16. Goode, J.E., K.H. Higgs, and K.J. Hyrycz. 1978. Nitrogen and water effects on the nutrition, growth, crop yield and fruit quality of orchard-grown 'Cox Orange Pippin' apple trees. J. Hort. Sci. 53:295–304.
17. Goode, J.E. and K.J. Hyryez. 1976. The effect of nitrogen on young, newly planted apple rootstocks in the presence and absence of grass competition. J. Hort. Sci. 51:321–327.
18. Haynes, R.J. 1980. Influence of soil management practice on the orchard agro-ecosystem. Agro-Ecosystems 6:3–32.
19. Haynes, R.J. and K.M. Goh. 1980. Some effects of orchard soil management on sward composition levels of available nutrients in the soil, and leaf nutrient content of mature 'Golden Delicious' apple trees. Scientia Hort. 13:15–25.
20. Hogue, E.J., G.H. Neilsen, J.L. Mason, and B.G. Drought. 1983. The effect of different calcium level on cation concentration in leaves and fruit of apple trees. Can. J. Plant Sci. 63:473–479.
21. Lord, W.J., J.H. Baker, and R.A. Bamm, Jr. 1981. Soil, tree, and fruit responses to lime and to type and timing of nitrogenous fertilizer application under 'Sturdeespur Delicious' apple trees. J. Amer. Soc. Hort. Sci. 106(5):616–619.
22. Lord, W.J. and J. Costante. 1977. Establishment and management of compact apple trees. Mass. Coop. Ext. Serv. Circ. 107.
23. Lord, W.J., R.A. Damon, and D.E. Robinson. 1970. Comparative response of three apple rootstocks to soil-incorporated simazine. J. Amer. Soc. Hort. Sci. 95(6):737–739.
24. Mage, Fi. 1982. Black plastic mulching, compared to other soil management methods. Scientia Hort. 16:131–136.
25. Mason, J.L. 1964. Yield and quality of apples grown under four nitrogen levels in uncultivated grass sod. Proc. Amer. Soc. Hort. Sci. 85:42–47.
26. Miller, S.S. 1983. Response of young 'Topred Delicious' apple trees to orchard floor management and fertilization. J. Amer. Soc. Hort. Sci. 108(4):638–642.
27. Pearson, R.W., H.V. Jordan, O.L. Bennett, C.E. Scanbrook, W.E. Adams, and A.W. White. 1961. Residual effects of fall and spring applied nitrogen fertilizers on crop yields in the southeastern United States. USDA Tech. Bul. 1254:1–19.
28. Pienaar, W.J., A.V. Betts, and K.H. Gürgen. 1971. Uptake of calcium by 'Golden Delicious' apple trees after soil applications of calcium nitrate. Deciduous Fruit Grow. 21:38–40.
29. Poling, E.B. and G.H. Oberly. 1979. Effect of rootstock on mineral composition of apple leaves. J. Amer. Soc. Hort. Sci. 104(6):799–801.
30. Pulver, E.L. and S.K. Ries. 1973. Action of simazine in increasing plant protein content. Weed Sci. 21:233–237.
31. Ries, S.K., R.P. Larsen, and A.L. Kenworthy. 1963. The apparent influence of simazine on nitrogen nutrition of peach and apple trees. Weeds 11:270–272.
32. Vang-Petersen, O. 1980. Calcium nutrition of apple trees: a review. Scientia Hort. 12:1–9.
33. Weeks, W.D., F.W. Southwick, M. Drake, and G.W. Olanyk. 1965. Relation of differential N and K fertilization to tree performance, fruit quality and storage disorders of 'Delicious' apples. Mass. Agr. Expt. Sta. Bul. 552.

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Composition and Color of Fruit and Juice of Thornless Blackberry Cultivars

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Abstract. **Ripe fruit of 40 thornless blackberry cultivars and selections, and juice samples obtained therefrom, were compared to determine differences in color and composition after freezing, thawing, and heating. Color changes (reddening) during frozen storage were associated with within-sample variability in ripeness. Red subsamples of frozen blackberries were lower than black subsamples in soluble solids and total anthocyanin contents and higher in titratable acidity and anthocyanin recovery in the pressed juice. When juice samples were standardized to compensate for differences in pH and anthocyanin concentration, ripeness and cultivar effects on juice tristimulus parameters were small. Rapid thawing of frozen fruit resulted in less anthocyanin loss than did slow thawing. Heating darkened blackberry juice samples and increased values of A_{440}/A_{513}.**

Considerable interest has been shown in the breeding, production, and utilization of thornless blackberries (2, 6, 20). Information on composition, quality, and processability is needed to guide breeders and to expedite the commercialization of this crop. Limited data are available on the sugars, nonvolatile acids, phenolics, and anthocyanins of thornless blackberry cultivars (12, 13, 21, 23, 24). Jennings and Carmichael (7) described the tendency of frozen blackberries to turn red, a phenomenon they attributed to cellular disruption and intracellular pH changes in fruit that were not fully ripe. Crivelli and Rosati (1) studied the suitability of 'Smoothstem' and 'Thornfree' blackberries for freezing but did not report a color change during frozen storage. Comprehensive evaluations such as those performed with the fruit of thorny cultivars, 'Cherokee', 'Comanche', and 'Cheyenne' (10, 11, 17) have not been reported for thornless cultivars.

Our objective in this study was to investigate the composition of fruit and juice of thornless blackberry cultivars and selections

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with special emphasis on factors affecting processability and color.

Materials and Methods

Source of blackberries and initial evaluation. Fruit samples of 40 thornless blackberry cultivars and selections were obtained from plantings at the Beltsville Agricultural Research Center and at the Univ. of Maryland, College Park, during 1982 and 1983. The blackberries were iced in insulated coolers and transported to Philadelphia within 4–5 hr of harvest. After overnight storage at 1°C, the samples were sorted to remove debris and damaged or underripe fruit, washed, drained, and packaged in polyethylene freezer containers (25 × 29 × 7 cm). Tristimulus reflectance measurements for whole fruit, placed in a cylindrical optical cell (57.1 mm I.D. × 40 mm depth), were made with a Gardner XL-23 colorimeter (Illuminant A, corrected to Illuminant C by the filter-photodetector assemblies), using the Hunter Lab scale. Because of their extreme perishability, samples were frozen immediately at −13°C and stored until analytical studies could be performed.

Evaluation of frozen blackberries. Frozen samples were sorted to determine the proportion of fruit that had turned red during storage and to permit separate evaluation of the red and black fruit. Tristimulus reflectance measurements were made on these subsamples in the frozen state. For analytical and spectral studies, duplicate 50 g portions of frozen subsamples were thawed by holding them either for 24 hr in a refrigerator or for 3–4 hr at room temperature. The thawed blackberries were mixed with 1.5 g rice hulls (a commercial pressing aid), placed in a Succulometer Cell (Model CR-1, Food Technology Corp., Rockville, Md.), covered with a 5.72 cm diameter felt filter pad, and pressed for 10 min at 70.3 kg/cm^2 (1000 psi) in a Carver Model C 12-Ton laboratory press (Fred S. Carver, Inc., Menomonee Falls, Wis.) to obtain the juice. After the volume was measured, the juice was clarified by adding about 2 g Celite analytical filter aid and filtering through Whatman No. 2 paper with suction.

Analysis of fruit and juice. The juice samples were analyzed for pH, titratable acidity, soluble solids, and anthocyanin (pH differential method), as described previously (4,16). Juice anthocyanin was measured at 513 nm and expressed as absorbance units (A.U.) per ml. UV-visible absorption spectra of diluted juice samples, adjusted to pH 3.3 with 1.5 M HCl or 2.5 M NaOH, were obtained with a Perkin-Elmer Model 552 UV-visible spectrophotometer. Tristimulus reflectance and transmission measurements were made on 25 ml aliquots of undiluted juice or juice adjusted to pH 3.3 and diluted with H_2O such that an absorbance of 2.00 ± 0.02 was obtained at the visible absorption maximum. For reflectance measurements, the colorimeter was standardized against a pink tile (Y = 44.92, X = 53.11, Z = 42.63).

Total anthocyanin in blackberry samples was determined by spectrophotometric analysis at 533 nm of acidified ethanolic extracts of homogenized fruit (16), and was expressed as absorbance units (A.U.) per gram (absorbance × dilution factor/sample weight). An estimate of the percentage of recovery of fruit anthocyanin in the pressed juice was calculated with the following equation:

$$\text{Anthocyanin recovery (\%)} = \frac{\text{total anthocyanin (juice)}}{\text{total anthocyanin (fruit)}} \times \text{juice yield} \times \frac{\text{E alcohol}}{\Delta\text{E water}};$$

where the extinction coefficient ratio E alcohol/ΔE H_2O was used to convert total anthocyanin values in A.U. to a weight basis. This ratio was obtained from values of $E^{1\%}_{1cm}$ 535 and $\Delta E^{1\%}_{1cm}$ 510 reported by Fuleki and Francis (3, 4) for the 4 major anthocyanins found in cranberries (cyanidin-3-galactoside, cyanidin-3-arabinoside, peonidin-3-galactoside, and peonidin-3-arabinoside) after we determined that the ratios for these pigments were constant (1.23–1.30). We used a mean value of 1.27 for E alcohol/ΔE water. Pectin analyses were performed on berry homogenates, prepared by blending partially thawed samples for 5 min at high speed with a Waring base and a semimicro stainless steel blending container (250 ml capacity). The method of Blumenkrantz and Asboe-Hansen, as modified by Kintner and Van Buren (8), was used.

Effects of heating. The effects of heating on the spectral and tristimulus characteristics of blackberry juice were determined with juice pressed from fruits thawed at room temperature. Following filtration, 30 ml of juice were placed in a 150 ml beaker containing a 1 inch stirrer bar and covered with a watch glass. Juice samples were heated for 4 min with stirring on a preheated Corning PC-351 stirrer-hot plate with the temperature and stirrer controls set to 5 and 2, respectively. During heating, the juice temperature increased to 92° to 98°C. Immediately after heating, the samples were brought rapidly to room temperature by holding at −18° for 8 min followed by 8 min at 3°. After several minutes at room temperature, the heated samples and unheated controls were adjusted to pH 3.3 and diluted so that tristimulus and spectral measurements could be made.

Statistical methods. Comparisons of means were made by application of the Waller-Duncan K-ratio *t* test (22). All statistical computations were performed with the Statistical Analysis System (SAS Institute, Inc., Cary, N.C.) General Linear Models Procedure.

Results and Discussion

Color of fresh and frozen thornless blackberries. Fresh fruit samples of thornless and blackberry cultivars and selections were harvested when judged to be ripe, based on their dull black color and ease of separation from the plant. When the blackberries were tasted, variability in sweetness and sourness was noted, both within and between samples. Tristimulus reflectance measurements, made on the intact fruit (Table 1), indicated small but significant differences among cultivars in Hunter L, a and b values.

When the samples were re-examined after about 6 months of frozen storage, we found that many fruit in each sample had turned red while still in the frozen state. Tristimulus reflectance measurements indicated a pronounced elevation of Hunter "a" values with the red fruit and a smaller increase in Hunter "a" with fruit that retained their black color (Table 1). Hunter "b" values were greater (less negative) with frozen, red fruit than with frozen, black or fresh fruit. Differences among cultivars in tristimulus parameters for frozen fruit were significant. The proportion of red fruit in each sample varied from 12% to 82%. Presumably, this variability as well as the observed variability in sample sweetness and sourness were indications of heterogeneity in sample ripeness, since the tendency of blackberries to turn red is linked with incomplete ripeness (7). Because the proportion of red fruit in frozen samples varied for successive harvests of the same cultivar in 1982 and between 1982 and 1983 samples, we could not confirm cultivar tendencies of blackberries to turn red when frozen.

Table 1. Tristimulus reflectance parameters for fresh and frozen thornless blackberries (1982).

Cultivar	Percentage red fruit[z]	Treatment	Reflectance L	a	b
Black Satin	54	Fresh	15.2	3.3	−4.4
		Frozen, red fruit	14.6	6.7	−2.1
		Frozen, black fruit	14.5	4.5	−3.1
Dirksen Thornless	40	Fresh	14.6	2.7	−3.9
		Frozen, red fruit	14.4	5.3	−3.1
		Frozen, black fruit	15.5	3.7	−3.7
Means[x,y]	---	Fresh	15.3 a	2.9 c	−4.1 b
		Frozen, red fruit	15.2 a	6.6 a	−3.3 a
		Frozen, black fruit	15.2 a	3.9 b	−3.9 b
Range[y] (Low/High)	12–82	Fresh	13.8/16.6	2.2/3.3	−4.8/−3.1
		Frozen, red fruit	13.8/16.9	5.3/7.6	−4.0/−2.1
		Frozen, black fruit	14.5/16.8	3.1/5.5	−5.0/−3.0
F-value[w]					
Cultivar effects		Fresh	2.4*	2.6*	2.7*
		Frozen, red fruit	12.3**	NS	4.1**
		Frozen, black fruit	3.2**	11.7**	4.1**
Treatment comparisons		Frozen, red vs. fresh	NS	933.7**	39.6**
		Frozen, black vs. fresh	NS	65.8**	NS
		Frozen, black vs. red	NS	699.1**	28.1**

[z]In frozen sample.
[y]For 13 cultivars and selections.
[x]Mean separation in columns by Waller-Duncan K-ratio *t* test at $P = 0.05$.
[w]Not significant (NS) at $P = 0.05$; other values significant at $P = 0.05$ (*) or $P = 0.01$ (**).

Composition of thawed fruit and juice. The color of individual blackberries observed in the frozen state was retained during thawing. Thawed red and black subsamples and the pressed juice obtained therefrom differed in pH, titratable acidity, soluble solids, the soluble solids-acidity ratio (SS/A), and fruit total anthocyanin (Table 2). Acidity and soluble solids data for the red subsamples were similar to values reported by Walsh et al. (23) for purple or shiny black fruit of SIUS 68-6-17, a thornless blackberry breeding line. Whereas total anthocyanin values of blackberry fruit were higher for black than for red subsamples, total anthocyanins in the juice were similar. The percentage of fruit total anthocyanin recovered in the pressed juice was higher for red fruit than for black fruit. Naumann and Wittenburg (13) reported that the anthocyanin content of juice from ripening blackberries increased to a maximum, and then decreased. They suggested that the anthocyanins in the skin continued to increase while the anthocyanin in the fruit mesocarp, which would appear in the juice, decreased during ripening, a hypothesis con-

Table 2. Composition of red and black subsamples of frozen thornless blackberries.[z]

Parameter	Means[y] Red subsamples 1982	Red subsamples 1983	Black subsamples 1982	Black subsamples 1983	F-value[x] Subsample color	Cultivar	Season	Cultivar × color	Cultivar × season	Color × season
Juice composition										
pH	2.9	3.0	3.6	3.8	2522	24	164	8	3	20
Titratable acidity (% citric)	1.8	1.5	0.8	0.6	1579	13	103	3	3	11
Soluble solids (% @ 20°C)	8.0	9.3	10.8	11.5	311	16	75	3	7	NS
Soluble solids/titratable acidity	4.5	6.5	16.4	20.3	1207	35	123	13	6	31
Total anthocyanin (A.U./ml)	30	31	34	27	NS	15	43	3	5	14
Fruit composition										
Juice yield (ml/100 g)	75	75	72	72	27	3	NS	NS	4	NS
Pectin (%)	0.54	---	0.58	---	NS	NS	---	NS	---	---
Total anthocyanin (A.U./g)	76	78	110	103	269	19	NS	4	3	NS
Anthocyanin recovery (%)[w]	36	39	29	26	42	5	5	NS	NS	NS

[z]Blackberries thawed at room temperature.
[y]Thirty-seven cultivars and selections (except 13 for pectin) in 1982; 31 in 1983.
[x]All F-values significant at $P = 0.01$ except those designated NS (not significant).
[w]Recovery = total anthocyanin (juice) × juice yield × extinction coefficient ratio/total anthocyanin (fruit).

Table 3. Composition of black fruit of frozen thornless blackberry.[z]

Cultivar or selection	Juice composition[y] pH	Titratable acidity (% citric)	Soluble solids (% @ 20°C)	Total anthocyanin (A.U./ml)	Fruit composition[y] Juice Yield (ml/100 g)	Total pectin (%)	Total anthocyanin (A.U./g)	Anthocyanin recovery[x] (%)
Black Satin	3.5 c	0.8 cd	9.0 cd	40 bcd	76 a	0.49 a	114 de	34 a
Dirksen Thornless	3.5 c	0.8 cd	9.5 c	35 de	77 a	0.52 a	118 cde	28 a
Hull Thornless	3.8 a	0.6 e	12.5 a	20 f	74 ab	0.49 a	75 f	25 a
Smoothstem	3.5 cd	1.1 a	9.8 bc	50 a	74 ab	0.56 a	123 abc	38 a
Thornfree	3.5 c	0.9 bc	8.6 cd	31 e	73 ab	0.50 a	121 bcd	24 a
C-33	3.6 c	0.9 bc	9.6 bc	41 bcd	74 ab	0.60 a	120 cde	32 a
C-52	3.4 de	0.9 bc	7.7 d	24 f	73 ab	0.63 a	76 f	30 a
C-55	3.3 ef	1.0 ab	10.2 bc	34 de	74 ab	0.56 a	111 e	29 a
C-57	3.3 f	1.1 a	9.4 cd	43 b	73 ab	0.62 a	130 ab	28 a
C-58	3.4 ef	0.8 bc	9.9 bc	33 e	74 ab	0.48 a	---	---
C-60	3.4 ef	0.9 bc	9.1 cd	38 bc	74 ab	0.52 a	120 cde	32 a
C-62	3.5 cd	0.8 cd	10.0 bc	20 f	68 b	0.48 a	70 f	24 a
SIUS 68-6-17	3.7 b	0.7 de	11.4 ad	36 cde	74 ab	0.53 a	133 a	25 a
Means[w]								
1982	3.6	0.8	10.8	34	72	0.58	109	28
1983	3.8	0.6	11.5	27	72	---	103	26
Range (Low/High)[w]								
1982	3.2/4.1	0.4/1.3	7.7/13.9	17/62	61/77	0.48/0.63	67/155	17/39
1983	3.4/4.5	0.3/1.2	7.3/14.5	13/39	68/76	---	57/144	12/42

[z]Fruit samples thawed at room temperature.
[y]Data for individual clones from 1982 season. Mean separation in columns by Waller-Duncan K-ratio t test at $P = 0.05$.
[x]Recovery = total anthocyanin (juice) × juice yield × extinction coefficient ratio/total anthocyanin (fruit).
[w]Thirty-seven cultivars and selections (except 13 for pectin) in 1982; 31 in 1983.

Table 4. Spectral and tristimulus properties of juice from red and black fruit of frozen thornless blackberries.[z]

Cultivar	A_{513} × diln factor Red	A_{513} × diln factor Black	A_{440}/A_{513} Red	A_{440}/A_{513} Black	Transmission L Red	Transmission L Black	Transmission θ[y] Red	Transmission θ[y] Black
Black Satin[x]	12.2	16.6	0.44	0.48	54.0	50.9	21.0	20.5
Dirksen Thornless[x]	14.1	15.3	0.45	0.50	54.2	50.2	20.9	20.2
Hull Thornless[x]	10.9	10.2	0.44	0.57	52.9	43.5	19.9	18.2
Smoothstem[x]	13.8	20.0	0.42	0.44	54.2	53.9	20.4	20.8
Thornfree[x]	15.4	14.4	0.44	0.50	54.6	49.0	20.8	19.6
Means, 1982[w]	13.2	13.1	0.43	0.51	54.2	48.8	20.7	19.7
Means, 1983[w]	12.1	12.0	0.43	0.52	55.2	48.7	20.6	19.5
F-value, 1982 + 1983[v]								
Subsample color	NS		891		678		185	
Cultivar	21		32		16		9	
Season	26		30		NS		13	
Cultivar × color	5		10		8		6	
Cultivar × season	5		4		4		8	
Color × season	NS		13		9		NS	

[z]Thawed at room temperature; juice adjusted to pH 3.3, $A_{513} = 2.0$.
[y]Hue angle $\theta = \tan^{-1} b/a$.
[x]Data for individual clones from 1982 season.
[w]Thirty-seven cultivars and selections in 1982; 31 in 1983.
[v]Significant at $P = 0.01$.

sistent with our results. It is not clear, however, whether the pigment changes reported by Naumann and Wittenburg were real or represented changes in anthocyanin color expression due to a pH increase during ripening. Sági et al. (14) reported a progressive increase in the anthocyanin concentration of aqueous extracts from raspberry fruit classified as unripe, ripe, and overripe. Previously, we found considerable variability in the recovery of anthocyanins in the juice pressed from thawed, frozen cranberries (15).

Juice yields were slightly larger with red than with black subsamples. Red and black subsamples were similar in pectin content.

Fruit and juice composition data for important cultivars and selections of thornless blackberries, determined over 2 seasons, are summarized in Table 3. Variability in composition generally was small or inconsistent and not likely to affect the value of any one cultivar. Since thornless blackberries are considered by some *Rubus* specialists to be too acid for fresh consumption (5),

Table 5. Effect of fruit thawing conditions on total anthocyanin concentration and transmission tristimulus parameters of blackberry juice (1982).

Cultivar	Subsample color	Juice total anthocyanin (A.U./ml)		Transmission[z]			
				L		θ	
		Slow	Rapid	Slow	Rapid	Slow	Rapid
Black Satin	Black	27.7	39.9	12.8	9.5	6.6	3.6
Dirksen Thornless	Black	25.9	34.6	12.2	9.4	6.7	3.8
Hull Thornless	Black	14.1	19.8	14.9	11.3	9.1	6.3
Smoothstem	Black	44.5	50.4	10.4	8.4	4.3	2.0
Thornfree	Black	24.7	30.9	14.0	9.9	7.7	4.5
Means[y]	Red	25.4	29.9	20.4	17.4	10.3	9.0
Means[y]	Black	27.2	35.4	14.3	10.6	7.6	4.7
F-value[y,x]							
Thawing	Red	17		20		33	
	Black	31		422		319	
Cultivar	Red	12		6		13	
	Black	18		79		50	

[z]Undiluted juice at fruit pH.
[y]Thirteen cultivars and selections.
[x]Significant at $P = 0.01$.

the tendency of a selection to be low in acidity might be advantageous with respect to reducing product sourness and the extent of reddening in frozen fruit. (A tendency towards synchronous ripening also would be advantageous in minimizing sample heterogeneity in color and taste.)

'Hull Thornless' fruit were the least acidic of the cultivars compared; C-61, SIUS 64-36-1, US 1520, and SIUS 64-37-2 were the least acidic selections, having titratable acidity values (means for 1982 and 1983 samples) of 0.32%, 0.38%, 0.43%, and 0.44%, respectively. Selecting for low acidity should be done with considerable caution, however, since insufficient acidity might limit fresh product storage life, as is the case with blueberries (5), and also decrease anthocyanin stability in processed products (9). 'Hull Thornless' and selections C-51, C-59, C-67, and US 1520 were high in soluble solids, the 2-season means falling between 12.7% and 13.2%. 'Dirksen Thornless', 'Smoothstem', and selections US 1520, C-33, C-57, SIUS 64-21-4, SIUS 64-36-1, and SIUS 68-6-17 had relatively high fruit anthocyanin contents (2-season means between 120 and 142 A.U./g), a desirable attribute for producing blackberry juice. Naumann and Wittenburg (13) showed that the composition of blackberry juice is affected by preharvest temperature, the magnitude of the effect depending on cultivar and on climatic conditions early in the growing season. Seasonal variation in our data may reflect such environmental effects. Differences between clones in juice yield, anthocyanin recovery, and pectin content generally were not significant.

Spectral and tristimulus properties of juice. Visible absorption spectra showed a maximum (λ_{max}) at 510–515 nm, larger λ_{max} values corresponding to samples with higher pH values (Table 4). At pH 3.3, to which juice samples were adjusted to permit direct comparison of spectral and tristimulus data, λ_{max} was 513 nm. Juices obtained from red and black subsamples were similar in absorbance at 513 nm (A_{513} × dilution factor). Cultivar differences in absorbance paralleled juice anthocyanin values (Table 3). The ratio of absorbance in the 400–440 nm region of the visible spectrum to the anthocyanin absorption maximum, or the reciprocal of this ratio, has been used as an index of pigment degradation for various fruit juices (4, 19). We have determined the ratio A_{440}/A_{513}, obtaining significantly higher values for the juice from black subsamples compared to red subsamples. Whether this observation has any significance with respect to juice color is not clear.

There seems to be a strong negative correlation, however, between the transmission and reflectance "L" values (samples with low "L" values being darker) and A_{440}/A_{513} ($r = -0.95$ and -0.96 for transmission "L" vs. A_{440}/A_{513} in 1982 and 1983, respectively). This correlation is due primarily to variation in A_{513} ($r = 0.38$ and 0.36 for transmission "L" vs. A_{513} × dilution factor in 1982 and 1983, respectively). Transmission "L" values were about 10% lower for the juice obtained from

Table 6. Effect of heating on tristimulus parameters and visible absorption spectra of juice from frozen thornless blackberries (1982).[z]

Cultivar	Subsample color	Transmission L		Transmission θ		A_{440} × diln factor		A_{513} × diln factor		A_{440}/A_{513}	
		Not heated	Heated	Not heated	Heated	Not heated	Heated	Not heated	Heated	Not heated	Heated
Black Satin	Red	54.5	53.0	20.7	20.0	3.9	4.0	8.9	8.7	0.44	0.46
	Black	48.7	46.2	19.6	18.8	4.8	5.0	9.3	9.1	0.52	0.55
Dirksen Thornless	Red	55.7	53.1	21.0	20.2	4.6	4.7	10.6	10.4	0.43	0.45
	Black	50.1	46.5	20.2	19.6	6.2	6.4	12.3	11.8	0.51	0.54
Hull Thornless	Red	54.2	54.0	20.5	20.3	4.1	4.1	9.4	9.2	0.44	0.45
	Black	45.3	42.2	18.7	18.2	5.0	5.3	9.0	9.0	0.56	0.59
Means[y]	Red	54.7	53.0	20.4	20.0	4.9	5.2	11.4	11.5	0.43	0.45
	Black	49.0	44.6	19.6	19.0	5.9	6.0	11.6	11.1	0.51	0.54
F-value[x]											
Heating		13		66		NS		NS		115	
Subsample color		69		203		159		NS		1388	
Cultivar		NS		10		80		74		18	
Subsample color × cultivar		NS		18		16		16		12	
Subsample color × heating		NS		NS		NS		NS		16	

[z]Juice adjusted to pH 3.3 and diluted to give $A_{513} = 2.0$.
[y]Twelve cultivars and selections.
[x]Significant at $P = 0.01$.

black subsamples as compared to juice from red subsamples. Smaller (although still highly significant) differences in hue angle value ($\theta = \tan^{-1} b/a$) were obtained for these juices. Significant cultivar effects on "L" and "θ", similar in magnitude to the subsample color effects, also were seen. These effects probably reflect qualitative and/or quantitative differences in anthocyanin composition. In a parallel study still in progress, we have demonstrated such differences by HPLC analysis of the anthocyanins extracted from red and black fruits of various blackberry clones. Taking the magnitude of the tristimulus differences into consideration, however, we conclude that ripeness and cultivar effects on juice lightness and hue are of little practical importance, provided, of course, that the juice has been standardized in pH and anthocyanin concentration.

Effect of thawing conditions. The juice obtained from black subsamples contained 20% to 30% less anthocyanin when the blackberries were thawed slowly in a refrigerator than when they were thawed rapidly at room temperature. Red subsamples behaved similarly, but the thawing effect was smaller in magnitude (Table 5). Tristimulus measurements made in the transmission mode showed that the undiluted juice from slowly thawed fruit was significantly lighter (larger L-value), and more orange (larger θ-value) than was the juice from rapidly thawed fruit. These differences were greater with the juice from black subsamples than with that from red subsamples. During slow thawing, enzymatic degradation of anthocyanins may have increased. In an analogous study of changes in the sugars of thawing strawberries, Skrede (18) reported that slow thawing resulted in more sucrose degradation than did rapid thawing, degradation being attributed to invertase activity. We found no difference between slowly and rapidly thawed fruit in juice absorbance at 440 nm. Therefore, it is unlikely that differences in the extent of browning contributed to thawing effects on "L" and "R". Differences in these parameters due to thawing method were generally smaller than differences among cultivars or between red and black subsamples and may not be of practical importance.

Effect of heating. Heated blackberry juice samples were darker than unheated controls as indicated by smaller transmission L-values, and also had slightly smaller hue angle values (Table 6). Heating increased the ratio $A_{440/513}$ slightly; however, changes in the individual values of A_{440} (indicative of browning) and A_{513} (indicative of anthocyanin degradation) were not significant. The increase in A_{440}/A_{513} was greater with juice from black than from red fruit. Anthocyanins may be less stable in juice from black subsamples because of the increased pH (9). Other cultivars and selections yielded tristimulus and spectral data similar to those given in Table 6. In general, heating effects were small in comparison to differences between red and black subsamples.

Literature Cited

1. Crivelli, G. and P. Rosati. 1975. Researches on suitability of raspberry and blackberry varieties to quick freezing. Annali dell'Istituto Sperimentale per la Valorizzazione Tecnologica dei Prodotti Agricoli 6:61–65.
2. do Carmo M. Bassols, M. and J.N. Moore. 1981. 'Ebano' thornless blackberry. HortScience 16(6):686–687.
3. 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.
4. 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.
5. Galletta, G.J., W.E. Ballinger, R.J. Monroe, and L.J. Kushman. 1971. Relationships between fruit acidity and soluble solids levels of highbush blueberry clones and fruit keeping quality. J. Amer. Soc. Hort. Sci. 96(6):758–762.
6. Galletta, G.J., A.D. Draper, and R.G. Hill, Jr. 1980. Recent progress in bramble breeding at Beltsville, Maryland. Acta Hort. 112:95–102.
7. Jennings, D.L. and E. Carmichael. 1979. Colour changes in frozen blackberries. Hort. Res. 19:15–24.
8. Kintner, P.K., III and J.P Van Buren. 1982. Carbohydrate interference and its correction in pectin analysis using the m-hydroxydiphenyl method. J. Food Sci. 47:756–759, 764.
9. Markakis, P. 1974. Anthocyanins and their stability in foods. CRC Critical Reviews in Food Tech. 4:437–456.
10. Moore, J.N., E. Brown, and W.A. Sistrunk. 1976. Cheyenne, a new blackberry for Arkansas. Ark. Farm Res. 25:3.
11. Morris, J.R., S.E. Spayd, J.G. Brooks, and D.L. Cawthon. 1981. Influence of postharvest holding on raw and processed quality of machine-harvested blackberries. J. Amer. Soc. Hort. Sci. 106(6):769–775.
12. Mosel, H.-D. and K. Herrmann. 1974. Phenolics of fruits. IV. The phenolics of blackberries and raspberries and their changes during development and ripeness of the fruits. Z. Lebensm. Unters.-Forsch. 154:324–327.
13. Naumann, W.D. and U. Wittenburg. 1980. Anthocyanins, soluble solids, and titratable acidity in blackberries as influenced by preharvest temperatures. Acta Hort. 112:183–190.
14. Sági, F., L. Kollányi, and I. Simon. 1974. Changes in the colour and anthocyanin content of raspberry fruit during ripening. Acta Alimentaria 3:397–405.
15. 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(2):246–249.
16. 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(2):241–246.
17. Sims, C.A. and J.R. Morris. 1982. Effects of cultivar, irrigation, and ethephon on the yield, harvest distribution, and quality of machine-harvested blackberries. J. Amer. Soc. Hort. Sci. 107(4):542–547.
18. Skrede, G. 1983. Changes in sucrose, fructose and glucose content of frozen strawberries with thawing. J. Food Sci. 48:1094–1100.
19. Skrede, G., T. Naes, and M. Martens. 1983. Visual color deterioration in black currant syrup predicted by different instrumental variables. J. Food Sci. 48:1745–1749.
20. Swartz, H.J., G.J. Galletta, and R.H. Zimmerman. 1983. Field performance and phenotypic stability of tissue culture-propagated thornless blackberries. J. Amer. Soc. Hort. Sci. 108(2):285–290.
21. Torre, L.C. and B.H. Barritt. 1977. Quantitative evaluation of *Rubus* fruit anthocyanin pigments. J. Food Sci. 42:488–490.
22. Waller, R.A. and D.B. Duncan. 1969. A Bayes rule for the symmetric multiple comparisons problem. J. Amer. Stat. Assoc. 64:1484–1503.
23. Walsh, C.S., J. Popenoe, and T. Solomos. 1983. Thornless blackberry is a climacteric fruit. HortScience 18(4):482–483.
24. Wrolstad, R.E., J.D. Culbertson, D.A. Nagaki, and C.F. Madero. 1980. Sugars and nonvolatile acids of blackberries. J. Agr. Food Chem. 28:553–558.