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Antioxidant Capacity in Cranberry Is Influenced by Cultivar and Storage Temperature

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Ten cranberry (*Vaccinium macrocarpon* Aiton) cultivars were evaluated for oxygen radical absorbance capacity (ORAC), anthocyanins, and total phenolics contents after three months of storage at 0, 5, 10, 15, and 20 °C. The antioxidant capacity of cranberry was affected by cultivars and storage temperatures. Among the 10 cranberry cultivars used in this study, Early Black, Crowley, and Franklin had higher antioxidant capacities than the other cultivars. ORAC values, anthocyanins, and total phenolics contents increased during storage. The highest increases in antioxidant activity, anthocyanin, and phenolics contents occurred at 15 °C storage. Fruit stored at 20 °C had lower ORAC values than those stored at 15 °C. A positive relationship existed between ORAC values and anthocyanin or phenolic content in all 10 cranberry cultivars at different storage temperatures.

Keywords: *Antioxidant; anthocyanin; phenolics; free radical; cranberry; Vaccinium macrocarpon Aiton*

INTRODUCTION

Fruits of *Vaccinium* species, which include lowbush blueberry, bilberry, cranberry, and lingonberry, are rich sources of antioxidants and have exhibited potential anticarcinogenic activity during in vitro screening tests (*6*). The juices of blueberry and cranberry are reported to contain proanthocyanidins that are useful in treating urinary tract infections (*16*, *27*). Members of the *Vaccinium* genus are especially rich in flavonoids (anthocyanins, flavonols, and proanthocyanidins) and other phenolic compounds, which are more stable and more significant constituents of their total antioxidant capacity compared to other fruit antioxidants such as vitamin C (*6*, *17*, *30*). In fact, plant phenols have been shown to protect against ascorbic acid destruction (*21*). Flavonoids such as anthocyanins, flavonols, and proanthocyanidins have been found to significantly reduce mortality rates due to coronary heart disease (*3*, *15*, *36*, *38*) and to have anticancer properties (*1*, *2*, *6*, *10*, *41*).

Members of the *Vaccinium* genus, such as blueberries, contain high amounts of anthocyanins, as can be seen by their deep violet pigmentation (*17*). Anthocyanins have been used for several therapeutic purposes including the treatment of diabetic retinopathy, fibrocystic disease, and vision disorders (*22*, *29*, *32*, *35*). Anthocyanins also have the potential to serve as radiation-protective agents, vasotonic agents, and chemoprotective agents (*39*). In addition to its antioxidant effects, blueberry anthocyanins can act against carbon tetrachloride-induced lipoperoxidation (*25*).

Similar to blueberries, bilberries are also rich sources of antioxidants. More than 184 *Vaccinium* pharmaceutical products have been introduced (*17*). Bilberry anthocyanins also decrease the fragility of capillaries, inhibit blood platelet aggregation, and strengthen the collagen matrix, which is the protein component of connective tissues (*5*, *23*, *25*, *28*).

Although the large-fruited American cranberry is also a member of the *Vaccinium* genus, very little research has been conducted on the antioxidant activity and phenolic content of this species. Virtually no information is available on the changes of these constituents after harvest. This research was undertaken to assess the oxygen radical absorbance capacity of 10 different cultivars of *V. marcrocarpon*. The effect of various storage temperatures on total antioxidant activity, anthocyanins, and total phenolics of 10 cranberry cultivars was also determined.

MATERIALS AND METHODS

Chemicals. R-phycoerythrin (R-PE) from *Porphydium cruentum* was purchased from Sigma (St. Louis, MO). 2′, 2′ Azobis (2-amidinopropane) dihydrochloride (AAPH) was purchased from Wako Chemicals USA Inc. (Richmond, VA). 6-Hydroxy-2,5,7,8-tetramethylchroman-2-carboxylic acid (Trolox) was obtained from Aldrich (Milwaukee, WI).

Fruit Sample Preparation. Cranberry fruits used in this study were grown at the Rutgers Blueberry and Cranberry Research Center in Chatsworth, NJ. Because cultural practices were all the same, cultivar differences observed at harvest were primarily due to different cultivar traits. The cranberries were harvested at commercial maturity from four replicates per cultivar and stored for three months at 0, 5, 10, 15, and 20 °C. At harvest and after three months of storage, undamaged berries were selected, the seeds were removed, and the berries were cut into small slices and mixed. To prepare the juice samples, three 50-g samples of berries from four replicates of each cultivar were pulverized and then centrifuged at 14 000*g* for 20 min. The supernatant (juice fraction) was transferred to vials, stored at −80 °C, and then used for

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Table 1. Antioxidant Activity of Fruit of Cranberry Cultivars Stored for Three Months at Different Storage Temperatures[b]

	storage temperature (°C)						
cultivar	initial	0 °C	5 °C	10 °C	15 °C	20 °C	mean[d]
Ben Lear	10.1 ± 0.4[a]	11.6 ± 0.3	12.0 ± 0.2	12.6 ± 0.1	16.1 ± 0.5	14.3 ± 0.3	12.8bc[e]
Cropper	8.6 ± 0.3	10.9 ± 0.3	11.5 ± 0.1	12.7 ± 0.2	13.0 ± 0.2	11.6 ± 0.2	11.4a
Crowley	11.9 ± 0.5	14.4 ± 0.2	15.1 ± 0.5	15.3 ± 0.4	17.9 ± 0.8	17.2 ± 0.5	15.3d
Early Black	14.1 ± 0.2	14.6 ± 0.5	15.1 ± 0.4	16.9 ± 0.9	20.6 ± 1.2	19.3 ± 0.7	16.8e
Franklin	12.7 ± 0.3	13.9 ± 0.2	15.0 ± 0.6	15.6 ± 0.7	17.0 ± 0.6	16.2 ± 0.4	15.1d
Howes	9.3 ± 0.6	11.4 ± 0.2	11.8 ± 0.3	13.2 ± 0.3	15.8 ± 0.4	13.7 ± 0.1	12.5b
Pilgrim	8.2 ± 0.4	9.8 ± 0.1	11.0 ± 0.1	13.8 ± 0.2	14.4 ± 0.5	11.1 ± 0.1	11.4a
Stevens	9.1 ± 0.3	11.0 ± 0.2	12.5 ± 0.2	13.2 ± 0.1	13.9 ± 0.3	12.3 ± 0.3	12.0ab
Wilcox	10.3 ± 0.5	12.0 ± 0.2	13.5 ± 0.4	14.2 ± 0.2	16.3 ± 0.6	14.6 ± 0.4	13.5c
#35	9.8 ± 0.2	12.3 ± 0.1	13.4 ± 0.3	14.7 ± 0.3	15.7 ± 0.4	12.7 ± 0.2	13.1c
mean[c]	10.4a[e]	12.2b	13.1c	14.2d	16.1e	14.3c	
significance[f]							
cultivar [*C*]	**	**	**	**	**	**	
temp [*T*]	**	**	**	**	**	**	
C × *T*	**	**	**	**	**	**	

[a] Data expressed as mean ± SEM. [b] Data expressed as micromoles of Trolox equivalents (TE) per gram of fresh weight: total ORAC (μmol TE/g). [c] Mean value of the different cultivar stored at a designated temperature. [d] Mean value of a designated cultivar stored at different temperatures. [e] Within the row (for different temperature treatments) or the column (for different cultivars) with different letters is significant at $p \leq 0.05$. [f] Significant at $p \leq 0.05$.

analyses of oxygen radical absorbance capacity (ORAC), anthocyanin, and total phenolics.

ORAC Assay. The procedures for the ORAC assay on cranberries were modified from a method previously described by Cao et al. (*7*). This assay measures the effect of antioxidant components in fruit juices of cranberries on the decline in R-phycoerythrin (R-PE) fluorescence induced by a peroxyl radical generator, 2′,2′ azobis (2-amidinopropane) dihydrochloride (AAPH). The reaction mixture contained 1.7 mL of 75 mM phosphate buffer (pH 7.0), 100 μL of R-PE (3.4 mg/l), 100 μL of 320 mM AAPH, and 100 μL of sample. Phosphate buffer was used as a blank and 1 μM of Trolox (a water-soluble α-tocopherol analogue) was ued as a standard during each run. The final volume of 2 mL was used in a 10 mm wide fluorometer cuvette. R-PE, phosphate buffer, and samples were preincubated at 37 °C for 15 min. The reaction was started by the addition of AAPH. Fluorescence was measured and recorded every 5 min at the emission of 570 nm and excitation of 540 mm using a Shimadzu RF-Mini 150 Recording Fluorometer (Columbia, MD) until the fluorescence of the last reading declined to less than 5% of the first reading. This usually took approximately 70 min. One blank, one standard, and a maximum of 10 samples were analyzed at the same time. Each sample was repeated three times. The ORAC value refers to the net protection area under the quenching curve of R-PE in the presence of an antioxidant. The final results (ORAC value) were calculated and expressed using Trolox equivalents per gram fresh weight (*7*). Dry matter was determined after lyophilization.

Analysis of Total Anthocyanin Content. Total anthocyanin contents in fruit juice were determined by using the pH differential method (*8*). Absorbance was measured in a Shimadzu Spectrophotometer (Shimadzu UV-160) at 510 nm, and 700 nm in buffers at pH 1.0 and 4.5, using $A = [(A_{510} - A_{700})_{\text{pH } 1.0} - (A_{510} - A_{700})_{\text{pH } 4.5}]$ with a molar extinction coefficient of cyanidin-3-glucoside (29 600). Results were expressed as milligrams of cyanidin-3-glucoside equivalent per 100 g of fresh weight.

Total Phenolic Compound Analysis. Total soluble phenolics in the fruit juice extracts were determined with Folin-Ciocalteu reagent by the method of Slinkard and Singleton (*33*) using gallic acid as a standard. Results were expressed as milligrams gallic acid equivalent (GAE) per 100 g fresh weight.

Statistical Analysis. Correlation and regression analyses of ORAC versus total phenolics, or total anthocyanin were performed using NCSS (*26*). Data were subjected to analysis of variance, and the effects of cultivar and storage temperature on ORAC values, anthocyanin, and total phenolics contents were evaluated by the Tukey-Kramer multiple-comparison test used in NCSS. Differences at $p < 0.05$ were considered significant.

RESULTS

Differences in Antioxidant Activity, Anthocyanin, and Total Phenolics Contents Among Various Cultivars of Cranberries. Significant differences were found in antioxidant activity, anthocyanin, and total phenolics contents among various cultivars of cranberries (Tables 1−3). There were also differences in which cultivars had higher or lower antioxidant, anthocyanin, and total phenolics contents at various storage temperatures. At harvest, cv. Early Black had the highest ORAC value (14.1 μmol TE/g), followed by Franklin, Crowley, Wilcox, Ben Lear, #35, Howes, Stevens, Cropper, and Pilgrim. After storage at 0 °C, cv. Early Black and Crowley had the highest ORAC values (14.6 and 14.4 μmol TE/g, respectively), and were followed by Franklin, #35, Wilcox, Ben Lear, Howes, Stevens, Cropper, and Pilgrim. Based on the mean ORAC values (obtained by averaging all the results from cranberries of the same cultivar at the different storage temperatures) for each cultivar, cv. Early Black had the highest ORAC value (16.8 μmol TE/g), followed by Crowley, Franklin, Wilcox, #35, Ben Lear, Howes, Stevens, Pilgrim, and Cropper (Table 1).

Anthocyanin content also differed significantly among the different cultivars. Under initial conditions after harvest, cv. Crowley and Early Black had the highest anthocyanin content (65.6 and 63.4 mg/100 g, respectively) (Table 2) and Cropper had the lowest. In addition, at storage temperatures of 0, 5, and 10 °C, Early Black continued to yield the highest anthocyanin (72.4, 88.6, and 93.0 mg/100 g, respectively), and Pilgrim remained the cultivar with the lowest anthocyanin content at 0, 5, 10, and 15 °C. Early Black cranberries also had the most anthocyanins compared to the other cultivars at 15 and 20 °C, whereas Pilgrim, Stevens, and Cropper had the lowest anthocyanin contents at 20 °C (47.4, 52.4, and 52.2 mg/100 g, respectively). When comparing the mean anthocyanin contents of each cultivar, which were calculated from the results of the different storage temperatures, Early Black had the

Table 2. Anthocyanin Content of Fruit of Cranberry Cultivars Stored for Three Months at Different Storage Temperatures[b]

	storage temperature (°C)						
cultivar	initial	0 °C	5 °C	10 °C	15 °C	20 °C	mean[d]
Ben Lear	25.0 ± 1.3[a]	46.0 ± 2.5	54.6 ± 2.9	62.0 ± 4.3	76.6 ± 3.5	66.2 ± 1.8	55.1c[e]
Cropper	19.8 ± 1.3	34.8 ± 1.6	49.2 ± 3.0	55.8 ± 1.9	60.4 ± 2.1	52.4 ± 1.1	45.4a
Crowley	65.6 ± 2.0	65.4 ± 3.4	80.8 ± 3.7	81.0 ± 6.0	109.2 ± 2.9	89.8 ± 4.2	82.0f
Early Black	63.4 ± 1.5	72.4 ± 5.2	88.6 ± 4.1	93.0 ± 5.7	117.2 ± 3.2	96.0 ± 5.1	88.4f
Franklin	54.1 ± 3.6	60.4 ± 1.8	69.6 ± 3.2	74.8 ± 2.1	93.6 ± 1.4	78.0 ± 1.3	71.8e
Howes	23.5 ± 1.1	33.0 ± 1.4	49.4 ± 1.6	58.2 ± 2.4	71.0 ± 2.2	63.3 ± 2.1	49.7bc
Pilgrim	20.7 ± 1.1	30.8 ± 1.5	38.6 ± 1.0	48.0 ± 1.3	60.0 ± 2.3	47.4 ± 1.9	41.5a
Stevens	22.8 ± 1.3	31.6 ± 1.2	47.4 ± 2.5	57.8 ± 3.5	65.6 ± 1.8	52.2 ± 2.0	46.1a
Wilcox	24.3 ± 1.2	54.8 ± 2.7	64.6 ± 2.8	68.4 ± 3.2	72.4 ± 1.7	65.4 ± 2.3	58.3d
#35	28.6 ± 1.7	51.4 ± 2.1	54.3 ± 2.6	61.4 ± 2.9	76.6 ± 2.5	66.6 ± 2.6	56.5cd
mean[c]	34.8a[e]	48.4b	59.7c	66.0d	80.3e	67.7d	
significance[f]							
cultivar [*C*]	**	**	**	**	**	**	
temp [*T*]	**	**	**	**	**	**	
C × *T*	**	**	**	**	**	**	

[a] Data expressed as mean ± SEM. [b] Data expressed as milligrams of cyanidin-3-galactoside per 100 g of fresh weight (mg/100 g). [c] Mean value of the different cultivar stored at a designated temperature. [d] Mean value of a designated cultivar stored at different temperatures. [e] Within the row (for different temperature treatments) or the column (for different cultivars) with different letters is significant at $p \leq 0.05$. [f] Significant at $p \leq 0.05$.

Table 3. Total Phenolic Contents of Fruit of Cranberry Cultivars Stored for Three Months at Different Storage Temperatures[b]

	storage temperature (°C)						
cultivar	initial	0 °C	5 °C	10 °C	15 °C	20 °C	mean[d]
Ben Lear	137.5 ± 2.5[a]	140.3 ± 2.6	143.3 ± 2.7	159.8 ± 3.4	192.0 ± 3.3	185.3 ± 4.7	159.7bc[e]
Cropper	121.5 ± 2.0	127.3 ± 1.7	138.5 ± 2.4	147.0 ± 2.8	147.5 ± 8.6	133.0 ± 1.6	136.6a
Crowley	159.0 ± 7.3	185.3 ± 4.5	216.3 ± 7.6	220.8 ± 6.4	230.0 ± 2.3	223.0 ± 4.2	205.7d
Early Black	176.5 ± 5.2	191.3 ± 3.8	205.3 ± 5.4	221.5 ± 7.3	306.5 ± 9.7	235.0 ± 5.7	222.7e
Franklin	165.8 ± 2.8	169.8 ± 3.2	187.0 ± 6.8	198.5 ± 3.7	240.0 ± 5.8	216.3 ± 3.5	196.2d
Howes	128.3 ± 2.1	137.3 ± 2.4	157.3 ± 3.5	172.8 ± 3.6	195.3 ± 2.6	175.3 ± 3.2	161.1c
Pilgrim	120.0 ± 1.7	122.5 ± 2.0	160.8 ± 3.7	173.5 ± 2.9	182.0 ± 2.1	154.8 ± 2.3	152.3b
Stevens	126.0 ± 3.2	128.5 ± 1.9	169.8 ± 5.1	171.3 ± 2.1	177.0 ± 3.0	148.0 ± 3.9	153.4b
Wilcox	149.5 ± 3.6	153.0 ± 3.2	162.3 ± 4.3	169.5 ± 4.5	215.5 ± 2.5	176.5 ± 2.7	171.1c
#35	127.8 ± 2.5	138.3 ± 2.7	152.8 ± 3.2	158.5 ± 3.5	194.8 ± 3.6	150.5 ± 2.4	153.8b
mean[c]	141.2a[e]	149.4a	169.8b	179.3c	208.1d	179.8c	
significance[f]							
cultivar [*C*]	**	**	**	**	**	**	
temp [*T*]	**	**	**	**	**	**	
C × *T*	**	**	**	**	**	**	

[a] Data expressed as mean ± SEM. [b] Data expressed as milligrams of gallic acid (GAE) equivalents per 100 g of fresh weight (mg/100 g). [c] Mean value of the different cultivar stored at a designated temperature. [d] Mean value of a designated cultivar stored at different temperatures. [e] Within the row (for different temperature treatments) or the column (for different cultivars) with different letters is significant at $p \leq 0.05$. [f] Significant at $p \leq 0.05$.

highest anthocyanin content (88.4 mg/100 g), followed by Crowley, Franklin, Wilcox, #35, Ben Lear, Howes, Steven, Cropper, and Pilgrim which had average anthocyanin contents of (82.0, 71.8, 58.3, 56.5, 55.1, 49.7, 46.1, 45.4. and 41.5 mg/100 g, respectively) (Table 2).

Significant differences in total phenolics contents among the cultivars were also evident. Under initial conditions, cv. Early Black had the highest total phenolics content (176.5 mg/100 g) followed by cv. Franklin, Crowley, Wilcox, Ben Lear, Howes, #35, Stevens, Cropper, and Pilgrim (Table 3). Early Black, Crowley, and Franklin cranberries continued to have higher total phenolics contents at the various storage temperatures, and Pilgrim cranberries had the lowest total phenolics content at 0 °C. However, for storage temperatures at 5, 10, 15, and 20 °C, Cropper had the lowest total phenolics content compared to the other cultivars at the same storage temperatures. After averaging the results of the different storage temperatures within the same cultivar, Early Black had the highest mean total phenolics content (222.7 mg/100 g) and Cropper had the lowest (136.6 mg/100 g) (Table 3).

Effect of Storage Temperature on Antioxidant Activity, Anthocyanin, and Total Phenolics Contents. Temperatures during 3 months of storage significantly affected ORAC values, anthocyanin, and total phenolics contents in cranberries (Tables 1−3). The ORAC values were higher with higher storage temperatures between 0 and 15 °C in all cultivars (Table 1). However, fruit stored at 20 °C had lower ORAC values than those stored at 15 °C (Tables 1).

The cranberry cultivars Cropper, Pilgrim, Stevens, Howes, Wilcox, Ben Lear, and #35, had the lowest anthocyanin contents at the initial harvest. Increasing storage temperatures up to 15 °C also significantly increased the anthocyanin contents of the cranberries, and in some cultivars, there was a 3- to 5-fold increase compared to those of freshly harvested berries. For instance, Ben Lear had an initial anthocyanin content of 25.0 mg/100 g, but at storage temperatures of 0, 5, 10, and 15 °C, the anthocyanin contents increased to 46.0, 54.6, 62.0, and 76.6 mg/100 g, respectively (Table 2). Similar to Ben Lear, the cultivars Early Black, Crowley, Franklin, #35, Wilcox, Howes, Stevens, Crop-

Table 4. Correlation Coefficients between Antioxidant Activity (ORAC), Anthocyanin, and Total Phenolics Contents in Fruit of Cranberry Cultivars after 3 Months of Storage at Various Temperatures (0, 5, 10, 15, and 20 °C)

	correlation coefficient (temperature effect)	
cultivar (cv.)	ORAC vs total phenolics	ORAC vs anthocyanin
Ben Lear	0.902	0.895
Cropper	0.945	0.929
Crowley	0.941	0.899
Early Black	0.953	0.904
Franklin	0.950	0.902
Howes	0.935	0.925
Pilgrim	0.952	0.879
Stevens	0.917	0.893
Wilcox	0.934	0.887
#35	0.946	0.869

per, and Pilgrim had the highest anthocyanin content when stored at 15 °C for three weeks (Table 2). Mean anthocyanin contents for the 10 cranberry cultivars tested at 0, 5, 10, 15, and 20 °C were 48.4, 59.7, 66.0, 80.3, and 67.7 mg/100 g, respectively (Table 2). The optimum storage temperature for maximum anthocyanin content was 15 °C.

Total phenolics contents also increased significantly with storage. All cultivars started to show a rise in total phenolics contents after storage at 0, 5, 10, and 15 °C for three months. Cultivars Pilgrim, Cropper, Stevens, #35, and Howes had low total phenolics contents initially, compared to those after temperature and storage treatments. After three months of storage, Early Black, Franklin, Crowley, and Wilcox had the highest total phenolics contents at 15 °C (306.5, 240.0, 230.0, and 215.5 mg/100 g, respectively) compared to those at other storage temperatures. The average total phenolics contents for the 10 cultivars of cranberries stored at 0, 5,s 10, 15, and 20 °C were 149.4, 169.8, 179.3, 208.1, and 179.8 mg/100 g, respectively (Table 3), and results again indicated that the optimal storage temperature for maximum total phenolics content was 15 °C.

ORAC, anthocyanin, and total phenolics contents were significantly different among cultivars. They also were significantly affected by different storage temperatures. A significant interaction between cultivars and temperatures was found in ORAC values, anthocyanin, and total phenolics contents (Tables 1−3). On a dry matter basis, the influence of cultivar and storage temperature on ORAC, anthocyanin, and total phenolics were also evident and followed the same patterns as expressed on fresh weight basis (data not shown).

Correlation Between ORAC and Total Phenolics Content or Anthocyanin Content in Response to Storage Temperature or Cultivars. Correlation coefficients for the ORAC values and total phenolics contents ranged from $r = 0.902$ for cv. Ben Lear to $r = 0.953$ for cv. Early Black (Table 4). At different storage temperatures, the correlation coefficients, which ranged from $r = 0.917$ for 10 °C to $r = 0.970$ for 20 °C, also showed a significant relationship between antioxidant and total phenolics contents (Table 5).

A positive relationship between ORAC values and anthocyanin contents also existed in all cultivars. The correlation ranged from $r = 0.869$ for cv. #35 to $r = 0.929$ for Cropper (Table 4). The correlation coefficient between ORAC and anthocyanin in all cultivars in response to different temperatures (0 to 20 °C), ranged from 0.879 to 0.929 (Table 5). On a dry matter basis, the same patterns of the correlation between ORAC versus total phenolics, or total anthocyanins, were also evident (data not shown).

Table 5. Correlation Coefficients between Antioxidant Activity (ORAC), Anthocyanin, or Total Phenolic Contents in Fruit of Ten Cranberry Cultivars at Designated Temperatures after 3 Months of Storage

	correlation coefficient (cultivar effect)	
temperature	ORAC vs total phenolic	ORAC vs anthocyanin
0 °C	0.926	0.879
5 °C	0.922	0.895
10 °C	0.917	0.865
15 °C	0.950	0.917
20 °C	0.970	0.938

DISCUSSION

Members of the genus *Vaccinium* (Ericaceae) are rich sources of anthocyanins, flavonols, proanthocyanidins, and other phenolics. Anthocyanin and phenolic content in cranberry vary in different cultivars and storage temperatures. Differences in cranberry anthocyanin contents among cultivars in fruit or juice are due in part to differences in berry size (*11*, *31*, *37*). Heritable differences in cranberry size have been shown in breeding programs (*12*). The berry sizes for cv. Ben Lear, Cropper, Crowley, Early Black, Franklin, Howes, Pilgrim, Stevens, Wilcox, and #35 were 2.18, 2.59, 1.75, 1.45, 1.59, 1.98, 2.70, 2.50, 1.90, and 2.07 g/berry, respectively. An inverse relationship exists between cranberry fruit size and anthocyanin content ($r = -0.895$). This is probably because cranberry pigment is located in the skin (*11*, *31*, *37*). Crowley, Early Black, and Franklin cultivars have higher anthocyanin contents than other cranberry cultivars used in this study. This may be due to their smaller berry size. Pre- and postharvest environmental conditions, such as temperature (*13*) and light (*9*) also influence the anthocyanin concentration of cranberries. The relative antioxidant activity of cranberry was affected by cultivars, fruit size, and storage temperatures. A negative correlation between ORAC values and fruit size was found ($r = -0.838$), but anthocyanins and phenolic content in the cranberry cultivars were positively correlated with antioxidant activity. Lower anthocyanin and phenolic contents may contribute to lower antioxidant activities in cranberries. Prior et al. (*30*) found different antioxidant capacities in various species and cultivars of blueberry and bilberry. They also showed a linear relationship between ORAC and anthocyanin or total phenolic content. The antioxidant activities of cranberries are similar to those of strawberries, but are lower than those of blueberries, blackberries, and raspberries (*30*, *40*). Anthocyanin content in cranberries mainly consists of cyanidin-3-monogalactosides, cyanidin-3-arabinoside, peonidin-3-monogalactoside, and peoniden-3-arabinoside (*34*). These compounds are weaker antioxidants than cyanidin-3-glucoside which is present in high amounts in other berries (*37*). ORAC values, anthocyanins, and total phenolic contents increased during storage. Increases in anthocyanin content during storage also have been reported for strawberries (*20*), lowbush blueberries (*19*), rabbiteye blueberries (*4*), and raspberries (*24*). During storage, decreases in titratable acidity and organic acids may provide carbon skeletons for the synthesis of phenolics, including both anthocyanin and nonanthocyanin phenolics (such as ascorbic acid) (*24*). The synthesis of both anthocyanins and nonanthocyanins may have contributed to the increase in ORAC in cranberry fruit. The highest antioxidant content after three months of storage occurred at 15 °C. However, even though antioxidant activity was the highest at 15 °C, this elevated temperature might not be the best for maintaining storage quality of cranberries. The recommended storage temperature for cranberries is 2−4 °C (*14*). Kalt et al. (*18*) also showed that the content of anthocyanin and total phenolics increased substantially in raspberries and strawberries stored at temperatures greater than 0 °C, and this increase was accompanied by an increase in total antioxidant capacity. The low ORAC values, anthocyanins, and phenolics contents after three months of storage at 20 °C was probably due to deterioration.

Correlation coefficients for the ORAC values and total phenolic contents in cranberries ranged from $r = 0.902$ to 0.953, indicating that the changes of ORAC in response to various temperatures were significantly correlated to total phenolic content in a specific cranberry cultivar. At different storage temperatures, the correlation coefficients between the antioxidant and total phenolic contents were also high, ranging from $r = 0.917$ to 0.970. This indicates that, at a given temperature, cranberry cultivars with high ORAC values also contain high total phenolic content. A significant relationship between ORAC values and anthocyanin contents also existed in all cultivars, indicating that, at a given temperature, cultivars with high ORAC values were also high in anthocyanin content.

Collectively, our data suggest that ORAC, anthocyanin, and total phenolics contents were significantly different in various cranberry cultivars. They were also significantly affected by different storage temperatures. A significant interaction between cultivars and temperatures was found for ORAC values, anthocyanins, and total phenolics contents.

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