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Research Report

# Effect of Maturity Stage at Harvest on Antioxidant Capacity and Total Phenolics in Kiwifruits (*Actinidia* spp.) Grown in Korea

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**Abstract.** Six cultivars of kiwifruits grown in Korea, including *Actinidia eriantha* 'Bidan', *A. arguta* 'Chiak', *A. arguta* 'Darae No. 2', *A. chinensis* 'Haegeum', *A. chinensis* 'Haehyang', and *A. arguta* × *A. deliciosa* 'Mansoo', were harvested at various maturity stages to test whether kiwifruit maturity has an influence on antioxidant capacity or total phenolic and flavonoid contents. Kiwifruit extracts were isolated using absolute methanol and then 80% ($v \cdot v^{-1}$) aqueous methanol during homogenization. 'Bidan', collected at the second harvest stage, contained the greatest amount of total phenolics (775.3 mg gallic acid equivalents·100 $g^{-1}$ fresh weight) and had the highest antioxidant capacity [816.5, 633.2, and 2,662.7 mg vitamin C equivalents·100 $g^{-1}$ fresh weight for 2,2'-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid) scavenging, 1,1-diphenyl-2-picrylhydrazyl scavenging, and oxygen radical absorbance capacity assays, respectively] among cultivars tested, while 'Haehyang', collected at the first harvest, contained the greatest amount of total flavonoids (13.1 mg catechin equivalents·100 $g^{-1}$ fresh weight). Kiwifruit cultivar and genotype influenced antioxidant capacity, as well as total phenolic and flavonoid contents. No trend, however, was observed in total phenolic and flavonoid contents, and in the antioxidant capacity with respect to maturity stage. Antioxidant capacity had a higher linear correlation coefficient with total phenolic contents than with total flavonoid contents. The results above suggest that kiwifruits at various maturity stages are a valuable source of phenolics and antioxidants for industrial application and consumer health benefit.

***Additional key words***: *A. arguta* × *A. deliciosa*, *A. chinensis*, *A. arguta*, *A. eriantha*, cultivar, vitamin C equivalent antioxidant capacity

## Introduction

Reactive oxygen species (ROS), including singlet oxygen ($^1O_2$), hydrogen peroxide ($H_2O_2$), superoxide radical anion ($O_2^{\bullet-}$), and hydroxyl radical ($OH^{\bullet}$), are generated during normal and abnormal metabolic processes that use molecular oxygen (Mohsenzadegan and Mirshafiey, 2012). When ROS generation overwhelms the neutralizing capacity of endogenous antioxidants in the body, it leads to oxidative damage to proteins, sugars, lipids, DNA, and RNA in cells, and various degenerative diseases such as cardiovascular disease, cancer, diabetes, immune system decline and brain dysfunction (Sosa et al., 2013; Shaw et al., 2014). Exogenous antioxidants need to be consumed to compensate for the production of excessive ROS. Fruits, vegetables, coffee, and tea are valuable sources of various antioxidants such as phenolic compounds and vitamins in the human diet (Chun et al., 2005; Floegel et al., 2011; Lim et al., 2012; Lima et al., 2014). Many epidemiological studies have suggested that fruit and vegetable consumption can reduce the risk of certain chronic diseases such as cancer, Alzheimer's disease, and heart disease (Pandey and Rizvi, 2009; Lima et al., 2014).

Kiwifruits (*Actinidia* spp.), which belong to the *Actinidiaceae* family, are a popular fruit consumed worldwide. Kiwifruit seedlings were introduced in Korea in 1977 for the first time and Korean kiwifruits appeared on the market in 1981 (Jung

et al., 2005). The most common commercially available kiwifruit is *A. deliciosa* 'Hayward', a green kiwifruit with green flesh and fuzzy skin. *Actinidia chinensis* 'Hort16A' is a golden kiwifruit with yellow flesh and smooth, bronze skin. *Actinidia arguta* kiwifruit has hairless, smooth, edible skin, and is a relatively small fruit with a good shelf life compared to golden and green kiwifruits (Kim et al., 2014). The kiwifruit of *A. arguta* is referred to as hardy kiwifruit, kiwi berry, baby kiwi, grape kiwi, or cocktail kiwi. *Actinidia eriantha* kiwifruits have hairy skin and a fruit size larger than *A. arguta* and smaller than *A. chinensis* and *A. deliciosa* (Lim et al., 2014). *Actinidia eriantha* kiwifruits have been reported to contain higher levels of vitamin C than the other *Actinidia* species (Park et al., 2011; Lim et al., 2014). An interspecific hybrid between *A. deliciosa* and *A. arguta* is a sweet kiwifruit with hairless skin (Cho et al., 2007). More recently, some *Actinidia* species including *A. arguta, A. kolomikta*, and an *A. deliciosa* × *A. arguta* hybrid have attracted attention due to cold tolerance (Fisk et al., 2006; Cho et al., 2007; Kim et al., 2014).

Kiwifruits contain various bioactive compounds including ascorbic acid, carotenoids, dietary fiber, minerals, and phenolic compounds (Sommerburg et al., 1998; Tavarini et al., 2008; Park et al., 2011; Lim et al., 2014). Kiwifruit extracts have shown antioxidative, anti-cancer and anti-HIV activity (Motohashi et al., 2002). The bioactive compounds contained in kiwifruits differ depending on cultivar, genotype, location with the fruit, and degree of maturity (Fisk et al., 2006; Park et al., 2011; Kim et al., 2014; Lim et al., 2014; Lee et al., 2015; Pal et al., 2015). Characteristics of various kiwifruit cultivars such as soluble solid content, solid matter, fruit weight, and fruit length have been previously reported (Kim et al., 2014; Lim et al., 2014). Phenolics such as caffeic, *p*-coumaric, ferulic, protocatechuic, syringic, and vanillic acids were quantitatively identified in golden, green, and *A. eriantha* kiwifruits (Park et al., 2011). The physicochemical properties of hardy kiwi wine have also been evaluated (Park et al., 2013). Limited information, however, is available on the antioxidant capacity and total phenolic and flavonoid contents in terms of the different maturity stages of various kiwifruit cultivars grown in Korea.

Therefore, in this study, six cultivars of various *Actinidia* species at various maturity stages harvested in 2013 were selected and analyzed to comparatively evaluate the total phenolic and total flavonoid content, in addition to the antioxidant capacity. The antioxidant capacity of the different kiwifruits was measured using three different assays including 2,2'-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid) (ABTS), 1,1-diphenyl-2-picrylhydrazyl (DPPH), and oxygen radical absorbance capacity (ORAC) assays. The various kiwifruits used in this study included one cultivar of *A. eriantha*, two cultivars of *A. arguta*, two cultivars of *A. chinensis*, and one hybrid cultivar of *A. arguta* × *A. deliciosa*. The aim of the current study was to provide comparative information on total phenolics, total flavonoids, and antioxidant capacities at various stages of kiwifruit maturity.

## Materials and Methods

### Chemicals

Ascorbic acid, 2,2'-azobis(2-amidinopropane) dihydrochloride (AAPH), ABTS diammonium salt, DPPH, catechin, fluorescein, Folin-Ciocalteu's phenol reagent, and gallic acid were purchased from Sigma Aldrich LLC., Co. (St. Louis, MO, USA).

### Samples

Six different types of *Actinidia* cultivars, including 'Bidan', 'Chiak', 'Darae No. 2', 'Haegeum', 'Haehyang', and 'Mansoo' were selected (Table 1). 'Mansoo' is a sweet kiwifruit with hairless skin produced by interspecific hybridization between *A. deliciosa* and *A. arguta*. Kiwifruit vines were trained on pergola with trellis in an open field in Gwangyang, Jeonnam (35.0114 latitude and 127.5862 longitude) and harvested four times between September and October 2013 at approximately one week intervals. The harvest days of each cultivar are displayed in Table 2. The last harvested kiwifruits were further ripened by ethylene gas. Harvested kiwifruits were stored at -20°C until analysis.

### Sample Extraction

Kiwifruits were peeled. The flesh of kiwifruit (50 g) was mixed with 100 mL of absolute methanol and homogenized

**Table 1.** Origins of six cultivars of kiwifruits (*Actinidia* spp.) grown in Korea

| Cultivar | Species | Origin |
|---|---|---|
| Bidan | *A. eriantha* | Korea |
| Chiak | *A. arguta* | Korea |
| Darae No. 2 | *A. arguta* | Korea |
| Haegeum | *A. chinensis* | Korea |
| Haehyang | *A. chinensis* | Korea |
| Mansoo | *A. arguta* × *A. deliciosa* | Korea |

**Table 2.** Harvest date of six cultivars of kiwifruits (*Actinidia* spp.) at different maturity stages in 2013

| Cultivar | Harvest date | | | |
|---|---|---|---|---|
| | 1st | 2nd | 3rd | 4th |
| Bidan | September 30 | October 8 | October 14 | October 21 |
| Chiak | September 30 | October 4 | October 8 | October 16 |
| Darae No. 2 | September 30 | October 4 | October 8 | October 16 |
| Haegeum | September 30 | October 8 | October 14 | October 21 |
| Haehyang | September 30 | October 8 | October 14 | October 21 |
| Mansoo | September 30 | October 4 | October 14 | October 21 |

using a Polytron homogenizer (PT 10/35, Kinematica, Kriens-Luzern, Switzerland) at 15,000 rpm for 2 min with continual nitrogen gas purging to prevent possible degradation of phenolics. The homogenized mixture was filtered through Whatman #2 filter paper (Whatman International Limited, Kent, England) using an aspirator. Filter cakes were re-extracted using the procedure above with 100 mL of 80% ($v \cdot v^{-1}$) aqueous methanol instead of absolute methanol. The two filtrates were combined and evaporated until dry under reduced pressure using a rotary evaporator (Eyela, Tokyo, Japan) in a water bath at 37°C. The concentrated extracts were dissolved in 50 mL of absolute methanol and brought to a final volume of 100 mL with deionized water. Prepared extracts were stored at -20°C until analysis. All experiments were performed in triplicate.

## Determination of Total Phenolics

Total phenolic content was measured via the colorimetric method using Folin-Ciocalteu's phenol reagent (Singleton and Rossi, 1965). Properly diluted extract (0.2 mL) was mixed with 2.6 mL of deionized water. An aliquot (0.2 mL) of Folin-Ciocalteu's phenol reagent was added to the mixture. At 6 min, 2.0 mL of 7% ($w \cdot v^{-1}$) $Na_2CO_3$ solution was added to the reaction mixture. At 90 min, absorbance was measured at 750 nm. A gallic acid standard was used to build a calibration curve with concentrations of 10, 30, 60, and 100 $mg \cdot L^{-1}$. The content of total phenolics was expressed as mg gallic acid equivalents (GAE)·100 $g^{-1}$ fresh weight (FW) of kiwifruits. Each extract was analyzed in triplicate.

## Determination of Total Flavonoids

Total flavonoid content was measured using a modified version of the method described by Jia et al. (1999). Briefly, a mixture of 500 μL of properly diluted extracts and 3.2 mL of distilled water was added to 150 μL of 5% ($w \cdot v^{-1}$) $NaNO_2$. At 5 min, 150 μL of 10% ($w \cdot v^{-1}$) $AlCl_3$ was added. At 6 min, 1 mL of 1 M NaOH was added. Absorbance of the mixture was measured immediately at 510 nm versus a deionized water blank. A calibration curve was built using catechin standard solution at 10, 30, 60, and 100 $mg \cdot L^{-1}$. The total flavonoid content of each kiwifruit was expressed as mg catechin equivalents (CE)·100 $g^{-1}$ FW of kiwifruits. Each fraction was analyzed in triplicate.

## Measurement of Antioxidant Capacity using ABTS Radical

The antioxidant capacity of kiwifruit extracts was measured using ABTS radicals (Kim and Lee, 2004). AAPH (1 mM) was mixed with 2.5 mM ABTS in phosphate buffered saline, which was heated in a water bath at 70°C for 30 min to create ABTS radicals. The solution of ABTS radicals was adjusted to an absorbance of 0.650 ± 0.020 at 734 nm. The reaction between ABTS radical solution (980 μL) and the appropriately diluted extracts (20 μL) was conducted at 37°C for 10 min. Absorbance at 734 nm was measured immediately. A vitamin C standard was used to build a calibration curve with concentrations of 10, 30, 60, and 100 $mg \cdot L^{-1}$. The antioxidant capacity of kiwifruits was expressed as mg vitamin C equivalents (VCE)·100 $g^{-1}$ FW of kiwifruits.

## Measurement of Antioxidant Capacity using DPPH Radical

A method described by Brand-Williams et al. (1995) was used to measure DPPH radical scavenging capacity. The absorbance of fresh DPPH radicals in 80% ($v \cdot v^{-1}$) aqueous methanol was set to 0.650 ± 0.020 at 517 nm. The reaction between DPPH radical solution (2.95 mL) and the appropriately diluted extracts (50 μL) took place at 23°C for 30 min. The reduction of absorbance at 517 nm was measured immediately. A vitamin C standard was used to build a calibration curve with concentrations of 10, 30, 60, and 100 $mg \cdot L^{-1}$. The antioxidant capacity of kiwifruits was expressed as mg VCE·100 $g^{-1}$ FW of kiwifruits.

## Measurement of Oxygen Radical Absorbance Capacity (ORAC)

The ORAC assay was performed as described by Huang et al. (2002). Appropriately diluted extracts or the standard (25 μL) with 150 μL of 81.6 nM fluorescein solution were

added to a 96-well plate and incubated at 37°C for 10 min with 3 min of shaking. Twenty-five microliters of 153 mM AAPH solution was added and fluorescence was then detected every minute for 90 min using a microplate reader (Infinite M200, Tecan Austria GmbH, Grödig, Austria) with 485-nm excitation and 520-nm emission wavelengths. Antioxidant capacity was expressed as mg VCE·100 $g^{-1}$ FW of kiwifruits.

### Statistical Analysis

All experiments were performed in triplicate. Statistically significant tests were performed using a dedicated software package (SAS 9.0, SAS Institute, Inc., Cary, NC, USA). Significant difference was verified by Duncan's multiple range test with a 95% confidence level.

## Results and Discussion

### Total Phenolics and Total Flavonoids

Total phenolic and total flavonoid contents of the flesh extracts of six cultivars of kiwifruits at various maturity stages are shown in Table 3. Each cultivar showed different levels of total phenolic and total flavonoid contents according to maturity stage. Previous studies have reported that the bioactive compounds of kiwifruits vary depending on maturity stage (Park et al., 2006b; Tavarini et al., 2008; Pal et al., 2015). The flesh of 'Bidan' showed the highest total phenolic content among the six cultivars of kiwifruits tested in this study. The total phenolic content of the 'Bidan' flesh ranged from 433.5 to 775.3 mg GAE·100 $g^{-1}$ FW, where 'Bidan' obtained from the second harvest date showed the highest total phenolic content, compared with other stages. Total phenolic content of 'Mansoo' ranged from 118.2 to 130.5

**Table 3.** Total phenolic and flavonoid contents of six cultivars of kiwifruits (*Actinidia* spp.) at different maturity stages harvested in 2013

| Cultivar | Maturity stage[z] | Total phenolics (mg gallic acid eq·100 $g^{-1}$ fresh weight) | Total flavonoids (mg catechin eq·100 $g^{-1}$ fresh weight) |
|---|---|---|---|
| Bidan | 1st | 433.5 ± 19.8 d[y] | 7.0 ± 1.0 ef |
| | 2nd | 775.3 ± 30.2 a | 2.9 ± 0.1 lm |
| | 3rd | 666.5 ± 19.4 b | 2.5 ± 0.1 mn |
| | 4th | 566.1 ± 45.2 c | 1.4 ± 0.1 o |
| Chiak | 1st | 100.4 ± 1.2 g | 9.2 ± 1.0 c |
| | 2nd | 102.4 ± 5.4 g | 7.4 ± 0.4 e |
| | 3rd | 105.8 ± 3.4 fg | 8.3 ± 0.3 d |
| | 4th | 88.5 ± 2.5 g | 5.9 ± 0.1 gh |
| Darae No. 2 | 1st | 110.9 ± 5.8 g | 6.6 ± 0.5 fg |
| | 2nd | 106.5 ± 3.9 g | 6.1 ± 0.4 gh |
| | 3rd | 112.6 ± 8.3 g | 5.8 ± 0.2 gh |
| | 4th | 103.7 ± 1.1 fg | 5.5 ± 0.1 h |
| Haegeum | 1st | 85.8 ± 1.5 g | 5.4 ± 0.5 hi |
| | 2nd | 97.1 ± 4.3 fg | 6.1 ± 0.3 gh |
| | 3rd | 119.8 ± 3.4 fg | 7.5 ± 0.3 e |
| | 4th | 116.1 ± 3.8 ef | 2.4 ± 0.1 mn |
| Haehyang | 1st | 96.8 ± 5.6 fg | 13.1 ± 1.0 a |
| | 2nd | 132.5 ± 6.9 fg | 10.4 ± 0.2 b |
| | 3rd | 128.6 ± 2.0 fg | 7.6 ± 0.3 de |
| | 4th | 122.9 ± 5.0 ef | 4.4 ± 0.5 j |
| Mansoo | 1st | 118.9 ± 8.0 fg | 4.0 ± 0.5 jk |
| | 2nd | 130.5 ± 2.7 fg | 4.7 ± 0.2 ij |
| | 3rd | 118.2 ± 1.8 fg | 4.0 ± 0.3 jk |
| | 4th | 123.4 ± 6.3 ef | 3.5 ± 0.4 kl |

[z]Kiwifruits harvested in the 4th maturity stage were ripened under ethylene treatment.
[y]Data are presented as mean ± standard deviation (n = 3). Different letters in the same column indicate significant differences by Duncan's multiple range test ($p < 0.05$).

mg GAE·100 $g^{-1}$ FW. Total phenolic content of 'Haehyang' ranged from 96.8 to 132.5 mg GAE·100 $g^{-1}$ FW. Total phenolic content of 'Haegeum' ranged from 85.8 to 119.8 mg GAE·100 $g^{-1}$ FW, where the third harvest of 'Haegeum' showed higher concentrations of total phenolics than the first and second stages. 'Darae No. 2' had total phenolic content between 103.7 and 112.6 mg GAE·100 $g^{-1}$ FW. 'Chiak' had total phenolic contents between 88.5 and 105.8 mg GAE·100 $g^{-1}$ FW. Total phenolic content was dependent on kiwifruit cultivars, but no trend was observed among various stages of maturity in this study.

Kiwifruits ripened by treatments with ethylene contained only significantly ($p < 0.05$) lower total phenolic content of 'Bidan' compared with unripen kiwifruits collected during the third harvest stage, while there was no significant difference in the total phenolic content of the other cultivars of kiwifruits (Table 3). Similarly, a previous study showed that the total flavonoid content of green kiwifruits ('Hayward') was higher than those of samples treated with ethylene for ripening (Park et al., 2006a). Ethylene treatment on *A. deliciosa* 'Hayward', however, significantly ($p < 0.05$) increased total phenolic content compared with its untreated counterpart, unlike the results seen in our study (Park et al., 2006b). In ripe kiwifruits, the total phenolic content (mg GAE·100 $g^{-1}$ FW) of six cultivars decreased in the following order (Table 3): 'Bidan' (566.1) > 'Mansoo' (123.4) > 'Haehyang' (122.9) > 'Haegeum' (116.1) > 'Darae No. 2' (103.7) > 'Chiak' (88.5). Ripe kiwifruit of 'Bidan' had a 6.4-fold higher total phenolic content than 'Chiak'. Ripe kiwifruits of 'Haehyang', 'Haegeum', 'Bidan', 'Mansoo', and 'Chiak' had similar levels of total phenolics to the results of this study (Lee et al., 2015). Ripe hardy kiwifruit 'Ananasnaya', however, had a higher level of total phenolics than both 'Chiak' and 'Darae No. 2' used in this study (Fisk et al., 2006).

The amounts of total flavonoids of six cultivars of unripe kiwifruits ranged from 2.5 ('Bidan', 3rd harvest date) to 13.1 mg CE·100 $g^{-1}$ FW ('Haehyang', 1st harvest date) (Table 3). Of the six cultivars of kiwifruits used in this study, 'Bidan', 'Darae No. 2', and 'Haehyang' showed a tendency toward decreased total flavonoid content with greater maturity. Although all ethylene-ripened kiwifruits showed the lowest levels of total flavonoids, 'Chiak', 'Haegeum', and 'Haehyang' only showed significant ($p < 0.05$) differences in total flavonoid content when compared to the last-harvested, unripe respective cultivars. A previous study showed that the total flavonoid content of green kiwifruit ('Hayward') were higher when not treated with ethylene for ripening (Park et al., 2006a). The levels of total flavonoids (mg CE·100 $g^{-1}$ FW) of ripe kiwifruits tested in this study are as follows, in decreasing order (Table 3): 'Chiak' (5.9) > 'Darae No. 2' (5.5) > 'Haehyang' (4.4) > 'Mansoo' (3.5) > 'Haegeum' (2.4) > 'Bidan' (1.4). Total flavonoid content of ripe 'Chiak' kiwifruit were observed to be 4.2 times higher than those of 'Bidan'. In support of what we found in our study, the ripe flesh of 'Haehyang', 'Haegeum', 'Bidan', 'Mansoo', and 'Chiak', harvested in 2012, were measured to have total flavonoid contents of 1.1 to 11.1 mg CE·100 $g^{-1}$ FW (Lee et al., 2015).

## Antioxidant Capacity

Antioxidant capacities, measured using ABTS, DPPH, and ORAC assays, of the six cultivars of kiwifruits at different maturity stages are shown in Table 4. Each cultivar expressed different levels of antioxidant capacity depending on maturity stage. In the ABTS assay, the antioxidant capacity of the flesh of various kiwifruits ranged from 99.0 mg VCE·100 $g^{-1}$ FW in ripe 'Chiak' to 816.5 mg VCE·100 $g^{-1}$ FW in 'Bidan' collected during the second harvest stage (Table 4). The antioxidant capacity (mg VCE·100 $g^{-1}$ FW) of unripe kiwifruits on average over all maturity stages of each cultivar decreased as follows: 'Bidan' (739.9 ± 52.6) > 'Mansoo' (167.1 ± 3.6) > 'Haehyang' (161.4 ± 14.8) > 'Darae No. 2' (148.2 ± 11.8) > 'Haegeum' (138.6 ± 16.3) > 'Chiak' (116.3 ± 8.9). In six cultivars of ripened kiwifruits, antioxidant capacities (mg VCE·100 $g^{-1}$ FW) decreased in the following order: 'Bidan' (701.4) > 'Mansoo' (172.2) > 'Haegeum' (142.6) > 'Haehyang' (133.6) > 'Darae No. 2' (121.0) > 'Chiak' (99.0).

In the DPPH assay, the antioxidant capacities of various kiwifruit flesh were measured to be in the range of 46.0 to 633.2 mg VCE·100 $g^{-1}$ FW (Table 4). The antioxidant capacities (mg VCE·100 $g^{-1}$ FW) of each cultivar of unripe kiwifruit on average over all the maturity stages, decreased as follows: 'Bidan' (579.4 ± 54.1) > 'Haehyang' (112.8 ± 8.4) > 'Mansoo' (112.7 ± 8.1) > 'Haegeum' (111.5 ± 14.2) > 'Darae No. 2' (98.4 ± 2.1) > 'Chiak' (88.1 ± 3.5). In six cultivars of ripened kiwifruits, antioxidant capacities (mg VCE·100 $g^{-1}$ FW) decreased in the following order: 'Bidan' (429.8) > 'Mansoo' (116.4) > 'Haehyang' (97.9) > 'Haegeum' (97.3) > 'Darae No. 2' (62.5) > 'Chiak' (46.0). All of the ripe kiwifruits had significantly ($p < 0.05$) lower antioxidant capacities than the unripe kiwifruits according to the DPPH assay, except for the flesh of 'Mansoo'.

In the ORAC assay, the antioxidant capacities of the flesh of kiwifruits ranged from 595.7 to 2,662.7 mg VCE·100 $g^{-1}$ FW (Table 4). The ethylene-ripened kiwifruits showed lower antioxidant capacities than the unripe kiwifruits, with the exception of 'Bidan' and 'Haegeum' flesh. The average antioxidant capacities (mg VCE·100 $g^{-1}$ FW) of unripe kiwifruits over all maturity stages of each cultivar decreased as follows: 'Bidan' (2,431.2 ± 286.9) > 'Mansoo' (976.3 ± 87.5) > 'Chiak' (955.4 ± 46.6) > 'Darae No. 2' (912.4 ± 147.0) > 'Haehyang' (829.3 ± 60.7) > 'Haegeum' (651.4 ± 40.6). The antioxidant capacities (mg VCE·100 $g^{-1}$ FW) of ripe kiwifruits tested in this study decreased in the following order: 'Bidan' (2,235.0)

**Table 4.** Antioxidant capacity of six cultivars of kiwifruits (*Actinidia* spp.) at different maturity stages harvested in 2013.

| Cultivar | Maturity stage[z] | Antioxidant capacity (mg vitamin C eq·100 $g^{-1}$ fresh weight) | | |
|---|---|---|---|---|
| | | ABTS | DPPH | ORAC |
| Bidan | 1st | 733.2 ± 55.5 b[y] | 617.7 ± 41.9 a | 2,614.3 ± 94.0 a |
| | 2nd | 816.5 ± 25.9 a | 633.2 ± 7.4 a | 2,662.7 ± 131.0 a |
| | 3rd | 702.4 ± 31.7 b | 542.8 ± 20.2 b | 2,415.9 ± 228.9 b |
| | 4th | 701.4 ± 66.8 b | 429.8 ± 14.7 c | 2,235.0 ± 57.9 c |
| Chiak | 1st | 110.6 ± 0.9 gh | 86.4 ± 3.6 gh | 988.0 ± 10.4 de |
| | 2nd | 111.7 ± 5.9 fgh | 92.1 ± 1.8 efgh | 976.2 ± 18.3 de |
| | 3rd | 126.5 ± 10.1 efgh | 85.7 ± 5.0 h | 902.1 ± 40.7 efg |
| | 4th | 99.0 ± 4.2 h | 46.0 ± 0.7 i | 811.4 ± 39.1 fgh |
| Darae No. 2 | 1st | 153.7 ± 13.7 cdef | 95.9 ± 1.2 defgh | 897.9 ± 53.4 efg |
| | 2nd | 134.6 ± 2.8 defgh | 99.7 ± 2.7 defgh | 911.9 ± 46.2 efg |
| | 3rd | 156.2 ± 4.3 cdef | 99.5 ± 3.3 defgh | 927.3 ± 69.0 ef |
| | 4th | 121.0 ± 12.0 fgh | 62.5 ± 1.5 i | 925.9 ± 106.9 ef |
| Haegeum | 1st | 129.0 ± 10.0 efgh | 90.6 ± 3.8 fgh | 650.9 ± 31.3 jk |
| | 2nd | 121.2 ± 3.0 fgh | 121.9 ± 10.1 d | 595.7 ± 37.1 k |
| | 3rd | 147.4 ± 11.1 cdefg | 115.2 ± 5.6 def | 691.1 ± 25.6 hijk |
| | 4th | 142.6 ± 11.4 cdefg | 97.3 ± 2.5 defgh | 799.0 ± 40.4 fghi |
| Haehyang | 1st | 151.1 ± 5.9 cdef | 102.7 ± 1.2 defgh | 773.8 ± 42.4 ghij |
| | 2nd | 178.3 ± 7.1 c | 119.3 ± 2.0 d | 894.1 ± 5.5 efg |
| | 3rd | 154.7 ± 0.5 cdef | 116.3 ± 2.8 def | 820.0 ± 20.2 fgh |
| | 4th | 133.6 ± 10.6 defgh | 97.9 ± 7.9 defgh | 715.5 ± 38.1 hijk |
| Mansoo | 1st | 171.2 ± 12.3 cd | 121.0 ± 3.0 d | 885.9 ± 56.8 efg |
| | 2nd | 165.7 ± 7.6 cde | 112.4 ± 2.9 defg | 1,060.7 ± 37.6 d |
| | 3rd | 164.3 ± 8.7 cde | 104.8 ± 3.4 defgh | 982.4 ± 53.5 de |
| | 4th | 172.2 ± 5.4 cd | 116.4 ± 3.4 def | 870.9 ± 35.1 efg |

[z]Kiwifruits harvested in the 4th maturity stage were ripened under ethylene treatment.
[y]Data are presented as mean ± standard deviation (n = 3). Different letters in the same column indicate significant differences by Duncan's multiple range test ($p < 0.05$).

> 'Darae No. 2' (925.9) > 'Mansoo' (870.9) > 'Chiak' (811.4) > 'Haegeum' (799.0) > 'Haehyang' (715.5).

As we saw in our data for total phenolic content, the second harvest of 'Bidan' showed the highest level of antioxidant capacity according to all three assays, ABTS, DPPH, and ORAC (Table 4). In a previously published study, kiwifruits of 'Bidan' had a higher antioxidant capacity than other cultivars, including golden kiwifruit, 'Haenam', and green kiwifruits, 'Hayward' and 'Daeheung', as measured by ABTS and DPPH assays (Park et al., 2011). The antioxidant capacities of 'Chiak' and 'Darae No. 2' in this study were lower than that of ripe hardy kiwifruit 'Ananasnaya' in a previous study (Fisk et al., 2006). 'Bidan' was reported to have very high amounts of antioxidative vitamin C compared to the standard *A. deliciosa* 'Hayward' (Jo et al., 2007; Park et al., 2011). In general, ethylene-ripened kiwifruits in this study showed lower antioxidant capacities than their unripe counterparts, which might be ascribed to decreases in the total phenolic and flavonoid content during ripening (Park et al., 2006a). The different cultivars of kiwifruit influenced their antioxidant capacities, but maturity stages were not associated with differing antioxidant capacities in this study, as was previously seen in various cultivars of *A. deliciosa* grown in India (Pal et al., 2015). The antioxidant capacity of the ripe flesh of kiwifruits such as 'Haehyang', 'Haegeum', 'Mansoo', 'Chiak', and 'Bidan', harvested in 2012, showed similar results to those in this study (Lee et al., 2015).

The six cultivars of kiwifruits showed a variety of antioxidant capacities according to the three assays used in this study, which can be attributed to various factors, including the different assays, redox mechanisms, solvents, and quantification methods, together with their diverse chemical compositions (Yoo et al., 2007; Apak et al., 2013). Antioxidant capacities measured using ORAC assay appeared to be higher than those measured using the ABTS and DPPH assays

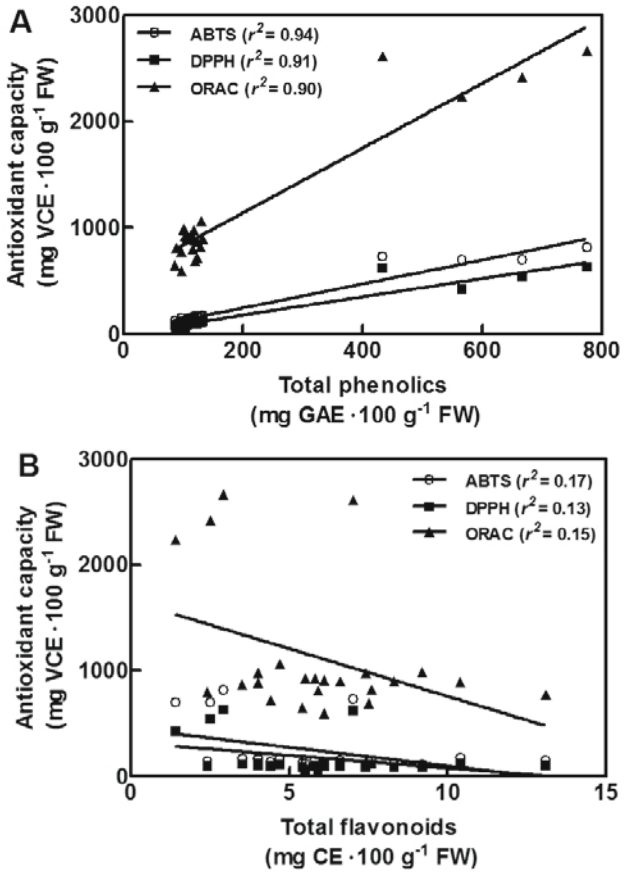


**Fig. 1.** Relationship between antioxidant capacity and total phenolics (A) and total flavonoids (B) of six cultivars of kiwifruits at various maturity stages.

(Table 4). The ORAC assay evaluates antioxidant capacity based on a hydrogen atom transfer reaction, whereas both the ABTS and DPPH assays are based on a single electron transfer reaction (Huang et al., 2005). To reliably compare and quantitatively evaluate antioxidant capacities in foods such as fruits, it is recommended that more than two commonly accepted antioxidant capacity assays should be used, based on the same unit, for reliable results (Huang et al., 2005; Yoo et al., 2007).

### Relationship among Antioxidant Capacity, Total Phenolics, and Total Flavonoids

A linear correlation analysis was conducted if total phenolics, total flavonoids, or both, had an influence on the antioxidant capacity of kiwifruits. Antioxidant capacity had a higher linear correlation with total phenolics than with total flavonoids (Fig. 1). The correlation coefficients ($r^2$) between total phenolics and antioxidant capacity, measured using the ABTS, DPPH, and ORAC assays, were 0.94, 0.91, and 0.90, respectively (Fig. 1A). Antioxidant capacity measured using the ABTS, DPPH, and ORAC assays had correlation coefficients ($r^2$) of 0.17, 0.13, and 0.15 with total flavonoids, respectively (Fig. 1B). These results in kiwifruits tested in this study suggest that phenolic compounds contribute more than flavonoids to antioxidant capacity. Many researchers have shown that total phenolic contents are more positively correlated with antioxidant capacity than flavonoid contents (Cho et al., 2011; Tsantili et al., 2011; Hwang et al., 2015).

Six cultivars of kiwifruits (*Actinidia* spp.) were grown in Korea in 2013, and included *A. eriantha* 'Bidan', *A. arguta* 'Chiak', *A. arguta* 'Darae No. 2', *A. chinensis* 'Haegeum', *A. chinensis* 'Haehyang', and *A. arguta* × *A. deliciosa* 'Mansoo'. Their antioxidant capacities, total phenolic contents and total flavonoid contents were measured and found to be dependent on cultivars and genotypes. No trends were seen in the contents of total phenolics and flavonoids as well as in antioxidant capacity associated with any particular maturity stage. Among various ripe kiwifruits tested in this study, 'Bidan' had the highest total phenolics and antioxidant capacity, but the lowest total flavonoids. 'Chiak' had the highest level of total flavonoids, but the lowest antioxidant capacity, as measured using ABTS and DPPH assays. The results of this study suggest that kiwifruits grown in Korea may be a valuable source of antioxidants and phenolic compounds. Further studies should be conducted to quantitatively evaluate individual phenolic compounds, in order to select kiwifruits that are rich in bioactive phenolics for industrial application and optimal benefit to consumers.

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