were detected in three species (except *Sumi* potatoes), i.e., 11.2 μg/100 g

Table 3. β -Carotene contents ($\mu\text{g}/100\text{ g}$) of raw and boiled pulses, nuts and potatoes

Description	Boiled time (min)	β -Carotene contents ($\mu\text{g}/100\text{ g}$)			μgRE
		Mean	SD ¹⁾	RSD	
Kidney beans, raw (just from bean pod)		52.6* ²⁾	4.3	8.1	8.8
Kidney beans, boiled	6	90.3	1.4	1.6	15.0
Mung beans, dried		243.5*	2.9	1.2	40.6
Mung beans, boiled	60	111.5	1.8	1.6	18.6
Chestnuts, raw (just from husk)		28.6	2.7	9.4	4.8
Chestnuts, boiled	30	20.2	2.3	11.3	3.4
Peas, raw (just from bean pod)		382.8*	6.7	1.8	63.8
Peas, boiled	5	463.2	15.7	3.4	77.2
Potato, purpled flesh, raw		ND	-	-	ND
Potato, purpled flesh, boiled	35	11.2	1.4	12.4	1.9
Potato, yellowed flesh, raw		ND	-	-	ND
Potato, yellowed flesh, boiled	35	7.5	0.6	7.8	1.3
Potato, <i>Daeji</i> , raw		ND	-	-	ND
Potato, <i>Daeji</i> , boiled	40	8.5	0.3	4.0	1.4
Potato, <i>Sumi</i> , raw		ND	-	-	ND
Potato, <i>Sumi</i> , boiled	35	ND	-	-	ND

All values are expressed as mean $\pm$ standard deviation of duplicated determinations.

¹⁾SD, standard deviation; RSD, relative standard deviation; ND, not detected

²⁾*Values between raw and boiled samples are significantly different by student's *t*-test at $p < 0.05$, respectively.

for purple-fleshed potatoes, 8.5 $\mu\text{g}/100\text{ g}$ for *Daeji* potatoes, and 7.5 $\mu\text{g}/100\text{ g}$ for general potatoes (yellow-fleshed). These results attributed to the fact that β -carotene components were not well extracted from the tissues of raw potatoes but that these tissues were disrupted and softened by boiling. According to the USDA-ARS National Nutrient Database, the β -carotene contents of raw red potatoes (red, flesh, and skin) and baked red potatoes (red, flesh, and skin) are 4 and 6 $\mu\text{g}/100\text{ g}$, respectively (4). This tendency for higher β -carotene contents in cooked than in raw materials was similar to the results observed in the present study. When β -carotene contents ($\mu\text{g}/100\text{ g}$) detected in raw and boiled peas were converted into vitamin A (μgRE), the measured values were 63.8 and 77.2 μgRE , respectively, which corresponded to 1/10 of the daily standard vitamin A intake value (700 μgRE). Granado *et al.* (19) reported that β -carotene content of green beans after boiling (35 min) increased from 166 $\mu\text{g}/100\text{ g}$ (raw) to 238 $\mu\text{g}/100\text{ g}$ (approximately 43%). β -Carotene contents of raw and boiled (20 min) potatoes were 1 and 1.5 $\mu\text{g}/100\text{ g}$ (approximately 50%), respectively (19). Furthermore, it is mentioned that the reason is due to the increase of the chemical extractability of carotenoid by heat treatment (19). Therefore, we may expect that β -carotene levels can be improved in suitably processed vegetables than in unprocessed ones.

β -Carotene contents in raw and steamed samples Table 4 shows changes in β -carotene contents in pumpkins, regular millets (dried), taros, and perilla leaves when cooked by steaming for appropriate times. The β -carotene contents of pumpkins (mature) did not show any significant difference after steaming for 30 min ($p > 0.05$). The β -carotene contents of regular millets (polished grain) dried and steamed were 23.2 and 4.4 $\mu\text{g}/100\text{ g}$, respectively, showing a significant

decreasing tendency after cooking ($p < 0.05$). The decrease in the β -carotene content of regular millets after cooking was considered because of component losses due to the cooking process (70 min). Conversely, the β -carotene contents of raw and steamed (30 min) taros were 9.8 and 17.4 $\mu\text{g}/100\text{ g}$, respectively, showing a significantly increasing tendency ($p < 0.05$). A high β -carotene content of 7,565.3 $\mu\text{g}/100\text{ g}$ was detected in raw perilla leaves (a species of leaf vegetable), and this content decreased nonsignificantly to 7,207.3 $\mu\text{g}/100\text{ g}$ after steaming for 10 min ($p > 0.05$, Table 4). When β -carotene contents ($\mu\text{g}/100\text{ g}$) of raw perilla leaves and steamed samples were converted into vitamin A (μgRE), relatively high vitamin A contents were obtained, i.e., 1,260.9 μgRE in raw perilla leaves and 1,201.2 μgRE in steamed samples. These values correspond to 1.7–1.8 times daily standard vitamin A intake (700 μgRE). According to Vimala *et al.* (7), the variation of β -carotene content depends on food type, variety, processing method, and initial carotene content of the material.

β -Carotene contents in raw, baked, and steamed sweet potatoes

White-fleshed sweet potatoes and yellow-fleshed sweet potatoes were cooked in accord with practice (baked and steamed), and β -carotene contents were compared (Table 5). β -Carotene contents of 31.7 and 896.2 $\mu\text{g}/100\text{ g}$ were detected from raw white-fleshed sweet potatoes and yellow-fleshed sweet potatoes, respectively. These results are also consistent with previous reports, which indicated that β -carotene contents are higher in yellow colored vegetables (1). The β -carotene contents of white-fleshed sweet potatoes after steaming and baking were 37.2 and 39.0 $\mu\text{g}/100\text{ g}$, respectively, and these values were not significantly different from that of raw materials ($p > 0.05$). Conversely, the β -carotene contents of steamed and baked yellow-fleshed sweet potatoes were 553.1 and 786.4 $\mu\text{g}/$

Table 4. β-Carotene contents (μg/100 g) of raw and steamed pumpkin, millet, taro, and perilla leaves

Description	Steamed time (min)	β-Carotene contents (μg/100 g)			μgRE
		Mean	SD ¹⁾	RSD	
Pumpkin, mature, raw		50.8	0.6	1.1	8.5
Pumpkin, mature, steamed	30	53.6	3.0	5.7	8.9
Regular millet, polished grain, dried		23.2* ²⁾	0.2	0.9	3.9
Regular millet, polished grain, steamed	70	4.4	0.2	4.6	0.7
Taro, raw		9.8*	0.2	2.1	1.6
Taro, steamed	30	17.4	1.4	7.8	2.9
Perilla leaves, raw		7,565.3	79.7	1.1	1,260.9
Perilla leaves, steamed	10	7,207.3	588.7	8.2	1,201.2

All values are expressed as mean±standard deviation of duplicated determinations.

¹⁾SD, standard deviation; RSD, relative standard deviation

²⁾*Values between raw and steamed samples are significantly different by student's *t*-test at *p*<0.05, respectively.

Table 5. β-Carotene contents (μg/100 g) of raw, baked and steamed sweet potatoes

Description	Cooking time (min)	β-Carotene contents (μg/100 g)			μgRE
		Mean	SD ¹⁾	RSD	
Sweet potato, white-fleshed, raw		31.7 ^{a2)}	1.9	6.0	5.3
Sweet potato, white-fleshed, baked	140°C (20 min), 200°C (20 min)	39.0 ^a	3.9	9.9	6.5
Sweet potato, white-fleshed, steamed	35	37.2 ^a	1.5	4.1	6.2
Sweet potato, yellow-fleshed, raw		896.2 ^a	18.5	2.1	149.4
Sweet potato, yellow-fleshed, baked	140°C (20 min), 200°C (10 min)	786.4 ^b	23.5	3.0	131.1
Sweet potato, yellow-fleshed, steamed	25	553.1 ^c	18.5	3.3	92.2

¹⁾SD, standard deviation; RSD, relative standard deviation

^{2)a-c}Means with different letters along the same samples are significantly different at *p*<0.05 by Duncan's multiple range test.

100 g, and both showed a decreasing tendency as compared with the raw potatoes. Furthermore, these results might indicate that less β-carotene can be lost during baking (1st: 140°C, 2nd: 200°C), which is performed at higher temperatures than boiling (100°C) or steaming (100°C). In addition, different changes in β-carotene contents after cooking are considered attributable to the fact that different species of root and tuber crops have different flour textures and starch components with different viscosities. Therefore, different tissue structures and components react differently to time and temperature differences and the presence of water. Losses of *trans*-β-carotene in sweet potatoes processed by baking and steaming treatment occurred due to the isomerization of *trans*-β-carotene to 13-*cis*-β-carotene (20). The variation of β-carotene content depends on the variety and initial carotene content of the material as mentioned by Vimala *et al.* (7). Two types of sweet potato showed different initial carotene contents due to the difference derived from their fibrous tissue and variety.

Percent variation of weight and β-carotene content between before and after cooking and its true retention factor True retention factor and percent variation of weight and β-carotene content in the cooked and raw samples are shown in Table 6. After boiling, the β-carotene contents of mung beans and chestnuts decreased by approximately 54.2 and 29.3%, respectively. Moreover, the weight of

mung beans increased by 100.5%, whereas the weight of chestnuts decreased by 1.8% versus the raw materials (Table 6). Thus, true retention factors of mung beans and chestnuts were 91.8 and 69.4%, respectively. True retention factors of β-carotene from kidney beans and peas after boiling treatments were 174.2 and 128.3%, respectively. In case of kidney beans and peas, boiling process may increase the bioavailability of β-carotene possibly by liberating them from bound complexes as shown in a previous work (21). Of the steamed samples (pumpkin, dried regular millets, taros, perilla leaves, white-fleshed sweet potatoes, and yellow-fleshed sweet potato), the weights of regular millets and perilla leaves increased by 284.0 and 4.5%, respectively, versus their dried and raw materials, whereas β-carotene contents decreased by 81.1 and 4.7%, respectively. Their true retention factors were 72.4% in the steamed regular millet and 99.6% in the steamed perilla leaves. In the case of steamed pumpkin and taro, although weights decreased by 29.4 and 9.3%, β-carotene contents increased by 5.4 and 77.4%, respectively. Therefore, true retention factors of steamed pumpkin and taro were 74.4 and 160.9%, respectively. In pumpkin, after steaming, β-carotene content was changed much lesser compared to the weight. However, in taro, β-carotene content was dramatically increased, whereas weight change was lower than that of pumpkin, resulting in high true retention factor (160.9%). It seems that weight change in pumpkin and taro occurs due to loss of water and water soluble materials

Table 6. True retention factor and percent variation in the selected cooked samples

Description	Percent variation of weight (%) ¹⁾	Percent variation of β -carotene content (%) ²⁾	Weight yield factor (%)	True retention factor (%)
Kidney beans, boiled	1.5	71.6	101.5	174.2
Mung beans, boiled	100.5	-54.2	200.5	91.8
Chestnuts, boiled	-1.8	-29.3	98.2	69.4
Peas, boiled	6.0	21.0	106.0	128.3
Potato, purpled flesh, boiled	-3.8	-	96.2	-
Potato, yellowed flesh, boiled	-2.9	-	97.1	-
Potato, <i>Daeji</i> , boiled	-4.4	-	95.6	-
Potato, <i>Sumi</i> , boiled	-4.3	-	95.8	-
Pumpkin, mature, steamed	-29.4	5.4	70.6	74.4
Regular millet, polished grain, steamed	284.0	-81.1	384.0	72.4
Taro, steamed	-9.3	77.4	90.7	160.9
Perilla leaves, steamed	4.5	-4.7	104.5	99.6
Sweet potato, white-fleshed, baked	-11.0	22.9	89.0	109.3
Sweet potato, white-fleshed, steamed	-1.8	17.2	98.2	115.1
Sweet potato, yellow-fleshed, baked	-14.9	-12.2	85.1	74.7
Sweet potato, yellow-fleshed, steamed	-4.2	-38.2	95.8	59.1

¹⁾Percent variation of weight (%)=(weight (g) of cooked vegetable weight of raw vegetable)/weight of raw vegetable $\times$ 100

²⁾Percent variation of β -carotene content (%)=[β -carotene content (μ g/100 g) of cooked vegetable β -carotene content (μ g/100 g) of raw vegetable]/[β -carotene content (μ g/100 g) of raw vegetable] $\times$ 100

during steaming. This phenomenon shows the different degree of weight change possibly caused by compositional difference of fibrous tissues between pumpkin and taro. Little change of weight with high level of β -carotene was observed in taro after steaming, resulting from efficient release and extractability of β -carotene through destruction of carotenoprotein complexes (1).

Percent variation of weight in baked and steamed white-fleshed sweet potatoes decreased by 11.0 and 1.8%, whereas their β -carotene contents increased by approximately 22.9% (baked) and 17.2% (steamed) compared to raw samples, respectively. In the case of the baked and steamed yellow-fleshed sweet potatoes, both percent variations of weight and β -carotene content in cooked samples decreased by 14.9 and 4.2% (weight in baked and steamed) and by 12.2 and 38.2% (β -carotene content in baked and steamed), respectively. As a result, higher true retention factors were observed in baked and steamed white-fleshed sweet potatoes (109.3 and 115.1%) than in cooked yellow-fleshed samples (74.7 and 59.1%). In our result, the retention factor of β -carotene varied with cooking methods and variety of materials, ranging from 59.1 to 115.1%. Higher content of β -carotene was obtained from steaming (35 min) than baking (140°C for 20 min followed by 200°C for 20 min) in white-fleshed sweet potatoes. In case of yellow-fleshed sweet potatoes, however, baking (140°C for 20 min followed by 200°C for 10 min) induced higher retention factor than steaming (25 min).

In the present study, β -carotene contents of vegetables and changes in their contents caused by the cooking methods commonly used were investigated. In general, it has been known that amounts of nutritive components in vegetables are greater when vegetables are raw because they are partially destroyed by cooking. However, according to our results, increases in the contents of β -carotene in

certain food materials after cooking are observed, and such increases are considered to be due to the liberation and elution facilitated by cooking. We may expect the improved bioavailability of β -carotene in human as increasing β -carotene liberated from cooked vegetables.

Acknowledgments This work was carried out with the support of “Cooperative Research Program for Agriculture Science & technology Development (Project No. PJ01083806)” Rural Development Administration, Republic of Korea.

Disclosure The authors declare no conflict of interest.

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