nucellar and zygotic progeny from these crosses may then be identified as described. Furthermore, browning and nonbrowning *Citrus* taxa have characteristic inner and outer spot colors. For example, browning species *C. aurantium*, *C. sinensis*, and *C. reticulata* can be distinguished easily from one another by the shade and intensity of browning of their inner and outer spots. Within *C. reticulata*, 2 cultivar-specific shades of browning were observed while no such differences were detectable among cultivars of *C. aurantium* and *C. sinensis*. Inter- and intra-specific differences in the color of inner and outer spots were also observed in the nonbrowning taxa. Spot colors of hybrids from crossing of 2 different nonbrowning taxa were either different from both parents or similar to one of the parents. Thus, it appears that identification of nucellar and zygotic seedlings may be accomplished even following browning × browning and nonbrowning × nonbrowning crosses if parents with contrasting spot colors are used. The dependability of shade and intensity differences of browning between and within the browning taxa as a marker and its biochemical and genetic basis still remains to be fully explored. This is also true with differences between and within nonbrowning taxa.

Taxon-specificity of enzymatic browning was also found to be useful in distinguishing hybrids and variants among both browning and nonbrowning taxa. For example, there were 8 browning accessions of "acid lemons" among 50, and 3 of shaddocks among 39 tested. Since both taxa are nonbrowning, these browning accessions were most likely hybrids from crossing with browning taxa, which was also suspected from their morphological characters. Likewise the parentage of certain presumed hybrids was checked by comparing their spot colors with those of the presumed parents. Results confirmed the presumed origin of several hybrid cultivars. In fact, we propose that the description of *Citrus* cultivars should include information with respect to enzymatic browning or any other chemical information available. This along with information based on morphological characteristics would be useful in checking the identity of certified and patented material as well as that imported from elsewhere.

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Relation of Quality Indices of Individual Blueberries to Photoelectric Measurement of Anthocyanin Content[1]

L. J. Kushman and W. E. Ballinger[2]

USDA, ARS, and Noth Carolina State University, Raleigh

Abstract. Individual fruit pH, total acidity (AC as %), soluble solids (SS as %), and SS/AC ratios correlated significantly with anthocyanin contents of 'Wolcott', 'Morrow', 'Jersey', and 'Tifblue' blueberries as measured by light transmission (ΔOD740-800 nm). Fruit orientation with respect to the light path influenced readings. The relationships of the light transmission values to the quality indices differed among cultivars.

Commercial harvesting of blueberries is shifting from the customary hand-harvesting operation to a mechanized one with large over-the-row units. With hand harvesting there is no opportunity, and usually no need, for sorting or grading the fruits because the blue, ripe fruits are selectively removed at several harvests from the bushes and placed directly into the pint container that is shipped to market. In contrast, the mechanical harvester removes any fruits that shake loose when they are subjected to its action. This produces a mass of fruits representing all stages of maturity from the smallest green fruits to the most mature blue fruits on the bushes. Mechanical harvesters also bruise some fruits excessively (12, 13). Consequently, some sorting is required before mechanically-harvested fruits can be packaged for shipment.

In other work, data were developed to document the factors that affect firmness of blueberry fruits (3) and show how fruits can be separated on the basis of firmness with a vibration technique (8). Firmness was not found to be a good index of ripeness because the berries softened noticeably upon turning from green to blue, but thereafter, softened slowly with additional ripening (3). However, only a small amount of bruising decreased firmness considerably. Consequently separate methods for sorting fruits for ripeness and softness (or bruising) are needed.

If harvesting is delayed or if ripe fruits are left on the bushes at one harvest, overripe fruits are included in the next harvest. From a practical point of view, some non-destructive mechanical sorting system capable of screening large numbers of individual fruits is needed. Present sorting-line personnel can identify and manually eliminate green fruits without excessive costs (12, 13) but do not differentiate overripe fruits from other blue fruits. Yet, overripe fruits constitute a greater quality problem than unripe green fruits because of their short shelf-life.

Table 1. Correlation of anthocyanin content of individual blueberries with light transmission difference meter reading.

Anthocyanin content	Correlation coefficient	
	710–800 nm[z]	740–800 nm[y]
μg/berry	+.929	+.916
μg/cm² of berry surface	+.943	+.943
μg/g of berry	+.844	+.972

[z] 50 'Berkeley' fruits.
[y] 24 'Wolcott' fruits.

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[2] Research Plant Physiologist, Agricultural Research Service, USDA, (now retired); and Professor, Dept. of Horticultural Science, North Carolina State University respectively. The authors are indebted to John Skinner, Jr. and Eleanor P. Maness for assistance in carrying out the work.

Table 2. Variation in light transmission difference meter readings due to position of fruit in light path[z].

	Average OD readings for indicated clone					
	Wolcott[y]		NC 683[x]	54 257[w]	NC 854[v]	
	A	B			A	B
Blossom end down	.271a[u]	.413a	.289ab	.325a	.291a	.309a
Side down[t]	.251b	.371b	.301a	.318a	.280b	.308a
Stem scar down	.250b	.365b	.278b	.302b	.256c	.273b
Standard deviation, each berry:						
All 6 positions—maximum	.021	.039	.023	.016	.017	.022
—minimum	.008	.009	.003	.007	.007	.007
—all berries	.011	.021	.013	.010	.012	.015
Side position only—maximum	.009	.013	.009	.009	.008	.011
—minimum	.003	.004	.002	.002	.002	.003
—all berries	.006	.009	.004	.006	.005	.006
Minimum difference	.025	.020	.010	.015	.020	.020
Maximum difference	.055	.100	.055	.045	.055	.065

[z] 740–800 nm, 10 fruits per sample for each cultivar or seedling selection (clone).
[y] Widely-grown commercial highbush cultivar; A and B represent 2 samples.
[x] A relatively oblate fruit, highbush type (NC seedling selection).
[w] A nearly spherical fruit, highbush type (NC seedling selection).
[v] A nearly spherical fruit, rabbiteye-type seedling.
[u] Values followed by the same letter are not significantly different by Duncan's multiple range test, vertical comparisons only.
[t] Four readings at 90° intervals/fruit were averaged.

Table 3. Correlation of light transmission difference values ($\Delta OD_{740\text{-}800}$ nm) for individual fruits of four blueberry cultivars with fruit pH, total acidity (AC), soluble solids (SS), and soluble solids to acid ratio (SS/AC)[z].

Cultivar	Factor correlated	Coeff. of determination (r^2)	Regression coefficients b_0	b_1
Wolcott	pH	0.75	1.35	+7.80
	AC, %	.70	2.00	−4.18
	Log AC, % × 10	.73	1.74	−3.12
	SS, %	.68	1.53	+35.18
	SS/AC	.65	−67.13	+306.18
Morrow	pH	.29	3.19	+5.00
	AC, %	.22	.90	−2.22
	Log AC, % × 10	.22	1.19	−2.90
	SS, %	.69	2.02	+31.42
	SS/AC	.39	−31.82	+314.24
Jersey	pH	.74	1.96	+6.52
	AC, %	.89	3.64	−10.68
	Log AC, % × 10	.85	2.22	−5.44
	SS, %	.78	.86	+43.18
	SS/AC	.65	−58.51	+336.18
Tifblue	pH	.76	2.88	+1.08
	AC, %	.86	1.49	−2.74
	Log AC, % × 10	.88	1.31	−1.66
	SS, %	.57	5.69	+20.06
	SS/AC	.88	−8.68	+93.72

[z] The number of fruits used were 'Wolcott' 41, 'Morrow' 40, 'Jersey' 40, and 'Tifblue' 50.

Our previous studies showed that as blueberries ripen, titratable acidity (AC) decreases; whereas pH, soluble solids (SS) or sugars, and anthocyanin (ACY) contents increase (1, 9, 10). Shelf-life has been correlated inversely with the SS/AC (7, 9, 15) directly with AC (1, 7) and pH (7, 9) of the fruits. ACY content was highly correlated with sugar/acid ratios (r = +0.944) and with SS/AC ratios (r = +0.948) (1).

Differences in ACY contents of blueberries have been measured with light transmission techniques and correlated with shelf-life and SS/AC (2, 4). Dekazos and Birth (6) stated that light transmission measurements of whole berries "afford a reliable index of stage of maturity as related to their anthocyanin content". This observation

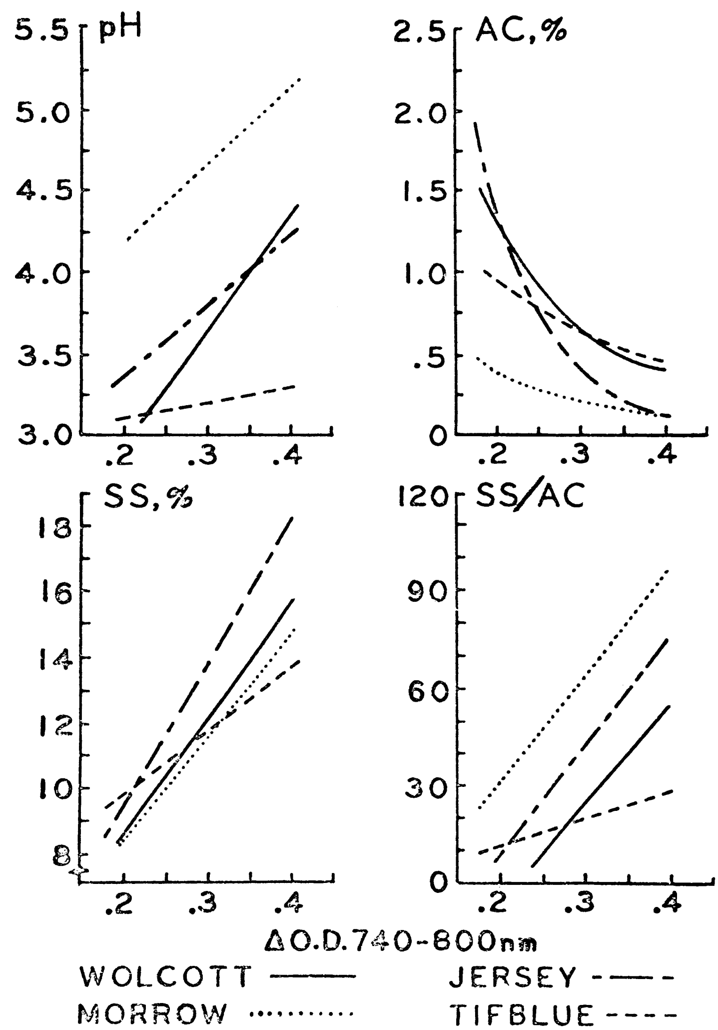

Fig. 1. Comparison of regressions of pH, total acid (AC as %), soluble solids (SS as %), and SS/AC on light transmission values (ΔOD740-800 nm) of 4 blueberry cultivars.

was based upon visual distinctions of ripeness and not upon physical or chemical properties of the fruits associated with ripeness. Our objective is to relate light transmission difference measurements to several parameters of quality and to determine their usefulness for separation of commercially-harvested blueberries on a quality basis.

Materials and Methods

Based on absorption spectra of unripe and ripe blueberries obtained with a multipurpose spectrophotometer (14) equipped with a Cary 14 monochronometer, 2 pairs of wavelengths (710-800 nm and 740-800 nm) were selected and tested with a light transmission difference meter (LTDM) (5). A Corning #2030 filter (isolation filter) was placed in the light path to remove any light below 650 nm passed by the test filters. Individual sample berries were positioned on the LTDM over a ¼-inch hole drilled in a No. 9 neoprene stopper. Light was concentrated with a condensing lens (0.70 normalized aperture, focal length ⅜-inch) before it came up through the stopper hole. The photodetector was a Dumont 6911 end-on photomultiplier tube with an S-10 response curve. A Corning #6000 blue filter covered with a 1.9 ΔOD screen was used as the standard for calibrating the LTDM to read 0.25 ΔOD[3]. This reading was selected as berries with little or no blue color read below 0.25 ΔOD and those that had been blue a week before harvest read 0.30 to 0.35 ΔOD.

When we found that the ACY content of individual fruits, regardless of how this was expressed, correlated well with LTDM readings at both pairs of wavelengths (Table 1), we selected the 740-800 nm wavelengths for further work because they were better related to ACY content measurements than the 710-800 wavelengths (Table 1). This selection agreed well with the data of Dekazos and Birth (6). Our scatter diagrams and regression equations are similar to theirs and therefore are not shown.

Because blueberries usually turn blue first at the blossom end and last at the stem end, several sets of fruit were read to measure the effect of orientation. Fruits (cv. Wolcott; 3 NC seedling selections) representing a wide range of responses were oriented and read in several ways: on the LTDM blossom end down, stem end down, and side down in each of 4 positions by turning the fruits about 90 degrees between readings. Because orientation had some effect on ΔOD readings (Table 2), fruits in all subsequent tests were placed in the side-down position on the LTDM to minimize the effect of orientation.

The ΔOD of blue fruit (40 berries each, representing a wide range of ripeness) of the highbush cv. Wolcott, Morrow, and Jersey (*Vaccinium corymbosum*, L. or *V. australe*, Small), and the rabbiteye cv. Tifblue (*V. ashei*, Reade) was read on the LTDM. The individual fruits then were weighed to the nearest ¹⁄₁₀₀th g and frozen until determinations of SS, PH, AC, and ACY, were made as in earlier work (1).

The LTDM readings were correlated with other fruit quality measurements: pH, AC, SS and SS/AC.

Results and Discussion

Fruit orientation. Orientation of blueberry fruits with respect to the light path influenced readings up to 0.10 ΔOD on the LTDM meter, but usually differences much less than this were encountered (Table 2). With the blossom end down, meter readings of fruit of most cultivar or seedling selections were usually 0.004 to 0.02 ΔOD higher than those obtained with the side or stem scar of the fruit down. Orientation had little affect on LTDM readings of fruit of the seedling NC 683. With the fruits on their sides, the average of the standard deviations for individual fruits of the different cultivar and seedlings ranged from 0.04 and 0.09 ΔOD; whereas, with all positions of orientation the standard deviation ranged from 0.10 to 0.21 units. Consequently reading fruits in a side-down position reduced variation significantly and indicated that separation of fruits into categories that differed from one another by 0.05 ΔOD (on the average) should represent distinct differences in ACY contents and, therefore, presumably distinct differences in ripeness and quality.

Fruit quality. For cvs. Wolcott, Morrow, Jersey and Tifblue, the ΔOD values of the fruits were significantly correlated with individual fruit pH, AC, log AC, SS, and SS/AC. Except for fruits of 'Morrow' the ΔOD values accounted for the following percentages of the variation in: pH (74-76%), AC (70-89%), log AC (73-88%), SS (57-78%), and SS/AC (65-88%) (Table 3).

For fruit of 'Morrow', the ΔOD values accounted for only 22 to 39 percent of the variation in pH, AC, log AC, and SS/AC, but about 69 percent of the variation in SS. The low correlations for pH and AC appeared to be associated with rapid ripening of the cultivar fruit; low levels of acid were reached early in the ripening sequence so that subsequent changes in ACY contents did not have an opportunity to reflect much change in acidity.

Fruit size, as expressed by wt of fruit, was poorly ('Wolcott' r^2 = 0.04) or fairly well ('Jersey' r^2 = 0.64) correlated with LTDM readings. As observed in other tests, size may or may not be correlated with ripeness because fruit size usually decreases as the season progresses and eventually ripe, small fruits are evident. The correlation of size with LTDM is therefore influenced by duration of ripening and time of harvest. The correlations of LTDM readings with pH, AC, and SS were not improved significantly by including fruit size.

Although ΔOD values of fruits of each cultivar correlated well with quality indices, several of the regressions differed considerably among cultivars in each of the quality indices except SS (Fig. 1). Thus specific ΔOD values, or ACY contents, did not reflect specific pH, AC, or SS values for all cultivars. Subsequent tests reported elsewhere (11), were designed to determine whether specific ΔOD values would reflect relatively specific pH, AC, and SS values of fruits of one cultivar harvested from different locations, or on different dates of harvest and season; and whether the ΔOD values of individual fruits would reflect the shelf-life of these fruits when the fruits were handled in pint packages in a commercial manner.

[3]The authors are indebted to Dr. Karl Norris, Pioneering Instrumentation Laboratory, Plant Industry Station, and Mr. John Yeatman, formerly of the Horticultural Crops Branch, Market Quality Research Division, ARS, USDA, for assistance in equipping the light transmission difference meter and making it available to us for the tests.

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Effect of Season, Location, Cultivar, and Fruit Size upon Quality of Light-Sorted Blueberries[1]

L. J. Kushmann and W. E. Ballinger[2]
USDA, ARS and North Carolina State University, Raleigh

Abstract. Regardless of season, location, harvest date, or size, 'Wolcott' blueberry fruits sorted with transmitted light according to their anthocyanin (ACY) contents were reasonably well separated for quality as expressed by pH, titratable acid (AC), soluble solids (SS) and the SS/AC ratio. Quality of fruits of the same ACY class differed according to cultivar ('Wolcott', 'Berkeley', and 'Jersey'). AC content of the fruit decreased slightly during the season regardless of ACY class or cultivar. This consistent reduction in AC as the season progressed was accompanied by increases in the SS/AC ratios and development of decay. Location of harvest (farm to farm) influences SS somewhat. A long harvest interval produced a small but consistent effect on all quality parameters.

When harvested by hand, generally unbruised ripe or overripe fruits are placed directly into pint containers in which the fruit is transported to market. There is neither opportunity nor means to visually separate ripe from overripe fruits.

Recent development of mechanical blueberry harvesters has produced a need for new methods of grading and packaging the fruits. Fruits arrive at the grading station in bulk and may be green, ripe, overripe, bruised, or essentially unbruised (12, 13). The obviously green or mashed fruits are removed by hand on a sorting table. To date, however, there is no way to remove overripe and/or bruised but intact blue fruits because they cannot be readily distinguished from other blue fruit. Since overripe (2, 9, 14) and bruised fruits (4, 8) do not keep well and are of inferior quality, some means is needed to detect and remove them from those fruits suitable for marketing.

In previous (2, 11) or preliminary reports (3, 6) we have shown that quality of individual berries of a given cultivar as expressed by pH, titratable acidity (AC), soluble solids (SS) and the SS/AC ratio, is significantly correlated with ACY content as measured with a light transmission difference meter (LTDM, ΔOD 740–800 nm). Cultivars differed considerably in the relationships of the ΔOD readings to the quality indices of the fruit, as might be expected from the fact that ACY development occurs earlier in the ripening process in some clones than in others (5, 7). Our objective was to determine whether season, location, harvest date, and size affected quality of berries that were sorted by light transmittance (LTDM).

Tests made to measure berry firmness, the effect of bruising upon berry firmness, and the separation of fruits according to firmness with a vibration technique are reported elsewhere (4, 8).

Materials and Methods

The LTDM has been described (11). All fruits were placed on their sides on the LTDM to minimize the effect of fruit orientation in the light path (11).

Fruits were classified according to ΔOD values into 6 ACY classes as follows: below ΔOD 0.200, trace or no ACY; ΔOD 0.200 to 0.249, very low; ΔOD 0.250 to 0.299, low; ΔOD 0.300 to 0.349, medium; ΔOD 0.350 to 0.399, high; and ΔOD 0.400 to 0.499, very high. All fruits from a given harvest were sized first by passing them through grids with holes that differed by 1.59 mm in diam (1/16"). Berries of each size class were sorted into ACY classes until at least 1 pint of fruit was collected for each available ACY class. Representative 50 g samples of each available size-ACY class were frozen and later analyzed for pH, AC, SS, and SS/AC (2, 9, 10). The remaining fruits were stored 1 week in pint pulp cups with acetate caps at 21.1°C (70°F) and 80–90% RH. Shelf-life is expressed as percentage of fruits decayed, by number, after the holding period (12).

In 1969 fruits of 'Wolcott' were harvested weekly from one plot of bushes, and only once after at least 3 weeks of fruit ripening (first harvest) from a second plot of bushes on the same farm (Farm B). Single harvests were made from bushes on 3 randomly-selected farms (Farms A, C, D) in the commercial blueberry area; these bushes had been harvested commercially, at unknown intervals, prior to the test harvests. Replication was not feasible due to the length of time required to lightsort the berries one by one.

Data collected in 1969 showed that size of fruit did not influence the ACY-quality relationship for 'Wolcott.' Harvest interval and season influenced this relationship to some degree. Therefore, in 1970 testing was limited to 1 size within a cultivar. Bushes of 'Wolcott', 'Berkeley' and 'Jersey' were harvested weekly at 1 farm. To obtain a second location for each of the 3 cultivars, we used plots of 'Jersey' and 'Berkeley' at a second farm, and plots of 'Wolcott' at a third farm. Fruits of the most prevalent size, 12.7 to 14.3 mm for 'Wolcott' and 'Jersey' fruits, and 14.3 to 15.9 mm for 'Berkeley' fruits were sorted into the different ACY classes. Samples were handled as above for quality evaluation.

Results and Discussion

'Wolcott' fruit, 1969. When 'Wolcott' fruits of each size were sorted according to ACY content into subclasses, differences in pH, AC, and SS contents within an ACY class, due to fruit size, were small (Table 1). Consequently, the SS/AC ratio and decay were not greatly affected by fruit size (Table 2).

Date and location of harvest produced some fairly consistent responses. The pH of the fruit from bushes harvested only once late in the season, after at least 3 weeks of ripening (Farm B, June 19), was

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[2] Research Plant Physiologist, Agricultural Research Service, USDA (now retired) and Professor, Department of Horticultural Science, respectively. The authors are indebted to John Skinner, Jr. and Eleanor P. Maness for assistance in carrying out the work.