J. AMER. SOC. HORT. SCI. 111(4):612–617. 1986.

# Factors Affecting the Anthocyanin Content of Cranberry

**Gerald M. Sapers, Gavin R. Graff, and John G. Phillips**
*Eastern Regional Research Center, Agricultural Research Service, U.S. Department of Agriculture, Philadelphia, PA 19118*

**Karl H. Deubert**
*University of Massachusetts Cranberry Experiment Station, East Wareham, MA 02538*

*Additional index words.* *Vaccinium macrocarpon*, cranberry cultivars, cranberry fruit size, cranberry fruit ripeness, cranberry fruit composition

***Abstract.*** **Samples of 16 cranberry (*Vaccinium macrocarpon* Ait.) clones, sorted into subsamples on the basis of berry size and coloration, were analyzed for juice content, soluble solids, titratable acidity, and anthocyanin content. The soluble solids : acidity ratio was greater for more highly colored subsamples but did not vary with berry size. The anthocyanin content of subsamples of different berry size varied in proportion to the surface to volume ratio. Anthocyanin recovery in expressed juice was independent of berry coloration and size. Variability in anthocyanin content within samples reflected differences in environmental factors, such as light exposure, superimposed on ripeness differences. Variability in sample anthocyanin content depended more on berry size differences than on differences in surface coloration.**

The anthocyanin content of cranberries is of prime importance in determining the surface color of fresh berries as well as the color of products such as juice and sauce. The anthocyanins of cranberry have been well characterized (11, 26) and quantitative methods for their determination in fruit and juice have been described (5, 10, 12, 13). Among the factors affecting berry color and anthocyanin content, cultivar is most important (2, 4, 22, 27). In a recent study of 45 cultivars, we reported that the anthocyanin content of ripe berries varied between 46 and 172 mg/100 g (21). Differences among cultivars in fruit or juice anthocyanin content are due in part to differences in berry size, i.e., in the surface-to-volume ratio. Francis (9) demonstrated an inverse relationship between cranberry fruit size and anthocyanin content for 'Early Black', 'Howes', and 'McFarlin' cranberries of comparable surface coloration. This relationship follows from the fact that cranberry pigments are located in the skin, the total quantity per berry being about proportional to the surface area. The fruit mass or juice volume on which the anthocyanin content is based is derived from the entire berry and would be proportional to the berry volume. Recently, Vorsa and Welker (24) reported a study of 6 cranberry cultivars in which the extractable anthocyanins in samples of similar color decreased linearly as the fruit size increased. Heritable differences in cranberry size have been demonstrated in breeding programs (14). Pre- and postharvest environmental conditions, such as temperature (15), light (3), and the application of growth regulators (1, 3, 8, 18) can influence the anthocyanin content of cranberries. The anthocyanin concentration in cranberry juice also depends on the extent to which pigments are extracted from the crushed berries during juice expression (19). While the influences of these different factors have been investigated individually, quantitative comparisons of berry size effects, genetic differences in anthocyanin accumulation, and variation in anthocyanin extractability for samples grown under similar conditions are lacking. Our objectives in this study were: 1) to assess the relative importance of berry size and surface coloration in determining the anthocyanin content of cranberry fruit and juice samples; and 2) to determine the relationship between the anthocyanin content and the soluble solids : acidity ratio (SS:A) in individual cranberry fruits. In a companion paper we have examined the implications of these results with regard to cultivar differences, alternative breeding strategies, and the manipulation of environmental factors to increase the anthocyanin content of cranberries.

## Materials and Methods

*Preparation of cranberry subsamples.* Samples of 16 cranberry clones (11 cultivars and 5 selections), weighing 3 to 4 kg each, were harvested from adjacent bogs at the USDA, Rutgers Univ. Blueberry and Cranberry Research Center in Chatsworth, N.J., over a period of several days in mid-Oct. 1983. Among these 'Ben Lear', 'Early Black', and 'Franklin' were classified as early maturing; 'Beckwith', 'Howes', 'McFarlin', 'Pilgrim', 'Wilcox', No. 20, and No. 35 as late maturing; and 'Crowley', 'Searles', 'Stevens', AJ, BD, and CN as intermediate in earliness (2, 4, 6; P.E. Marucci, personal communication). The berries in each sample were sorted for color into dark-red, medium-red, light-red, and white-pink subsamples, each of which was weighed, packaged in polyethylene freezing containers, and stored at −18°C for 3 to 4 months prior to analysis. While in the frozen state, each subsample was separated further according to berry size with a vibrating-screen size grader, producing 3 new subsamples: large berries, retained by a 14.3 mm (9/16 inch) screen; medium-sized berries, passing through the 14.3 mm screen but retained by a 11.1 mm (7/16 inch) screen; and small berries, passing through both screens. All new subsamples were weighed and immediately returned to frozen storage until they could be evaluated. Subsamples weighed between 50 g and 2 kg, depending on the weight distribution of berries of different coloration and size found in each sample. In some instances, especially the smallest size category for dark-red or light-red berries, the subsamples contained too few berries to permit further study.

Received for publication 14 Aug. 1985. Reference to brand or firm name does not constitute endorsement by the USDA over others of a similar nature not mentioned. We acknowledge the technical assistance of Anita M. Burgher, Sandra P. Graham, and Michael J. Kelley, employees of the Eastern Regional Research Center. We also thank Eric G. Stone, formerly of the USDA, Rutgers Univ. Blueberry and Cranberry Research Center, Chatsworth, N.J., who provided the cranberry samples. The cost of publishing this paper was defrayed in part by the payment of page charges. Under postal regulations, this paper therefore must be hereby marked *advertisement* solely to indicate this fact.

*Evaluation of subsamples*. Following storage, portions of cranberry subsamples weighing about 100 g were thawed overnight at 3°C and evaluated by procedures described previously (21). Tristimulus reflectance measurements were made on duplicate 50-g portions of whole berries with a Gardner XL-23 tristimulus colorimeter, calibrated against a Gardner pink standard (Y = 44.92, X = 53.11, Z = 42.63). The mean berry weight of each subsample was calculated from the portion weights and number of berries in each portion. The weighed berries were chopped, mixed with rice hulls (a pressing aid), and pressed in a Carver Press to extract the juice. The yield of juice was calculated from the volume of recovered juice and the berry weight.

$$\text{Juice yield (\%)} = \text{Juice volume (ml)}/\text{Berry weight (g)} \times 100$$

Aliquots of cranberry juice were analyzed in duplicate for soluble solids (corrected to 20°) with a Bausch & Lomb Abbe-3L refractometer, for titratable acidity (calculated as the percentage of citric acid) by titration with 0.1 N NaOH to a pH 8.1 endpoint, and for total anthocyanin by the pH differential spectrophotometric method of Fuleki and Francis (13) with a Perkin-Elmer Model 552 UV-visible spectrophotometer at 510 nm. In addition, berry samples (duplicate 50-g portions) were analyzed for total anthocyanin by the method of Deubert (5), as modified by Sapers et al. (21), which entailed extraction with acidic ethanol followed by spectrophotometric analysis of the filtered extracts at 533 nm. Values of the SS:A and anthocyanin recovery (the percentage of total anthocyanin extracted from berries in the expressed juice = juice total anthocyanin × juice yield ÷ berry total anthocyanin) were calculated from these data. The surface anthocyanin content of each subsample, expressed as milligrams of anthocyanin per square centimeter, was calculated from the berry anthocyanin content (TAcy) and mean berry weight (W) with the following equation, which assumes a spherical berry [an approximation, since cranberries may be round, oval, oblong, pyriform, or intermediate between these shapes, depending on cultivar (2, 17)] and a density of 1.04 $g \cdot cm^{-3}$ (20):

$$\text{Surface anthocyanin } (mg \cdot cm^{-2}) = TAcy \times W^{1/3}/47.1$$

*Composition of individual berries*. The 40 darkest berries from each of 6 cultivars ('Crowley', 'Early Black', 'Franklin', 'Howes', 'McFarlin', and 'Wilcox') were selected by visual examination of the dark-colored subsamples and analyzed individually to determine the upper limits in anthocyanin content for each cultivar and the extent of variation in anthocyanin content and SS:A for the darkest berries. To measure the total anthocyanin content of individual berries, we used a scaled-down adaptation of our ethanol extraction method (21). Twenty of the darkest berries were each subdivided while frozen, into small pieces with a razor blade, then weighed, combined with 1.5 g Celite analytical filter-aid and 10 ml of 95% ethanol:1.5 M HCl (85:15) in a stainless steel microblender jar (Eberbach), and blended for 2 min at high speed on a Waring base. The homogenate was transferred quantitatively with additional solvent to Whatman No. 2 paper in a Buchner funnel, and extract was collected under vacuum. Residual anthocyanin was extracted from the filter cake by adding 3 successive 25-ml portions of solvent. The volume of the combined filtrates was measured, and the anthocyanin concentration determined spectrophotometrically at 533 nm. Twenty additional berries were thawed at ambient temperature (21°–27°C) for 20 min and individually squeezed in a garlic press to obtain samples of juice for the determination of soluble solids and titratable acidity.

*SS:A of ripening cranberries*. To determine the effect of ripening on the SS:A of cranberry fruits, duplicate random samples of 'Howes' cranberries were taken at weekly intervals from three 2.32-$m^2$ (25-$ft^2$) locations in an East Wareham, Mass. bog during 1980, 1981, and 1982. Berries (100 g) were homogenized with 200 ml distilled $H_2O$ for 1 min at high speed with a Waring blender, and the resulting puree was filtered through Whatman No. 42 filter paper. The percentage of soluble solids of the filtrate was determined with a hand refractometer (American Optical, 0°–30° Brix). The titratable acidity was determined by titrating a 10-ml aliquot of filtrate, diluted with 40 ml boiled, distilled $H_2O$, with 0.1 N KOH to a phenolphthalein endpoint.

*Statistical methods*. Comparisons of means were made by application of the Bonferroni *t* test (16). Weight distributions for clones were based on single weighings of each subsample and therefore could not be compared by a mean separation test. Weighted mean values of the berry size and composition parameters for each clone were calculated from the subsample means and subsample weight distributions (weighted mean = Σ subsample mean × subsample weight percentage ÷ 100). The effects of cultivar, surface color, and berry size on the anthocyanin content and related functional properties of cranberry samples were determined by analysis of variance (ANOVA), using a nested model with 9 subcategories (subsamples) for each clone, each subsample being represented by duplicate analytical values. Variation in these parameters among subsamples were evaluated by comparing unweighted means, while variation among samples of each clone, due to the combined effects of subsample variability and differences in subsample weight distributions, were evaluated by comparing weighted means. All statistical computations were performed with the Statistical Analysis System General Linear Models and Nested Procedures (SAS Institute, Cary, N.C.)

## Results and Discussion

*Size and color distribution of cranberry cultivars*. Cultivars differed greatly in their proportions of small-, medium-, and large-sized berries as determined from the subsample weights, and in mean berry weight, as determined from the number of berries in each weighed portion (Table 1). By both criteria, 'Ben Lear', 'Pilgrim', No. 20, and No. 35 had larger berries than the other clones while 'Early Black' tended to be smaller. Our results were generally consistent with berry size data reported in the literature (2, 4, 7, 14, 22, 23). 'Howes', 'McFarlin', and 'Wilcox' were more uniform in size than the other clones, with 80% or more of the berries classified as medium.

The proportions of light-, medium-, and dark-red berries also varied greatly among the various cranberry clones. 'Ben Lear', 'Crowley', 'Early Black', 'Franklin', AJ, and BD (all of which are early maturing or intermediate in earliness) had a greater proportion of dark-red berries than did the other clones. 'Early Black' and 'Franklin' were described previously as dark in color (4). Samples of 'Crowley' and selection No. 35 appeared to be more uniform in coloration than the other clones, the former containing 70% dark-red berries and the latter containing 66% medium-red berries.

*Characteristics of cranberry subsamples*. Reflectance and size data obtained with subsamples of 'Early Black', a dark-colored, early cultivar; 'Stevens', a light-colored, mid-late maturing cultivar; and 'McFarlin', a light-colored, late-maturing cultivar (Table 2), illustrated the degree of separation achieved by our sorting

Table 1. Berry size and color distributions of cranberry clones.

| Clone | Ripening[z] season | Berry wt (g/berry)[y] | Size distribution (%)[x] | | | Color distribution (%)[w] | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | Small | Medium | Large | Dark-red | Medium-red | Light-red | Colorless |
| Beckwith | Late | 1.57 ab | 5.4 | 43.9 | 50.6 | 14.1 | 54.7 | 25.0 | 6.3 |
| Ben Lear | Early | 1.71 a | 0.5 | 52.6 | 46.9 | 41.6 | 48.2 | 10.2 | 0 |
| Crowley | Mid-late | 1.51 ab | 4.7 | 47.4 | 47.8 | 70.0 | 27.8 | 2.2 | 0 |
| Early Black | Early | 1.02 b | 21.3 | 69.6 | 9.1 | 40.5 | 52.1 | 7.4 | 0 |
| Franklin | Early | 1.37 ab | 5.6 | 56.4 | 38.0 | 44.7 | 48.1 | 7.2 | 0 |
| Howes | Late | 1.20 ab | 10.7 | 79.8 | 9.5 | 20.9 | 52.9 | 20.6 | 7.7 |
| McFarlin | Late | 1.23 ab | 10.2 | 81.3 | 8.6 | 31.4 | 40.7 | 18.9 | 9.0 |
| Pilgrim | Late | 1.82 a | 2.1 | 35.1 | 62.8 | 33.6 | 57.6 | 8.9 | 0 |
| Searles | Mid | 1.46 ab | 7.0 | 54.8 | 38.1 | 15.0 | 46.5 | 29.0 | 9.5 |
| Stevens | Mid-late | 1.67 ab | 4.8 | 39.8 | 55.4 | 24.4 | 47.3 | 17.2 | 11.0 |
| Wilcox | Late | 1.23 ab | 4.5 | 91.7 | 3.8 | 16.2 | 58.8 | 14.3 | 10.6 |
| AJ | Mid | 1.50 ab | 3.6 | 66.4 | 30.0 | 40.8 | 52.9 | 5.0 | 1.3 |
| BD | Mid | 1.43 ab | 4.5 | 63.9 | 31.6 | 43.2 | 49.9 | 6.4 | 0.6 |
| CN | Mid | 1.62 ab | 3.2 | 51.8 | 45.1 | 32.3 | 48.0 | 16.5 | 3.1 |
| No. 20 | Late | 1.72 a | 2.8 | 47.8 | 49.4 | 28.6 | 59.4 | 10.3 | 1.7 |
| No. 35 | Late | 1.84 a | 2.0 | 51.9 | 46.1 | 19.1 | 66.3 | 13.0 | 1.6 |

[z]As described in literature (2, 4, 5).
[y]Weighted mean for all subsamples. Mean separation in column by Bonferroni $t$ test at $P = 0.05$.
[x]Percent by weight; size distribution defined by screen size.
[w]Percent by weight; color distribution determined by visual sorting.

Table 2. Tristimulus parameters, berry weight, juice yield, composition, and anthocyanin recovery for 'McFarlin', 'Stevens', and 'Early Black' cranberries sorted by color and size.[z]

| Cultivar | Color | Size | Cranberry reflectance | | | Berry weight (g/berry) | Juice yield (ml/100 g) | Total anthocyanin | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | L | a | b | | | SS:A[y] | Berry (mg/100 g) | Juice (mg/100 ml) | Surface ($mg \cdot cm^{-2}$) | Recovery (%) |
| McFarlin | Dark | Small | 16.8 bc | 21.2 ab | 2.6 c | 0.71 c | 73 a | 4.5 a | 46 a | 26 a | 0.9 a | 41 a |
| | | Medium | 18.0 bc | 21.6 ab | 1.4 b | 1.33 b | 73 a | 4.3 a | 40 bc | 22 b | 0.9 a | 41 a |
| | | Large | 16.4 c | 19.6 b | 1.1 c | 1.75 a | 75 a | 4.2 a | 35 c | 17 c | 0.9 a | 37 a |
| | Medium | Small | 19.6 bc | 25.1 ab | 3.8 abc | 0.71 c | 75 a | 4.2 a | 27 d | 14 d | 0.5 b | 38 a |
| | | Medium | 21.3 b | 28.4 ab | 4.6 abc | 1.28 b | 76 a | 4.3 a | 20 e | 10 e | 0.5 b | 38 a |
| | | Large | 19.4 bc | 26.8 ab | 4.2 abc | 1.87 a | 73 a | 4.2 ab | 17 e | 10 e | 0.4 b | 45 a |
| | Light | Small | 31.4 a | 24.6 ab | 9.8 ab | 0.73 c | 74 a | 3.7 b | --- | 4 f | --- | --- |
| | | Medium | 27.4 a | 24.5 ab | 8.9 a | 1.33 b | 76 a | 3.6 b | 8 f | 4 f | 0.2 c | 40 a |
| | | Large | 27.9 a | 31.0 a | 8.1 abc | 1.81 a | 76 a | 3.9 ab | --- | 3 f | --- | --- |
| Stevens | Dark | Small | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| | | Medium | 18.1 b | 23.8 b | 2.8 bc | 1.30 b | 76 a | 4.4 a | 35 a | 21 a | 0.8 a | 46 a |
| | | Large | 17.1 b | 181.1 c | 0.2 c | 3.06 a | 75 a | 4.0 a | 34 a | 15 b | 1.0 a | 34 a |
| | Medium | Small | 21.3 b | 28.5 a | 5.2 ab | 0.63 bc | 76 a | 4.0 a | 21 b | 14 b | 0.4 c | 49 a |
| | | Medium | 21.2 b | 29.0 a | 5.1 ab | 1.23 b | 78 a | 3.9 a | 18 b | 10 c | 0.4 b | 41 a |
| | | Large | 21.2 b | 25.7 ab | 2.9 bc | 2.40 a | 78 a | 4.0 a | 15 bc | 8 c | 0.4 b | 39 a |
| | Light | Small | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| | | Medium | 27.0 a | 28.3 a | 6.8 a | 1.24 b | 80 a | 3.0 b | 7 c | 3 d | 0.2 c | 38 a |
| | | Large | 31.2 a | 27.8 a | 7.7 a | 2.47 a | 77 a | 2.9 b | 7 c | 3 d | 0.2 bc | 35 a |
| Early Black | Dark | Small | 15.7 a | 17.5 c | 1.0 cd | 0.65 c | 78 a | 4.5 a | 72 a | 38 a | 1.3 a | 42 a |
| | | Medium | 16.6 b | 18.9 bc | 1.0 cd | 1.16 b | 76 ab | 4.3 a | 58 a | 30 b | 1.3 a | 39 a |
| | | Large | 17.1 b | 16.6 c | 1.3 c | 1.74 a | 75 abc | 4.0 a | 49 ab | 24 bc | 1.2 ab | 34 a |
| | Medium | Small | 18.1 b | 23.1 a | 3.1 bc | 0.65 c | 76 ab | 3.9 a | 37 b | 24 bc | 0.7 cd | 51 a |
| | | Medium | 17.1 b | 22.7 ab | 2.3 c | 1.12 b | 76 ab | 3.9 a | 34 b | 19 cd | 0.8 c | 42 a |
| | | Large | 17.0 b | 25.1 a | 2.7 bc | 1.82 a | 69 c | 4.2 a | 30 bc | 15 d | 0.8 bc | 36 a |
| | Light | Small | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| | | Medium | 24.4 a | 25.4 a | 6.0 a | 1.28 b | 71 c | 4.2 a | 12 c | 7 e | 0.3 d | 42 a |
| | | Large | 23.5 a | 24.8 a | 4.6 ab | 1.77 a | 71 bc | 4.3 a | --- | 5 e | --- | --- |

[z]For a given variety, means within a column separated by the Bonferroni LSD test, $P = 5\%$.
[x]SS:A = soluble solids (percentage at 20°C) ÷ titratable acidity (percentage of citric).
[w]Total anthocyanin in 100 g berries ÷ surface area of 100 g berries.
[z]Recovery = juice anthocyanin × juice yield ÷ berry anthocyanin.

procedures. The reflectance parameters L, a, and b decreased with increasing subsample surface color, but were constant for berries of different size within the same color set. Mean berry weights for comparable subsamples were similar.

Juice yield, an important characteristic for processing that, together with berry anthocyanin content, determines juice color, did not vary greatly with berry coloration or size. Values of SS:A, an indication of fruit ripeness with blueberries (25), were consistently increased for the dark-colored subsamples, primarily because of their lower acidity.

As expected, berries and juice obtained from cranberry subsamples having relatively low surface color contained less total anthocyanin than these with high color. The berry total anthocyanin content decreased in proportion to the berry surface-to-volume ratio, as can be seen by the constant surface anthocyanin values obtained for small-, medium-, and large-sized subsamples of similar color. Anthocyanin recovery, the relationship between the juice and berry anthocyanin contents, appeared to be independent of berry coloration and size in our study.

Previously, we reported correlations between tristimulus reflectance parameters for whole berries and their total anthocyanin contents in berries and juice (21). In the present study, we obtained higher correlations when we compared tristimulus data with surface anthocyanin values ($r = -0.79$, $-0.68$, and $-0.87$ for surface anthocyanin vs. L, a, and b, respectively; N = 103). To make use of this relationship in selecting cranberry seedlings for high anthocyanin content, tristimulus colorimetry might be used in conjunction with measurements of berry size, as suggested by Francis (9).

Evaluation of the analytical data for 16 clones by ANOVA (Table 3) indicated that subsample surface color had a greater effect than berry size on subsample values of SS:A and total anthocyanin. The surface anthocyanin content was not affected by berry size as a consequence of the proportionality between total anthocyanin and surface area for berries of similar color. Francis (9) and Vorsa and Welker (24) reported inverse relationships between total anthocyanin content and fruit size for cranberries of similar coloration. When their total anthocyanin data were recalculated as surface anthocyanin values by our equation, these values also were about constant for different-size berries of similar coloration. An ANOVA was performed on these transformed data to test the effect of fruit size on surface anthocyanin value for each color category. No evidence of a significant effect was seen for either of the 2 studies. In our study, neither surface color nor berry size exerted significant effects on subsample values of juice yield or anthocyanin recovery. Cultivar effects on juice yield, SS:A, juice anthocyanin, and anthocyanin recovery, based on the comparison of weighted means, were not significant.

A comparison of variance components due to cultivar, berry size, and surface color (Table 4) indicated that the berry and juice total anthocyanin contents of cranberry samples were affected more by berry size than by subsample surface color. Berry size effects on the total anthocyanin content appeared to be greater with late-maturing clones than with early maturing clones or with those of intermediate earliness. These results, which appear to be in conflict with the observed differences in anthocyanin content between subsamples, were a consequence of differences in weight distribution between the 2 classes of subsamples, berry size, and surface color, the former being more variable (Table 3). More highly skewed berry size distributions, in which small-sized berries predominate, would have even greater impact on the anthocyanin content of cranberry samples than did the size distributions seen in this study.

*Anthocyanin content and SS:A of individual dark berries.* Total anthocyanin contents of the darkest individual cranberries in dark-red subsamples of 6 cultivars fell within a 2-fold range; the means for these berries exceeded the subsample means by 36–68% (Table 5). Soluble solids : acidity values for the darkest individual berries fell within a broad range (3.0–6.4). In contrast to the anthocyanin data, means values of SS:A for the darkest berries were similar to the subsample means, indicating no large differences in SS:A between berries of greater and lesser anthocyanin content within dark subsamples.

*Soluble solids : acidity ratio of ripening cranberries.* The relationship between SS:A and sample ripeness, which underlies our observations with individual cranberries and subsamples of different coloration, can be seen in comparisons of 'Howes'

Table 3. Analysis of variance for cultivar and subsample effects on cranberry anthocyanin content and related functional properties.

| | F value[z] | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Subsample means | | | | | | | Weighted subsample means[x] | | | | |
| Source of variation (DF) | Weight[y] distribution | Juice yield | SS:A | Total anthocyanin Berry | Juice | Surface | Recovery | Juice yield | SS:A | Total anthocyanin Berry | Juice | Recovery |
| Cultivar (15) | NS | 7.6** | 7.2** | 29.5** | 111.8** | 23.7** | 2.2* | NS | NS | 2.6* | NS | NS |
| Color (2) | 35.9** | NS | 55.6** | 350.1** | 2181.4** | 266.2** | NS | 35.6** | 34.5** | 13.4** | 7.5** | 31.3** |
| Size (2) | 54.4** | NS | 5.1* | 37.0** | 147.6** | NS | NS | 53.9** | 51.0** | 45.5** | 21.9** | 46.4** |
| Cultivar × color (30) | 2.1* | NS | 2.8** | 4.9** | 16.0** | 3.8** | NS | 2.1* | 1.8* | 4.1** | 2.4** | 4.0** |
| Cultivar × size (29) | 3.3** | NS | NS | NS | 6.2** | NS | NS | 3.2** | 3.1** | 3.4** | NS | 4.9** |
| Color × size (4) | 7.2** | NS | NS | 3.8* | 28.5** | NS | NS | 6.9** | 8.3** | 4.4** | 5.4** | 8.3** |
| Mean square for error | 36.0 | 2.34 | 0.063 | 5.83 | 0.61 | 0.0034 | 19.47 | 21.19 | 0.065 | 2.90 | 0.14 | 4.73 |
| Total degrees of freedom | 117 | 117 | 117 | 105 | 117 | 102 | 103 | 117 | 117 | 103 | 117 | 103 |

[z]NS = not significant at $P = 0.05$; other values significant at $P = 0.05$ (*) or $P = 0.01$ (**).
[y]Weight distribution of subsamples.
[x]Subsample mean × subsample weight percentage ÷ 100.

Table 4. Relative contribution of cultivar, subsample color, and berry size to variance of total anthocyanin content of berries and juice.

| | Percentage of total variance | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Total anthocyanin in berry[z] | | | | Total anthocyanin in juice[z] | | | |
| | | Cultivars | | | | Cultivars | | |
| Variance source | All | Early | Intermediate | Late | All | Early | Intermediate | Late |
| Cultivar | 3.2 | 0 | 3.3 | 0 | 3.1 | 0 | 6.2 | 0 |
| Subsample color | 24.9 | 28.5 | 34.1 | 13.9 | 26.3 | 26.1 | 36.3 | 16.3 |
| Berry size | 71.6 | 71.2 | 62.5 | 85.3 | 70.6 | 73.9 | 57.5 | 83.7 |
| Error | 0.4 | 0.3 | 0.1 | 0.8 | 0.0 | 0.0 | 0.0 | 0.0 |

[z]Weighted mean.
[y]Error term represents variability between replicate analyses pooled over all subsamples and clones in each earliness category.

Table 5. Total anthocyanin and SS:A values for darkest individual berries in medium-sized dark-red subsamples of cranberry cultivars.

| | Total anthocyanin (mg/100 g) | | | SS:A | | |
|---|---|---|---|---|---|---|
| | | Mean ± SE[y] | | | Mean ± SE[y] | |
| Cultivar | Range for darkest berries | Darkest individual berries | Dark subsample | Range for darkest berries | Darkest individual berries | Dark subsample |
| Crowley | 67–127 | 86 ± 3.5 | 56 ± 0.7 | 3.4–5.6 | 4.2 ± 0.13 | 3.9 ± 0.09 |
| Early Black | 54–117 | 79 ± 3.7 | 58 ± 0.8 | 3.0–5.6 | 3.9 ± 0.14 | 4.3 ± 0.13 |
| Franklin | 73–130 | 95 ± 2.8 | 63 ± 1.7 | 3.5–6.4 | 4.7 ± 0.14 | 4.7 ± 0.12 |
| Howes | 36–71 | 53 ± 2.4 | 39 ± 0.4 | 4.0–6.4 | 5.0 ± 0.16 | 4.7 ± 0.10 |
| McFarlin | 44–104 | 67 ± 3.3 | 40 ± 0.7 | 3.6–6.0 | 4.5 ± 0.14 | 4.3 ± 0.09 |
| Wilcox | 38–58 | 45 ± 1.3 | 30 ± 1.6 | 3.9–5.8 | 4.8 ± 0.12 | 4.9 ± 0.12 |

[z]Range for 20 berries selected at random from 40 darkest.
[y]SE = standard error.

cranberries sampled during the course of the growing season (Fig. 1). The SS:A of the developing berries decreased to a minimum value of 3.0–3.5 in August, largely due to an increase in titratable acidity. As the berries ripened during September and October, the SS:A increased to values as high as 4.5–5.0, because of an increase in the soluble solids content that was accompanied by a smaller decrease in titratable acidity.

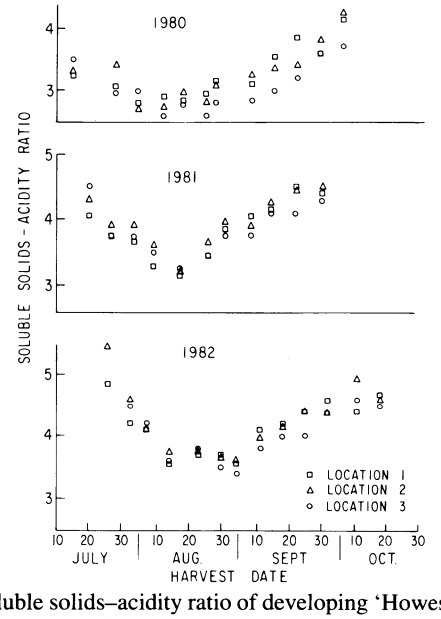


Fig. 1. Soluble solids–acidity ratio of developing 'Howes' cranberries grown in East Wareham, Mass.

Soluble solids : acidity values for our light-colored subsamples correspond to the 'Howes' late summer minima, while SS:A values for the dark-red subsamples are close to the 'Howes' end-of-season values. Thus, the light-, medium-, and dark-red subsamples may have represented berries at different stages of ripeness. On the other hand, the SS:A range for the darkest individual berries in dark subsamples included low values typical of August berries as well as high values typical of late-season berries. Although ripeness is a factor affecting the extent of anthocyanin accumulation, a substantial part of berry-to-berry variability in anthocyanin content must reflect other factors. Environmental factors such as light exposure and the temperature history of individual berries, which are known to affect anthocyanin accumulation in cranberry (3, 15, 18), are responsible for seasonal differences in cranberry coloration, and may account for variability in the anthocyanin content of berries of similar ripeness.

In conclusion, the inverse relationship between fruit size and anthocyanin content in cranberries of similar coloration can be explained in terms of the fruit surface-to-volume ratio.

The fruit size distribution has a greater effect than variation in surface coloration on the total anthocyanin content of berries and juice, especially with late-maturing clones. Juice yield and anthocyanin recovery (the relationship between the berry and juice total anthocyanin contents) are independent of berry coloration and size.

Values of SS:A for cranberries increase during ripening in parallel with color development. Extensive variability in the

anthocyanin content of individual fruits in cranberry samples having similar SS:A values demonstrates the importance of environmental factors as well as ripening in controlling anthocyanin accumulation.

### Literature Cited


1. Bramlage, W.J., R.M. Devlin, and J.M. Smagula. 1972. Effects of preharvest application of ethephon on 'Early Black' cranberries. J. Amer. Soc. Hort. Sci. 97:625–628.
2. Chandler, F.B. and I. Demoranville. 1958. Cranberry varieties of North America. Mass. Agr. Expt. Sta. Bul. 513.
3. Cracker, L.E. 1971. Postharvest color promotion in cranberry with ethylene. HortScience 6:137–139.
4. Demoranville, I.E. 1976. Cranberry varieties, p. 83–84. In: The modern art of cranberry cultivation. Publ. No. 112. Coop. Ext. Ser. Univ. of Massachusetts, Amherst.
5. Deubert, K.M. 1978. A rapid method for the extraction and quantitation of total anthocyanin of cranberry fruit. J. Agr. Food Chem. 26:1452–1453.
6. Doughty, C.C. and R. Garren, Jr. 1970. "Crowley," a new, early maturing cranberry variety for Washington and Oregon. Fruit Var. Hort. Dig. 24:88–89.
7. Eaton, G.W. and E.A. MacPherson. 1978. Morphological components of yield in cranberry. Hort. Res. 17:73–82.
8. Eck, P. 1972. Cranberry yield and anthocyanin content as influenced by ethephon, SADH, and malathion. J. Amer. Soc. Hort. Sci. 97:213–214.
9. Francis, F.J. 1957. Color and pigment measurement in fresh cranberries. Proc. Amer. Soc. Hort. Sci. 69:296–301.
10. Francis, F.J. 1982. Analysis of anthocyanins, p. 181–207. In: P. Markakis (ed.). Anthocyanins as food colors. Academic, New York.
11. Fuleki, T. and F.J. Francis. 1967. The co-occurence of monoglucosides and monogalactosides of cyanidin and peonidin in the American cranberry, *Vaccinium macrocarpon*. Phytochemistry 6:1705–1711.
12. Fuleki, T. and F.J. Francis. 1968. Quantitative methods for anthocyanins: 1. Extraction and determination of total anthocyanin in cranberries. J. Food Sci. 33:72–77.
13. Fuleki, T. and F.J. Francis. 1968. Quantitative methods for anthocyanins: 2. Determination of total anthocyanin and degradation index for cranberry juice. J. Food Sci. 33:78–83.
14. Galletta, G.J. 1975. Blueberries and cranberries, p. 154–196. In: J. Janick and J.N. Moore (eds.). Advances in fruit breeding. Purdue Univ. Press, West Lafayette, Ind.
15. Hall, I.V. and R. Stark. 1972. Anthocyanin production in cranberry leaves and fruit, related to cool temperatures at a low light intensity. Hort. Res. 12:183–186.
16. Miller, R.G., Jr. 1981. Simultaneous statistical inference, p. 67–70. Springer-Verlag, New York.
17. Rigby, B. and M.N. Dana. 1971. Seed number and berry volume in cranberry. HortScience 6:495–496.
18. Rigby, B., M.N. Dana, and L.K. Binning. 1972. Ethephon sprays nd cranberry fruit color. HortScience 7:82–83.
19. Sapers, G.M., S.B. Jones, and G.T. Maher. 1983. Factors affecting the recovery of juice and anthocyanin from cranberries. J. Amer. Soc. Hort. Sci. 108:246–249.
20. Sapers, G.M. and J.G. Phillips. 1984. Leakage of anthocyanins from skin of raw and cooked highbush blueberries (*Vaccinium corymbosum L.*). J. Food Sci. 50:437–439, 443.
21. Sapers, G.M., J.G. Phillips, H.M. Rudolf, and A.M. DiVito. 1983. Cranberry quality: Selection procedures for breeding programs. J. Amer. Soc. Hort. Sci. 108:241–246.
22. Schmid, P. 1977. Long term investigation with regard to the constituents of various cranberry varieties (*Vaccinium macrocarpon Ait*). Acta Hort. 61:241–254.
23. Swanson, B.G. and K.G. Weckel. 1975. Refrigerated storage of fresh cranberries. J. Food Sci. 40:259–261.
24. Vorsa, N. and W.V. Welker. 1985. Relationship between fruit size and extractable anthocyanin content in cranberry. HortScience 20:402–403.
25. Woodruff, R.E., D.H. Dewey, and H.M. Sell. 1960. Chemical changes of Jersey and Rubel blueberry fruit associated with ripening and deterioration. Proc. Amer. Soc. Hort. Sci. 75:387–401.
26. Zapsalis, C. and F.J. Francis. 1965. Cranberry anthocyanins. J. Food Sci. 30:396–399.
27. Zuckerman, B.M., I.E. Demoranville, F.J. Francis, K. Hayes, R.L. Norgren, S. Regling, C.W. Miller, and S.M. Paracer. 1966. Pigment and viscosity of juice and sauce of several cranberry varieties. Proc. Amer. Soc. Hort. Sci. 89:248–254.