Research Reports

Effect of Cultivar, Controlled Atmosphere Storage, and Fruit Ripeness on the Long-term Storage of Highbush Blueberries

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SUMMARY. Controlled-atmosphere storage had little effect on the quality of fruit of eight cultivars held under 2 kPa oxygen (O₂) and 8 kPa carbon dioxide (CO₂) versus ambient air. 'Elliott' fruit harvested from bushes with only 30% ripe fruit had significantly better storage quality than fruit picked later; however, there was no significant difference in the storage life of fruit that was stored fully blue versus partially green. Fruit from the first harvest of four cultivars had superior storage quality to that of the second. In one comparison of the long-term storability of nine cultivars, 'Bluegold', 'Brigitta', and 'Legacy' performed the best, storing for 4 to 7 weeks. In another postharvest trial of 17 cultivars, 'Brigitta' stored the longest (8 weeks) followed by 'Aurora' and 'Draper' (7 weeks). The most resistant genotypes to *Alternaria* spp. were 'Brigitta', 'Aurora', 'Elliott', and 'Draper', whereas the most resistant genotypes to *Colletotrichum* spp. were 'Elliott', 'Brigitta', 'Toro', 'Draper', and 'Bluejay'.

The ability to store blueberries for long periods of time allows marketers to hold fruit during periods of heavy production until prices improve, particularly in the late season when supplies are at their lowest and prices become the highest. The storage life of blueberry fruit has previously been shown to be enhanced by harvesting less-mature fruit (Ballinger et al., 1978; Beaudry et al., 1998; Galletta et al., 1971) and maintenance under a controlled

atmosphere (CA) (Beaudry et al., 1998; Smittle and Miller, 1988). However, a number of new cultivars have been released since these studies were undertaken and little work has been done to optimize the post-harvest keeping quality of 'Elliott'

blueberry fruit, the latest-ripening cultivar grown widely in Michigan. This study was designed to determine the stage of bush and fruit ripening most appropriate for long-term storage of 'Elliott' blueberries and compare the long-term storability and resistance to decay of 'Elliott' and a large set of new cultivars.

Materials and methods

INFLUENCE OF FRUIT RIPENESS AND CA ON STORAGE LIFE OF 'ELLIOTT' FRUIT. Fully blue fruit were hand-harvested in 1999 from 'Elliott' bushes in which 30%, 60%, and 80% of the fruit were fully colored blue and in 2000 when 30% and 60% of the fruit on the bush were blue. In 1999, the fruit were placed into 6-fl oz ventilated plastic containers, which were then placed into 20-L plastic pails fitted with airtight lids and ventilated with air or with an atmosphere of 2 kPa O₂ and 8 kPa CO₂. This atmosphere was regarded as being nonharmful in terms of inducing fermentation based on the findings of Beaudry (1993) yet of sufficient CO₂ content to curb decay development (Beaudry et al., 1998). CA conditions were established using nitrogen (N₂) gas from a N₂ generator (CPA-1; Permea, St. Louis) and blending it with O₂ contained in compressed air and gaseous CO₂ from a pressurized CO₂ gas cylinder (Linde Gas, Independence, OH). Gas concentrations were established manually. Pressure was maintained using two-stage regulators and flow was adjusted using needle valves. Blended gas was humidified by first bubbling the gas into water contained in a 5-L glass jar in the cold room where the fruit were stored. Relative humidity (RH) was estimated to be in excess of 90%. The humidified gas was then directed to a flow board and distributed to individual lines using a manifold outfitted with glass capillary tubes. Gas flow

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Units

Units To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
1	cbar	kPa	1
29.5735	fl oz	mL	0.0338
3.7854	gal	L	0.2642
25.4	inch(es)	mm	0.0394
0.1751	lb/inch	N-mm ⁻¹	5.7101
28.3495	oz	g	0.0353
0.4732	pt	L	2.1134
(°F - 32) ÷ 1.8	°F	°C	(1.8 × °C) + 32

from the flow boards was returned to the 20-L plastic buckets containing fruit and was maintained at ≈ 75 mL/min⁻¹. In 1999, the fruit were held at 0 °C. Gas composition was determined by withdrawing duplicate 0.1-mL gas samples from the mixed gas inlet lines with an insulin-type plastic syringe and analyzing O₂ using a paramagnetic gas analyzer (Ametek Co., Thermox Instrument Div., Pittsburgh, PA) and CO₂ with an infrared gas analyzer (model 225-MK3; Analytical Development Co., Hoddeston, UK) in series with N₂ as a carrier gas. Gas concentrations were calculated relative to a certified gas mixture (4.85% CO₂, 1.95% O₂ balanced with N₂). In 2000, the fruit was stored at 5 °C using only ambient air.

In 2000, fruit were picked from 'Elliott' bushes when the bushes were 30% ripe and were sorted into three classes: fully blue, greater than 75% to less than 100% ripe and greater than 50% to less than 75% ripe. These fruit were stored in 6-fl oz ventilated

plastic containers at 5 °C under ambient air and 90% RH. An attempt was also made to sort fruit into different ripening classes in 1999 and 2001, but almost all the fruit were either totally blue or green when the 'Elliott' bushes were 30% ripe.

Fruit from each treatment were removed at 4, 5, and 6 weeks of storage in 1999 and tested for firmness, weight, soluble solids (SS), titratable acidity (TA), and internal discoloration (darkening and water-soaking). Percentage decay was also evaluated after holding the fruit an additional 3 d at 20 °C and elevated humidity (greater than 90% RH). In 2000, fruit were removed after 4 weeks of storage and were tested for the same quality parameters. Measurements were abandoned when over 50% of the fruit had greater than 50% internal discoloration.

INFLUENCE OF CULTIVAR AND CA ON STORAGE LIFE OF BLUEBERRY FRUIT. In 1999, ripe fruit from 'Bluegold', 'Brigitta', 'Elliott', 'Legacy',

'Little Giant', and 'Nelson' were placed into 6-fl oz ventilated plastic containers and stored either under ambient O₂ and CO₂, 90% RH, and 0 °C or at 2 kPa O₂, 8 kPa CO₂, 90% RH, and 0 °C as described previously. Fully blue fruit were hand-harvested when the bushes were $\approx 30\%$ blue. At 4, 5, and 6 weeks, fruit from each treatment were removed and tested for firmness, weight, SS, TA, and internal discoloration. Percentage decay was also evaluated after holding the fruit an additional 3 d at 20 °C and elevated humidity (greater than 90% RH); little decay was observed in storage.

In 2000, the fruit from 'Bluecrop', 'Bluegold', 'Brigitta', 'Elliott', 'Jersey', 'Legacy', and 'Liberty' were placed into 6-fl oz ventilated plastic containers and held at 5 °C under ambient O₂ and CO₂ and 90% RH. Fully blue fruit were hand-harvested from bushes when 30% of the fruit on a bush were fully colored blue and placed under ambient storage

Table 1. Effect of bush maturity (30%, 60%, and 80% blue fruit) and type of storage on fruit quality of Elliott highbush blueberries kept in storage for 0, 4, 5, and 6 weeks in 1999.^z

Factor	Fruit wt (g) ^y	Soluble solids [SS (%)]	Titratable acidity [TA (%)]	SS:TA ratio	Firmness (N·mm ⁻¹) ^y	Sound fruit (%)
Bush maturity						
30%	1.02	11.9	1.1	11.3	135.4	42.6
60%	0.96	11.3	1.2	9.9	121.4	41.0
80%	0.93	11.5	1.1	10.2	137.8	27.2
Type of storage						
CA	0.95	11.6	1.0	11.2	127.0	39.8
RA	0.97	11.5	1.1	10.6	136.1	42.5
Weeks of storage						
0	0.95	11.9	1.1	11.3	135.4	85.5
4	0.96	11.2	—	—	121.6	38.3
5	0.93	11.3	—	—	121.8	21.8
6	0.97	11.5	1.0	11.2	136.1	18.5
Mean	0.97	10.8	1.1	10.8	131.5	41.1
SE	0.03	0.3	0.1	0.3	2.0	2.8
Analysis of variance						
Bush maturity (M)	218.5[*]	1.86	0.00	5.13	4,334.7	42.6
Whole-plot error	2.8	0.95	0.06	6.19	201.4	53.3
Type of storage (S)	6.5	0.46	0.00	0.01	2,497.8	127.2
S × M	6.8	2.24	—	—	471.6	12.3
Sub-plot error	9.4	1.77	0.01	3.66	118.3	5.5
Weeks of storage (W)	66.1	7.55	0.34	10.18	4,368.7	2,024.8
W × M	44.6	1.19	0.14	1.46	811.1	14.9
W × S	5.3	1.38	—	—	296.7	11.5
W × M × S	3.9	1.74	—	—	197.5	197.0
Sub-sub-plot error	7.9	0.86	0.04	2.98	263.5	45.9

^zTwo types of storage conditions were compared: 1) refrigerated air (RA) at 0 °C (32.0 °F) with ambient oxygen (O₂), carbon dioxide (CO₂), and 90% relative humidity (RH); or 2) controlled atmosphere (CA) at 0 °C with 2 kPa (2.0 cbar) O₂, 8 kPa (8.0 cbar) CO₂, and 90% RH. Fruit were harvested at the Southwest Michigan Research and Extension Center of Michigan State University near Benton Harbor.

^y1 g = 0.0353 oz, 1 N·mm⁻¹ = 5.7101 lbf/inch.

^{*}Significant values (5%) are displayed in boldface type.

Table 2. Effect of bush maturity (30% and 60% blue fruit) and fruit ripeness (50% to 75%, 75% to 90%, and 100% of the surface blue) on quality of Elliott highbush blueberries held in storage at 5 °C (41.0 °C) for 4 weeks in 2000.

Factor	Fruit wt (g) ^z	Soluble solids (%)	pH	Firmness (N·mm ⁻¹) ^z	Sound fruit (%)
Bush maturity					
30%	2.06	9.6	2.9	206.4	54
60%	2.27	8.0	2.6	227.1	23
Fruit ripeness					
50% to 75% blue	2.95	7.4	2.6	295.4	38
75% to 99% blue	1.74	9.1	2.7	173.5	35
100% blue	1.78	10.9	3.2	178.1	52
Mean	2.17	8.6	2.8	216.9	30
SE	0.13	0.3	0.1	12.5	4
Analysis of variance					
Bush maturity (M)	120	10.0^y	0.0	120.6	1.14
Whole-plot error	516	0.6	0.0	10.9	0.01
Fruit ripeness (F)	87,379	27.4	0.2	1,604.7	0.07
M × F	11,487	4.5	0.0	127.2	0.13
Split-plot error	6,063	0.9	0.0	17.8	0.02

^z1 g = 0.0353 oz, 1 N·mm⁻¹ = 5.7101 lbf/inch.

^ySignificant values (5%) are displayed in boldface type.

conditions at 5 °C. Fruit were removed at weekly intervals from each treatment for 4 weeks and tested for the previously mentioned quality parameters.

In 2001, we compared the characteristics of fruit from the first and second harvests of 'Bluegold', 'Liberty', 'Elliott', and 'Nelson'. Fruit were first hand-harvested when the bushes were 30% ripe and then again ≈10 d later. Fruit were stored at 0 °C in ambient air like in 2000 and evaluated at 1-week intervals for SS, fruit weight, firmness, and percentage internal discoloration.

FRUIT QUALITY PARAMETERS. SS and TA were measured from juice extracted from 25-fruit samples blended at high speed in a tissue homogenizer (Ultra Turrax T25; Janke and Kunkel Co., Staufen, Germany). SS was determined using a

Table 3. Effect of type of storage and weeks of storage on the fruit quality of six highbush cultivars in 1999.^z

Factor	Fruit wt (g) ^y	Soluble solids [SS (%)]	Titrateable acidity [TA (%)]	SS:TA ratio	Firmness (N·mm ⁻¹) ^y	Sound fruit (%)
Cultivar						
Bluegold	2.30	11.9	1.0	11.7	209.1	82.7
Brigitta	2.50	11.4	1.0	12.0	183.5	70.9
Elliott	2.07	11.9	1.1	11.3	135.4	42.6
Legacy	2.46	13.7	0.8	17.7	171.3	76.5
Little Giant	0.73	15.3	0.7	22.8	108.6	18.5
Nelson	2.38	12.2	0.8	16.6	125.2	29.4
Type of storage						
CA	2.08	12.7	0.8	17.1	151.9	42.1
RA	2.06	12.9	0.9	15.1	162.6	44.9
Weeks of storage						
0	2.05	13.4	0.9	15.0	175.8	82.1
3	2.20	12.5	—	—	157.3	51.5
5	2.01	12.7	—	—	148.2	51.4
6	2.08	12.4	—	—	150.6	44.2
7	2.07	12.9	0.8	16.6	154.3	37.5
Mean	0.05	12.8	0.9	16.1	157.2	53.7
SE	2.08	0.1	0.0	0.62	3.5	2.8
Analysis of variance						
Cultivar (C)	14,163.7[*]	100.3	0.3	284.2	73,272	11,384
Whole-plot error	9.4	0.6	0.0	6.7	558	76
Type of storage (S)	0.6	2.8	0.0	17.7	13,006	109
C × S	9.1	0.8	0.0	12.7	1931	365
Sub-plot error	2.1	0.4	0.0	3.7	950	90
Weeks of storage (W)	145.9	5.5	0.1	6.2	6,481	812
W × C	41.3	2.0	0.0	24.8	2,529	2,146
W × S	21.3	0.5	—	—	2,789	251
W × C × S	4.2	0.3	—	—	1,199	120
Sub-sub-plot error	7.5	0.4	0.0	5.6	613	51

^zTwo types of storage conditions were used: 1) refrigerated air (RA) at 0 °C (32.0 °F) with ambient oxygen (O₂), carbon dioxide (CO₂), and 90% relative humidity (RH), or 2) controlled atmosphere (CA) at 0 °C with 2 kPa (2.0 cbar) O₂, 8 kPa (8.0 cbar) CO₂, and 90% RH. Fruit were harvested from the MBG Marketing Test Plot, Grand Junction, MI.

^y1 g = 0.0353 oz, 1 N·mm⁻¹ = 5.7101 lbf/inch.

^{*}Significant values (5%) are displayed in boldface type.

handheld refractometer (Westover model RHB-32; Southwest United Industries, Tulsa, OK). Results are reported in percent SS (wt/wt) on a fresh weight basis. TA was determined from 10 mL of juice diluted to 100 mL with distilled water, titrated with 0.1 N sodium hydroxide (NaOH) to pH 8.2, and expressed as percentage citric acid (wt/wt) on a fresh weight basis. Firmness was evaluated on 50 individual fruit per sample using a portable firmness-measuring instrument (Timm et al., 1993). Data were reported in Newtons required to deform the surface of the fruit 1 mm. Internal discoloration was rated on a 50-fruit sample by cutting each fruit in half and determining what proportion of the flesh displayed water-soaking or pigment leakage. A fruit was considered "sound" if it had less than 25% internal discoloration.

STORAGE LIFE AND FRUIT ROT RESISTANCE. Storage life and rot resistance of fruit were determined from cultivars hand-harvested at Grand Junction, MI, for 3 years (2002 to 2004). The fruit were picked when $\approx 30\%$ of the fruit in a

bush were fully blue. To determine storage life, 4 pt of fruit from each genotype were kept at 2 °C in perforated plastic zip-lock bags to minimize moisture loss but avoid modification of O₂ and CO₂ and evaluated every 3 to 4 d for salability. The fruit were considered salable if the fruit in the pint were without any visible decay and over 50% of a 50-fruit sample were firm to the touch. Little evidence of fruit-rotting organisms was observed during storage. To determine resistance to fruit rots, 50 fruit were randomly selected from 4 pt of each genotype, placed separately on a wire grid, and evaluated for rot after being held an additional 10 d at room temperature in the zip-lock bags. Specific rot organisms were identified by visual symptoms.

STATISTICAL COMPARISONS. The experimental design used for all experiments was a completely randomized factorial of five subsamples of fruit from each treatment combination. An analysis of variance was performed on the data. An arcsine square root transformation was performed on all percentage data before statistical analysis.

Results

INFLUENCE OF FRUIT RIPENESS AND CA ON STORAGE LIFE OF 'ELLIOTT' FRUIT. The percentage of blue fruit on 'Elliott' bushes at harvest in 1999 had a significant effect on fruit weight and firmness (Table 1). The earliest picked fruit were largest, but no trend was seen in firmness. Type of storage had a significant effect on sound fruit (percent) and firmness with the refrigerated air (RA) fruit having slightly more sound and firm fruit than those held under CA. Weeks of storage significantly affected all the quality parameters measured, although only percentage sound fruit showed a trend with the longest held fruit being the least sound. There were several significant interactions between bush maturity and weeks of storage for the quality parameters; the earliest picked fruit maintained their size, TA, and firmness at higher levels than the later-picked fruit (data not shown).

Many of the quality parameters measured in 2000 on 'Elliott' fruit were also significantly affected by bush maturity and fruit ripeness

Table 4. Effect of weeks of storage at 5 °C (41.0 °F) on the fruit quality of seven highbush blueberry cultivars in 2000.^z

Factor	Fruit wt (g) ^y	Soluble solids [SS (%)]	Titratable acidity [TA (%)]	SS:TA ratio	pH	Firmness (N·mm ⁻¹) ^y	Sound fruit (%)
Cultivar							
Bluecrop	2.06	9.5	1.2	10.0	3.4	129.1	49.3
Bluegold	1.82	10.2	2.1	5.9	3.1	172.3	49.2
Brigitta	2.64	12.7	1.4	9.1	3.2	222.7	70.2
Elliott	2.04	11.9	1.1	11.3	3.2	135.4	32.6
Jersey	1.55	10.0	0.9	12.8	3.7	155.4	53.0
Legacy	1.85	11.3	1.5	8.6	3.6	209.5	63.8
Liberty	1.93	11.3	1.4	9.9	3.4	234.1	67.9
Weeks of storage							
0	1.61	12.1	1.5	9.0	3.4	160.8	72.3
1	1.81	10.5	—	—	3.1	181.4	54.0
2	1.98	11.1	—	—	—	197.8	33.2
3	1.75	10.3	—	—	—	174.6	35.2
4	1.88	10.1	—	—	3.1	188.1	30.0
Mean	1.98	11.0	1.5	9.0	3.4	179.8	55.1
SE	0.10	0.1	0.1	0.5	0.0	1.4	0.0
Analysis of variance							
Cultivar (C)	27,625.7^x	15.6	0.6	16.5	0.2	3,989.7	0.7
Whole-plot error	316.2	0.9	0.2	5.7	0.0	9.4	0.0
Week of storage (W)	2,752.8	19.7	—	—	0.0	204.1	0.9
C × W	2,050.1	1.1	—	—	—	51.6	0.0
Sub-plot error	249.9	0.7	—	—	0.1	9.9	0.0

^zFruit were harvested from the MBG Marketing Test Plot, Grand Junction, MI.

^y1 g = 0.0353 oz, 1 N·mm⁻¹ = 5.7101 lbf/inch.

^xSignificant values (5%) are displayed in boldface type.

(Table 2). The 2000 crop had much larger fruit with greater firmness but with lower SS than in 1999. After 4 weeks of storage, the fruit picked when the bushes held 30% ripe fruit were slightly softer, had higher SS, and a higher percentage of sound fruit than fruit harvested when 60% of the fruit on the bush were ripe. The fruit picked when they were 100% blue were significantly larger, had higher SS, and were less firm than the greenest fruit. Only a few of the fruit picked at 50% to 75% blue turned fully blue in storage, whereas most of those at 75% to 99% did (data not shown). A significant interaction was observed between length of storage and fruit maturity for SS, firmness, and percentage sound fruit.

INFLUENCE OF CULTIVAR AND CA ON STORAGE LIFE OF BLUEBERRY FRUIT. Fruit of 'Bluegold', 'Brigitta', and 'Legacy' had the highest percentage of sound berries in 1999 (Table 3) and they held up much better in storage than 'Elliott', 'Little Giant', and 'Nelson'. The fruit of 'Bluegold', 'Brigitta', and 'Legacy' were also the firmest cultivars and had among the lowest SS:TA ratio except 'Legacy', which was second behind 'Little Giant'. 'Little Giant' had the highest SS, lowest TA, and highest SS:TA ratio of any cultivar tested in 1999. Type of storage (RA versus CA) had a significant effect on SS, SS:TA ratio, and firmness with the fruit held under RA having higher SS, lower SS:TA ratio, and firmer berries.

In 2000, 'Bluegold' had only an average percentage of sound berries, but 'Brigitta' and 'Legacy' were again listed at the top of all the cultivars along with 'Liberty', which was evaluated for the first time (Table 4). Over 50% of the 'Brigitta', 'Legacy', and 'Liberty' fruit were still sound after 4 weeks of storage. 'Brigitta', 'Legacy', and 'Liberty' also had the firmest fruit and had among the lowest SS:TA ratio. 'Little Giant' again had the highest SS, but its TA was much higher than in 1999, dramatically reducing its SS:TA ratio. This year, 'Jersey' had the highest SS:TA ratio followed by 'Elliott'.

In 2001, harvest date had a significant effect on fruit weight, SS, firmness, and sound fruit (percent) with fruit from the first harvest of all five cultivars having greater weight, higher SS, lower firmness, and higher percentages of sound fruit (Table 5).

Table 5. Effect of picking date and weeks of storage at 0 °C (32 °F) on the fruit quality of five highbush blueberry cultivars in 2001.^z

Factor	Fruit wt (g) ^y	Soluble solids [SS (%)]	Firmness (N·mm ⁻¹) ^y	Sound fruit (%)
Cultivar				
Bluegold	1.60	11.4	210.7	36.7
Brigitta	2.05	12.2	200.6	57.2
Elliott	1.39	11.0	230.9	12.0
Liberty	1.67	11.6	193.9	31.2
Nelson	1.70	12.9	181.5	24.6
Harvest date				
1st pick	1.72	12.2	203.4	39.8
2nd pick	1.54	11.3	204.4	16.8
Weeks of storage				
0	1.67	12.4	193.6	56.8
3	1.61	11.8	199.3	36.6
4	1.61	11.5	201.9	21.3
5	1.65	11.5	219.0	20.7
6	1.67	11.6	205.4	10.4
Mean	1.64	11.8	203.8	29.2
SE	0.10	0.1	3.8	1.8
Analysis of variance				
Cultivar (C)	13,787.3^x	19.1	782.0	2,947.3
Whole-plot error	575.8	0.5	7.3	48.3
Harvest date (H)	2.3	31.4	252.8	8,902.2
C × H	37,751.2	1.8	252.3	1,353.8
Split-plot error	261.7	0.7	6.4	23.5
Weeks of storage (W)	2,737.8	4.7	20.4	5,704.8
C × W	6,096.7	1.1	21.8	345.2
H × W	3,221.9	0.9	8.9	655.4
C × H × W	6,905.8	0.3	25.1	376.1
Split-split-plot error	656.7	0.6	8.3	77.5

^zFruit were harvested from the MBG Marketing Test Plot, Grand Junction, MI.

^y1 g = 0.0353 oz, 1 N·mm⁻¹ = 5.7101 lbf/inch.

^xSignificant values (5%) are displayed in boldface type.

Fig. 1. Mean storage life of eight highbush blueberry cultivars at 0 °C (32.0 °F) from 1999 to 2001. Storage life was calculated as the number of weeks that a cultivars fruit were greater than 50% sound. Fruit were harvested from the MBG Marketing Test Plots, Grand Junction, MI. Error bars represent SD.

Overall, fruit of 'Brigitta' had the highest percentage of sound berries, whereas those of 'Elliott' were the most firm. 'Liberty' was only average for percentage firmness and sound fruit in 2001; 'Legacy' was not analyzed in 2001.

From 1999 to 2001, 'Brigitta', 'Legacy', and 'Nelson' averaged 4 weeks or more of successful storage, whereas 'Elliott', 'Bluecrop', 'Nelson', 'Little Giant', and 'Jersey' all averaged less than 3 weeks (Fig. 1, Table 1).

STORAGE LIFE AND FRUIT ROT RESISTANCE. In the cultivar comparisons from 2002 to 2004, there were significant differences among years and cultivars for percentage decay and weeks of successful storage (Table 6). The average percentage of decay was higher in 2004 than the other 2 years. Those cultivars with the longest average storage life were 'Brigitta',

'Aurora', and 'Draper'. The least decay overall was found on 'Brigitta', 'Elliott', 'Draper', and 'Aurora'. The most resistant genotypes to *Alternaria* spp. were 'Brigitta', 'Aurora', 'Elliott', and 'Draper'. The most resistant types to *Colletotrichum* spp. were 'Elliott', 'Brigitta', 'Toro', and 'Draper'.

Discussion

In a number of studies conducted in the 1970s, the harvesting of less mature fruit was often found to enhance storage life (Ballinger and Kushman, 1970; Ballinger et al., 1978; Galletta et al., 1971). In our investigations on 'Elliott' blueberries, we found that unripe fruit did not store any better than 100% blue fruit and that few fruit picked before they were 75% blue were able to fully color in storage. However, we did find that fruit picked when the bush was 30%

ripe were generally firmer, had higher SS, and a higher percentage of sound fruit than those fruit harvested when 60% of the bush was ripe (Tables 1 and 2). The key to the long-term storage of fully blue fruit may simply be how long it has been ripe. Our study on fruit maturity was conducted when only a small percentage of the fruit on the bush was ripe, and as a result, most of the fruit we picked were in an early stage of ripening before too much softening had occurred.

A considerable amount of research has been done on optimizing O₂ and CO₂ in blueberry storage (Beaudry, 1993; Ceponis and Cappellini, 1979, 1983, 1985). In general, a CO₂ partial pressure in the range of 8 to 15 kPa has been found to be effective in preserving fresh blueberries stored for periods longer than 3 weeks (Beaudry, 1993; Borecka and Plizka, 1985). The level of O₂, however, seems to have had little impact on fruit quality, although there is some indication that O₂ levels can alter tolerance to CO₂ (Beaudry, 1993). In our studies, we did not observe a significant enhancement in storage life of fruit from seven cultivars held under controlled atmospheric conditions. It is possible that because we picked the fruit at an early stage of overall bush ripeness, the fruit may have been at an early stage of ripeness that was less responsive to CA storage. The longest storing fruit have been previously shown to be firm and have low SS:TA ratios (Ballinger et al., 1978; Galletta et al., 1971). We also had little *Botrytis* infection, which has been shown to be effectively controlled by high CO₂ atmospheres (Forney et al., 2003; Harb and Stief, 2004).

A number of new cultivars were found to store much longer than the widely planted 'Duke', 'Bluecrop', 'Jersey', and 'Elliott'. Overall, the top performers were 'Aurora', 'Draper', and 'Brigitta', with storage lives up to 8 weeks in RA. 'Draper' and 'Brigitta' were also highly resistant to *Alternaria* spp. and *Colletotrichum gloeosporioides* fruit infections, whereas 'Aurora' was highly resistant to *Alternaria* spp. and moderately resistant to *Colletotrichum* spp. These long-storing cultivars could enhance the prices received by growers for their blueberry fruit by allowing them

Table 6. Storage life and rot resistance of fruit harvested from highbush blueberries at the MBG Marketing Test Plot, Grand Junction, MI from 2002 to 2004.^z

Factor	Decay (%)				Storage life (weeks)
	<i>Alternaria</i>	<i>Colletotrichum</i>	Other	Total	
Year					
2002	8.4	6.1	0.9	15.1	3
2003	7.8	17.2	1.7	26.0	6
2004	11.3	20.3	1.5	33.1	6
Cultivar					
Aurora	3.4	10.5	1.4	13.8	7
Bluecrop	16.6	25.3	2.6	44.5	5
Bluegold	14.5	23.4	0.5	36.4	5
Bluejay	8.6	7.3	3.6	19.5	5
Blueray	14.6	18.1	2.3	35.0	6
Bluetta	11.7	32.7	1.2	45.5	4
Brigitta	3.3	3.6	0.3	7.1	8
Draper	4.0	6.5	1.3	11.8	7
Duke	7.0	7.5	2.6	17.1	4
Elliott	3.8	3.3	0.3	7.4	5
Jersey	6.2	37.1	0.0	43.3	3
Legacy	12.3	22.3	1.6	36.3	5
Liberty	11.7	15.9	1.4	29.0	5
Nelson	8.1	8.0	1.8	17.8	6
Rubel	14.1	22.1	0.9	35.3	4
Spartan	8.8	19.8	2.2	30.7	5
Toro	12.3	5.9	1.3	19.1	6
Mean	9.2	15.4	1.4	25.6	5.3
SE	0.5	1.2	0.1	1.4	0.2
Analysis of variance					
Year (Y)	149^y	2,662	3.8	3,705	145.7
Whole-plot error	28	51	2.5	138	0.0
Cultivar (C)	201	1,176	8.0	1,812	17.0
Y × C	127	457	6.5	752	11.7
Split-plot error	11	24	2.5	41	0.0

^zTo determine resistance to fruit rots, 50 fruit were randomly selected from 4 pt of each cultivar and evaluated for rot after 10 d at room temperature.

^ySignificant values (5%) are displayed in boldface type.

to hold fruit longer at the end of the season and during peak production periods.

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