Postharvest Quality of Mechanically and Hand-harvested, Southern Highbush Blueberry Fruit for Fresh Market

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SUMMARY. Three southern highbush blueberry cultivars (*Vaccinium corymbosum* hybrids) were mechanically harvested (MH) or hand-harvested (HH) and commercially packed before storage for 14 days at 1 °C in two successive years. MH fruit were softer, had lower ratings for overall appearance, and lost up to 20% more fresh weight than HH fruit after 14 days storage. MH ‘Meadowlark’ had fewer soft fruit (<35%) during storage than either ‘Sweetcrisp’ or ‘Farthing’; however, the latter two cultivars had lower incidences of shrivel and weight loss. Fruit in the 2010 season were more susceptible to bruising than those from the 2009 season; however, soluble solids content (SSC), total titratable acidity (TTA), and ascorbic acid concentration remained constant during storage and between seasons. ‘Meadowlark’ had the highest sugar to acid ratio (25.0). Successful implementation of MH of southern highbush blueberries for fresh market will only be commercially feasible if harvest impacts are further reduced.

Rabbiteye blueberries (*Vaccinium virgatum*) are more resistant to mechanical harvesting and have been MH for fresh market for many years. Mainland et al. (1975) studied the quality of HH highbush blueberry (*Vaccinium corymbosum*) cultivars compared with MH fruit using side-slapper finger harvest technology from that era; they reported that MH fruit were softer than HH fruit, resulting in significantly higher losses and increased decay during storage. Since then, several studies have evaluated MH as newer harvest technologies and cultivars became available. The older, side-slapper finger units have been replaced in favor of dual vertical-shaft vibrating finger units (now known as continuous canopy shakers) (Mainland, 1993). Fruit of early yielding, southern highbush blueberry

cultivars grown in low-chill regions in the United States were considered too susceptible to mechanical injury to be MH (Takeda et al., 2008). Currently, southern highbush blueberries are MH only late in the season typically for the frozen processing market with a value ranging from \$0.50/lb to \$1.20/lb. In contrast, Florida blueberry (*Vaccinium* sp. and hybrids) growers sold early season fruit for fresh market at almost five times the price for the processing market [\$5.56/lb (Perez and Plattner, 2012)]. Consumer demand for blueberries continues to rise, in part due to reports that they have some of the highest antioxidant properties among fresh fruit (Clark et al., 2002; Connor et al., 2002; Prior et al., 1998; Sellappan et al., 2002). This has led to significant increases in acreage of southern highbush blueberry cultivars in

Florida and other southeastern states to obtain the high, early season prices. In 2011, Florida growers produced the largest yield on record, estimated at 21.4 million pounds (Perez and Plattner, 2012); in 2012, total harvested area in Florida reached an all-time high of 4500 acres (U.S. Department of Agriculture, 2013).

Labor cost and availability are primary concerns of southern highbush blueberry growers, prompting them to explore the potential for using mechanical harvesters for fresh market (Fonsah et al., 2008). However, for MH to become viable, these early season, high-value fruit must be of sufficiently high quality to fetch fresh-market prices; the price received for the process market is not high enough to offset the savings from reduced labor. Blueberries destined for fresh markets must maintain acceptable quality for 2 to 3 weeks after harvest to meet market demands.

Identifying cultivars that maintain good postharvest quality during transport and marketing is critical to a successful MH program. Firm fruit texture is one of the most critical characteristics because it improves the probability that fresh packed blueberries will be received by buyers with acceptable quality. NeSmith et al. (2002) reported that MH rabbiteye blueberry lost 20% to 30% firmness as compared with HH fruit. The University of Florida’s breeding program has produced advanced selections of southern highbush blueberry hybrids with higher firmness, among other key characteristics (Lyrene, 2002). Blueberry growers could potentially realize significant cost savings if cultivars and equipment were developed or identified that would allow MH for fresh market. This could dramatically increase production efficiencies, and potentially revolutionize the fresh-market blueberry industry.

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Units

To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
0.4047	acre(s)	ha	2.4711
29.5735	fl oz	mL	0.0338
0.3048	ft	m	3.2808
2.54	inch(es)	cm	0.3937
0.4536	lb	kg	2.2046
1.6093	mph	km-h ⁻¹	0.6214
28.3495	oz	g	0.0353
0.1	ppm	mg/100 g	10
(°F - 32) ÷ 1.8	°F	°C	(°C × 1.8) + 32

The objective of this research was to determine the potential for MH southern highbush blueberry cultivars that are destined for fresh market. Selected blueberry cultivars and breeding lines were harvested by hand or with a commercial mechanical harvester during two successive seasons and fruit quality attributes were assessed following harvest, commercial packing, and storage.

Materials and methods

LOCATIONS AND PLANT MATERIAL.

The study was conducted at two locations in cooperation with Straughn Farms. In 2009 (Season One), plots were located at farms near Windsor, FL, and Waldo, FL, while in 2010 (Season Two) all plots were located at the farm near Waldo, FL. The bushes were planted in raised beds (12 to 18 inch in height) formed with pine bark-incorporated native soil and pine bark mulch over the top. Spacing in the plots was 10 ft between rows and ≈ 3 ft within rows. Fertigation and supplemental irrigation were provided with two driplines per row on either side of the plant. Standard Florida blueberry commercial management practices (irrigation, fertilization, pest control, and pruning) were followed at both locations for both seasons (Williamson et al., 2006).

Since the University of Florida blueberry breeding program focuses on plants adapted to low-chill production areas, several southern highbush blueberry cultivars and selections were studied in Season One. However, on the basis of that data only 'Farthing', 'Sweetcrisp', and 'Meadowlark' were deemed as having potential for MH for study in Season Two. These three cultivars are widely grown commercially in central and northern Florida. In Season One, 'Meadowlark' and 'Sweetcrisp' fruit were harvested from plots located at the Waldo, FL, farm, and all plants were 3.5 years old at the time of harvest. 'Farthing' was harvested from 2.5-year-old plants located at the Windsor, FL, farm. In Season Two, 'Meadowlark', 'Sweetcrisp', and 'Farthing' plants were harvested from 5.5-year-old plants at the Waldo, FL location.

In Season One, 15 to 20 plants of each genotype were selected ≈ 1 month before fruit maturity. All plants

were base-pruned to remove small-diameter twigs and canes that would potentially interfere with the catch plates on the harvester. In the center of each plot, four uniform plants were marked for subsequent yield measurements after MH. Four plants at the beginning and end of each plot were HH before MH. In Season Two, there were eight replicate plots of 20 plants each for 'Meadowlark' and 'Sweetcrisp' and eight plots of eight plants each for 'Farthing'. Plants were base-pruned in a similar manner to Season One. Four replicate plots were randomly assigned for both harvest methods. In the MH plots, all plants were harvested, while in the HH plots, six plants were harvested on the first harvest date and four plants on the remaining harvest dates.

HARVEST AND POSTHARVEST METHODS. In Season One, there were two harvest dates per cultivar: 16 April ('Meadowlark'), 21 April ('Sweetcrisp'), 22 April ('Farthing'), 29 April ('Meadowlark' and 'Sweetcrisp'), and 1 May ('Farthing'). Before each harvest, the ground underneath each plot was cleared of any previously fallen fruit. HH plots were picked before MH. A Korvan 8000 blueberry harvester (Oxbo International, Lynden, WA) was used on all harvest dates except 1 May. The harvester was operated at a ground speed of 1.5 mph with the rotor set at 600–700 rpm. For the harvest on 1 May, a Littau Over-The-Row harvester (Littau Harvester, Stayton, OR) harvested 'Farthing' with a ground speed of 0.75 mph. Both harvesters use the dual vertical-shaft, canopy shaker technology.

In Season Two, all plots (HH and MH) were HH on 29 April to remove the initial ripe fruit and reduce cluster compactness, similar to commercial preparations for MH for fresh market (W.O. Cline, personal communication). Harvest dates for all three cultivars were 6 May, 13 May, and 20 May (28 May for the third 'Farthing' harvest only). HH plots were picked first then all MH plots were harvested with the Korvan 8000 blueberry harvester operated at a ground speed of 0.75 to 1 mph and with the rotor set at 700 to 750 rpm. For both seasons and harvesters, detached fruit dropped onto conveyors on the harvester and were conveyed

into field lugs ($23\text{-}1/2 \times 15\text{-}1/2 \times 6\text{-}1/2$ inch).

For Season One, all MH fruit in the field lugs were placed in the commercial cooler at 50 °F/42% relative humidity (RH) and stored overnight, a typical commercial practice. The next morning out-of-grade fruit (small, soft, poor/off-color) were graded out and quantified; marketable fruit were volume-filled into rigid, vented clamshell containers [125-g capacity ($5 \times 4\text{-}3/8 \times 1\text{-}1/4$ inch)] then packed into corrugated, fiberboard cartons [also known as flats ($15\text{-}3/4 \times 9\text{-}3/4 \times 3\text{-}1/4$ inch)]. There were 12 clamshell containers per carton. HH fruit were field-packed directly into clamshell containers and transported to the Postharvest Horticulture Laboratory in Gainesville, FL, where they were stored at 1 °C for the duration of the storage test.

In Season Two, MH and HH fruit were held overnight in the field lugs at 50 °F/45% RH and the following morning were packed on the same commercial packing line as in Season One (Straughn Farms, Waldo, FL). The only difference in Season Two was that fruit were packed into 170-g clamshell containers ($5 \times 4\text{-}3/8 \times 1\text{-}5/8$ inch).

FRUIT QUALITY ASSESSMENTS. For both seasons initial MH and HH samples from each cultivar ($n = 4$ clamshells/treatment) were rated (1 d after harvest) for overall appearance, percent soft fruit and percent shriveled fruit, then the contents of each clamshell were frozen at -30 °C for future analysis. Overall appearance was rated hedonically on a whole-clamshell basis using the following scale: 1 = very poor, 2 = poor, 3 = fair (limit of marketability), 4 = good, and 5 = very good (field fresh). A subsample (10 fruit/clamshell) was individually rated tactilely as firm or soft by the same individual. Additional clamshell replicates ($n = 4$ /treatment) were weighed and stored at 1 °C for subsequent evaluations after 7 and 14 d storage for these variables plus shrivel rating (1 to 5 scale as above) and incidence of decay. At each evaluation the contents of each clamshell were frozen at -30 °C.

For compositional analyses, blueberry samples were thawed, homogenized, and centrifuged at 17,600 g_n for 25 min. The blueberry juice supernatant was filtered through

cheesecloth and was used to determine SSC, TTA, and pH. SSC was measured with an Abbe refractometer (Cambridge Instruments, Buffalo, NY) and expressed as percent. TTA and pH were measured using an automatic titrimeter (model 719 S; Metrohm Ion Analysis, Titrino, Switzerland). Aliquots (6 g) of blueberry juice were diluted with 50 mL deionized water and TTA was determined by titration with 0.1 N sodium hydroxide to an endpoint of pH 8.2. TTA was expressed as percent citric acid.

For determination of total ascorbic acid, frozen blueberry fruit samples were thawed and 2 g of homogenized blueberry tissue were mixed with 20 mL of 6% metaphosphoric acid and 2N acetic acid, and then centrifuged for 20 min at 17,600 g_n . The analysis was performed by the dinitrophenylhydrazine method of Terada et al. (1978). The concentration of ascorbic acid was calculated from the absorbance measured at 540 nm using a standard curve prepared from an ascorbic acid standard solution (Sigma-Aldrich, St. Louis, MO) and expressed on fresh weight basis.

Data were analyzed using a completely randomized design with Proc GLM (SAS version 9.2; SAS Institute, Cary, NC). Means for season and harvest method with significant interactions were compared using Duncan's multiple range test ($P \leq 0.05$).

Results and discussion

Harvest date did not significantly affect fruit quality variables and therefore these data were merged for each season. Blueberries from Season One had higher initial quality than those from Season Two, and the former maintained higher overall appearance with fewer soft and shriveled fruit throughout storage at 1 °C. Initial ratings for overall appearance ranged from 4.3 to 5.0 for blueberries from both seasons (Table 1). There was virtually no difference due to harvest method following harvest or after 7 d storage at 1 °C. However, after 14 d storage, MH fruit from Season One were rated as much as 30% lower (mean=2.77) in overall appearance than HH fruit (mean = 3.97). A similar trend occurred for fruit from Season Two, although after 14 d storage fruit from both harvest methods were

rated below market acceptability (<3.0); 'Meadowlark' was rated lower than the other cultivars in Season Two.

In Season One, MH 'Sweetcrisp' had the highest initial amount of soft fruit (12.5%) compared with either 'Meadowlark' (2.0%) or 'Farthing' (0.0%) and for undetermined reasons; HH fruit had essentially no soft fruit, irrespective of cultivar (Table 1). After 7 d storage, 11.9% to 25.6% of MH fruit were rated as soft compared with 0.0% to 5.0% for HH fruit. In Season Two, MH fruit were consistently rated softer than HH fruit following harvest and after 7 and 14 d storage (Table 1). 'Meadowlark' had higher initial amounts of soft fruit, 4.27% (MH) and 2.69% (HH), roughly twice the respective values for either 'Farthing' or 'Sweetcrisp'. However, after 14 d storage, 'Meadowlark' had the lowest number of soft fruit for both seasons with values ranging from 35.0% to 59.2% (MH) and from 14.2% to 20.8% (HH).

NeSmith et al. (2002) studied 'Brightwell' (rabbiteye type) and reported that MH fruit were 22% softer than HH fruit after harvest.

Table 1. Effect of harvest method, hand harvest (HH) or mechanical harvest (MH), on ratings for overall appearance, soft fruit and shriveled fruit for three southern highbush blueberry cultivars during 14 d of storage at 1 °C (33.8 °F).

Trait	Cultivar	Initial				7 d				14 d			
		HH		MH		HH		MH		HH		MH	
Season One ^z													
Overall appearance rating (1–5 scale) ^y	Meadowlark	5.0	a A ^x	5.0	a A	4.0	a B	4.5	a A	3.9	a A	2.5	a B
	Sweetcrisp	4.3	b A	4.3	b A	4.0	a A	3.9	b A	4.0	a A	2.8	a B
	Farthing	4.5	b A	5.0	a A	3.5	b A	3.5	b A	4.0	a A	3.0	a B
Soft fruit (%)	Meadowlark	0.5	a A	2.0	b A	5.0	a B	11.9	b A	5.0	a B	26.9	b A
	Sweetcrisp	0.5	a B	12.5	a A	0.0	b B	20.0	a A	0.0	b B	48.8	a A
	Farthing	0.0	a A	0.0	b A	1.7	b B	25.6	a A	1.7	b B	38.1	ab A
Shrivel (%)	Meadowlark	0.0	a A	0.0	a A	0.0	b A	3.8	b A	12.5	a B	58.8	a A
	Sweetcrisp	0.0	a A	0.0	a A	0.0	b A	0.0	b A	1.7	b A	7.5	b A
	Farthing	0.0	a A	0.0	a A	10.0	a A	14.4	a A	16.7	a B	27.5	ab A
Season Two													
Overall appearance rating (1–5 scale)	Meadowlark	4.7	b A	4.7	b A	3.4	b A	3.2	b A	2.5	b A	2.1	b B
	Sweetcrisp	5.0	a A	4.9	a A	4.0	a A	3.7	a A	2.9	a A	2.5	a B
	Farthing	4.9	a A	4.9	a A	3.8	a A	3.7	a A	2.7	ab A	2.5	a A
Soft fruit (%)	Meadowlark	2.7	a B	4.3	a A	23.3	a A	33.3	a A	14.2	a B	35.0	b A
	Sweetcrisp	1.2	b B	2.3	b A	5.8	b B	38.3	a A	17.5	a B	58.3	a A
	Farthing	1.3	b B	2.8	b A	10.8	b B	27.5	a A	20.8	a B	59.2	a A
Shrivel (%)	Meadowlark	0.0	a A	0.0	a A	39.2	a A	49.2	a A	87.5	a A	76.7	a B
	Sweetcrisp	0.0	a A	0.0	a A	15.8	b A	20.0	b A	50.0	b B	61.7	b A
	Farthing	0.0	a A	0.0	a A	15.0	b A	15.8	b A	46.7	b A	53.3	b A

^zSeason One = April/May 2009, Season Two = May 2010.

^ySubjective visual scale: 1 = very poor, 2 = poor, 3 = fair (limit of marketability), 4 = good, 5 = excellent.

*For each storage evaluation, means followed by the same lowercase letter within the same column by season, or by the same uppercase letter within the same row, do not differ significantly according to Duncan's multiple range test ($P \leq 0.05$).

Following 10 d storage at 5 °C, they observed that fruit from both methods softened $\approx 20\%$, although HH fruit remained significantly firmer than MH fruit. Miller and Smittle (1987) found differences in firmness due to cultivar (all rabbiteye blueberry) during 7 and 14 d at 3 °C; HH fruit ('Climax') were 20% firmer than MH fruit, whereas HH fruit ('Woodard') were $\approx 50\%$ firmer than MH fruit. These results were comparable to the incidences of soft fruit reported in this study.

Many reports have positively correlated fruit firmness with incidence of decay; however, despite the softening encountered in this study, no decay was observed in any treatments. Miller and Smittle (1987) reported differences in susceptibility to decay during storage due to cultivar. There was 0.5% and 1.7% decay for HH and MH 'Climax' fruit, respectively, after 14 d storage at 3 °C; whereas 'Woodard' fruit had higher incidences of decay (5.35% and 8.9% for HH and MH, respectively). It is possible that the newer released cultivars used in this study were more resistant to decay pathogens during storage. Also, clamshell containers reduce mechanical injury during storage for two reasons: inside surfaces are smooth and a restricted number of vent openings limit air movement within the clamshell, creating a favorable high-RH internal environment ($\approx 90\%$). In contrast, in the 1987 study, the fruit were packed in cellophane-topped plastic baskets that typically consisted of open sides and bottom that would have caused more mechanical injury to the fruit.

Impact frequency and intensity have also been reported to affect fruit firmness. Demir et al. (2011) dropped 'Misty' southern highbush blueberries multiple times from 200 mm and, although they reported no decay after 24 d at 2 °C, those fruit dropped 10 times were softer to the touch than those dropped six times from the same height. Yu et al. (2012) quantified impacts to blueberries during MH by suspending a miniature, instrumented sphere in the blueberry bush and tracking impacts as the harvester removed the sphere from the bush. They reported that the majority of impacts occurred at two drop points—the drop to the catch plates (30%) and the drop into the harvest lug (20%)—and they suggested

that manufacturers should focus on reducing/minimizing impacts at these locations to significantly reduce bruising. Although MH resulted in a significant amount of unripe, small, and stemmy fruit in this study (data not shown), these were adequately removed during grading operations.

Shriveling became evident on fruit from both harvest methods after 7 d storage in both seasons; after 14 d storage, MH fruit tended to show more shrivel symptoms than HH. 'Meadowlark' was most susceptible to shriveling (Table 1). The low rate of shrivel in HH fruit found in Season One may have been due to those fruit having been packed in clamshells and cooled to 1 °C the day of harvest.

Fresh weight loss during storage has been reported in the literature to vary considerably by blueberry type and cultivar. In this study, all fruit lost 3% to 5% fresh weight after 14 d storage at 1 °C (Table 2). 'Meadowlark' lost significantly more fresh weight than either 'Sweetcrisp' or 'Farthing', and MH fruit lost $\approx 12\%$ and 20% more fresh weight than HH in Seasons One and Two, respectively. During 14 d storage at 3 °C, Miller and Smittle (1987) found that rabbiteye cultivars lost $\approx 10\%$ as much fresh weight during storage as the three southern highbush cultivars used in this study. However, fruit in the former test were most likely cooled to final storage temperature the day of harvest, in contrast to the fruit in this study that were held overnight at 50 °F in Season Two. This faster cooling rate would have resulted in 3% to

8% less fresh weight loss than blueberries held overnight at the higher temperature (NeSmith et al., 2002). The fact that 'Meadowlark' had the highest fresh weight loss during storage concurs with it also having the highest incidence of shrivel (Table 1).

Although there were minor differences in initial handling and storage methods between Seasons One and Two, these do not completely explain differences in the results. In Season One, HH fruit were cooled to 1 °C the day of harvest, whereas in Season Two, HH and MH fruit were held overnight at 50 °F before commercial packing. This may account for the overall higher incidences of soft fruit and shrivel for HH fruit Season Two. However, the higher rates for these variables for MH fruit appear to be due to seasonal effects, since they were commercially packed both seasons and fresh weight loss for corresponding harvest methods was fairly similar for both seasons.

Values for SSC, TTA, and pH remained constant, irrespective of harvest method, storage period, and season. Of the three cultivars, Sweetcrisp had the highest SSC (13.0%) and TTA (0.783%), followed by Farthing (10.6%, 0.523%), and Meadowlark (8.47%, 0.387%) (Table 3). Although 'Meadowlark' had the lowest values for SSC and TTA, the resulting ratio of SSC/TTA was the highest (25.0) making it, presumably, the sweetest tasting of the three cultivars. Other studies have also reported that these values remained constant during storage (Chiabrando et al., 2009; Miller and Smittle, 1987).

Table 2. Effect of harvest method, hand harvest (HH) or mechanical harvest (MH), on weight loss for three southern highbush blueberry cultivars during 14 d of storage at 1 °C (33.8 °F).

Cultivar	Weight loss (%)							
	7 d				14 d			
	HH		MH		HH		MH	
	<i>Season One^s</i>							
Meadowlark	2.35	a A ^y	1.43	a B	4.02	a A	3.11	a B
Sweetcrisp	1.76	b A	1.44	a A	2.55	b A	3.06	a A
Farthing	1.37	b A	1.54	a A	2.47	b A	2.96	a A
	<i>Season Two</i>							
Meadowlark	2.22	a B	2.74	a A	4.46	a B	4.98	a A
Sweetcrisp	1.85	b B	2.08	b A	3.67	b B	4.04	b A
Farthing	1.80	b B	2.08	b A	3.72	b B	4.29	b A

^aSeason One = April/May 2009, Season Two = May 2010.

^yMeans followed by the same lowercase letter within the same column by season, or by the same uppercase letter within the same row, do not differ significantly according to Duncan's multiple range test ($P \leq 0.05$).

Table 3. Selected compositional analyses for three southern highbush blueberry cultivars (overall means for both harvest methods and both seasons).

Cultivar	SSC(%) ^a		TTA(%) ^a		pH		SSC/TTA		Ascorbic acid ^b (mg/100 g)	
Meadowlark	8.47	c ^x	0.387	c	3.95	a	25.01	a	37.16	b
Farthing	10.59	b	0.523	b	3.43	b	21.38	b	41.32	a
Sweetcrisp	13.01	a	0.783	a	3.29	c	17.35	c	42.55	a

^aSSC = soluble solids content, TTA = total titratable acidity (% citric acid).

^bAscorbic acid only determined in Season Two; 1 mg/100 g = 10 ppm.

^xMeans followed by the same lowercase letter within the same column do not differ significantly according to Duncan's multiple range test ($P \leq 0.05$).

Ascorbic acid is an important antioxidant that serves to breakdown hydrogen peroxide in cells. It was only measured in Season Two, and the overall mean was 40 mg/100 g (fresh weight basis); 'Meadowlark' had slightly lower ascorbic acid content, but there were no differences because of harvest method or storage time. This value is similar to the findings of Wang et al. (2011), who determined the mean ascorbic acid content for northern highbush blueberry (*V. corymbosum*) cultivars to be 40.6 mg/100 g (fresh weight basis). They also reported the means for three *V. corymbosum* derivative cultivars (18.2 mg/100 g) and for 36 rabbiteye blueberry cultivars (45.7 mg/100 g).

Conclusions

The results from this study revealed that impacts due to MH resulted in significantly more soft fruit, and that this fruit softened at a faster rate during subsequent storage than HH fruit, irrespective of cultivar. MH fruit from all three cultivars maintained acceptable quality after 7 d storage at 1 °C, as measured by overall appearance, firmness (percent soft fruit) and shriveling. However, after 14 d storage, HH fruit had higher overall appearance and lower incidences of soft fruit and shrivel than MH fruit. MH fruit ranged from 26% to 59% soft fruit and >53% shriveled fruit. After 14 d storage 'Meadowlark' had the least soft fruit, although 'Sweetcrisp' and 'Farthing' were more resistant to fresh weight loss and had correspondingly lower incidence of shrivel. For the cultivars studied, MH fruit showed accelerated softening compared with HH fruit during storage. There is the promise of breeding new cultivars with greater resistance to

impacts and modification of harvest equipment that would protect fruit quality sufficiently to make MH commercially viable for southern highbush blueberries.

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