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Storage Quality of Hand- and Machine-harvested Rabbiteye Blueberries

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Abstract. **Rabbiteye blueberry [*Vaccinium ashei* (Reade)] production is increasing rapidly and growers of large plantings are converting rapidly from hand harvesting to machine harvesting. In three tests conducted during 1985, machine-harvested 'Climax' and 'Woodard' blueberries were softer and had higher moisture loss and decay than handpicked fruit after 1, 2, or 3 weeks of storage at 3°C. For both cultivars, berry firmness remained relatively constant during storage, whereas decay and weight loss increased. Berries of 'Climax' were firmer, less acidic, and developed less decay than 'Woodard'. These results will assist in identifying the best fresh-market berries for export from the United States to Western Europe.**

Plantings and production of blueberries (mostly rabbiteye) in some southeastern states in the United States (Alabama, Florida, Georgia, Louisiana, Mississippi, South Carolina, and Texas) are increasing rapidly. Results of an informal survey conducted by us covering the industry in these states indicated that total harvested hectares (plants >3 years old) and total production increased more than 100% between 1982 and 1985. Total plantings for 1983 and 1984 were about 2 times greater than harvested hectares, indicating significant increases in future production. Use of berries produced by these states for the fresh market has remained relatively constant at 70%. In 1985, ≈1990 ha were planted, 1172 ha were harvested, and ≈4091 t of the 5991 t of total production were marketed as fresh. Growers with large plantings or cooperatives responsible for harvesting large areas are converting rapidly to machine harvesting.

Machine-harvested berries are reportedly softer and have a higher incidence of postharvest decay than hand-harvested berries (1, 14). Recent studies on highbush berries grown in New Jersey have shown that the stem scar was a prevalent site for fungal invasion (4), rapid cooling of berries after harvesting reduced decay (13), and sweating after removal from storage temperature did not affect incidence of decay (5). Controlled or modified atmospheres have effectively inhibited decay of relatively long-term storage of fresh-market berries (7–9), especially when combined with fungicides (6). Other studies (10, 12, 16) show that packaging material has a profound effect on the quality of blueberries during storage. Packaging berries in plastic film provides a moisture barrier that reduces weight loss but has a detrimental effect on berry firmness and decay. Ballinger et al. (2, 3) developed a model for predicting berry firmness and a procedure using the ratio of total soluble solids (TSS) to acidity (Ac) to predict shelf life, which allows for the selective channeling of berries into specific markets.

The need for distributing berries farther and farther from the production area will increase as the production volume of fresh-market berries increases. Blueberries exported to Western Europe via air freight may arrive at market within 48 hr of harvest; however, optimum pulp temperatures usually are not maintained during air transport, resulting in more rapid quality deterioration of berries than when held at optimum temperature. This study

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was conducted to determine the effects of cultivar, harvest, and storage method on quality and chemical characteristics of rabbiteye blueberries.

Handpicked (HP) and machine-harvested (MH) blueberries were obtained from the Georgia Blueberry Association in Alma on 13, 20, and 27 June 1985. 'Woodard' fruit were harvested on all three dates. 'Climax' fruit were available only on the 13 and 20 June harvest dates. On each harvest date, HP and MH samples of each cultivar were harvested from the same or adjacent row. The HP samples were harvested by the same picking crew. On 13 June, MH samples were harvested by a pull-type (PAL) machine with a synchronous shaker (beater) system, whereas on 20 and 27 June, MH fruit were harvested with a self-propelled BEI (Blueberry Equipment, South Haven, Mich.) Model RS machine with a nonsynchronous slapper system. Both HP and MH samples were placed in plastic field trays, identified in the field, and were handled during grading and packaging as nonexperimental berries. In the packinghouse, berries were emptied from plastic field trays onto the grading line and were graded and packaged into 0.55-liter (1-pint) consumer baskets capped with cellophane and a rubber band. Twelve 0.55-liter baskets were placed into commercial fiberboard flats and all packaged samples were returned to the laboratory in an air-conditioned automobile within 4 to 6 hr of harvest.

Three baskets of berries of each cultivar–harvest method combination were weighed and inspected after each time–temperature interval, 8 hr at 3°C (initial inspection) and after 1, 2, or 3 weeks at 3°, and after an additional 3 days at 16°; and also after a simulated export shipping regime of 2 days at 3° plus 2 days at 10° plus 1 day at 3° plus 2 days at 16°. Temperatures during storage were maintained at ±0.5°; relative humidity ranged from 85% to 95%.

All berries were evaluated for firmness, "leakage," decay, and culls following each storage regime. Percentages reported for each class were calculated on a weight basis. Berry firmness was determined by rotating berries between the thumb and index finger and applying light pressure. Berries yielding to light pressure were rated soft; those not yielding were classified as firm. Decay was scored on visible symptoms. Berries were scored as "leakers" when juice was leaking from either stem scar or surface cracks, and leakers were listed as decay. Berries of immature color or excessively dehydrated (preharvest condition) were rated culls. After the quality evaluations, firm and soft berries from each basket were mixed, and a 300-g aliquot from each was identified and frozen for chemical analysis at the Univ. of Georgia Coastal Plain Experiment Station. Each sample was blended with an equal weight of distilled water for 5 min. Sugar was extracted from a 2-g aliquot of the tissue–water blend with 100 ml of 100% ethanol for 30 min at 60°C. Sugar concentration of the filtered extracts was determined by the method of Dubois et al. (11). Total solids were determined by drying 25 g of the blend at 72° for 24 hr. Twenty millimeters of distilled water was added to a 2.5-g aliquot of the blend, the pH determined, and the acidity measured by titrating to pH 7.0 with 0.01 N NaOH. Titratable acidity is reported as percentage of citric acid. Results were tested using analysis of variance (ANOVA) procedures.

The initial evaluation of berries was made after about 8 hr at 3°C, instead of at ambient temperature, to lessen the effect of temperature on berry firmness results when comparing initial ratings to those obtained after 7, 14, and 21 days of storage. The export air freight regime simulates expected environmental conditions except shock and vibration of movement when exporting berries from Alma, Ga., to Amsterdam, Netherlands via Miami, Fla., and Frankfurt, F.R.G. This regime is based on observations of commercial air freight shipments conducted previously (15). The additional 3 days at 16°, following continuous storage of 1, 2, or 3 weeks at 3°, simulates a marketing period during which storage temperatures are likely to be higher than optimum. The effects of cultivar, harvest method, and storage duration and their interactions were tested using ANOVA procedures. Means for each condition or quality index by selected time–temperature regime grouping were subjected to factorial analysis using orthogonal contrast tests, where total error sums of squares are partitioned based on the degrees of freedom for each factor and tested. Means were divided into three distinct time–temperature regime groupings and tested. Group 1 included means of initial evaluation and those after 7, 14, or 21 days at 3°. Group 2 included means of initial evaluation and those after the 7, 14, or 21 days at 3° plus the 3 days at 16° marketing period. Group 3 compared means of initial evaluation to those obtained after simulated air freight and marketing.

Means for time–temperature regimes of Groups 1 and 2 are listed in Tables 1 or 2 by condition or quality index heading. Generally, the level of significance for each of the main effects or interaction effects for each of the three time–temperature storage regime groups tested are similar, thus allowing for the presentation of a single significance symbol in the table. When, however, the significance level for each of the two time–temperature regime groups shown in Table 2 is not the same, an additional explanation is provided by a footnote. Mean values after simulated air freight storage for the same indices are shown in Table 3.

Weight loss. Weight loss was highest when 'Woodard' fruit were machine harvested and least when 'Climax' fruit were hand harvested (Table 1). Weight loss of hand-harvested 'Climax' changed ≈0.2%/week, which was about half the rate of change for weight loss of hand-harvested 'Woodard' fruit during storage at 3°C. Weight loss of machine-harvested 'Woodard' fruit was about double that of the hand-harvested fruit. Weight loss during the 3-day simulated marketing period increased as the length of storage duration at 3° increased. Weight loss of fruit during the simulated air freight regime (Table 3) was similar to that during 7 days at 3° storage (Table 1).

Firmness. After the initial evaluation, there were ≈20% more firm berries for hand-harvested 'Climax' fruit than for those that were machine harvested. With 'Woodard' berries, hand harvesting produced about twice as many firm berries as machine harvesting. The percentage of firm berries remained relatively constant as storage duration increased, regardless of cultivar or harvest method.

Decay. Decay generally increased as storage duration increased. Decay of hand-harvested 'Climax' fruit was comparatively low, not exceeding 2% even after 21 days at 3°C plus the 3-day marketing period, whereas decay of machine-harvested 'Climax' fruit exceeded 2% shortly after 2 weeks of storage. Decay was excessive for both hand- and machine-harvested 'Woodard' fruit. After 21 days at 3°, decay was 12.5% and 24.2% for hand-harvested and machine-harvested 'Woodard' fruit, respectively. Decay of 'Climax' fruit during simulated air freight storage was 0.5% and 1.0% for hand- and machine-harvested fruit, respectively, whereas decay was 4.5% and 11.7% for hand- and machine-harvested 'Woodard' fruit, respectively (Table 3).

Table 1. Effect of storage regime on weight loss, firmness, and decay of hand- and machine-harvested rabbiteye blueberry cultivars.

Storage regimes	Climax[z]		'Woodard'[y]	
	Hand	Machine	Hand	Machine
	Weight loss (%)			
Group 1				
Initial	0.0	0.0	0.0	0.0
7 days at 3°C	0.1	0.1	0.3	0.8
14 days at 3°C	0.3	0.4	0.7	1.4
21 days at 3°C	0.5	0.9	1.2	2.0
Group 2				
7 days at 3°C + M[x]	0.5	0.7	0.7	1.4
14 days at 3°C + M	0.5	0.9	1.2	2.0
21 days at 3°C + M	1.9	2.2	2.2	3.0
	Firm fruit (%)			
Group 1				
Initial	93	78	67	32
7 days at 3°C	88	71	60	29
14 days at 3°C	93	81	58	35
21 days at 3°C	92	81	54	30
Group 2				
7 days at 3°C + M	96	82	61	36
14 days at 3°C + M	91	81	54	30
21 days at 3°C + M	86	78	52	29
	Decayed fruit (%)			
Group 1				
Initial	0.3	1.9	1.8	5.2
7 days at 3°C	0.8	1.9	3.2	6.9
14 days at 3°C	0.5	1.7	5.3	8.9
21 days at 3°C	1.3	3.6	12.5	24.2
Group 2				
7 days at 3°C + M	0.6	2.0	7.8	14.2
14 days at 3°C + M	1.3	3.6	12.5	24.2
21 days at 3°C + M	1.6	3.9	19.8	30.3

	Weight loss	Firmness	Decay
Factorial effects[w]			
Storage regime (Stor)	**	NS	**
Cultivar (Cult)	**	**	**
Harvest method (Har)	**	**	**
Stor × Cult	**	NS	NS[v]
Cult × Har	**	*	NS

[z]Each value based on the average of six baskets of berries.
[y]Each value based on the average of nine baskets of berries.
[x]Simulated marketing period of 3 days at 16°C.
[w]Statistical procedures applied independently to storage regimes of Group 1 or Group 2. Where statistical notation is dissimilar for Group 1 or Group 2, explanation is given by footnote. Values given for initial inspection are the same for Group 1 or Group 2.
[v]The Stor × Cult effect was signficant (*) for decay for berries after storage of 7, 14, or 21 days at 3°C plus 3 days at 16° (M).
**,*,NS Significant at 1%, 5%, or nonsignificant, respectively, by analysis of variance procedures, orthogonal contrast tests.

Table 2. Effect of storage regime on total sugar and acidity of hand- and machine-harvested rabbiteye blueberry cultivars.

Storage regimes	'Climax'[z]		'Woodard'[y]	
	Hand	Machine	Hand	Machine
	Sugar (%)			
Group 1				
Initial	14.9	13.4	12.8	11.8
7 days at 3°C	13.8	13.9	12.7	12.1
14 days at 3°C	13.8	13.8	12.6	11.9
21 days at 3°C	13.6	13.8	12.5	12.1
Group 2				
7 days at 3°C + M[x]	13.8	13.8	12.7	11.9
14 days at 3°C + M	13.7	13.9	12.4	11.6
21 days at 3°C + M	13.3	13.7	12.1	11.9
	Acid (%)			
Group 1				
Initial	0.53	0.57	0.74	0.73
7 days at 3°C	0.50	0.53	0.64	0.58
14 days at 3°C	0.52	0.51	0.63	0.59
21 days at 3°C	0.50	0.50	0.62	0.56
Group 2				
7 days at 3°C + M	0.52	0.51	0.63	0.59
14 days at 3°C + M	0.48	0.50	0.60	0.56
21 days at 3°C + M	0.50	0.50	0.63	0.58
	Sugar : acid			
Group 1				
Initial	28	23	18	16
7 days at 3°C	28	26	20	21
14 days at 3°C	27	27	20	21
21 days at 3°C	28	28	21	22
Group 2				
7 days at 3°C + M	28	28	20	22
14 days at 3°C + M	29	28	21	21
21 days at 3°C + M	27	27	20	21

	Sugar	Acid	Sugar : acid
Factorial effects[w]			
Storage regime (Stor)	NS	**	*
Cultivar (Cult)	**	**	*
Harvest method (Har)	*[v]	NS	NS
Stor × Cult	NS	NS[u]	NS
Cult × Har	NS	*	NS[t]

[z]Each value based on the average of six baskets of berries.
[y]Each value based on the average of nine baskets of berries.
[x]Simulated marketing period of 3 days at 16°C.
[w]Statistical procedures applied independently to storage regimes of Group 1 or Group 2. Where statistical notation is dissimilar for Group 1 or Group 2, explanation is given by footnote. Values given for initial inspection are the same for Group 1 and Group 2.
[v]Har effect was NS for sugar for berries after simulated marketing.
[u]Stor × Cult effect was significant (*) for acidity for berries after simulated marketing.
[t]Cult × Har effect was significant for sugar : acid for berries after simulated marketing.
**,*,NS Significant at 1%, 5%, or nonsignificant, respectively, by analysis of variance procedures, orthogonal contrast tests.

Quantity of cull fruit was affected only by harvest method, and it averaged about 1.0% for hand-picked fruit and about 2.0% for those berries machine harvested (data not shown).

Sugars. Total sugars averaged 13.8% for 'Climax' compared to 12.2% for fruit of 'Woodard' (Table 2). For 'Woodard', average sugars were 12.5% and 11.9% for those fruit hand or machine harvested, respectively. Sugar differences resulting from the harvest method within a cultivar are most likely explained by the relatively large percentage of decayed fruit in machine-harvested samples compared to that of hand-harvested samples. Riper fruit tend to decay sooner than less-ripe fruit. The removal of decayed fruit from a sample will tend to decrease the average ripeness of the remaining fruit in the sample, thus lowering the percentage of sugar in a sample with high amounts of decay compared to a similar fruit sample with lesser amounts of decay.

Acid. Average acidity during storage was 0.51% for 'Climax' fruit and 0.62% for 'Woodard' fruit. Acidity decreased initially for fruit of both cultivars, but then remained relatively constant

Table 3. Effect of simulated air freight[z] storage on selected physical and chemical factors of hand- and machine-harvested blueberry cultivars.

Variable	'Climax'[y] Hand	'Climax'[y] Machine	'Woodard'[x] Hand	'Woodard'[x] Machine
Weight loss (%)				
Initial	0.0	0.0	0.0	0.0
Air freight	0.2	0.3	0.3	1.1
Firm fruit (%)				
Initial	93	78	67	32
Air freight	95	84	68	34
Decayed fruit (%)				
Initial	0.3	1.9	1.8	5.2
Air freight	0.5	1.0	4.5	11.7
Sugar (%)				
Initial	14.9	13.4	12.8	11.8
Air freight	13.9	14.1	12.3	12.2
Acid (%)				
Initial	0.53	0.57	0.74	0.73
Air freight	0.45	0.49	0.61	0.55
Sugar : Acid (TSS:Ac)				
Initial	28	23	18	16
Air freight	31	29	20	23

Factorial effects	*Weight loss*	*Firm*	*Dk*	*Sugar*	*Acids*	*TSS:Ac*
Storage regime (Stor)	**[w]	NS	*	NS	*	*
Cultivar (Cult)	**	**	*	*	*	*
Harvest method (Har)	**	**	*	NS	NS	NS
Stor × Cult	**	NS	NS	NS	**	NS
Cult × Har	*	**	NS	NS	**	*
Stor × Har	**	NS	NS	**	NS	*

[z]Air freight time–temperature storage = 48 hr at 3°c + 48 hr at 10° + 24 hr at 3° + 48 hr at 16°.
[y]Each value based on the average of six baskets of berries.
[x]Each value based on the average of nine baskets of berries.
[**,*,NS]Significant at 1%, 5%, or nonsignificant, respectively, by analysis of variance procedures.

during the 3-week storage period including the simulated marketing time. Acidity for fruit held at simulated air freight conditions tended to be slightly less than that for each corresponding cultivar–harvest method combination (Table 3).

Sugar : acid ratio. Except in hand-harvested 'Climax', the TSS:Ac ratio generally increased following the initial measurement, then remained relatively constant during storage. The storage TSS:Ac ratio averaged 28 for 'Climax' fruit and 21 for 'Woodard' fruit.

Dry weights of 'Climax' and 'Woodard' fruits were not significantly different and averaged 19.9% and 18.1%, respectively, over all storage regimes (data not shown).

These findings generally are consistent with previous reports that show that fruit of either rabbiteye or highbush cultivars are softened significantly due to bruising by machine harvesting (1, 14), resulting in higher incidences of decay compared to hand-harvested fruit. Further, our study showed that 'Climax' fruit (initial TSS:Ac = 28) were significantly firmer with less decay and, thus, had longer inherent shelf life than 'Woodard' (initial TSS:Ac = 18) fruit during relatively long-term storage. The susceptibility to decay varies from one cultivar to another (3); however, within a particular cultivar, the ripeness of fruit, i.e., TSS:Ac ratio is related to the amount of decay. These findings are not consistent with the work of Ballinger et al. (3), which related higher TSS:Ac ratios to decreasing shelf-life durations. This apparent inconsistency may be due to differences in: a) methodologies used in the two different studies; b) inherent proportional chemical differences between rabbiteye and highbush fruit; c) seasonal differences due to climatic or cultural changes; or d) morphological differences in factors such as stem scar area, cuticle, wax, etc.; or e) atypical differences between fruit of these specific rabbiteye cultivars. Additional study relating sugar : acid ratios to shelf life of rabbiteye fruit seems warranted. These results do indicate that berries of 'Climax' can be shipped to distant markets that require relatively long transport time. Berries of 'Climax' can be expected to arrive in acceptable marketing condition without the aid of special treatments such as altered atmospheres or special packaging.

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