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ARTICLE

Antioxidant profile, antioxidant activity, and physicochemical characteristics of strawberries from different cultivars and harvest locations

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Abstract Three major cultivars of strawberries ('Yukbo,' 'Seolhyang,' and 'Janghee') harvested from three different locations (Gyeongsan, Nonsan, and Daegu) in Korea were used for this study. The soluble solid content of 'Yukbo' harvested from Nonsan was the highest among the samples. The ranges of titratable acidity and pH from the samples were 0.48–0.65 and 3.70–4.01 %, respectively. Fructose, glucose, and citric acid contents of 'Janghee' harvested from Daegu were significantly higher than other strawberries ($p < 0.05$). The ascorbic acid contents of 'Seolhyang' and 'Janghee' grown in Nonsan were significantly higher than in other strawberries ($p < 0.05$). Total flavonoid and phenolic concentrations, and total antioxidant activities of 'Janghee' harvested from Daegu were significantly higher than other samples ($p < 0.05$). Total flavonoids and total phenolics were highly correlated with the antioxidant activities, and the relationships between total flavonoids and total phenolics were also strong. Cultivars and harvest locations may affect to the physicochemical quality and antioxidant activity of the fruit.

Keywords Antioxidant · Ascorbic acid · Cultivar · Harvest location · Strawberry

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Introduction

The exact origin of the modern cultivated strawberry, *Fragaria* × *ananassa* Duch., is unclear, but it was derived from a cross between two American species, *Fragaria virginiana* Duch. and *Fragaria chiloensis* Linn. (Pritts and Watkins 1998). The USA is the leading producer, with approximately 20 % of the world's crop, followed by Spain, Japan, Poland, Italy, and Korea (Pritts and Watkins 1998). It is a popular fruit with high visual appeal, and desirable flavor, but it is highly perishable, being susceptible to mechanical injury, water loss, decay, and physiological deterioration. Although the potential storage life of the fruit is affected by cultivar and ripening stage at harvest, the fruit can be stored for up to 7 days at 0 °C with 90–5 % relative humidity depending on disease presence (Mitcham 2004).

While many studies have been conducted on physicochemical properties of strawberries, little has been done on individual profiles of sugars and organic acids in strawberries considering both fruit cultivars and harvest locations (Wang and Lin 2000; Moing et al. 2001; Cordenunsi et al. 2002; Meyers et al. 2003). Recently, interest in the health benefits of fruits has increased. Strawberries are a good source of vitamin C (Hagg et al. 1995; Aaby et al. 2007) and anthocyanin (Cheel et al. 2007). Other antioxidants and phytochemicals in strawberries include catechin, quercetin, kaempferol (Gil et al. 1997; Hakkinen and Torronen 2000; Hannum 2004), and ellagic acid which are recognized as a major phenolic acid in strawberries (Hakkinen et al. 2000). Moreover, strawberries have high antioxidant activity (Sun et al. 2002; Rekika et al. 2005) and antiproliferation activity (Sun et al. 2002; Meyers et al. 2003) compared to other fruits such as banana, grapefruit,

and peach. Ascorbic acid is an important vitamin, more than 90 % of it in the nutritious human diet is supplied by fruits and vegetables. It is a common nutrient found in nearly all fresh foods and it is essential for human health (Asard et al. 2004; Hancock and Viola 2005). However, ascorbic acid concentrations decrease when the commodity is subjected to adverse handling and storage conditions include chilling injuries from extended storage, higher temperatures, low relative humidity, and physical damage (Lee and Kader 2000). Therefore, in addition to physical qualities such as color, firmness, and soluble solid content, the nutritional value (ascorbic acid, antioxidant, and activity) should be considered when evaluating fruit quality. The interest in the role of antioxidants in human health has prompted research in the fields of horticulture and food science to assess fruit and vegetable antioxidants, both specific components such as ascorbic acid, anthocyanin, flavonoid, phenolic compounds, and total antioxidant activity. It is important to determine how antioxidant concentrations can be maintained or even improved through cultivar development, production practices, postharvest storage, and food processing.

The objective of this study is to investigate how physicochemical properties and antioxidant concentrations and activities can vary depending on cultivars and harvest locations.

Materials and methods

Plant materials

Three major strawberry cultivars (*Fragaria ananassa* Duch.), 'Yukbo,' 'Seolhyang,' and 'Janghee,' were cultivated in open-fields. They were harvested at the red ripe stage from three different major locations in Korea such as Gyeongsan in Gyeongbuk, Nonsan in Chungnam, and Daegu on April in 2013. After harvest, fruits were then sorted to eliminate damage fruit, and selected for uniform size and color. The samples were directly used to measure general qualities. Then, the remaining fruit samples were frozen in liquid nitrogen and kept at −20 °C until used for antioxidant analysis.

Soluble solids content (SSC), titratable acidity (TA), and pH

The fruits were then wrapped in gauze and hand squeezed, and the juice was used for measurements of SSC, TA, and pH. SSC was determined at room temperature using an Atago PAL-1 refractometer (Atago Co. Ltd., Japan). TA was determined by titrating juice to pH 8.2 using 0.1 M/L NaOH. The pH level was measured by Ohaus Starter 300 pH-meter (Ohaus Corporation, USA). All the measurements were repeated three times (Shin et al. 2007).

Sugar content

The quantification of sugars was performed using the method as described by Hernández et al. (1998) with some modifications. Strawberry extracts were diluted tenfold in distilled water and then the samples were filtered through a syringe filter of 0.45 μm for high-performance liquid chromatography (HPLC) analyses. Multiple HPLC analyses were carried out using an Agilent 1200 series with a Refractive Index detector (USA). For individual sugar separation, a Carbohydrate high-performance column (250 × 4.6 mm i.d., 4 μm, Waters, USA) was used at 30 °C. The mobile phase was 81 % acetonitrile in distilled water with a 1.0 mL/min flow rate. The injection volume was 10 μL. Sugar standards (glucose, fructose, sucrose, and maltose) were purchased from Sigma (St. Louis, USA). The calibration curves were obtained with standard solutions and results were expressed as g/kg of fresh weight (FW).

Organic acid content

Organic acids were analyzed using the method by Bordonaba and Terry (2010) with some modifications. The HPLC instrument consisted of an Agilent 1200 series with a diode array detector. Strawberry extracts were diluted 10-fold in distilled water and then filtered through a 0.45-μm syringe filter. For individual organic acid separation, a Prevail organic acid column (250 × 4.6 mm id., 5 μm, Alltech, USA) was used at 25 °C. The mobile phase was 25 mM KH_2PO_4 (adjusted to pH 2.1 by H_3PO_4) with a 1.0 mL/min flow rate. The injection volume was 10 μL, while the diode array detector was positioned at 210 nm. Organic standards (oxalic acid, malic acid, citric acid, fumaric acid, acetic acid, tartaric acid, succinic acid, and lactic acid) were purchased from Sigma (St. Louis, USA). Sample quantification was calculated using standard calibration curves and results were expressed as mg/kg FW.

Ascorbic acid content

HPLC determination of ascorbic acid was carried out by using the method as described by Kim and Kim (2003). Strawberry extracts were diluted 10-fold in 2 % HPO_3 (containing 1 mM ethylene diamine tetra acetic acid) and then filtered through a 0.45-μm syringe filter prior to analysis. The HPLC system was an Agilent 1200 series, with diode array detector. Analytical separation was performed using a Zorbax Eclipse plus C18 column (150 × 4.6 mm

i.d., 5 μm, Agilent) at 25 °C. The mobile phase was distilled water (adjusted to pH 2.1 by H_2SO_4) with a 1.2 mL/min flow rate. The injection volume was 5 μL, while the diode array detector was monitored at 254 nm. Sample quantification was performed using standard calibration curve and the results were expressed as mg/kg FW.

Extraction for measurement of antioxidant compounds and activity

The frozen fruit tissues were crushed into coarse pieces, and 10 g samples were homogenized for 3 min with 100 mL of 80 % acetone using a commercial blender (Philips HR-2171, Korea) as described previously (Shin et al. 2008). The homogenate was filtered through #1 Whatman paper. The filtrate was recovered and the acetone was evaporated in a rotary evaporator (Eyela N-1000, Japan) at 45 °C. The samples were then brought to 10 mL with deionized water, divided into several aliquots, and kept frozen at −20 °C prior to analysis of total anthocyanin, total flavonoids, total phenolics, ascorbic acid concentrations, and total antioxidant activity.

Determination of total anthocyanin content

The total anthocyanin content of the strawberry extract was determined using a modified pH differential method (Boyles and Wrolstad 1993; Meyers et al. 2003; Shin et al. 2008). A spectrophotometer (Model UV-1201, Shimadzu, Japan) was used to measure absorbance at 510 and 700 nm in buffers at pH 1.0 and 4.5. Absorbance readings were converted to mg of cyanidin 3-glucoside per kg of fruit FW, using the molar extinction coefficient of 26,900 and absorbance of $A = [(A_{510} - A_{700})_{\text{pH}\ \ 1.0} - (A_{510} - A_{700})_{\text{pH}\ 4.5}]$. Total anthocyanin contents were expressed as cyanidin 3-glucoside on a FW basis, mg/kg FW.

Determination of total flavonoid content

The total flavonoid contents of the extracts were determined by a colorimetric assay described previously (Meyers et al. 2003; Shin et al. 2008). The absorbance of the solution versus a blank at 510 nm was measured immediately. The results were expressed as mg of catechin equivalents/kg FW of fruit using a standard curve.

Determination of total phenolic content

The total phenolic contents of the sample extracts were measured using a modified Folin–Ciocalteu colorimetric method (Meyers et al. 2003; Shin et al. 2008). Absorbance was measured at 750 nm versus a blank after 90 min at room temperature. The results are expressed as mg of gallic acid equivalents/kg FW of fruit using a standard curve.

2,2-Diphenyl-1-picrylhydrazyl (DPPH) radical scavenging activity

DPPH radical scavenging activity was determined using a modified method of Floegel et al. (2011). The DPPH radical scavenging activity of fruit extracts was expressed as g of vitamin C equivalent (vit C eq.)/kg FW of fruit and compared to the standard curve. Samples of each extraction were analyzed in triplicate.

Vitamin C equivalent antioxidant capacity (VCEAC)

The method developed by Floegel et al. (2011) was used in this study. The ABTS radical scavenging capacities of fruit extracts were expressed on the FW basis as g of vitamin C equivalent (vit C eq.)/kg FW of fruit. Samples of each extraction were analyzed in triplicate.

Oxygen radical absorbance capacity (ORAC)

The antioxidant activity was measured using the ORAC assay reported by Huang et al. (2002) and Wu et al. (2010). Prior to analysis, strawberry extracts were diluted 800- or 1000-fold in 75 mM phosphate buffer (pH 7.4). 25 μL of diluted extracts and 25 μL of 0, 6.25, 12.5, and 25 μM/L Trolox standards were placed in pre-warmed microtiter plates, and then 150 μL fluoroscein was introduced to each well. After the plates were incubated at 37 °C for 20 min, 25 μL AAPH reagent was added to each well. Fluorescence intensity was measured using a fluoroskan (Bio-Tek Instruments, Inc., USA) at excitation of 485 nm and emission of 520 nm every 1 min for up to 90 min. The ORAC was expressed as mM of Trolox equivalent (TE)/kg FW of fruit. Samples of each extraction were analyzed in triplicate.

Statistical analysis

Statistical significance was tested using Duncan's multiple range test in SAS version 9.3 (SAS Institute, Inc., USA) using a 95 % confidence level. The data are expressed as means ± standard errors for triplicate determinations

Results and discussion

SSC, TA and pH

The average SSCs of 'Yukbo,' 'Seolhyang,' and 'Janghee' from the three different locations were 10.49, 8.72, and

9.86°Bx, respectively. The SSC of 'Yukbo' harvested from Nonsan was highest (13.80 ± 0.12°Bx) among cultivars and harvest locations ($p < 0.05$). The ranges of TA and pH from the sources were 0.48–0.65 % and 3.70–4.01, respectively. However, the results were slightly different among cultivars and harvest locations (Table 1). According to Lee et al. (2013), the SSC, TA, and pH of 'Seolhyang' were 8.90°Bx, 0.82 %, and 3.80, respectively. Comparatively, Shin et al. (2007) reported that the TA and pH of 'Jewel' strawberries grown in New York were 0.57 % and 3.09, respectively. In addition, the SSC of 'Jewel' strawberries was 6.5°Bx, which was lower than any other cultivars in our experiment (Shin et al. 2007).

SSC/TA ratio

Soluble solids content (SSC), titratable acidity (TA) ratio is an important factor of raw fruit and fruit juice tastes (Green 1971; Perkins-Veazie 1995; Cordenunsi et al. 2002; Yang and Kang 2007). It is considered to determine the optimum time for strawberry harvesting because it affects the fruit quality including sensory aspect (Perkins-Veazie 1995; Cordenunsi et al. 2002). The ratio of all cultivars and locations was >14.19; especially, 'Yukbo' and 'Janghee' grown in Nonsan (23.79 and 22.22, respectively) were higher than other locations due to high SSC and low acidity (Table 1). Preharvest factors, such as cultivar, light, temperature, water availability, and soil condition, may affect the higher SSC/TA ratio of the strawberries harvested from Nonsan.

Sugar content

The quantification of individual sugars (fructose, glucose, sucrose, and maltose) was analyzed by cultivars and harvest locations. Maltose was not detected among the strawberry samples. Fructose and glucose were major sugars in all cultivars from each harvest location except for 'Janghee' from Nonsan. Fructose and glucose contents of 'Janghee' harvested from Daegu were significantly higher (32.5 ± 0.8 and 30.5 ± 0.5 g/kg FW, respectively) than other strawberries ($p < 0.05$). Interestingly, the sucrose contents of 'Janghee' harvested from Gyeongsan and Nonsan were (26.9 ± 0.1 and 25.2 ± 1.7 g/kg FW, respectively) significantly higher than other strawberries ($p < 0.05$). Therefore, the average total sum of the individual sugar content in 'Janghee' was higher (79.0 g/kg FW) than 'Yukbo' and 'Seolhyang' (65.6 and 66.3 g/kg FW, respectively) (Table 2). There are several researches on the cultivar effect on individual sugar contents (Moing et al. 2001; Choi et al. 2013). Choi et al. (2013) reported that fructose and glucose content of 'Daewang' and 'Seolhyang' strawberries at their fully ripened stage was higher than sucrose, which was similar to our result. In contrast, the individual sugar contents of 'Seolhyang' were higher than our strawberry samples. The harvest locations may affect the variations between these two experiments because the harvest location results were not considered in their study. Therefore, the results may differ by cultivars and harvest locations.

Organic acid content

The organic acid content is highly related to fruit titratable acidity. The quantification of individual organic acid contents (oxalic acid, malic acid, citric acid, fumaric acid, acetic acid, tartaric acid, succinic acid, and lactic acid) was analyzed by cultivars and harvest locations. It is known that citric acid is a major organic acid in strawberry (Moing et al. 2001; Choi et al. 2013). In our research, citric acid was also a major organic acid in all cultivars harvested from each location. The citric acid content of 'Janghee' harvested from Daegu was the highest (5888.8 ± 130.9 mg/kg FW) and 'Janghee' harvested from Nonsan

Table 1 Soluble solid content (SSC), titratable acidity (TA), and pH in strawberries

Cultivar	Harvest location	SSC (°Bx)	TA (%)	SSC/TA ratio*	pH
'Yukbo'	Gyeongsan	9.60 ± 0.06^{d}	0.60 ± 0.02^{ab}	16.00	4.01 ± 0.05^{a}
	Nonsan	13.80 ± 0.12^{a}	0.58 ± 0.04^{ab}	23.79	3.86 ± 0.07^{abc}
	Daegu	8.07 ± 0.03^{g}	0.55 ± 0.01^{bc}	14.67	3.83 ± 0.07^{abc}
'Seolhyang'	Gyeongsan	8.80 ± 0.06^{f}	0.62 ± 0.01^{ab}	14.19	3.92 ± 0.04^{ab}
	Nonsan	10.00 ± 0.06^{c}	0.65 ± 0.02^{a}	15.38	3.70 ± 0.06^{c}
	Daegu	7.37 ± 0.03^{h}	0.48 ± 0.04^{cd}	15.35	3.84 ± 0.05^{abc}
'Janghee'	Gyeongsan	10.57 ± 0.03^{b}	0.61 ± 0.01^{ab}	17.33	3.97 ± 0.07^{ab}
	Nonsan	10.00 ± 0.12^{c}	0.45 ± 0.02^{d}	22.22	3.90 ± 0.02^{abc}
	Daegu	9.03 ± 0.03^{e}	0.59 ± 0.03^{ab}	15.31	3.79 ± 0.09^{bc}

Data are expressed as mean ± SE ($n = 3$) on a fresh weight basis; different letters in a column are significantly different at $p < 0.05$

* SSC/TA ratio is calculated by SSC (°Bx)/Titratable acidity (%)

Table 2 Individual sugar contents in strawberries

Cultivar	Harvest location	Fructose (g/kg FW)	Glucose (g/kg FW)	Sucrose (g/kg FW)	Total sum (g/kg FW)
'Yukbo'	Gyeongsan	28.6 ± 0.1^{bc}	26.1 ± 0.1^{cd}	13.6 ± 0.2^{de}	68.3
	Nonsan	28.3 ± 0.4^{bc}	29.2 ± 0.6^{ab}	16.6 ± 0.2^{b}	74.1
	Daegu	22.5 ± 1.1^{d}	22.5 ± 1.1^{e}	9.5 ± 0.3^{f}	54.5
'Seolhyang'	Gyeongsan	27.5 ± 0.8^{bc}	25.0 ± 0.6^{d}	12.2 ± 0.5^{e}	64.7
	Nonsan	29.0 ± 0.7^{bc}	28.6 ± 0.1^{ab}	14.2 ± 0.2^{cd}	71.8
	Daegu	26.8 ± 0.1^{c}	25.8 ± 0.4^{d}	9.8 ± 0.1^{f}	62.5
'Janghee'	Gyeongsan	29.5 ± 0.1^{b}	27.8 ± 0.9^{bc}	26.9 ± 0.1^{a}	84.2
	Nonsan	24.0 ± 1.1^{d}	25.1 ± 0.6^{d}	25.2 ± 1.7^{a}	74.3
	Daegu	32.5 ± 0.8^{a}	30.5 ± 0.5^{a}	15.7 ± 0.3^{bc}	78.7

Data are expressed as mean ± SE ($n = 3$) on a fresh weight (FW) basis; different letters in a column are significantly different at $p < 0.05$

was the lowest (4214.5 ± 102.3 mg/kg FW) among the strawberry samples statistically ($p < 0.05$), which means the content may differ from harvest locations though they are the same cultivars. The second highest organic acid of strawberry samples was malic acid. The malic acid content of 'Seolhyang' harvested from Nonsan was the highest (1655.5 ± 9.6 mg/kg FW) ($p < 0.05$). The average total sum of organic acid was the highest in 'Seolhyang' (6518.6 mg/kg FW) compared to 'Yukbo' and 'Janghee' (6418.1 and 5974.0 mg/kg FW, respectively) ($p < 0.05$) (Table 3).

Ascorbic acid content

Ascorbic acid has long been considered a key nutritional factor of strawberry fruit. Ascorbic acid concentrations tend to decrease when a fruit is subjected to adverse handling and storage conditions (Lee and Kader 2000; Cordenunsi et al. 2005). The ascorbic acid contents of strawberries harvested from Nonsan were higher than other locations in all cultivars. The ascorbic acid contents of 'Seolhyang' and 'Janghee' grown in Nonsan (447.2 ± 14.3 and 439.0 ± 13.9 mg/kg FW) were significantly higher than other strawberries (Table 4). However, the ascorbic acid contents of each cultivar varied depending on the harvest locations. Cordenunsi et al. (2005) found that the effects of cultivars on ascorbic acid and anthocyanin of fruit at 6, 16, and 25 °C for 6 days were also shown, but flavonols, ellagic acid, and total phenolic concentrations were similar among cultivars. Further investigation is warranted to research antioxidant concentrations such as anthocyanins, flavonoids, phenolics, and total antioxidant activity of strawberries depending on cultivars and harvest locations.

Total anthocyanin content

The anthocyanin concentration of strawberries harvested from Daegu was significantly higher ($p < 0.05$) than others in all cultivars (Table 4). In contrast, the anthocyanin

Table 3 Individual organic acid contents in strawberries

Cultivar	Harvest location	Oxalic acid (mg/kg FW)	Malic acid (mg/kg FW)	Citric acid (mg/kg FW)	Total sum (mg/kg FW)
'Yukbo'	Gyeongsan	238.0 ± 1.6^{a}	884.0 ± 17.7^{f}	4793.1 ± 21.7^{d}	5915.1
	Nonsan	177.0 ± 2.6^{c}	1403.9 ± 12.9^{c}	5219.8 ± 46.2^{bc}	6800.7
	Daegu	173.0 ± 7.6^{c}	1274.7 ± 42.9^{e}	5090.8 ± 178.8^{c}	6538.5
'Seolhyang'	Gyeongsan	153.6 ± 3.1^{de}	1342.1 ± 21.8^{d}	4663.4 ± 79.7^{d}	6159.1
	Nonsan	148.8 ± 0.6^{e}	1655.5 ± 9.6^{a}	5423.1 ± 26.6^{b}	7227.4
	Daegu	156.4 ± 2.7^{de}	1474.9 ± 9.9^{b}	4537.9 ± 44.8^{d}	6169.2
'Janghee'	Gyeongsan	223.6 ± 1.8^{b}	609.8 ± 4.7^{h}	5123.1 ± 16.5^{c}	5956.5
	Nonsan	164.8 ± 7.4^{cd}	698.2 ± 24.4^{g}	4214.5 ± 102.3^{e}	5077.5
	Daegu	157.9 ± 3.7^{de}	841.4 ± 12.4^{f}	5888.8 ± 130.9^{a}	6888.1

Data are expressed as mean ± SE ($n = 3$) on a fresh weight (FW) basis; different letters in a column are significantly different at $p < 0.05$

Table 4 Ascorbic acids, anthocyanins, flavonoids, and phenolic contents in strawberries

Cultivar	Harvest location	Ascorbic acid (mg/kg FW)	Anthocyanin (mg/kg FW)	Flavonoids (mg/kg FW)	Phenolics (mg/kg FW)
'Yukbo'	Gyeongsan	183.4 ± 8.8^{f}	90.9 ± 1.1^{e}	455.9 ± 2.4^{e}	1772.4 ± 12.5^{d}
	Nonsan	359.5 ± 15.5^{c}	125.2 ± 0.6^{c}	533.9 ± 5.0^{c}	2031.6 ± 19.7^{b}
	Daegu	227.4 ± 3.2^{e}	166.4 ± 1.0^{a}	583.0 ± 4.2^{b}	2076.9 ± 27.9^{b}
'Seolhyang'	Gyeongsan	102.5 ± 7.1^{g}	50.3 ± 0.8^{g}	400.6 ± 7.1^{f}	1483.0 ± 15.7^{f}
	Nonsan	447.2 ± 14.3^{a}	85.6 ± 0.7^{f}	615.0 ± 5.8^{a}	2034.9 ± 3.2^{b}
	Daegu	303.9 ± 11.7^{d}	116.8 ± 1.2^{d}	551.5 ± 15.3^{c}	1939.8 ± 9.3^{c}
'Janghee'	Gyeongsan	282.2 ± 14.9^{d}	51.4 ± 0.8^{g}	434.0 ± 2.0^{e}	1706.7 ± 18.0^{e}
	Nonsan	439.0 ± 13.9^{ab}	114.7 ± 1.0^{d}	500.0 ± 17.0^{d}	1962.2 ± 27.7^{c}
	Daegu	407.0 ± 14.6^{b}	152.2 ± 1.8^{b}	602.4 ± 12.3^{ab}	2308.8 ± 15.9^{a}

Data are expressed as mean ± SE ($n = 3$) on a fresh weight (FW) basis; different letters in a column are significantly different at $p < 0.05$

concentration of fruit harvested from Gyeongsan was significantly lower ($p < 0.05$) than others in all cultivars. We assumed that the environmental factors such as light, temperature, rainfall precipitation, and soil condition might affect to the anthocyanin concentration. Meyers et al. (2003) found that the anthocyanin contents of 8 cultivars were similar; averaging 414 mg (cyanidin 3-glucoside)/kg of fruit, these were higher than our study. This result might come from different cultivars and harvest locations. The maturity stage at harvest also affects the amount of anthocyanin contents (Shin et al. 2008).

Total flavonoid and total phenolic content

The average flavonoid concentrations of 'Yukbo,' 'Seolhyang,' and 'Janghee' from three different locations were 524.3, 522.4, and 512.1 mg/kg FW, respectively. However, the total flavonoid concentrations of strawberries harvested from Gyeongsan were relatively lower than the other two locations in all cultivars (Table 4). Shin et al. (2008) found that the total flavonoid concentration of the 'Jewel' strawberry harvested at red ripe stage was 576 mg/kg FW, which was similar to our research. In contrast, they concluded that the flavonoid concentration of strawberries harvested at the white tip stage was higher (795 mg/kg FW) than red ripe fruit. Rekika et al. (2005) reported that the average total anthocyanin concentration of 18 different cultivars was 333 mg/kg FW. However, this result was lower than our finding.

The total phenolic concentration of 'Janghee' harvested from Daegu was significantly higher (2308.8 mg/kg FW) than other samples ($p < 0.05$) (Table 4). The total phenolic concentrations of strawberries harvested from Gyeongsan were relatively lower than the other two locations in all cultivar samples. The same is true for the flavonoid concentrations of our experiment. Among the cultivars, the total phenolic concentration of 'Janghee' from three locations was 1992.6 mg/kg FW, followed by 'Yukbo' and 'Seolhyang' (1960.3 and 1819.2 mg/kg FW). Some regional differences in phenolic concentrations were also observed by Hakkinen and Torronen (2000). The total phenolic concentration of 'Senga Sengana' strawberries varied depending on harvest nations. They found the same result with different blueberry cultivars grown in two different locations (Hakkinen and Torronen 2000). According to Wang and Lin's study (2000), the total phenolic concentration harvested at red ripe stage ranged from 950 to 1520 mg/kg FW, which was lower than our results. Our results also confirmed that the total phenolic concentrations of strawberries depending on the cultivar varied (Wang and Lin 2000; Meyers et al. 2003; Rekika et al. 2005).

Total antioxidant activity

The total antioxidant activities of the strawberry samples were measured by DPPH, VCEAC, and ORAC. Several studies reported that some reactions among antioxidant compounds such as anthocyanins, flavonoids, and phenolics may be synergistic, and therefore, total antioxidant activity analysis potentially supports a better estimation of the overall contribution of antioxidant components (Sun et al. 2002; Meyers et al. 2003; Shin et al. 2007, 2008). Strawberries contain high levels of antioxidants, which have been correlated with a decreased risk of chronic disease (Meyers et al. 2003). The health-promoting potential of strawberries may come from phytochemicals, bioactive compounds not designated as traditional nutrients (Hannum 2004).

DPPH, VCEAC, and ORAC of 'Janghee' harvested from Daegu were significantly higher (2.676 and 4.211 g vit C eq./kg FW, and 21.175 mM TE/kg FW, respectively) than other strawberries ($p < 0.05$) (Table 5). In contrast,

Table 5 Total antioxidant activities (DPPH, VCEAC, and ORAC) in strawberries

Cultivar	Harvest location	DPPH (g/kg FW)	VCEAC (g/kg FW)	ORAC (mM TE/kg FW)
'Yukbo'	Gyeongsan	1.743 ± 0.132^{d}	3.112 ± 0.082^{e}	19.755 ± 0.276^{bc}
	Nonsan	2.452 ± 0.042^{b}	3.882 ± 0.086^{bc}	20.482 ± 0.597^{ab}
	Daegu	2.330 ± 0.026^{bc}	4.020 ± 0.207^{ab}	21.179 ± 0.458^{a}
'Seolhyang'	Gyeongsan	1.718 ± 0.118^{d}	2.574 ± 0.024^{f}	15.688 ± 0.087^{d}
	Nonsan	2.294 ± 0.068^{bc}	3.535 ± 0.087^{d}	18.618 ± 0.142^{c}
	Daegu	2.342 ± 0.016^{bc}	3.686 ± 0.079^{cd}	19.527 ± 0.091^{bc}
'Janghee'	Gyeongsan	1.810 ± 0.033^{d}	2.663 ± 0.020^{f}	18.540 ± 0.420^{c}
	Nonsan	2.112 ± 0.050^{c}	3.757 ± 0.035^{bcd}	19.368 ± 0.157^{bc}
	Daegu	2.676 ± 0.068^{a}	4.211 ± 0.065^{a}	21.175 ± 0.770^{a}

Data are expressed as mean ± SE ($n = 3$) on a fresh weight (FW) basis; Different letters in a column are significantly different at $p < 0.05$

the total antioxidant activities of 'Seolhyang' harvested from Gyeongsan were relatively lower than other strawberries. Wang et al. (1996) showed in their study of the total antioxidant capacity of fruits that strawberry extracts had higher antioxidant activity, as indicated by the ORAC assay, than extracts from plum, orange, red grape, kiwifruit, pink grapefruit, white grape, banana, apple, tomato, pear, and honeydew melon. The maturity stage at harvest may also affect to antioxidant activity. The total antioxidant activity of the white tip strawberry was higher than the red ripe fruit (Shin et al. 2008).

Correlation between antioxidant contents and activities

Several studies were conducted to investigate the correlation between antioxidant concentrations (anthocyanin, flavonoids, and phenolics) and the activities of several fruits (Rekika et al. 2005; Shin et al. 2008; Shin 2012). In our research, the total flavonoids and total phenolics were highly correlated with the antioxidant activities, and the relationships between total flavonoids and total phenolics were also strong (Figs. 1, 2). The total anthocyanins were highly correlated with the total flavonoids and phenolics ($R^2 = 0.728$ and $R^2 = 0.844$, respectively) (data not shown). Strong correlations were found between total phenolics and antioxidant activities (DPPH and VCEAC) (Fig. 1). The correlation between VCEAC and DPPH was $R^2 = 0.724$, and the correlation between ORAC and VCEAC was $R^2 = 0.627$ (Fig. 2). The strong correlation between total phenolics and antioxidant activity of strawberry fruit has been reported (Wang and Lin 2000; Rekika et al. 2005; Shin et al. 2008). Shin (2012) also found a correlation between total phenolics and antioxidant activity of citrus fruit such as tangerine, lemon, orange, and yuja. Several studies also support this result. For example, antioxidant activities of blueberry, grape, and strawberry were correlated to total phenolics and anthocyanins (Wang et al. 1996; Wang and Lin 2000). The correlation between DPPH and VCEAC of citrus fruit also was strong especially fruit peels rather than fruit flesh (Shin 2012). Interestingly, there was weak correlation between ORAC and

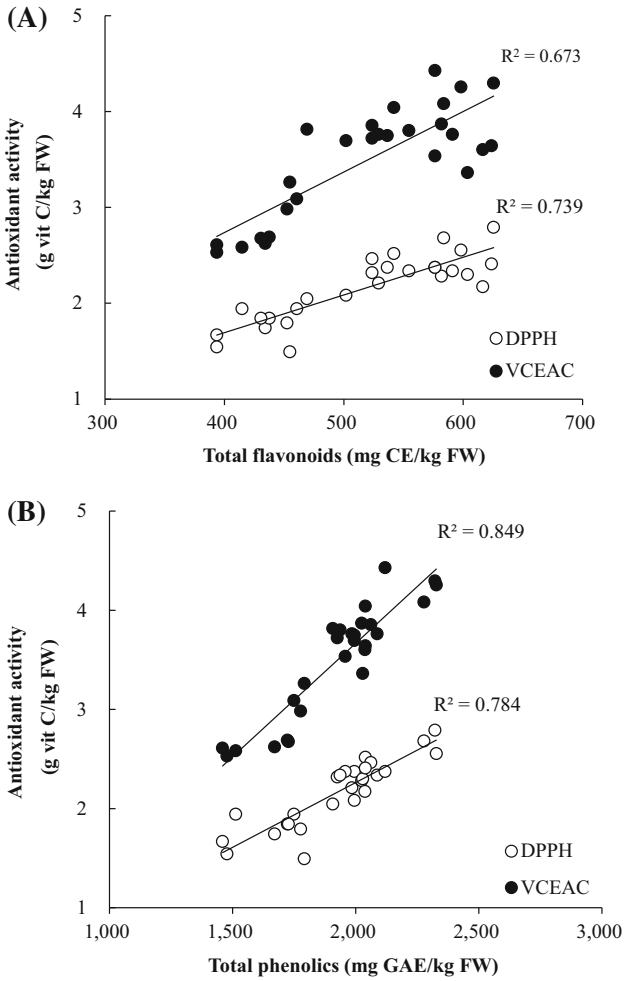

Fig. 1 Correlation between antioxidant concentrations (flavonoids and phenolics) and activities (DPPH and VCEAC)

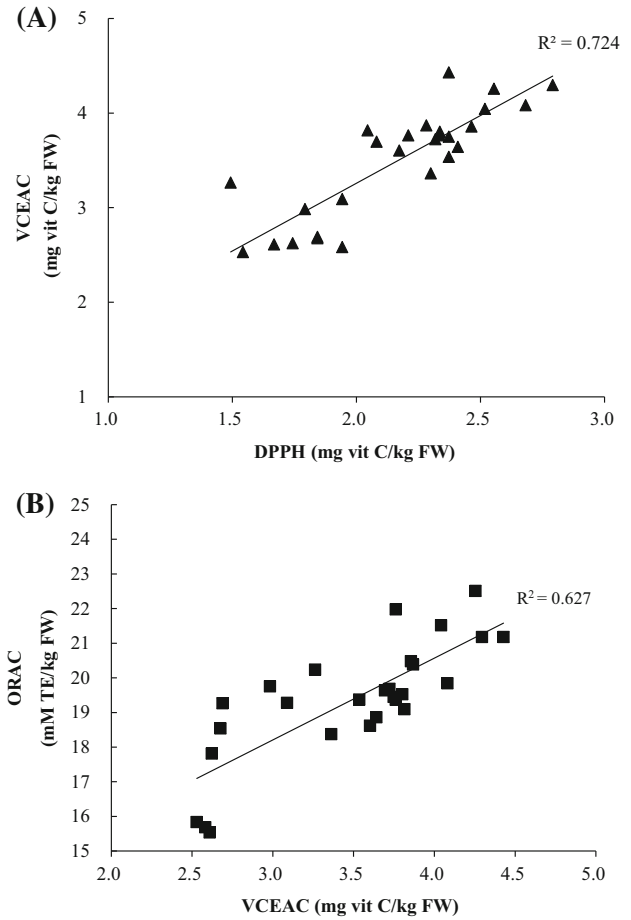

Fig. 2 Correlation between antioxidant activities (DPPH, VCEAC, and ORAC)

DPPH (data not shown). In conclusion, our study will give very valuable information to food industry when selecting high qualities of raw materials for developing functional food or nutraceutical product with fruits.

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