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Flower Bud and Shoot Hardiness of Southern Highbush Blueberry Cultivars

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Abstract

The southern highbush blueberry (*Vaccinium* spp.) cvs. 'Blue Ridge,' 'Cape Fear,' 'Cooper,' 'Georgiagem,' 'Gulf Coast' and 'O'Neal,' and selections A-109 and G-616, the rabbiteye (*V. ashei* Reade) cv. 'Climax' and the northern highbush (*V. corymbosum* L.) cvs. 'Bluecrop' and 'Sierra' were evaluated in December 1993 and January and February 1994 for shoot and flower bud damage following exposure to 0, -5, -10, -15, -20, -25 and -30C in a programmable freezer. All cultivars were hardier than 'Climax' at all sample dates. Hardiness among several southern highbush clones was similar to that for northern highbush at several dates and temperatures. The hardier southern highbush clones were A-109, 'Blue Ridge' and 'Cape Fear.' 'Sierra' exhibited equal or greater hardiness than 'Bluecrop,' depending on date of sampling and temperature.

Evaluations of hardiness of flower buds have been done on several species of blueberries, including northern highbush (*Vaccinium corymbosum* L.) (4, 5), lowbush (*V. angustifolium* Ait.) (6) and rabbit eye (*Vaccinium ashei* Reade) (7, 13, 15). Cultivars with comparatively higher levels of flower bud hardiness have been determined, including 'Northland,' 'Jersey' and 'Bluecrop' highbush and 'Tifblue' rabbiteye (8).

The southern, or low-chill, highbush blueberry consists of cultivars that were developed for areas of the United States that have fewer chilling hours than northern blueberry production regions. These cultivars resulted from hybridizing the highbush blueberry with other *Vaccinium* species, primarily *V. darrowi* Camp (11). A lower level of flower bud hardiness of southern

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highbush in comparison with northern highbush cultivars has been observed in Fayetteville, Ark. Southern highbush cultivars, which often have one-quarter *V. darrowi* in their parentage, commonly experience flower bud kill from dormant-season winter low temperatures (J. N. Moore, personal communication).

Patten et al. (14) reported that for similar stages of flower bud development, the southern highbush cultivars 'Blue Ridge,' 'Cape Fear,' 'O'Neal' and 'Georgiagem' had less freeze damage than the rabbiteye cultivars 'Tifblue,' 'Brightwell,' 'Baldwin' and 'Climax' following exposure of swelled flower buds to -10C at Overton, Tex. Although almost no flower bud damage was reported for the southern highbush cultivars, 'Climax' rabbiteye had 69% dead ovaries compared to 10% for 'Tifblue.' In this same report, 'Georgiagem' had 73% dead ovaries following exposure to -13C at Clarksville, Ark., compared to no ovary damage to 'Blue Ridge' and 'Cape Fear' and 1% damage to 'O'Neal.' At this same time, 'Climax' rabbiteye experienced 68% ovary damage.

Our study was conducted to determine the hardiness of flower buds and shoots of several southern highbush cultivars, developed at various locations in the south, from samples collected at three times during the dormant season. The intention was to sample the cultivars in early, middle and late dormancy to evaluate their levels of flower bud and shoot hardiness during the winter. Additionally, one rabbiteye and two northern highbush cultivars were included in this comparison.

Material and Methods

Six southern highbush blueberry cultivars, which were selected and released in three different states, and two selections (one USDA and one University of Arkansas) of southern highbush blueberry were included in this study. 'Georgiagem' (Georgia) (1) and 'Cooper' and 'Gulf Coast' (Mississippi) (9) are all one-quarter *V. darrowi* cultivars, with the remaining source of germplasm *V. corymbosum*. 'Blue Ridge' and 'Cape Fear' (North Carolina) are also one-quarter *V. darrowi* but have as a parent 'Patriot,' which is one-quarter *V. angustifolium* and three quarters *V. corymbosum* (3, 10). An additional southern highbush cultivar from North Carolina, 'O'Neal,' is largely *V. corymbosum* but also includes germplasm from *V. darrowi*, *V. ashei* and *V. augustifolium* (2). Two selections, A-109 and G-616, have common parentage and are a result of a cross of G-144 x Fla.4-76. G-144 is a *V. corymbosum* selection, but Fla. 4-76 contains germplasm from *V. corymbosum*, *V. darrowi* and *V. ashei*. In addition to the southern highbush clones, 'Climax' rabbiteye was included along with 'Bluecrop' and 'Sierra' northern highbush. 'Sierra' is considered a northern highbush cultivar, but it does contain small amounts of germplasm from *V. darrowi*, *V. ashei* and *V. constablaei* Gray, all southern species (12).

All cultivars sampled were growing at the University of Arkansas Fruit Substation, Clarksville, Ark. Temperatures were monitored near the planting, and a characterization of the temperature environment to which the plants were exposed is provided in Table 1. Plants ranged from 7 to 9 years of age, and the number of plants sampled of each cultivar ranged from 2 to 8. Samples were collected on 9, 10 Dec. 1993 and 11, 12 Jan. and 9, 10 Feb. 1994. Fruiting shoots approximately 15 cm in length were collected the afternoon of the day prior to the freezing of the shoots in a programmable freezer. Following collection, the shoots were held at 2C for 15 hr. Fourteen shoots were collected each day for each cultivar, and two shoots of each cultivar were assembled into seven groups containing shoots of all cultivars. Each of the seven groups of shoots containing two shoots of all cultivars was individually wrapped in moistened cheesecloth followed by wrapping in aluminum foil. A copper-constantan thermocouple monitored the temperature inside each bundle. The bundles were placed inside a programmable freezer (Tenney, Jr., Tenney Inc., Union, N.J.), and the freezer temperature was lowered from room temperature (19C) to 0C in 1 hr, followed by lowering the temperature 3C per hr to a minimum of -30C within the bundle. Single bundles were removed at 5C intervals at 0 to -30C. The following day, a second set of 14 shoots was subjected to the freezing session, providing two replications of frozen shoots for each date. A total of 28 shoots of each cultivar were included for the two days for each month, providing 8 to 20 buds of each cultivar for each temperature evaluated for freeze damage depending on bud number on each shoot.

Following removal from the freezer, the bundles were placed in a plastic bag in a refrigerator and held at 2C for 48 hr. After 48 hr in the refrigerator, the bundles were removed, and the shoots were placed with the cut end of the shoots in 1 cm of water. All shoots were held in a 100% RH chamber at 20C for 48 hr. Shoots and flower buds were examined for freeze damage by examining the tissue under a dissecting microscope and rating the tissue for oxidative browning. The shoots and flower buds were examined by cutting longitudinally with a scalpel and rating the damage on a scale of 1-5. For the shoots, a rating scale of 1 = no damage to 5 = complete browning was used based on examination of the phloem and cambial tissues. For the flower buds, the rating scale used was 1 = no damage to any ovaries or other flower parts, 2 = damage on one or two ovaries, 3 = approximately one-half of the ovaries damaged, 4 = all but one or two ovaries damaged and 5 = all ovaries damaged.

Data were analyzed by analysis of variance as a split-split plot, with the whole plot factor date, the split-plot factor temperature and the split-split plot factor cultivar. LSD values were calculated to compare means where appropriate. In the data analysis, certain date-temperature combinations were deleted from the data due to a lack of variation in the ratings (all or most ratings the same for all temperatures and cultivars) to ensure homogeneity of variances.

Results and Discussion

The analysis of variance of the data for shoot damage ratings revealed significant sources of variation for the cultivar x temperature interaction but not the date x cultivar or date x temperature x cultivar interactions (P = .05). For the flower bud ovary damage ratings, the date x temperature x cultivar interaction was significant (P = .05).

For all cultivars, no shoot damage was noted that resulted from prior freeze damage or from exposure to 0C as evidenced by the lack of damage rated in the 0C group (data not included in the analysis of variance and not shown). Slight stem damage ratings were found for some cultivars for -5 and -10C, but these damage ratings are questionable since 'Bluecrop,' for example, had slight damage at -5 and -10C but was among the hardier rated cultivars at the colder temperatures (Table 2). As expected, the first damage rating above 3.0 was found for the rabbiteye cultivar 'Climax' at -20C and was followed by very severe damage ratings for -25 and -30C, which were significantly different from all other cultivars.

For the shoot data, it is obvious that the minimum temperature utilized in this study was not cold enough to differentiate fully among the cultivars tested, with the exception of 'Climax,' which had severe shoot browning at -25 and -30C. The shoot damage data

Table 1. Temperatures prior to sampling blueberry shoots for freezing study conducted in 1993-94 at the University of Arkansas Fruit Substation.

	Temperature (C)		
Run date	-10 days min.[z]	-10 days max.[y]	low -10 days[x]
10 Dec.	2	13	-1
12 Jan.	-3	6	-11
10 Feb.	-3	8	-11

[z]Average minimum temperature the 10 days prior to collection of shoots.
[y]Average maximum temperature the 10 days prior to collection of shoots.
[x]Lowest individual temperature the 10 days prior to collection of shoots.

do not provide a clear gradation in shoot hardiness, since damage values are largely similar at -30C for all cultivars except 'Climax.' From the data presented, it can be concluded that large differences in hardiness among the southern highbush cultivars were not found and that shoot hardiness of some of the southern highbush cultivars tested appeared to be equal or near equal to that of the northern highbush cultivars ('Bluecrop' and 'Sierra') in the environment in which the plants were grown.

Since the three-way interaction of date x temperature x cultivar was significant for ovary damage, the means for each date and cultivar combination are presented (Table 3). For the December samples, almost no damage was noted for -5 and -10C for any cultivar, with the exception of 'Climax,' which had a mean rating of 2.24 for -10C. For -15C, slight or no damage was found for A-109, 'Bluecrop,' 'Blue Ridge,' 'Cape Fear,' 'Cooper,' G-616, 'Georgiagem' or 'Sierra,' while 'Gulf Coast' and 'O'Neal' had ratings of 2.00 and 2.25, respectively, and 'Climax' had significantly more damage with over one-half of the ovaries damaged. The damage ratings at -20C showed more separation, with A-109, 'Bluecrop,' 'Blueridge,' 'Cape Fear' and 'Sierra' having ratings less than 2.00, followed by G-616, 'Gulf Coast' and 'O'Neal' with ratings between 2.00 and 3.00, 'Georgiagem' with 3.15 and Cooper' and 'Climax' with ratings of 4.00 or above. For -25C, 'Sierra' had significantly less damage than other cultivars, followed by an intermediate damage group consisting of A-109, 'Bluecrop,' 'Blue Ridge,' 'Cape Fear' and 'O'Neal'. Complete or near complete damage ratings for -25C were found for 'Climax,' 'Cooper,' G-616, 'Georgiagem' and 'Gulf Coast.' In examining the mean damage ratings across temperatures within cultivar, 'Sierra' had no significant differences among temperatures between -5 and -25C. A-109, 'Bluecrop,' 'Blue Ridge' and 'Cape Fear' had similar damage ratings for all temperatures except for -25C. Significant differences within cultivar for damage ratings occurred at warmer temperatures than -25C for the remaining cultivars. Although not included in the data analysis because of the homogeneity of variances con-

Table 2. Mean shoot damage[z] to blueberry cultivars subjected to freezing temperatures. Data are an average of three dates of freezing, and are from shoot samples collected at the University of Arkansas Fruit Substation, Clarksville, Ark.

	Temperature (C)					
Cultivar	-5	-10	-15	-20	-25	-30
A-109	1.00	1.25	1.13	1.50	2.33	3.33
Bluecrop	1.75	1.50	1.38	1.83	1.92	2.92
Blue Ridge	1.00	1.25	1.88	1.67	1.67	2.75
Cape Fear	1.50	1.75	1.25	1.33	2.08	2.92
Climax	1.00	1.25	2.00	3.67	4.67	5.00
Cooper	1.50	1.25	1.25	1.17	2.75	3.33
G-616	1.25	1.00	1.00	1.25	2.92	3.75
Georgiagem	1.25	1.00	1.25	1.67	2.83	3.75
Gulf Coast	1.25	1.00	1.25	2.00	2.67	3.33
O'Neal	1.25	2.00	1.50	1.33	2.08	3.83
Sierra	1.00	1.00	1.50	1.25	2.00	2.92

[z]Ratings are 1-5, with 1 = no damage and 5 = severe stem browning. LSDs to compare cultivars within a temperature = 1.08 for -5 and -10; 0.76 for -15; 0.62 for -20, -25 and -30C. LSDs to compare cultivars among temperatures 1 = 1.12 for -5 vs. -10C; 0.71 for two temperatures among -15, -20, -25 and -30C; 0.79 for one temperature among -5 and -10C vs. any temperature among -20, -25 and -30; 0.92 for -5 or -10 vs. -15C.

Table 3. Mean ovary damage[z] to blueberry cultivars subjected to freezing temperatures on 10, 11 Dec. 1993, 11, 12 Jan. and 9, 10 Feb. 1994 from shoot samples collected from plants growing at the University of Arkansas Fruit Substation, Clarksville, Ark.

	Temperature (C)					
Cultivar	-5	-10	-15	-20	-25	-30
			December			
A-109	1.00	1.17	1.00	1.83	3.63	--
Bluecrop	1.00	1.00	1.00	1.67	3.54	--
Blue Ridge	1.00	1.00	1.25	1.54	3.92	--
Cape Fear	1.06	1.00	1.00	1.52	3.09	--
Climax	1.45	2.24	3.57	4.46	5.00	--
Cooper	1.08	1.13	1.63	4.00	5.00	--
G-616	1.00	1.05	1.06	2.39	4.71	--
Georgiagem	1.08	1.06	1.63	3.15	4.95	--
Gulf Coast	1.00	1.17	2.00	2.67	4.88	--
O'Neal	1.00	1.26	2.25	2.56	3.92	--
Sierra	1.00	1.17	1.00	1.29	1.92	--
			January			
A-109	1.00	1.08	1.00	1.08	2.15	3.81
Bluecrop	1.00	1.00	1.00	1.13	1.67	4.42
Blue Ridge	1.00	1.00	1.08	1.04	1.58	4.57
Cape Fear	1.00	1.00	1.00	1.25	3.13	5.00
Climax	1.83	3.36	2.41	4.30	5.00	5.00
Cooper	1.00	1.24	1.06	1.81	3.88	5.00
G-616	1.06	1.00	1.00	1.63	3.53	4.94
Georgiagem	1.00	1.20	1.23	2.11	4.14	5.00
Gulf Coast	1.06	1.00	1.00	3.17	4.38	5.00
O'Neal	1.06	1.00	1.26	2.25	4.50	5.00
Sierra	1.16	1.00	1.05	1.04	1.78	3.77
			February			
A-109	1.33	1.00	1.08	1.23	4.29	4.81
Bluecrop	1.00	1.00	1.08	1.08	2.79	4.84
Blue Ridge	1.00	1.13	1.58	2.08	4.33	5.00
Cape Fear	1.17	1.00	1.19	2.29	4.46	4.92
Climax	3.50	4.35	4.87	5.00	5.00	5.00
Cooper	1.00	1.42	1.77	2.94	5.00	5.00
G-616	1.00	1.00	1.32	3.15	5.00	5.00
Georgiagem	1.16	1.13	1.42	3.40	5.00	5.00
Gulf Coast	1.50	2.13	2.50	4.94	5.00	5.00
O'Neal	1.96	1.83	2.48	3.25	4.83	5.00
Sierra	1.00	1.06	1.21	1.81	3.72	4.81

[z]Ratings are 1-5, with 1 = no damage and 5 = all ovaries damaged.
LSD (.05) to compare ratings among cultivars within a temperature = 1.14.
LSD (.05) to compare ratings within cultivar across temperatures = 1.15.
LSD (.05) to compare cultivars across months = 1.29.

cern for data for -30C, 'Sierra' had a few surviving ovaries at -30C and had a mean damage rating of 4.38 for this temperature while all other cultivars had complete damage ratings for -30C (data not shown).

The samples from January were collected during the coldest period of the study (Table 1). No damage was found in any samples for 0C (data not included in the analysis of variance and not shown). Only slight or no damage was noted for -5, -10 or -15C for any cultivars for January (Table 3). Only 'Climax' had significant damage for -10C, although the damage rating is unusual since less damage for 'Climax' was recorded for -15C compared to -10C. Only slight and statistically nonsignificant damage differences were noted for most cultivars at -20C, except for 2.25 and 3.17 ratings for 'Gulf Coast' and 'O'Neal,' respectively, and 'Climax,' which had severe damage at -20C. The cultivars with the least damage for -25C included 'Blue Ridge,' 'Bluecrop,' 'Sierra' and A-109, followed by an intermediate damage group consisting of 'Cape Fear,' G-616 and 'Cooper' and a group of cultivars with ratings between 4.00 and 5.00 made up of 'Georgiagem,' 'Gulf Coast' and 'O'Neal,' and complete kill for 'Climax.' 'Sierra,' A-109, 'Bluecrop' and 'Blue Ridge' had the highest ovary survival at -30C. 'Cape Fear,' 'Climax,' 'Cooper,' 'Georgiagem,' 'Gulf Coast' and 'O'Neal' had complete kill at -30C. In examining the mean ratings across temperatures within cultivar, A-109, 'Bluecrop,' 'Blue Ridge' and 'Sierra' had similar ratings for all temperatures except -30C, where statistically significant differences were found. Significant differences within cultivar occurred between -20 and -25C for 'Cape Fear,' 'Cooper,' G-616 and 'Georgiagem,' while other cultivars had significant differences within cultivar at warmer temperatures.

Ratings for February samples indicated only slight damage at 0C for

'Climax' (1.35), 'Georgiagem' (1.08) and 'O'Neal' (1.65) and no damage for other cultivars (data not included in analysis of variance and not shown). For -5 and -10C, only 'Climax' had significant ovary damage ratings. For -15C, all cultivars had statistically similar and slight damage except for 'Gulf Coast' and 'O'Neal,' which had ratings between 2.00 and 3.00, and 'Climax,' which had near complete ovary damage. For -20C, A-109, 'Bluecrop,' 'Blue Ridge' and 'Sierra' had the lowest damage ratings, which were all statistically similar, followed by a range of ratings of other cultivars with the most damaged cultivars being 'Gulf Coast' and 'Climax'. For -25C, 'Bluecrop' and 'Sierra' were the least damaged and statistically similar, with all other cultivars having damage above 4.00 and statistically similar. At -30C, no statistical differences for damage were found among the cultivars. In examining the means across temperatures within cultivar, A-109, 'Bluecrop,' 'Blue Ridge' and 'Sierra' all had similar damage ratings from -5 to -20C, followed by subsequent increases in damage for colder temperatures. Other cultivars had significant differences that occurred at warmer temperatures.

In examining the data among months of sampling, most cultivars had decreased damage ratings, reflecting increased hardiness from December to January for all cultivars except 'O'Neal' and 'Cape Fear,' which had slight increases in damage between December and January at -25C. Comparing January to February values, all cultivars had increased damage, reflecting reduced hardiness in February for -25 and -30C. As expected, the rabbiteye cultivar 'Climax' was the least hardy cultivar compared to others in this study based on ovary damage of flower buds. 'Climax' has been found to be one of the least hardy rabbiteye cultivars in previous studies of bud hardiness (7, 14). Of particular importance is the finding that several of the southern highbush cultivars had equal hardiness to 'Bluecrop' and 'Sierra' at some of the dates tested. For December, A-109, 'Blue Ridge,' 'Cape Fear' and 'O'Neal' were similar to 'Bluecrop,' while 'Sierra' was the hardiest of all cultivars. For January, A-109 and 'Blue Ridge' were similar in hardiness to 'Bluecrop' and 'Sierra' at -25 and -30C. The February data revealed that 'Bluecrop' and 'Sierra' were the hardiest cultivars at -30C and the hardier southern highbush cultivars at -20C were A-109, 'Blue Ridge' and 'Cape Fear.' 'Sierra' is considered a northern highbush cultivar although it has in its parentage several southern *Vaccinium* species.

The report by Patten et al.(14) indicated less freeze damage to stage 2 (swelled), field-exposed buds of southern highbush compared to rabbiteye cultivars after exposure to -10C at Overton, Tex. in February, and our study agrees with that finding. In that report, 'Georgiagem' had more flower bud damage than the southern highbush cultivars 'Blue Ridge,' 'Cape Fear' and 'O'Neal' at Clarksville, Ark., following exposure to -13C. Our report agrees with that finding for 'Blue Ridge' and 'Cape Fear,' but our data show no differences between 'O'Neal' and 'Georgiagem' for any sample dates. One major difference in our study was that no bud swell had occurred at any sample date whereas the Patten et al. data was collected on buds subjected to freezing temperatures after bud swell.

In conclusion, our study revealed that the southern highbush cultivars tested had hardiness superior to that of 'Climax' rabbiteye blueberry at all sample dates, and that hardiness among certain southern highbush clones was similar to that for northern highbush cultivars at several dates and temperatures. Among the southern highbush clones, A-109, 'Blue Ridge' and 'Cape Fear' were hardiest. The hardiest southern highbush clones exhibited equal hardiness to the northern highbush cultivars 'Bluecrop' and 'Sierra' at several sample dates, although 'Bluecrop' was hardier than all southern highbush clones for February at -25C. 'Sierra,' although containing germplasm from several southern blueberry species, had hardiness higher than or comparable to that of 'Bluecrop' at all dates. From the data provided in this study, an evaluation of potential dormant-season hardiness is presented to assist in cultivar selection in areas where mid-winter hardiness of southern highbush cultivars is a concern.

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Seasonal Patterns of Apple Fruit Carbohydrates

The seasonal dry-weight accumulation of midseason 'Cox's Orange Pippin' and late-season 'Golden Delicious' apple fruits, followed the characteristic sigmoid growth pattern. Similar to patterns reported for peach fruits, apple fruit relative growth rates of dry-matter accumulation, calculated on a degree-day basis, declined rapidly in an exponential fashion early in the season, then decreased slowly taking an asymptotic course later in the season. Unlike peach, the relative growth rate curve of apple fruits did not exhibit a distinct phase shift between two physiological phases of growth. However, seasonal changes of the relative nonstructural carbohydrate composition of apple fleshy tissue, in particular, the rapid increase of sucrose later in the season, indicated that there may be two phases of fruit sink activity in both cultivars. Seasonal patterns of nonstructural carbohydrates of the two apple cultivars were different if expressed on a dry weight basis. In 'Cox's Orange Pippin,' sucrose was the main soluble carbohydrate later in the season, whereas 'Golden Delicious' accumulated high fructose concentrations. Estimated contribution of soluble carbohydrates to fruit solute potential declined over the season in both apple cultivars. Fructose contributed the largest amount to the solute potential, followed by sucrose. From Pavel and DeJong. 1995. J. Hort. Sci 70(1):127-134.