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Review Article

Carotenoids and total phenolic contents in plant foods commonly consumed in Korea

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Abstract

Phytochemicals are reported to provide various biological functions leading to the promotion of health as well as the reduced risk of chronic diseases. Fat-soluble plant pigments, carotenoids, are extensively studied micronutrient phytochemicals for their potential health benefits. It is noteworthy that specific carotenoids may be responsible for different protective effects against certain diseases. In addition, each carotenoid can be obtained from different types of plant foods. Considering the fact that the phytochemical content in foods can vary according to, but not limited to, the varieties and culture conditions, it is important to establish a database of phytochemicals in locally produced plant foods. Currently, information on individual carotenoid content in plant foods commonly consumed in Korea is lacking. As the first step to support the production and consumption of sustainable local plant foods, carotenoids and total phenolic contents of plant foods commonly consumed in Korea are presented and their potential biological functions are discussed in this review.

Key Words: Phytochemicals, carotenoids, total phenolics, plant foods in Korea

Introduction

Fruits and vegetables containing a wide variety of phytochemicals such as carotenoids and phenolics are consistently reported to reduce the risk of chronic diseases [1-4]. As systemic oxidative stress of cell membranes, DNA, and proteins can contribute to the aging process and risk of various degenerative conditions, the antioxidant functions of phytochemicals may contribute to their protective effect against chronic diseases [5-6]. Indeed, evidence of specific biological functions of various phytochemicals, e.g., anti-inflammation and anti-carcinogenesis, is accumulating [7-14]. In addition, phyrochemicals reported to be involved in direct modulation of signal transduction. In particular, carotenoids such as lycopene [15] and lutein have been suggested to control redox sensitive molecular targets and platelet-derived growth factor [16], respectively.

To understand the biological role of fruits and vegetables and apply this knowledge to human health, it is essential to characterize phytochemicals in plant foods. In an effort to document the bioactive phytochemical contents of foods, a carotenoid database for fruits and vegetables was reported in 1993 based on a review of various publications [17], and updated [18] in 1999 in the US. On the other hand, there is no publication available showing the individual carotenoid content of Korean plant foods except for a booklet written in Korean reported by us [19]. In addition, database for phenolic contents of selected foods have been reported in the US [20-22], France [23-25], and Brazil [26], whereas there is no such data available in Korea. Various plant foods commonly consumed in Korea are not found in Western countries. In addition, phytochemical contents in foods can be significantly different depending on the varieties [27-28], genotypes [29] growing conditions [30] as well as cultivation practices [31]. Therefore the characterization of the major phytochemical contents of fruits and vegetables in Korea is an important step toward understanding the biological functions of plant foods consumed in Korea.

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This review provides a spectrum of carotenoids and total phenolics in plant foods commonly consumed in Korea and discusses their potential biological functions.

Proposed biological functions of phytochemicals

Phytochemicals have been suggested to provide health benefits such as maintaining inflammation balance [32-33], providing cardiovascular [34-40], neurocognitive [41], and visual health [7-14, 42], and reducing the risk of cancer [43-44]**.** Even though numerous observational studies suggest that diets high in fruits and vegetables play a role in reducing chronic diseases [14, 45-47], several intervention trials failed to show a beneficial effect of relatively high doses of β-carotene (20-30 mg/d) against lung cancer in healthy [48] and high-risk populations [49-50]. Nevertheless, baseline serum β-carotene concentrations are inversely correlated with the subsequent incidence of lung cancer in two of these studies [49-50], suggesting a protective effect of fruit and vegetable consumption on the development of chronic diseases. Thus, it may be due to the combination of various phytochemicals in fruits and vegetables that are required to exert the biological actions that promote health.

For example, antioxidant nutrients in fruits and vegetables can work in a synergistic manner to remove free radicals [51]. Although ascorbic acid is a poor inhibitor of peroxyl radical formation [52], it can effectively recycle α-tocopherol from α-tocopheroxyl radicals (α-TO•) [53]. α-Tocopherol can reduce β-carotene peroxyl radicals (LOO-β-C•) as well as β-carotene radical cations ($\beta\text{-C}\bullet^{+}$) [54]. The combination of α-tocopherol and β-carotene has been reported to cooperatively slow down lipid peroxidation in *in vitro* systems [55]. Interestingly, β-carotene at physiologic concentrations does not show a protective effect against oxidation in a biological model system, whereas the oxidation was decreased by β-carotene with the presence of either α-tocopherol or ascorbic acid [51]. Further, flavanol can directly recycle α-tocopherol through a H-transfer mechanism [56]. Importantly, the additive/synergistic interactions between phytochemicals may occur with respect to not only antioxidant activity but also various other biological functions [57].

Biological functions of carotenoids

The various antioxidant actions of carotenoids have been reviewed extensively [58-61], although the existence of a clinical importance of antioxidant effect of these compounds has been questioned by some [62]. Epidemiological studies have suggested that dietary carotenoids play a role in reducing the risk of cancer [63], cardiovascular disease [64-66], macular degeneration [7], and cataracts [8-9]. Specific dietary carotenoids may be responsible for different protective effects. Hydrocarbon carotenoids such as β-carotene may be markers for reduced risk of cancer and heart disease [67-68] in physiological dose, whereas supra dietary doses may lead to increased risk of lung cancer [69-70] as well as gastric cancer [71]. Both epidemiological and laboratory studies consistently indicate an association between oxygenated carotenoids, lutein and zeaxanthin, and the protection of the retina and retinal pigment epithelium from damage induced by UV light and oxygen [10]. For example, Seddon *et al.* [7] found in a case ($n = 356$)-control ($n = 520$) study that the highest quintile of carotenoid intake had a 43% lower risk for age-related macular degeneration compared with those in the lowest quintile, and among the specific carotenoids, lutein and zeaxanthin were most strongly associated with the reduced risk for the disease ($P = 0.001$). Laboratory human studies identifying the macular pigments as lutein and zeaxanthin support these epidemiologic observations [11-12,72]. However, the intake of dark green vegetables, the major source of lutein, remains low at ~0.2 servings/d in Americans [73]. In addition, data from NHANES III indicate that for women 51-70 y, the medians for 50^{th} & 75^{th} percentiles of lutein/zeaxanthin intake were 1.7 and 2.4 mg/d, respectively [74]. Foods rich in an acyclic carotenoid, lycopene, one of the most abundant carotenoids in human blood and tissues, has been found to be associated with an inverse risk of cervical [75], prostate [76], and colon [77] cancers.

Green leafy vegetables contain both oxygenated and hydrocarbon carotenoids; yellow or orange vegetables have high amounts of β-carotene [78]; tomatoes and watermelon contain high amounts of lycopene [79]. It should be pointed out that most of the measurable carotenoids of human plasma can be increased by moderate alterations in diet within a short time, although the magnitude of the plasma response may be related to the baseline carotenoid concentrations [80].

Biological functions of phenolics

Phenolic compounds include a vast array of phenolic acids and polyphenols. Total phenolics in fruits and vegetables show a direct relationship with antioxidant capacity measured by *in vitro* assays [81-82]. The antioxidant and anti-inflammatory activities of plant foods may derive from the additive/synergistic interactions of the mixture of phenolic compounds and other phytochemicals rather than a single comopund or class of compounds [83-84]. Nonetheless, although the data are still limited, some individual phenolic compounds have been reported to show specific biological actions, e.g. anti-inflammation, anti-carcinogenesis.

Flavonoids are a large group of polyphenols present in fruits, vegetables, and beverages including wine and tea as well as tree nuts and whole grains. Flavonols such as quercetin and kaempferol are reported to be rich in onions [21,85] with less amounts in dark green leafy vegetables such as collard greens and kales [86-87]. Various studies have shown an inverse association between quercetin intake and risk of lung cancer [43], cardiovascular diseases [88] and biomarkers of inflammation [13]. Flavanols such as catechins rich in tea and dark chocolate can act to protect unsaturated phospholipids [89] and low-density lipoproteins [90] from oxidation and are correlated with a reduced risk of heart disease [91]. However, controlled intervention trials have been inconsistent in revealing a protective effect of tea drinking against *ex vivo* LDL oxidation [92-93]. The major food sources for flavanones such as hesperitin and naringenin are citrus fruits and citrus-based juices [94], which are also inversely associated with the risk of cardiovascular disease [95]. Importantly, the daily intake of flavonoids is extremely variable and could range from 25 to 1,000 mg/d [91,96].

Phytochemical contents in commonly consumed foods in Korea

WHO reported that up to 2.7 milliion lives could be saved annually with sufficient fruit and vegetable consumption and that low fruit and vegetable intake is among the top 10 selected risk factors for global mortality [97-98]. An WHO/FAO expert consultation report recommends a minimum 400 g (~5 servings) of daily fruits and vegetable intake for the prevention of chronic diseases [99]. As phytochemicals appear to be one of the responsible factors for reducing the risk of chronic diseases, profiling these phytochemicals in Korean fruits and vegetables may help promote consumption of local plant foods as a sustainable option to promote health. Table 1 shows individual carotenoid and total phenolic contents in plant foods commonly consumed in Korea.

Carotenoid contents in plant foods commonly consumed in Korea

The major carotenoids in the fruits and vegetables in plant foods commonly consumed in Korea were found to be β-carotene and lutein. Only 3 and 6 of the studied plant foods contained detectable amounts of *trans*-lycopene and β-cryptoxanthin, respectively. Fig. 1 shows β-carotene content as the median, 25th and 75th percentiles per 100 g fresh weight (FW) in plant foods grouped by family names. Plant families that contain the highest values of β-carotene were *Compositae*, *Umbelliferae,* and *Chenopodiaceae* in descending order (4.13, 4.00 and 3.10 mg/100 g FW, respectively). *Liliaceae*, *Cruciferae* and *Solanaceae* families contain 1.84, 0.56 and 0.33 mg/100 g FW of β-carotene, respectively. The families containing the lowest β-carotene were Cucurbitaceae, Leguminosae, Rosaceae and Rutaceae families (0.113, 0.064, 0.064 and 0 mg/100 g FW, respectively). The β-carotene content in Umbeliferae family was significantly higher than those in Leguminosae, Rosaceae and Rutaceae families.

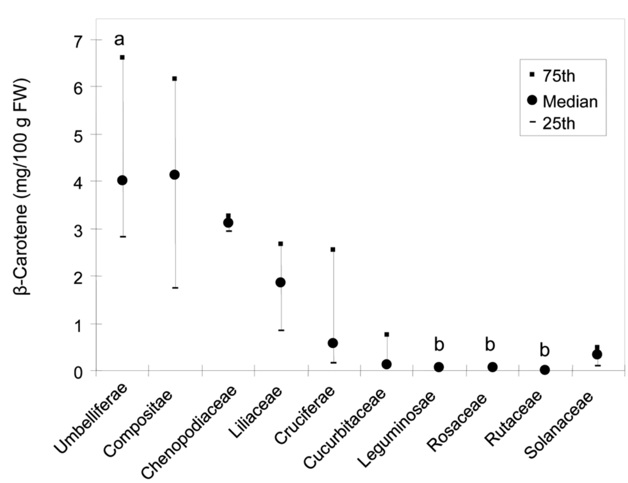

Fig. 1. β-Carotene contents in plant foods commonly consumed in Korea by family names. *Umbelliferae* (n = 10), *Compositae* (n = 10), *Chenopodiaceae* (n = 3), *Liliaceae* (n = 6), *Cruciferae* (n = 9), *Cucurbitaceae* (n = 6), *Leguminosae* (n = 7), *Rosaceae* (n = 9), *Rutaceae* (n = 3), *Solanaceae* (n = 8). Kruskal-Wallis one-way ANOVA on ranks with Dunn's test were performed to identify differences among median values. Different letters indicate significant differences (P < 0.05).

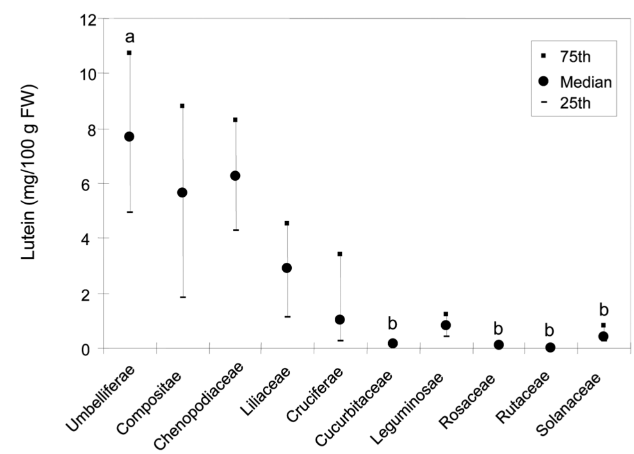

Fig. 2. Lutein contents in plant foods commonly consumed in Korea by family names. *Umbelliferae* (n = 10), *Compositae* (n = 10), *Chenopodiaceae* (n = 3), *Liliaceae* (n = 6), *Cruciferae* (n = 9), *Cucurbitaceae* (n = 6), *Leguminosae* (n = 7), *Rosaceae* (n = 9), *Rutaceae* (n = 3), *Solanaceae* (n = 8). Kruskal-Wallis one-way ANOVA on ranks with Dunn's test were performed to identify differences among median values. Different letters indicate significant differences (P < 0.05).

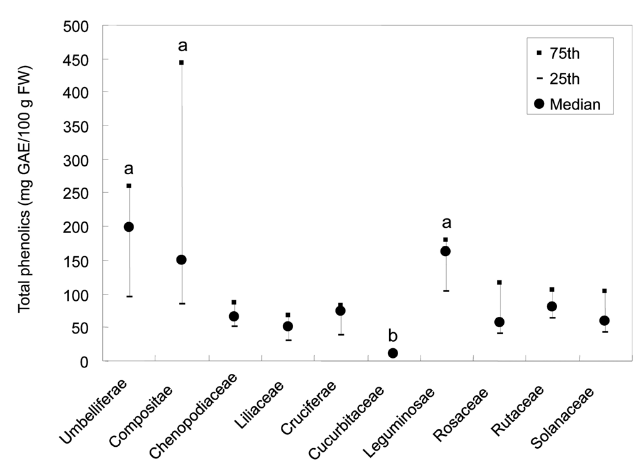

Fig. 3. Total phenolic contents in plant foods commonly consumed in Korea by family names. *Umbelliferae* (n = 10), *Compositae* (n = 10), *Chenopodiaceae* (n = 3), *Liliaceae* (n = 6), *Cruciferae* (n = 9), *Cucurbitaceae* (n = 6), *Leguminosae* (n = 7), *Rosaceae* (n = 9), *Rutaceae* (n = 3), *Solanaceae* (n = 8). Kruskal-Wallis one-way ANOVA on ranks with Dunn's test were performed to identify differences among median values. Different letters indicate significant differences (P < 0.05).

Table 1. Carotenoids, total phenolic contents in plant foods commonly consumed in Korea

English name	Latin name	Moisture (%)	Carotenoids[1] (mg/100 g FW)				Total phenolics[3] (mg GAE/ 100 g FW)
			Lutein	all-*trans*-β-carotene	Cryptoxanthin	*trans*-Lycopene	
Compositae Family							
Burdock	Aretium lappa	79.6	-	-	-	-	134.02
Butterbur	Petasites japonicus	94.2	0.06 ± 0.01	0.03 ± 0.01	-	-	84.24
Chicory	Cichorium intybus	94.1	3.54 ± 0.15	2.20 ± 0.08	-	-	64.24
Chwi	Aster scaber Thunberg	85.0	9.8 ± 0.54	6.15 ± 0.09	-	-	274.96
Crown daisy	Chrysanthemum coronarium	89.6	6.55 ± 0.64	4.39 ± 0.23	-	-	116.42
Gom-chwi	Coriandeum sativum	87.5	8.46 ± 0.33	6.25 ± 0.05	-	-	613.79
Head lettuce	Lactuca sativa capitata	94.2	0.36 ± 0.02	0.28 ± 0.02	-	-	17.74
Lactuca bungeama	Ixeris Sonchifolia	87.3	5.66 ± 0.18	4.13 ± 0.18	-	-	443.94
Lettuce	Lactuca sativa	93.5	2.34 ± 0.17	2.47 ± 0.11	-	-	164.6
Mugwort	Artemisia vulgaris	82.4	11.57 ± 1.11	7.21 ± 0.56	-	-	542.81
Cruciferae Family							
Broccoli	Brassica oleracea italica	88.9	1.00 ± 0.01	0.56 ± 0.02	-	-	53.19
Cabbage	Brassica oleracea capitata	92.7	0.14 ± 0.01	0.08 ± 0.01	-	-	38.34
Cauliflower	Brassica oleracea botrytis	90.8	0.02 ± 0.00	0.01 ± 0.00	-	-	77.26
Green mustard	Brassica juncea	90.0	3.6 ± 0.42	2.63 ± 0.42	-	-	80.73
Korean cabbage	Brassica Chinensis	94.4	0.60 ± 0.04	0.37 ± 0.01	-	-	37
Pak-choi	Brassica campestris	90.0	0.28 ± 0.18	2.24 ± 0.11	-	-	73.63
Radish	Raphanus sativus niger	94.6	-	-	-	-	13.03
Red cabbage	Brassica oleracea	93.1	-	-	-	-	91.78
Young radish	Raphanus sativus L	92.1	4.11 ± 0.35	2.87 ± 0.28	-	-	84.17
Cucurbitaceae Family							
Cucumber	Cucumis sativus	95.2	0.14 ± 0.01	0.07 ± .002	-	-	6.68
Melon, musk	Cucumis melo	90.9	0.06 ± 0.00	0.04 ± 0.00	-	-	12.61
Oriental melon	Cucumis melo L	88.8	-	-	-	-	25.71
Pumpkin	Cucurbita maxima	92.9	-	0.69 ± 0.05	-	-	7.17
Watermelon	Citrullus vulgaris	88.5	-	0.92 ± 0.08	-	3.33 ± 0.11	12.09
Zucchini	Cucurbita pepo	92.7	0.25 ± 0.02	0.11 ± 0.01	-	-	9.01
Chenopodiaceae Family							
Beets	Beta vulgaris	89.7	-	-	-	-	46.07
Chard	Beta vulgaris var. cicla	90.9	4.28 ± 0.13	2.94 ± 0.12	-	-	65.49
Spinach	Spinacia oleraceae	92.2	8.26 ± 0.43	3.25 ± 0.07	-	-	94
Leguminosae Family							
Black beans, dried	Glycine max Merr.	12.2	1.07 ± 0.05	0.12 ± 0.00[4]	-	-	161.38
Cowpeas, dried	Vigna sinensis	38.2	-	-[5]	-	-	125.01
Kidney beans	Phaseolus vulgaris	56.4	-	-	-	-	181.34
Mung beans,dried	Phaseolus radiatus	7.4	1.34 ± 0.10	0.05 ± 0.00	-	-	191.08
Peas	Pisum sativum	53.1	0.52 ± 0.03	0.10 ± 0.00	-	-	26.88
Small red beans, dried	Phaseolus angularis	9.0	-	-	-	-	176.40
Soy beans, dried	Glycine max	10.7	0.29 ± 0.02	-	-	-	97.40
Liliaceae Family							
Chinese chive	Allium tuberosum	92.1	4.19 ± 0.46	2.34 ± 0.20	-	-	58
Garlic	Allium sativum	63.4	-	-	-	-	67.18
Garlic young stem	Allium sativum	89.7	0.44 ± 0.14	0.31 ± 0.07	-	-	43.4
Leek	Allium porrum	91.1	1.78 ± 0.30	1.34 ± 0.21	-	-	29.17
Onion	Allium sepa	91.7	-	-	-	-	27.54
Scallion	Allium Fistulosum	91.0	4.85 ± 0.13	2.99 ± 0.10	-	-	81.81
Rosaceae Family							
Apple	Malus sylvestris	86.2	-	-[5]	-	-	45.92
Japanese apricot	Prunus mume	90.2	-	0.07 ± 0.02	0.01 ± 0.00	-	56.24
Nectarine	Prunus persica nectarina	89.7	-	0.09 ± 0.01	0.02 ± 0.00	-	57.48
Peach	Prunus persica	87.9	-	-	-	-	19.46
Pear	Pyrus communis	86.5	-	-	-	-	9.48

Table 1. Continuation

English name	Latin name	Moisture (%)	Carotenoids[1] (mg/100 g FW)				Total phenolics[3] (mg GAE/ 100 g FW)
			Lutein	all-*trans*-β-carotene	Cryptoxanthin	*trans*-Lycopene	
Plum	Prunus domestica	91.4	0.12 ± 0.01	0.04 ± 0.00	0.01 ± 0.00	-	160.48
Sour cherry	Prunus cerasus	85.9	-	0.06 ± 0.00	-	-	79.17
Strawberry	Fragaria elatior	87.6	-	-	-	-	149.34
Sweet cherry	Prunus avium	80.7	-	-	-	-	105.99
Rutaceae Family							
Lemon	Citrus limonis	88.1	-	-	0.01 ± 0.00	-	115.16
Orange	Citrus sinensis	85.2	-	0.01 ± 0.00	0.24 ± 0.06	-	79.73
Tangerine	Citrus reticulate	87.7	-	0.02 ± 0.01	0.42 ± 0.18	-	56.70
Solanaceae Family							
Cherry tomato	Lycopersicu esculentum Mill	92.7	-	0.48 ± 0.03[4]	-	4.68 ± 1.77	38.94
Eggplant	Solanum melongena	94.2	0.14 ± 0.02	0.06 ± 0.02	-	-	58.62
Green pepper	Capsicum annuum	91.7	1.23 ± 0.12	0.43 ± 0.05	-	-	107.2
Green sweet pepper	Capsicum annuum	94.8	0.41 ± 0.02	0.12 ± 0.01	-	-	60.36
Potato	Solanum tuberosum	79.5	-	-	-	-	43.39
Red pepper	Capsicum annuum	81.6	0.35 ± 0.04	1.63 ± 0.30		-	126.86
Red sweet pepper	Capsicum annuum	91.1	0.09 ± 0.03	-		-	100.74
Tomato	Lycoperiscon esculentum	94.6	-	0.33 ± 0.02		1.94 ± 0.11	17.89
Umbelliferae Family							
Myeong Il Yeop	Angelica keiskei	78.0	26.82 ± 1.72	11.53 ± 0.50	-	-	331.87
Celery	Apium graveolens	94.3	0.67 ± 0.08	0.26 ± 0.03	-	-	18.37
Cham	Pimpinella brachycarpa	87.8	5.45 ± 0.34	3.23 ± 0.21	-	-	82.69
Coriander	Coriandrum sativum	91.6	5.24 ± 0.58	3.00 ± 0.33	-	-	107.46
Dang-gwi	Radix angelica gigas	83.0	9.92 ± 0.70	6.62 ± 0.72	-	-	260.53
Kale	Brassica oleracea sabellica	91.3	4.91 ± 0.72	2.81 ± 0.43	-	-	95.89
Parsley	Petriselinum crispum	85.1	10.03 ± 1.60	5.53 ± 0.83	-	-	217.36
Pumpkin young leaves	Cucurbita maxima	88.4	10.72 ± 0.73	4.77 ± 0.38	-	-	181.14
Red pepper leaves	Capsicum annuum	84.1	17.45 ± 0.88	10.07 ± 0.40	-	-	409.25
Small water dropwort	Oenanthe javanica	90.1	3.40 ± 0.52	1.36 ± 0.26	-	-	238.65
Others							
Amaranth	Amaranthus mangostanus	88.5	9.4 ± 0.66	6.20 ± 0.47[4]	-	-	134.27
Bamboo shoot	Bambusa spp	91.1	-	-5	-	-	101.07
Banana	Musa Sapientum	96.6	0.01 ± 0.00	0.01 ± 0.00[4]	-	-	10.22
Bonnet bellflower root	Codonopis lanceolata	80	-	-	-	-	28.54
Bracken fern, boiled	Pteridium aquilinum	91.4	0.15 ± 0.01	0.02 ± 0.00[4]	-	-	1.58
Bud of aralia	Aralia elate	89.1	4.35 ± 0.16	2.40 ± 0.10	-	-	88.53
Carrot	Platycodon grandiflorum	90.5	0.17 ± 0.06	5.47 ± 1.30	-	-	6.92
Chinese bellflower root	Cornus officinalis	77.7	-	-	-	-	34.84
Cornus officinalis	Asarum canadense	6.6	-	-	-	-	1519.93
Ginger	Vitis vinifera	85.7	-	-	-	-	24.94
Grape berries	Vitis vinifera	81	0.05 ± 0.01	0.04 ± 0.01	-	-	112.43
Grape(campbell)	Actinida chinensis	84.2	0.19 ± 0.1	0.15 ± 0.01	-	-	161.19
Kiwi	Nelumbo nuoifera	82.3	0.02 ± 0.01	-	-	-	56.41
Lotus root	Malva verticillata	80.8	-	-	-	-	91.67
Mallow	Glycine max	90.2	8.03 ± 0.56	4.80 ± 0.22	-	-	139.9
Mungbean sprout	Perilla frutescens	95.2	0.03 ± 0.00	-	-	-	21.08
Perilla leaves	Ananas comosus	84	12.38 ± 0.80	7.36 ± 0.02	-	-	193.33
Pineapple	Raphanus sativus	84.4	-	0.05 ± 0.00	-	-	44.14
Radish sprouts	Sedum sarmentosum	91.4	3.73 ± 0.46	2.10 ± 0.17	-	-	120.02
Sedum	Glycine max	96	2.24 ± 0.21	1.25 ± 0.07	-	-	50.07
Soybean sprout	Ipomoea batatas	91.3	-	-	-	-	53.45
Sweet potato	Ipomoea batatas	58	-	-	-	-	89.46
Sweet potato stalk	Dioscorea batatas	94	0.02 ± 0.01	-	-	-	19.47
White yam	Amaranthus mangostanus	81.9	-	-	-	-	19.55

Lutein content grouped by plant family is shown in Fig. 2. The *Umbelliferae* family had the highest lutein content of 7.69 mg/100 g FW, followed by *Chenopodiaceae*, *Compositae* and *Liliaceae* families at 6.27, 5.66 and 2.90 mg/100 g FW, respectively. *Cruciferae* and *Leguminosae* families contained 1.0 and 0.80 mg/100 g FW of lutein. *Cucurbitaceae*, *Rosaceae* and *Rutaceae* families contained the lowest amount of lutein in the range of 0-0.14 mg/100 g FW and the content were significantly lower than those in Umbelliferae family.

According to USDA National Nutrient database [100], kale contains 8.17 mg/100 g of β-carotene. The β-carotene contents in pumpkin, carrot, spinach, parsley and lettuce in this database are 6.94, 5.77, 5.63, 5.05 and 4.44 mg/100 g, respectively. Vegetables commonly consumed in Korea are rich in carotenoids, in particular lutein and β-carotene. For example, Myeong Il Yeop and red pepper leaves contained 11.53 and 10.07 mg/100 g of β-carotene and 26.82 and 17.45 mg/100 g of lutein respectively.

Cryptoxanthin and lycopene were detected only in a few food items. Cryptoxanthin was present in red pepper (0.35 mg/100 g), red sweet pepper (0.089 mg/100 g) as well as nectarine, lemon, Japanese apricot and Korean cherry. Lycopene was present in cherry tomato, watermelon and tomato (4.68, 3.33 and 1.94 mg/100 g, respectively).

Total phenolic contents in plant foods commonly consumed in Korea

Umbelliferae (199.2 mg gallic acid equivalents [GAE]/100 g FW), *Leguminosae* (161.4 mg GAE/100 g FW) and *Compositae* families (149.3 mg GAE/100 g FW) contained the highest total phenolics, which were significantly higher than *Cucurbitaceae* family (10.6 mg GAE/100 g FW) containing the lowest total phenolic contents ($P < 0.05$). *Rutaceae*, *Cruciferae* and *Chenopodiaceae* families were in the range of 65.5-79.7 mg GAE/100 g FW of total phenolics. *Solanaceae*, *Rosaceae*, and *Liliaceae* families contained total phenolics in the amounts of 59.5, 57.5 and 50.7 mg GAE/100 g FW, respectively (Fig. 3).

Previous studies reported by others on total phenolics reported that broccoli and spinach contained the highest amount of total phenolics (101.63 and 90.99 mg GAE/100 g, respectively), followed by yellow onion, red pepper, carrot, cabbage, potato, lettuce, celery and cucumber [101]. Of the 10 most commonly consumed fruits in the US, the highest total phenolic contents were found in cranberry, apple, red grape and strawberry with values of 527.2 ± 21.5, 296.3 ± 6.4, 201.0 ± 2.9, 160.0 ± 1.2 mg GAE/100 g, respectively [102]. Compared to the commonly consumed fruit and vegetables in the US, much higher total phenolics were found in vegetables commonly consumed in Korea, where Gom-chwi (613.79 mg GAE/100 g FW), mugwort (542.81 mg GAE/100 g FW), lactuca bungeama (443.94 mg GAE/100 g FW) and red pepper leaves (409.25 mg GAE/100 g FW), Myeong Il Yeop (331.87 mg GAE/100 g FW), Chwi-namul (274.96 mg GAE/100 g FW), Dang-gwi (260.53 mg GAE/100 g FW) and small water dropwort (238.65 mg GAE/100 g FW). Korean local berries and legumes which were dried also showed high total phenolics.

Commonly consumed plant foods in Korea high in β-carotene, lutein and total phenolic contents

The top 20 foods for carotenoids and total phenolics in commonly consumed plant foods in Korea are summarized in

Table 2. Top 20 plant foods commonly consumed in Korea containing high lutein, β-carotene or total phenolics

	Plant foods	Lutein (mg/100 g FW)	Plant foods	β-Carotene (mg/100 g FW)	Plant foods	Total phenolics (mg GAE/100 g FW)
1	Myeong Il Yeop	26.82	Myeong Il Yeop	11.53	Cornus officinalis (dried)	1519.9
2	Red pepper, leaves	17.45	Red pepper, leaves	10.07	Gom-chwi	613.8
3	Perilla, leaves	12.38	Perilla, leaves	7.36	Mugwort	542.8
4	Mugwort	11.57	Mugwort	7.21	Lactuca bungeama	443.9
5	Pumpkin, young leaves	10.72	Dang-gwi	6.62	Red pepper leaves	409.3
6	Parsley	10.03	Gom-chwi	6.25	Myeong Il Yeop	331.9
7	Dang-gwi	9.92	Amaranth	6.20	Chwi-namul	275.0
8	Chwi-namul	9.80	Chwi-namul	6.15	Dang-gwi	260.5
9	Amaranth	9.40	Parsley	5.53	Small water dropwort	238.7
10	Gom-chwi	8.46	Mallow	4.80	Parsley	217.4
11	Spinach	8.26	Pumpkin, young leaves	4.77	Perilla leaves	193.3
12	Mallow	8.03	Crown daisy	4.39	Mung beans,dried	191.1
13	Crown daisy	6.55	Lactuca bungeama	4.13	Kidney beans	181.3
14	Lactuca bungeama	5.66	Carrot	3.97	Pumpkin young leaves	181.1
15	Cham-namul	5.45	Spinach	3.25	Small red beans, dried	176.4
16	Coriander	5.24	Cham-namul	3.23	Lettuce	164.6
17	Kale	4.91	Coriander	3.00	Black beans, dried	161.4
18	Scallion	4.85	Scallion	2.99	Grape(campbell)	161.2
19	Bud, Aralia elats	4.35	Chard	2.94	Plum	160.5
20	Chard	4.28	Leafy radish	2.87	Strawberry	149.3

Table 2. Myeong Il Yeop and red pepper leaves were the highest in both β-carotene (11.53 and 10.07 mg/100 g FW) and lutein (26.82 and 17.45 mg/100 g FW) contents, followed by perilla leves and mugwort. The top 10 foods containing high amounts of β-carotene were Dang-gwi, Gom-chwi, amanranth, Chwi-namul, parsley and mallow. Pumpkin young leaves, parsley, Dang-gwi, Chwi-namul, amanranth, and Gom-chwi were in top 10 foods with high lutein content.

Total phenolics were the highest in dried *Cornus officinalis* (Local Korean berry). Gom-chwi (613.8 mg GAE/100 g FW) and mugwort (542.8 μmol/g FW) showed high total phenolics, followed by lactuca bungeama, red pepper leaves, Myeong Il Yeop, Chwi-namul, and Dang-gwi (443.9, 409.3, 331.9, 275 and 260.5 mg GAE/100 g FW, respectively). As shown in Table 2, the top 20 plant foods with high β-carotene content were all green leafy vegetables plus carrots. Lutein was also high in green leafy vegetables. Total phenolics were high in green leafy vegetables and in non-green leafy vegetables such as Korean berry (dried), legumes, grapes, and plum. In general, the phytochemicals investigated in this study were higher in plant foods commonly consumed in Korea, especially in green leafy vegetables, than in common plant foods such as parsley, spinach, kale and lettuce, which are listed to contain high phytochemicals in the US database [21].

Conclusions

Plant foods commonly consumed in Korea, in particular, green-leafy vegetables belonging to the *Compositae* and *Umbelliferae* families, are good sources of phytochemicals such as β-carotene, lutein, and total phenolics, and their contents are higher than those of commonly consumed plant foods reported by others. These phytochemicals in plant foods commonly consumed in Korea may contribute substantially to reduce the risk of chronic diseases as illustrated in Fig. 4. Thus, plant foods commonly consumed in Korea can be an important source of phytochemicals that can contribute to the promotion of health and prevention of chronic diseases.

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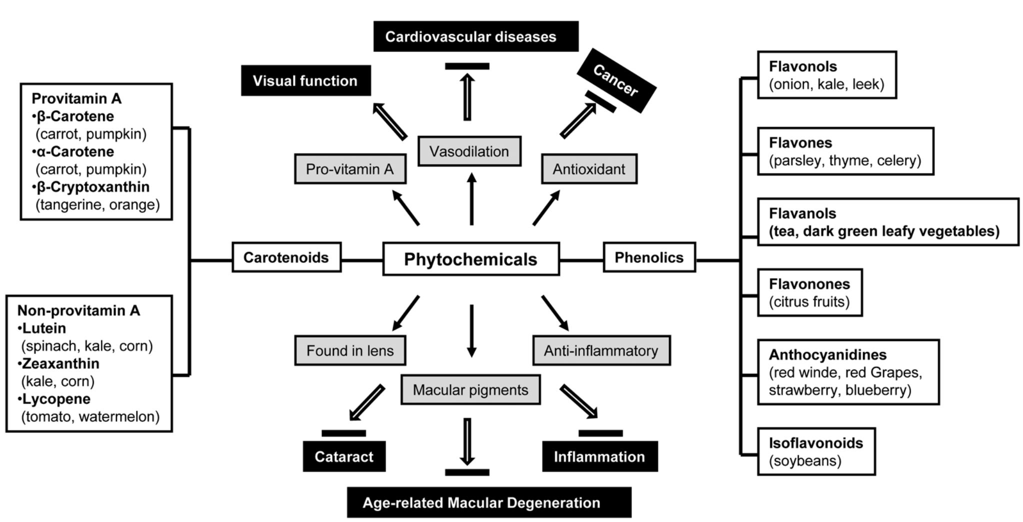

Fig. 4. Proposed functions of phytochemicals. Plant foods in parenthesis represent the major source of each phytochemical.

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