RESEARCH ARTICLE

Assessment of Phytochemicals, Quality Attributes, and Antioxidant Activities in Commercial Tomato Cultivars

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Abstract

To assess South Korean commercial tomato cultivars, regular and cherry tomato cultivars were grown in the greenhouse and evaluated for color attributes, titratable acidity, pH, total soluble solids, carotenoids (lycopene and β-carotene), total phenols, flavonoids, vitamin C, and antioxidant activity. Significant differences ($p < 0.05$ using Duncan's multiple range test (DMRT)) were observed in the levels of most phytochemicals, quality parameters, and antioxidant activity among the twenty South Korean tomato cultivars tested. Lycopene and β-carotene contents varied significantly ($p < 0.05$ using DMRT), from 0.95 mg·100 g^{-1} to 5.12 mg·100 g^{-1} and 0.65 mg·100 g^{-1} to 3.56 mg·100 g^{-1} of fresh weight, respectively. β-carotene contents exhibited the highest genetic variation (59.2%), followed by naringenin (52.8%) and other phytochemicals. Most of the cherry tomato cultivars had statistically higher levels ($p < 0.05$ using DMRT) of carotenoids, phenols, flavonoids, vitamin C, and antioxidant activity compared to the regular tomato varieties, suggesting their higher nutritional value. Lycopene content was highest in the cultivars YoYo, Jicored, Titi-Chal, TY-Endorphin, and Rubyking. Cultivars Rubyking, TY-Endorphin, and Titi-Chal also showed relatively higher antioxidant activities in three assays: 2,2-diphenyl-1-picrylhydrazyl (DPPH), 2,2'-azino-bis (3-ethylbenzothiazoline-6-sulfonic acid) (ABTS), and ferric ion reducing antioxidant power (FRAP) assays. All the antioxidants, except luteolin, were positively correlated with antioxidant activities; the highest correlation was observed between total phenol and antioxidant activities, followed by the correlation between rutin and vitamin C. Cultivars identified to have superior nutritional status would be useful in tomato breeding programs to further improve quality and health benefits of tomatoes for the fresh and processed markets.

Additional key words: acidity, carotenoids, color, flavonoids, total soluble solids, vitamin C

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Introduction

Tomato, a member of the Solanaceae family, is an important vegetable crop. Produced in 171

countries, with annual production levels of 173 million tons of fresh fruit, tomatoes are grown on 4,725,417 ha of farmland (FAO, 2013). In South Korea, tomatoes are one of the most important horticultural crops in terms of both cultivation area (6,054 ha) and annual production (388,524 tons) and annual per capita consumption averages 8.6 kg. Worldwide, the fruit is consumed fresh or processed into canned tomato, sauce, juice, ketchup, stews, and soups (Aguilo-Aguayo et al., 2010). Many epidemiological studies have associated tomato and its related products with a reduced risk of several chronic degenerative diseases, cardiovascular diseases, and age-related macular degeneration (Rao and Rao, 2007). In addition, tomato is known to possess antioxidant activity. These tomato health benefits are due to the presence of several bioactive compounds, such as carotenoids, vitamins (C and E), polyphenols, flavonoids, sugars, etc. (Vallverdu-Queralt et al., 2012; Choi et al., 2014). Carotenoids, in particular lycopene and β-carotene, are one of the most important bioactive compounds in tomato; their antioxidant and anti-proliferative activities associate them with protection from heart diseases and prostate cancer (Rissanen et al., 2003; Campbell et al., 2004). In addition, these carotenoids give tomato fruit their characteristic color. The antioxidative compounds in tomato also inhibit reactive oxygen species, which are contributing factors in many deadly diseases, via free-radical scavenging, metal chelation, inhibition of cellular proliferation, and modulation of enzymatic activity and signal transduction pathways. Furthermore, the sweet and sour flavors of tomato fruits are related to the reducing sugars (glucose and fructose) and organic acids such as citric and malic acids. These flavors are essential quality factors for consumers of the fresh fruit and for the processing industry. The color value also plays an important role in the exterior quality of the tomato fruit and impacts consumer preference (Stevens and Rick, 1986). Overall tomato quality for fresh consumption is determined by several factors including size, color, firmness, flavor, and nutritional properties.

The quantity and composition of beneficial compounds present in tomato vary significantly depending on various plant specific factors and environmental conditions. Antioxidant properties of the fruit are influenced by genotype, degree of ripening, soil and climate conditions, part of the fruit, light, temperature, growing season, agricultural practices, and postharvest conditions (Kotikova et al., 2011; Oms-Oliu et al., 2011; Kubota et al., 2012; Vallverdu-Queralt et al., 2012; Tinyane et al., 2013; Kuscu et al., 2014; Vinha et al., 2014; Riga, 2015). Of these factors, genotype is one of the most important for determining the quantity of phytochemicals, and consequently for the overall quality of the tomato fruit. Several studies have investigated the effect of genotype on phytochemical constituent values, quality attributes, and antioxidant activities in tomatoes with different origins, including those from India (Kaur et al., 2013; Kavitha et al., 2014), Italy (Erba et al., 2013), China (Li et al.; 2013), and the USA (Breksa III et al., 2015). Information about the nutritional quality of Korean tomatoes is limited (Choi et al., 2014). Furthermore, comparison of several phytochemicals and color attributes are yet to be assessed in detail in cherry and regular tomato varieties. The main aim of this study was to describe the nutritional value, quality parameters, and antioxidant activities of several commercial varieties of tomato commonly grown in South Korea. We selected 20 commercial cultivars, analyzed their carotenoid, vitamin C, flavonoid, and total polyphenols content, and calculated the total antioxidant activity. The results of this study provide useful information for breeders and farmers to select tomato cultivars with high quality and improved nutritional value.

Materials and Methods

Plant Materials and Cultivation

A total of 20 tomato cultivars were used in this study: seven cultivars with regular tomato fruit (Dafnis, Daylos, Lezaforta, Madison, Seyran, Tamesis, and TY-Altorang) and thirteen cultivars of cherry tomato with small fruit (Betatniy, Jicored, Minimaru, Olleh TY, Titi-Chal, TY-605, TY-Endorphin, TY-Miracle, Rubyking, TY-SenseQ, TY-Tinny, Unicon, and YoYo). Tomato seeds were obtained from Korean seed companies as described in Table 1. The seeds were sown on plug trays on April 5, 2015, and 35-day-old seedlings were transplanted to a greenhouse at the Chonbuk National University, Korea, with a planting distance of 50 x 90 cm. A drip irrigation system was used to supply water to the plants during the experiment. Fertilizer and pesticides were applied according to standard culture practices. During the experiment, no incidence of diseases was observed. Simple pruning management was carried out each morning with nylon strips used to train the plants for straight growth. Plants were grown until fruits had developed on the sixth cluster, whereupon topping was done above this cluster to prevent further growth. Mature fruits were harvested in August, 2015, and 1.5 kg samples were collected from each cultivar for qualitative measurements and phytochemical analysis. Color attributes were evaluated within 6 h of harvest. Vitamin C, total soluble solids, carotenoids, titratable acidity, and pH were measured on a fresh weight basis. The samples were ground into fine powder in liquid nitrogen, freeze dried, and stored at -80°C for subsequent analyses of total phenols, flavonoid profile, and antioxidant activity.

Table 1. Details about tomato cultivars grown in the greenhouse.

SN	Cultivar	Tomato type	Company	City
1	Dafnis	Regular	Mifkoseed	Hanam
2	Daylos	Regular	Syngenta	Seoul
3	Lezaforta	Regular	Mifkoseed	Hanam
4	Madison	Regular	Syngenta	Seoul
5	Seyran	Regular	Bayer	Anseong
6	Tamesis	Regular	Bayer	Anseong
7	TY-Altorang	Regular	Nongwoobio	Suwon
8	Betatniy	Cherry	n/a[z]	n/a
9	Jicored	Cherry	Ganaseed	Gwanju
10	Minimaru	Cherry	Nongwoobio	Suwon
11	Olleh TY	Cherry	Monsanto	Seoul
12	Rubyking	Cherry	Bunong	Suwon
13	Titi-Chal	Cherry	Nongwoobio	Suwon
14	TY-605	Cherry	Bunong	Suwon
15	TY-Endorphin	Cherry	Bunong	Suwon
16	TY-Miracle	Cherry	Bunong	Suwon
17	TY-SenseQ	Cherry	Nongwoobio	Suwon
18	TY-Tinny	Cherry	PPS	Yeoju
19	Unicon	Cherry	Dongbu	Nonsan
20	YoYo	Cherry	Konong	Busan

[z]n/a: Not available.

Determination of Quality Attributes

Tomato fruits were analyzed for color attributes, total soluble solids (TSS), titratable acidity (TA), and pH. Color was measured according to the International Commission on Illumination using a Konica Minolta CM 2002 spectrophotometer (Konica Minolta, Inc., Osaka, Japan). Three measurements were taken for each fruit (one on the blossom end and two in the equatorial region on each half of the tomato) and values were recorded for lightness (L), redness (a), yellowness (b), hue (h), and chroma (c). The mean value for each parameter was derived from the three measured locations for ten tomato fruits of each genotype. Furthermore, fresh fruits were homogenized, filtered through Whatman No. 2 filter paper, and the filtrate was used to measure TSS, TA, and pH. TSS was measured with a hand-held refractometer (Atago, Tokyo, Japan) calibrated with distilled water. TA was determined from a 10 mL aliquot using a direct titration method. The aliquot was diluted 10-fold with distilled water, stirred for 5 min, and titrated with 0.1 M NaOH using an EasyPlus Titrator (Mettler Toledo Inc., Greifensee, Switzerland). The results were expressed as a percentage of citric acid (mg of citric acid per 100 g of sample). The pH value of the aliquot was measured using a pH meter (HM-30P; DKK-TOA Corporation, Tokyo, Japan).

Analysis of Carotenoids

Lycopene and β-carotene contents were measured according to the method described by Nagata and Yamashita (1992). Briefly, 10 g of fresh tomato paste was extracted with 25 mL of acetone:hexane solution (2:3, v/v), the mixture was centrifuged, and the absorbance of the supernatant was measured at 453, 505, 645, and 663 nm using a microplate spectrophotometer (Multiskan GO; Thermo Scientific Inc., Waltham, MA, USA). The β-carotene and lycopene content in a sample were expressed in milligrams per 100 grams of fresh sample and calculated according to the following equations:

$$\beta\text{-carotene } (mg \cdot 100\ mL^{-1}) = 0.216 \times A663 - 1.220 \times A645 - 0.304 \times A505 + 0.452 \times A453,$$

$$\text{lycopene } (mg \cdot 100\ mL^{-1}) = -0.0458 \times A663 + 0.204 \times A645 - 0.304 \times A505 + 0.452 \times A453.$$

Analysis of Vitamin C

Vitamin C content was analyzed according to the methods described by Spinola et al. (2012) with modifications. Tomato fruits were ground into a fine paste and 5 g of the paste was extracted with 5% metaphosphoric acid solution. After the centrifugation and filtration of the extract (through a 0.20-μm syringe filter), the aliquot was analyzed using an 1260 Infinity HPLC system (Agilent Technologies, Santa Clara, CA, USA) equipped with an Acquity UPLC HSS T3 column (2.1 × 100 mm, 1.8 μm; Waters, Milford, MA, USA) and a diode array detector at 254 nm wavelength. An isocratic mobile phase composed of aqueous 0.1% (v/v) formic acid was used for the separation of the ascorbic acid peak at a flow rate of 0.3 $mL \cdot min^{-1}$. An authentic ascorbic acid standard at various concentrations (5–100 ppm) was used for the identification and quantification of the peak. The vitamin C content was calculated using the calibration curve ($y = 95.195x + 78.151$; $R^2 = 0.9993$), and the results were expressed as $mg \cdot 100\ g^{-1}$ of fresh weight.

Measurement of Total Phenolic Content

Total phenolic content was estimated using the Folin-Ciocalteu colorimetric method, using gallic acid as the standard phenolic compound, according to the protocol described by Singleton and Rossi (1965). Freeze-dried powdered samples (0.05 g) were extracted with 80% methanol for 1 h at 50°C in a water bath. The extracts were centrifuged and filtered

through 0.45-μm syringe filters and 200 μL of each supernatant was mixed with 0.6 mL distilled water in 1.5-mL centrifuge tubes. After adding 200 μL Folin's reagent, the solutions were incubated in a water bath at 27°C for 5 min followed by the addition of 200 μL of saturated sodium carbonate. After 1 h, absorbance of the extracts was measured at 760 nm using a microplate spectrophotometer (Multiskan GO; Thermo Scientific Inc., Waltham, MA, USA) and 80% methanol as a blank. Gallic acid standards of various concentrations (5.0–100.0 ppm) were used to calculate the standard curve ($y = 0.0084x + 0.1073$; $R^2 = 0.9992$), and total phenol content was expressed as milligrams of gallic acid equivalents (GAE) per 100 grams (mg GAE·100 g^{-1}) of dry weight.

Analysis of Flavonoids

Flavonoid analysis (of the four flavonols: kaempferol, quercetin, rutin, and myricetin; two flavones: luteolin and apigenin; and one flavanone: naringenin) was conducted following the method described by Hertog et al. (1992) with some modifications. Lyophilized tomato samples (0.05 g) were extracted for 2 h at 80°C with 50% methanol containing 1.2 M HCl and 0.4 g L^{-1} t-butyl hydroquinone. After cooling to room temperature, samples were centrifuged at 4,000 rpm for 10 min, diluted 10-fold with methanol, and filtered through a 0.2-μm syringe filter; 20 μL of the filtrate was analyzed using a 1260 Infinity HPLC system (Agilent Technologies, USA) equipped with a quaternary HPLC pump, autosampler, and diode array detector. Separation was performed in a Nova-Pak C18 4 μm column (3.9 × 150 mm) (Waters, USA) at 210 nm wavelength. The mobile phase consisted of isocratic 25% acetonitrile in 0.025 M KH_2PO_4 at a flow rate of 0.9 mL·min^{-1}. Identification and quantification of individual flavonoids was carried out using commercial standards with the linear range of 0.5-10.0 ppm. All the analyses were performed in triplicate and the results were expressed as milligrams per gram (mg·g^{-1}) of dry weight.

Measurement of Antioxidant Activities

Free Radical Scavenging Activity using DPPH Assay

The 2,2,-diphenyl-1-picrylhydrazyl (DPPH) assay is typically used to measure the scavenging ability of antioxidants toward the stable radical DPPH. This assay was performed according to the methods described by Koleva et al. (2002) with modifications. Briefly, 400 μM DPPH solution was prepared in 80% methanol and 100 μL was mixed with 100 μL of extract (50 mg sample extracted in 1.5 mL 80% MeOH) in 96-well plates. After 30 min, in the dark, at room temperature, absorbance was measured at 517 nm in a microplate spectrophotometer (Multiskan GO; Thermo Scientific Inc., Waltham, MA, USA) using 80% methanol without DPPH as a blank. Similarly, absorbance was measured by mixing 100 μL of sample with 100 μL of 80% methanol. Free-radical-scavenging activity (%) was calculated using the following equation:

$$\% \text{ DPPH radical-scavenging activity} = (B - A) \quad 100/B$$

Where, A is the absorbance of [(Sample + DPPH) – (Sample + Methanol)] and B is the absorbance of [(Methanol + DPPH) – (Methanol)].

Different concentrations of (±)-6-hydroxy-2,5,7,8-tetramethylchromane-2-carboxylic acid (trolox) (100-1,000 μmol) were used as a standard compound to calculate the standard curve ($y = -0.001x + 1.0862$; $R^2 = 0.9966$). Results were expressed as trolox equivalent antioxidant capacity per gram dry weight (μmol TE·g^{-1}).

Determination of 2,2'-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid) (ABTS) Assay

A 50-mg lyophilized sample was used to determine antioxidant activity after extraction with 1.5 mL of 80% MeOH for 1 h, followed by filtration. The ABTS assay was performed following the method described by Re et al. (1999) with slight modifications. First, ABTS radical cation ($ABTS^{*+}$) was produced by reacting 7 mM ABTS solution with 2.45 mM potassium persulfate in the dark, at room temperature, for 16 h. The $ABTS^{*+}$ solution was then diluted with methanol to an absorbance of 0.9 ± 0.02 at 734 nm. The sample extract (50 μL) was then added to 950 μL of $ABTS^{*+}$ solution and the absorbance was measured at 734 nm after 2 h of incubation in the dark using a micro plate spectrophotometer (Multiskan GO; Thermo Scientific Inc., Waltham, MA, USA). Different concentrations of trolox (100-1,000 μmol) were used as a standard to calculate the standard curve ($y = -0.001x + 1.0862$; $R^2 = 0.9966$). Results were expressed as trolox equivalent antioxidant capacity per dry weight (μmol TE·g^{-1}).

Determination of the Ferric Reducing Antioxidant Power (FRAP) Assay

The FRAP assay was performed according to the method described by Benzie and Strain (1996) with slight modifications. Stock solutions consisted of: 300 mM acetate buffer (3.1 g $C_2H_3NaO_2 \cdot 3H_2O$ and 16 mL $C_2H_4O_2$ pH 3.6), 10 mM 2,4,6-Tris (2-pyridyl)-s-triazine (TPTZ) solution in 40 mM HCl, and 20 mM $FeCl_3 \cdot 6H_2O$ solution. A fresh working solution was prepared by mixing acetate buffer, TPTZ solution, and $FeCl_3 \cdot 6H_2O$ solution in 10:1:1 ratio (v/v/v) just prior to use. Tomato extracts (50 μL) from 50 mg sample in 1.5 mL^{-1} 80% MeOH were allowed to react with 950 μL of the FRAP solution for 10 min at 37°C. Readings of the colored product were then taken at 593 nm using a microplate spectrophotometer (Multiskan GO; Thermo Scientific Inc., Waltham, MA, USA). Different concentrations of trolox (100–1,000 μmol) were used to calculate the standard curve ($y = 0.013x + 0.0681$; $R^2 = 0.9999$). Results were expressed in trolox equivalent antioxidant capacity per dry weight (μmol TE·g^{-1}).

Chemicals and Reagents

Authentic standards, for L-ascorbic acid, DPPH, gallic acid, trolox, kaempferol, quercetin, rutin, myricetin, luteolin, apigenin and (±)-naringenin, and also chemicals, including sodium hydroxide, sodium carbonate, potassium dihydrogen phosphate (KH_2PO_4), *tert*-butylhydroquinone (TBHQ), sodium acetate, Folin-Ciocalteu reagent, TPTZ, ferric chloride hexahydrate, potassium persulfate, and ABTS, were purchased from Sigma Aldrich (St. Louis, MO, USA). Metaphosphoric acid was purchased from Daejung Chemicals & Materials Co. (Siheung, Gyeonggido, Korea). Other chemicals including glacial acetic acid, acetonitrile (HPLC grade), methanol (HPLC grade), n-hexane (HPLC grade), acetone (HPLC grade), HCl (ACS reagent), and formic acid (ACS reagent) were purchased from J.T. Baker (Phillipsburg, NJ, USA).

Statistical Analyses

Color attributes were presented as a mean ± SD of 10 replications. Other parameters were presented as a mean ± SD of three replications. Statistical analysis was performed using SPSS version 20 (IBM Corp., Armonk, NY, USA). Analysis of variance followed by Duncan's multiple range test (DMRT) was used to assess statistical differences among the means at $p < 0.05$.

Results and Discussion

Quality Characteristics and Color Attributes

TSS are the key determinants of shelf life and crop quality in both fresh produce and processing tomatoes. TSS significantly contribute to tomato flavor and consistency and are related to the amount of sugars, mainly glucose and fructose, present in the fruit. TSS also impact sensory attributes, such as taste, sweetness, and acidity. TSS ranged from 4.10 °Brix in Tamesis to 8.77 °Brix in Rubyking (Table 2). The values observed in this study were similar to those reported by Kavitha et al. (2014) in their analysis of 54 tomato genotypes from India. All cherry tomato cultivars, in our study, exhibited higher levels of TSS (6.47 to 8.77 °Brix) than regular tomato cultivars, similar to observations by Causse et al. (2001). These TSS levels are higher than those observed in 10 cherry tomato varieties from India where TSS contents ranged from 4.66 to 5.86 °Brix (Kaur et al., 2013), suggesting that Korean cherry tomatoes are of high quality. TSS content among tomato fruits from regular varieties was relatively uniform and ranged from 4.10 to 5.13 °Brix in our study. The average pH value across all varieties was 4.44, ranging from 4.27 to 4.53. Acids are important factors that govern microbial stability and influence the processing time and temperature during preparation of tomato products. In this study, the acidity among the cultivars ranged from 0.17% to 0.27%, which was lower than that reported by Kaur et al. (2013) and Breksa III et al. (2015) and within the range of acidity reported by Vinha et al. (2014). The observed differences in TSS, pH, and acidity were likely due to different genotypes and growing conditions. TSS and TA are important for the processing industry because sugars and acids are important constituents of flavor in tomatoes, thus cherry tomato cultivars with higher TSS and acidity are most desirable for processing. Fruit color is a quality characteristic that has received considerable attention from fresh-market consumers

Table 2. Total soluble solids, pH, and acidity of selected tomato cultivars.

Cultivar	Category	TSS (°Brix)	pH	Acidity (%)
Dafnis	RT	4.47 ± 0.25[z] ab[y]	4.53 ± 0.06 i	0.18 ± 0.01 bc
Daylos	RT	4.67 ± 0.12 b	4.39 ± 0.02 b-d	0.25 ± 0.01 ij
Lezaforta	RT	4.20 ± 0.26 a	4.48 ± 0.02 h	0.17 ± 0.00 a
Madison	RT	4.77 ± 0.06 bc	4.58 ± 0.02 i	0.19 ± 0.00 c
Seyran	RT	4.20 ± 0.10 a	4.45 ± 0.05 e-h	0.17 ± 0.00 a
Tamesis	RT	4.10 ± 0.10 a	4.45 ± 0.01 e-h	0.18 ± 0.01 ab
TY-Altorang	RT	5.13 ± 0.06 c	4.27 ± 0.08 a	0.18 ± 0.01 ab
Betatniy	CT	6.47 ± 0.25 de	4.40 ± 0.04 b-e	0.24 ± 0.01 g-i
Jicored	CT	8.57 ± 0.40 i	4.56 ± 0.01 i	0.22 ± 0.00 d-f
Minimaru	CT	7.93 ± 0.15 h	4.41 ± 0.01 b-g	0.23 ± 0.01 e-g
Olleh TY	CT	6.87 ± 0.40 e-g	4.43 ± 0.01 c-h	0.22 ± 0.01 de
Rubyking	CT	8.77 ± 0.25 i	4.30 ± 0.04 a	0.27 ± 0.01 k
Titi-Chal	CT	6.93 ± 0.15 fg	4.46 ± 0.05 f-h	0.21 ± 0.01 d
TY-605	CT	6.80 ± 0.26 ef	4.35 ± 0.03 b	0.24 ± 0.01 h-j
TY-Endorphin	CT	7.93 ± 0.40 h	4.47 ± 0.01 g-h	0.23 ± 0.00 fg
TY-Miracle	CT	6.07 ± 0.21 d	4.45 ± 0.03 e-h	0.25 ± 0.01 j
TY-SenseQ	CT	7.27 ± 0.29 g	4.54 ± 0.01 i	0.22 ± 0.01 de
TY-Tinny	CT	7.27 ± 0.35 g	4.44 ± 0.01 d-h	0.22 ± 0.01 de
Unicon	CT	7.70 ± 0.17 h	4.37 ± 0.02 bc	0.25 ± 0.01 ij
YoYo	CT	6.53 ± 0.23 ef	4.41 ± 0.02 b-g	0.23 ± 0.01 gh

[z]Values are mean ± SD of three replicates. RT: regular tomatoes; CT: cherry tomatoes; TSS: total soluble solids.
[y]Values with the same letters within the column are not statistically significantly different by Duncan's multiple range test at $p < 0.05$.

Table 3. Color attributes of selected tomato cultivars.

Cultivar	Category	Lightness (L)	Redness (a)	Yellowness (b)	Chroma (c)	Hue (h)
Dafnis	RT	36.3 ± 2.5[z] e[y]	29.0 ± 2.2 gh	25.0 ± 1.7 de	37.7 ± 2.2 gh	38.8 ± 3.5 b-e
Daylos	RT	35.4 ± 1.4 e	31.4 ± 1.0 i	24.1 ± 1.7 d	39.3 ± 1.2 hi	36.8 ± 1.5 bc
Lezaforta	RT	35.6 ± 0.7 e	28.6 ± 1.0 fg	23.6 ± 1.1 d	37.1 ± 1.3 fg	39.5 ± 1.2 b-e
Madison	RT	37.7 ± 1.6 f	27.0 ± 2.3 e-g	27.0 ± 2.2 f	37.8 ± 3.1 gh	43.9 ± 3.1 f
Seyran	RT	38.1 ± 1.9 fg	31.6 ± 1.8 i	26.3 ± 2.3 ef	41.3 ± 1.7 i	39.7 ± 3.2 c-e
Tamesis	RT	39.0 ± 1.9 g	31.0 ± 2.7 hi	29.6 ± 2.9 g	43.1 ± 1.5 i	43.8 ± 4.9 f
TY-Altorang	RT	38.6 ± 2.5 fg	24.4 ± 2.5 b-d	13.8 ± 1.2 a	28.1 ± 2.9 a	29.4 ± 3.6 a
Betatniy	CT	32.5 ± 0.8 a-c	24.5 ± 2.3 b-d	19.6 ± 2.1 bc	31.4 ± 2.7 c	38.7 ± 2.8 b-e
Jicored	CT	35.2 ± 1.0 e	28.5 ± 1.8 fg	20.8 ± 1.6 c	35.3 ± 2.4 ef	36.2 ± 1.1 b
Minimaru	CT	33.6 ± 1.2 c-d	24.7 ± 2.1 d	20.3 ± 1.5 c	32.1 ± 2.0 cd	39.6 ± 2.7 b-e
Olleh TY	CT	32.9 ± 1.1 a-d	24.3 ± 2.1 b-d	19.1 ± 1.7 bc	31.0 ± 1.2 bc	38.3 ± 4.6 b-e
Rubyking	CT	33.0 ± 0.9 a-d	22.2 ± 1.7 ab	19.0 ± 1.2 bc	29.3 ± 1.4 ab	40.6 ± 3.0 d-e
Titi-Chal	CT	32.9 ± 1.1 a-d	25.0 ± 3.3 de	19.3 ± 1.9 bc	31.7 ± 3.5 c	37.9 ± 3.0 b-d
TY-605	CT	32.0 ± 0.7 a	22.4 ± 2.5 a-c	17.9 ± 1.3 b	28.7 ± 2.5 a	38.8 ± 2.7 b-e
TY-Endorphin	CT	33.3 ± 0.5 a-d	24.6 ± 2.4 cd	20.1 ± 0.9 c	31.9 ± 1.9 cd	39.5 ± 3.1 b-e
TY-Miracle	CT	32.2 ± 0.5 ab	22.2 ± 1.7 ab	18.1 ± 1.0 b	28.7 ± 1.4 a	39.3 ± 2.7 b-e
TY-SenseQ	CT	33.4 ± 0.4 b-d	24.5 ± 2.7 b-d	19.1 ± 0.9 bc	31.2 ± 2.2 bc	38.7 ± 3.6 b-e
TY-Tinny	CT	33.7 ± 1.0 cd	24.9 ± 2.9 de	20.1 ± 1.7 c	31.9 ± 2.5 cd	39.4 ± 4.1 b-e
Unicon	CT	34.0 ± 1.0 d	26.5 ± 2.6 d-f	20.4 ± 2.6 c	34.0 ± 1.4 de	38.6 ± 4.6 b-e
YoYo	CT	33.3 ± 1.3 a-d	21.3 ± 2.1 a	19.2 ± 2.2 bc	28.9 ± 2.4 a	41.7 ± 2.9 ef

[z]Values are the mean ± SD of 10 measurements RT: regular tomato; CT: cherry tomato.
[y]Means followed by the same superscripts are not significantly different using DMRT at $p < 0.05$.

as well as tomato processing industries. Tomato fruit color is the total amount and proportion of different carotenoids and is an important indicator of ripeness. In this study, L (lightness) values ranged from 32.0 to 38.6, a (redness) values ranged from 21.3 to 31.6, and b (yellowness) values ranged from 13.8 to 27.0 (Table 3). Chroma (c), representing the vividness of color, is a good indicator of consumer acceptance. This trait showed significant variation ($p < 0.05$ using DMRT) among the cultivars, with regular cultivars generally exhibiting higher color intensity values compared to the cherry tomato cultivars.

Carotenoid Contents

Analysis of carotenoid contents revealed that lycopene content was higher than β-carotene levels (Table 4). The lycopene and β-carotene contents varied significantly ($p < 0.05$ using DMRT) among the cultivars with lycopene content varied from 0.95 mg·100 g^{-1} in Daylos to 5.12 mg·100 g^{-1} in YoYo, and β-carotene content ranged from 0.65 mg·100 g^{-1} in Madison to 3.56 mg·100 g^{-1} in Rubyking. The carotenoid levels observed in the present study were similar to those reported by Kavitha et al. (2014), and higher than those reported by Pinela et al. (2012) and Tinyane et al. (2013). In contrast, the values obtained by Kotikova et al. (2011) were much higher compared to those reported herein, which might be due to differencest in varieties and growing conditions (Kuscu et al., 2014). Of the two carotenoids, lycopene exhibited higher overall cultivar-dependent variation, in line with observations by Taber et al. (2008) who also observed lycopene content influenced by genotype. Furthermore, almost all cherry tomato cultivars exhibited statistically higher lycopene and β-carotene content as compared to regular tomato varieties, suggesting higher nutritional value of cherry tomatoes.

Table 4. Variation in carotenoids (mg ·100 g^{-1} fresh weight) and vitamin C (mg ·100 g^{-1} fresh weight) in tomato cultivars.

Cultivar	Category	Lycopene	β-carotene	Total carotenoid	Vitamin C
Dafnis	RT	2.76 ± 0.10[z] e[y]	0.81 ± 0.05 b	3.57 ± 0.15 f	9.01 ± 0.57 bc
Daylos	RT	0.95 ± 0.13 a	0.68 ± 0.05 ab	1.63 ± 0.19 a	10.63 ± 0.36 ef
Lezaforta	RT	2.01 ± 0.04 c	0.69 ± 0.01 ab	2.70 ± 0.03 bc	8.59 ± 0.66 ab
Madison	RT	1.80 ± 0.07 b	0.65 ± 0.02 a	2.45 ± 0.09 b	10.89 ± 0.70 f
Seyran	RT	2.46 ± 0.06 d	0.83 ± 0.04 b	3.29 ± 0.10 e	9.53 ± 0.12 cd
Tamesis	RT	1.77 ± 0.08 b	0.83 ± 0.04 b	2.60 ± 0.10 b	8.26 ± 0.27 a
TY-Altorang	RT	2.15 ± 0.07 c	0.76 ± 0.09 ab	2.91 ± 0.16 cd	10.02 ± 0.12 de
Betatniy	CT	3.24 ± 0.03 f	1.47 ± 0.05 e	4.71 ± 0.07 g	22.54 ± 0.39 l
Jicored	CT	4.92 ± 0.08 i-k	2.87 ± 0.11 j	7.79 ± 0.15 kl	20.30 ± 0.41 j
Minimaru	CT	2.56 ± 0.17 d	1.20 ± 0.07 d	3.76 ± 0.22 f	20.62 ± 0.03 jk
Olleh TY	CT	3.70 ± 0.08 g	1.64 ± 0.08 f	5.35 ± 0.05 h	19.22 ± 0.45 i
Rubyking	CT	5.01 ± 0.10 k	3.56 ± 0.09 l	8.57 ± 0.04 m	19.02 ± 0.05 i
Titi-Chal	CT	4.98 ± 0.04 i-k	2.00 ± 0.10 g	6.98 ± 0.13 i	20.07 ± 0.39 j
TY-605	CT	4.76 ± 0.06 hi	2.70 ± 0.12 i	7.46 ± 0.10 j	22.06 ± 0.49 i
TY-Endorphin	CT	5.01 ± 0.16 k	2.92 ± 0.12 jk	7.92 ± 0.22 l	9.66 ± 0.39 cd
TY-Miracle	CT	4.57 ± 0.19 h	3.04 ± 0.05 k	7.62 ± 0.22 jk	18.79 ± 0.09 i
TY-SenseQ	CT	2.02 ± 0.07 c	0.98 ± 0.02 c	3.00 ± 0.05 d	21.07 ± 0.10 k
TY-Tinny	CT	3.33 ± 0.19 f	1.39 ± 0.08 e	4.71 ± 0.26 g	16.52 ± 0.48 h
Unicon	CT	4.80 ± 0.22 ij	3.54 ± 0.17 l	8.34 ± 0.36 m	17.03 ± 0.08 h
YoYo	CT	5.12 ± 0.09 k	2.28 ± 0.14 h	7.40 ± 0.22 j	12.51 ± 0.25 g

[z]Values are mean ± SD of three replicates. RT: regular tomatoes; CT: cherry tomatoes.
[y]Values with the same letters within the column are not statistically different using Duncan's multiple range test at $p < 0.05$.

Vitamin C Content

Vitamin C is a powerful water-soluble antioxidant that plays an important role in the suppression of free radicals. In this study, vitamin C content showed significant differences among the cultivars ($p < 0.05$ using DMRT), ranging from 8.26 mg·100 g^{-1} in Tamesis to 22.54 mg·100 g^{-1} in Betatniy (Table 4). All cherry tomato cultivars, except the cultivar TY-Endorphin, exhibited statistically higher vitamin C content compared to regular tomatoes. The vitamin C content in most of the cherry tomato cultivars was similar to that reported by Pinela et al. (2012) but lower than levels reported by Kaur et al. (2013) and Vinha et al. (2014). These differences in vitamin C content might be explained by light and temperature variations or by genotype. The higher vitamin C levels found in cherry tomato varieties further validate the higher nutrition in cherry over the regular tomato varieties evaluated in this study.

Total Phenol Content

Phenolic compounds are important secondary metabolites that possess various biological activities, most importantly antioxidant activity associated with reduced cancer risk (Manach et al., 2005). Total phenolic compounds, expressed as GAE, correspond to the mean response of all major phenolic compounds present in fruits and vegetables (George et al., 2005). The total phenol content measured in this study averaged 218.7 mg GAE·100 g^{-1}, but varied significantly from 168.2 mg GAE·100 g^{-1} in Seyran to 290.7 mg GAE·100 g^{-1} in TY 605 (Fig. 1). All cherry tomato cultivars had statistically higher ($p < 0.05$ using DMRT) total phenol content than regular varieties with the exception of Betatniy and YoYo. The overall genotypic variation for phenols was lower than that observed for carotenoids but higher than that of vitamin C content.

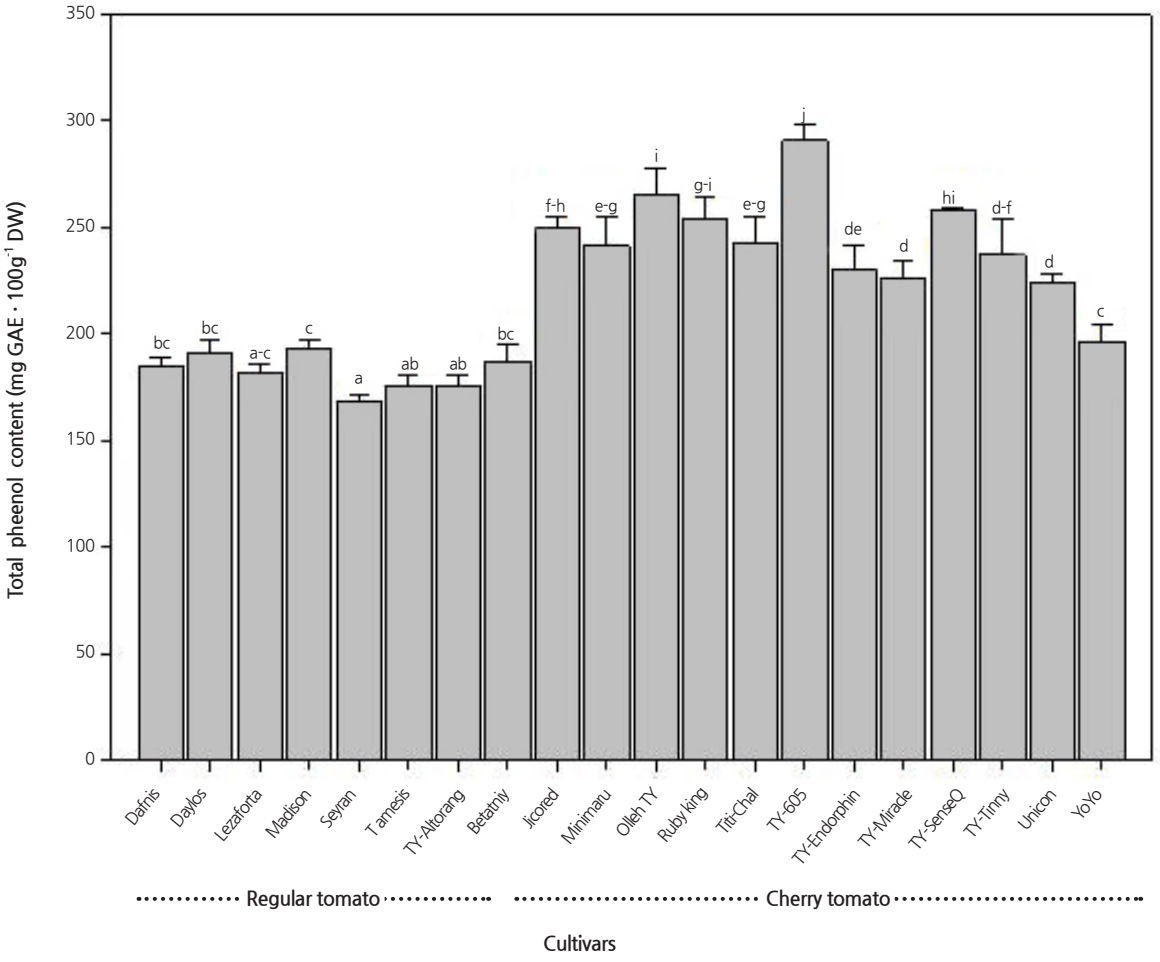

Fig. 1. Total phenol content in selected tomato cultivars. Each bar represents value of mean ± SD of three replicates. Different letters show statistically significant differences by Duncan's multiple range test at $p < 0.05$. DW: dry weight.

Overall, the total phenol content was comparable to that reported by Kavitha et al. (2014). However, lower phenol values were also reported by Tinyane et al. (2013) which might be due to genotype differences, agricultural practices, or environmental conditions. Similar to vitamin C and carotenoids, we found a statistically higher ($p < 0.05$ using DMRT) total phenol content in cherry tomato cultivars, suggesting their higher nutritional value and superior quality. Further quantitative studies of individual phenolic compounds are needed to confirm the contribution of each phenolic compound to total phenol content.

Flavonoid Content

Flavonoids are important plant secondary metabolites that possess strong antioxidant activity due to their ability to scavenge reactive oxygen species and thus decrease oxidative stress (Pourcel et al., 2006; Koh et al., 2009). The varietal differences in individual, as well as total, flavonoid content are presented in Table 5. Quercetin, the predominant flavonoid component identified in this study, varied from 0.86 mg·g^{-1} in Daylos to 1.24 mg·g^{-1} in TY-Endorphin. Rutin and naringenin were the second and third most abundant flavonoids, respectively, while luteolin was least abundant, and absent in some cultivars. The observed flavonoid amounts were higher than those reported by Kalogeropoulos et al. (2012). The total

Table 5. Variation in flavonoid contents (mg·g^{-1} dry weight) in tomato cultivars.

Cultivar	Category	Luteolin	Naringenin	Quercetin	Rutin	Total flavonoid
Dafnis	RT	0.16 ± 0.01^{z} a^{y}	0.07 ± 0.00 bc	0.94 ± 0.06 ab	0.72 ± 0.06 d	1.88 ± 0.04 c
Daylos	RT	0.15 ± 0.00 a	0.15 ± 0.02 e	0.86 ± 0.06 a	0.56 ± 0.05 ab	1.71 ± 0.09 a
Lezaforta	RT	0.15 ± 0.01 a	0.09 ± 0.01 d	0.98 ± 0.05 bc	0.65 ± 0.01 c	1.87 ± 0.04 bc
Madison	RT	0.15 ± 0.01 a	0.25 ± 0.01 i	0.88 ± 0.03 ab	0.54 ± 0.07 a	1.82 ± 0.10 a-c
Seyran	RT	ND	0.09 ± 0.01 cd	1.09 ± 0.02 de	0.56 ± 0.04 ab	1.74 ± 0.04 ab
Tamesis	RT	0.17 ± 0.01 b	0.19 ± 0.01 f	0.89 ± 0.09 ab	0.51 ± 0.03 a	1.76 ± 0.11 a-c
TY-Altorang	RT	0.15 ± 0.01 a	0.01 ± 0.00 a	0.90 ± 0.11 ab	0.62 ± 0.03 b	1.68 ± 0.10 a
Betatniy	CT	0.18 ± 0.00 b	0.06 ± 0.01 b	1.20 ± 0.03 gh	0.67 ± 0.02 cd	2.11 ± 0.03 d
Jicored	CT	0.15 ± 0.01 a	0.26 ± 0.02 ij	1.23 ± 0.01 h	0.83 ± 0.00 ef	2.48 ± 0.02 fg
Minimaru	CT	0.15 ± 0.00 a	0.28 ± 0.01 jk	1.13 ± 0.03 e-h	0.88 ± 0.05 fg	2.44 ± 0.05 f
Olleh TY	CT	0.15 ± 0.01 a	0.41 ± 0.03 o	1.10 ± 0.03 d-f	0.98 ± 0.04 i	2.65 ± 0.09 h
Rubyking	CT	ND	0.30 ± 0.01 kl	1.14 ± 0.10 e-h	0.98 ± 0.07 i	2.42 ± 0.12 f
Titi-Chal	CT	0.16 ± 0.01 a	0.31 ± 0.03 l	1.18 ± 0.03 f-h	0.95 ± 0.02 hi	2.59 ± 0.06 gh
TY-605	CT	ND	0.21 ± 0.00 h	1.21 ± 0.08 gh	1.07 ± 0.02 j	2.50 ± 0.10 fg
TY-Endorphin	CT	ND	0.33 ± 0.02 m	1.24 ± 0.02 h	1.01 ± 0.02 i	2.58 ± 0.05 gh
TY-Miracle	CT	0.22 ± 0.01 c	0.39 ± 0.02 n	1.04 ± 0.07 cd	0.85 ± 0.02 fg	2.51 ± 0.09 f-h
TY-SenseQ	CT	0.15 ± 0.01 a	0.43 ± 0.02 o	1.10 ± 0.05 d-f	0.86 ± 0.02 fg	2.54 ± 0.03 f-h
TY-Tinny	CT	0.16 ± 0.02 a	0.30 ± 0.01 l	1.15 ± 0.02 f-h	0.91 ± 0.02 gh	2.52 ± 0.03 f-h
Unicon	CT	ND	0.31 ± 0.01 l	1.10 ± 0.09 d-f	0.67 ± 0.04 cd	2.09 ± 0.13 d
YoYo	CT	0.16 ± 0.00 a	0.20 ± 0.01 gh	1.15 ± 0.04 e-h	0.79 ± 0.02 e	2.29 ± 0.06 e

^{z}Values are mean ± SD of three replicates. RT: regular tomatoes; CT: cherry tomatoes; ND: not detected.
^{y}Values with the same letters within the column are not statistically different using Duncan's multiple range test at $p < 0.05$.

flavonoid content significantly varied ($p < 0.05$ using DMRT) among the cultivars, ranging from 1.71 mg·g^{-1} in Daylos to 2.65 mg·g^{-1} in Olleh TY. All cherry tomato cultivars exhibited statistically ($p < 0.05$ using DMRT) higher individual, as well as total, flavonoid content than regular fruit cultivars, suggesting higher nutritional value of the cherry tomatoes. Furthermore, this is the first report to address the genotypic variation in both individual and total flavonoid content among tomato cultivars grown in South Korea.

Antioxidant Activity and Reducing Power of Tomato Extracts

Antioxidant capacity, the ability to inhibit the process of oxidation, is an important parameter in the health benefits of food products. Antioxidant activity of tomato extracts were evaluated using both DPPH and ABTS tests, to ensure antioxidant activity was sufficiently described. Methanol extract was used for the antioxidant evaluation because it shows higher antioxidant capacity as compared to other extracts (Kotikova et al., 2011). The free radical scavenging activity determined by the DPPH test varied significantly ($p < 0.05$ using DMRT) from 8.71 μmol TE·g^{-1} to 21.74 μmol TE·g^{-1} on a dry weight basis (Table 6). The differences observed among the regular tomato varieties were not statistically significant ($p < 0.05$ using DMRT). The antioxidant values determined by the ABTS method varied from 46.04 μmol TE·g^{-1} to 61.17 μmol TE·g^{-1}. Both testing methods identified generally higher antioxidant levels in cherry tomato cultivars than their regular variety counterparts. The significantly higher ($p < 0.05$ using DMRT) DPPH values seen in Rubyking, TY-605, Olleh TY, Jicored Titi-chal, Minimaru, and Unicon were likely due to higher phenol and flavonoid content in these cultivars (Nencini et al., 2011). However, the same trend was not observed for the ABTS value in most of the cultivars. Overall, the results suggest

Table 6. Antioxidant activities in tomato cultivars using three assays.

Cultivar	Category	DPPH (μmol·g^{-1} DW)	ABTS (μmol·g^{-1} DW)	FRAP (μmol·g^{-1} DW)
Dafnis	RT	8.71 ± 0.65^{z} a^{y}	51.85 ± 1.93 c-e	14.40 ± 0.36 ^{z} a^{y}
Daylos	RT	9.72 ± 0.38 a	48.77 ± 1.24 a-c	14.96 ± 0.67 a
Lezaforta	RT	9.46 ± 0.35 a	47.59 ± 0.85 a	15.28 ± 0.14 1a
Madison	RT	9.54 ± 0.54 a	51.01 ± 0.87 b-d	14.36 ± 0.87 a
Seyran	RT	9.80 ± 0.38 a	48.25 ± 0.85 ab	14.30 ± 0.25 a
Tamesis	RT	9.59 ± 0.62 a	54.48 ± 1.60 ef	14.34 ± 0.25 a
TY-Altorang	RT	8.84 ± 0.70 a	46.04 ± 0.62 a	15.80 ± 0.32 a
Betatniy	CT	13.92 ± 0.89 b	48.42 ± 1.21 ab	17.82 ± 1.02 b
Jicored	CT	20.73 ± 1.34 h	48.97 ± 1.00 a-c	21.36 ± 0.77 c
Minimaru	CT	17.52 ± 1.54 e-g	51.25 ± 1.88 b-e	20.72 ± 1.36 c
Olleh TY	CT	21.04 ± 0.23 h	52.58 ± 1.71 de	21.05 ± 1.01 c
Rubyking	CT	20.39 ± 1.10 h	57.92 ± 1.69 f	22.91 ± 1.06 d
Titi-Chal	CT	16.47 ± 0.68 de	56.30 ± 1.56 fg	20.90 ± 0.96 c
TY-605	CT	21.74 ± 0.82 h	61.17 ± 1.26 g	22.77 ± 0.51 d
TY-Endorphin	CT	18.10 ± 1.01 fg	53.23 ± 1.16 d-f	20.43 ± 1.12 d
TY-Miracle	CT	15.67 ± 0.39 cd	57.65 ± 1.15 f	18.84 ± 0.48 b
TY-SenseQ	CT	17.20 ± 1.00 ef	53.27 ± 0.72 d-f	21.56 ± 0.49 cd
TY-Tinny	CT	16.61 ± 0.69 de	51.57 ± 2.40 b-e	20.55 ± 1.22 c
Unicon	CT	18.70 ± 0.20 g	51.62 ± 0.47 b-e	20.36 ± 0.34 c
YoYo	CT	14.80 ± 0.94 bc	48.25 ± 5.12 ab	18.14 ± 1.16 b

^{z}Values are mean ± SD of three replicates. RT: regular tomatoes; CT: cherry tomatoes; DW: dry weight.
^{y}Values with the same letters within the column are not statistically difference using Duncan's multiple range test at $p < 0.05$. FRAP - Ferric reducing antioxidant power; ABTS - 2,2'-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid); DPPH - 2,2-diphenyl-1-picrylhydrazyl.

that cherry tomato cultivars possess alleles that can produce higher antioxidant activity.

FRAP, one of the most common methods used for the evaluation of the reducing power of extracts to reduce Fe^{3+} to Fe^{2+}, ranged from 14.30 μmol TE·g^{-1} to 22.91 μmol TE·g^{-1} on a dry weight basis (Table 6). Similar to the DPPH and ABTS assays, all cherry tomato cultivars exhibited statistically higher values of FRAP and higher genotypic variation than regular tomato cultivars. In contrast, no statistical differences ($p < 0.05$ using DMRT) were observed in the regular cultivars and genotypic variation was lower than levels observed in cherry tomato varieties.

Correlation between Antioxidant Activities and Antioxidants

To understand the accumulation pattern of different phytochemicals and their overall contribution to the antioxidant activity, we analyzed the correlations among antioxidants. All phytochemicals, except luteolin, significantly contributed ($p < 0.05$ using DMRT) to the antioxidant properties. Total phenols showed the highest correlation with antioxidant activity according to the FRAP assay (r = 0.930***), followed by rutin (r = 0.885***), vitamin C (r = 0.810***), and quercetin (r = 0.792***) ($p < 0.05$ using DMRT) (Table 7). Strong correlations were also observed between total phenols and antioxidant activity in other plants, including red pepper, broccoli, cauliflower, and garlic (Aires et al., 2011; Bhandari et al., 2013 & 2014). Total phenol content exhibited the highest correlation with the ABTS and DPPH assays. Taken together, all the antioxidants showed a significant ($p < 0.05$ using DMRT) positive correlation with each of the antioxidant assays. All phytochemicals also showed significant correlations to each other, with the exception of luteolin; also, total phenolic

Table 7. Correlation between antioxidant activity and antioxidants.

Antioxidant	Vitamin C	Lycopene	β-carotene	Total carotenoid	Rutin	Quercetin	Luteolin	Naringenin	Total flavonoid	FRAP	ABTS	DPPH
Total phenol	0.769***	0.561*	0.577**	0.581**	0.881***	0.636**	-0.251	0.740**	0.872***	0.930***	0.671**	0.921***
Vitamin C		0.471*	0.475*	0.484*	0.625**	0.660**	0.024	0.515*	0.732***	0.810***	0.446*	0.783***
Lycopene			0.907***	0.983***	0.698**	0.772***	-0.355	0.418	0.694**	0.701**	0.460*	0.743***
β-carotene				0.969***	0.597**	0.642**	-0.464*	0.492*	0.604**	0.710***	0.518*	0.764***
Total carotenoid					0.670**	0.734**	-0.411	0.460*	0.671**	0.721***	0.496*	0.769***
Rutin						0.745***	-0.244	0.613**	0.924***	0.885***	0.625**	0.846***
Quercetin							-0.356	0.392	0.788***	0.792***	0.289	0.802***
Luteolin								-0.044	-0.059	-0.300	-0.270	-0.347
Naringenin									0.786***	0.691**	0.555*	0.705**
Total flavonoid										0.902***	0.553*	0.883***
FRAP											0.553*	0.964***
ABTS												0.541**

*,**,*** Correlation is significant at 0.05, 0.01 and 0.001 levels, respectively using DMRT at $p < 0.05$. FRAP - Ferric reducing antioxidant power; ABTS - 2,2'-azino-bis (3-ethylbenzothiazoline-6-sulfonic acid); DPPH - 2,2-diphenyl-1-picrylhydrazyl.

compounds and flavonoids showed the strongest correlation among the antioxidants.

In conclusion, significant genotypic variation was observed in nutritional status and qualitative parameters in the tomato varieties commercially cultivated in South Korea. Most of the phytochemicals were present in higher quantities in cherry tomato cultivars while color attributes were higher in regular tomato varieties. Cultivars Jicored, Titi-Chal, TY-Endorphin, and Rubyking had high levels of lycopene and other anti-oxidative compounds and showed higher antioxidant activity compared to other cultivars. These results show that varieties can be identified with better nutritional value and these findings provide valuable nutritional information to consumers for selecting cultivars for fresh market consumption. Cultivation of those varieties with higher nutritional values for commercial purposes would also have health benefit to consumers.

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