Self- and Cross-fertility in Recently Released Highbush Blueberry Cultivars

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Abstract. Self- and cross-fertility were evaluated in the highbush blueberry (*Vaccinium corymbosum* L.) cultivars Bluegold, Duke, Legacy, Nelson, Sierra, Sunrise, and Toro, all of which have been released since 1985, by comparing them with 'Bluecrop' and 'Rubel', which were used as standards. Cross-pollination increased fruit set in all cultivars except 'Bluecrop', in which set was reduced 13%. The average increase among recently released cultivars was 43%. Cross-pollination also increased fruit weight for all cultivars except 'Rubel'. Average increase in fruit weight with cross-pollination of the recently released cultivars was 27%. Fruit set and fruit weight measurements suggest that 'Duke', 'Legacy', and 'Nelson' would perform satisfactorily in solid stands, and that 'Sierra' and 'Toro' probably need cross-pollination for maximum yields.

When a new highbush blueberry cultivar is released, one of the concerns of growers is whether the cultivar can be planted in solid blocks. Solid-block planting results in a high proportion of self-pollinated flowers, and, for many blueberry cultivars, a reduced yield. The primary yield components in blueberry are total bud and flower number, percentage of fruit set (i.e., number of fruit) and fruit weight. A significant reduction in any of these factors reduces yields. Fruit set is depressed by self-pollination (El-Agamy et al., 1981; Meader and Darrow, 1947; Morrow, 1943; Rabaey and Luby, 1988). Krebs and Hancock (1988, 1991) suggested that this effect was due to inbreeding effects and embryo abortion.

Fruit weight is positively correlated with seed number in highbush blueberry (Brewer and Dobson, 1969; Eaton, 1967; Meader and Darrow, 1947; Moore et al., 1972). Eaton (1967) found an overall correlation of 0.59 between fruit size and seed number across a group of 13 highbush cultivars and selections. Similarly, Moore et al. (1972) found a correlation of 0.64 across 13 cultivars of highbush blueberry. Similar positive correlations have been documented between seed number and fruit size in *V. angustifolium* Ait. (Aalders and Hall, 1961; Jackson et al., 1972) based on measurements both within and among cultivars. Rabiteye blueberries (*V. ashei* Reade) are considered marginally self-fertile and are substantially less self-fruitful than highbush blueberries (El-Agamy et al., 1981; Garvey and Lyrene, 1987; Meader and Darrow, 1944).

Hence, effects of self-pollination in rabbiteye are generally more severe than those in highbush. In rabbiteye, correlations of seed number with fruit weight ranging from 0.38 to 0.80 have been reported (Ehlenfeldt and Hall, 1996; Kushima and Austin, 1979; Moore et al., 1972).

An additional concern related to the need for cross-pollination in highbush blueberry cultivars is how self-pollination will affect the time to fruit maturity. Fruit resulting from self-pollination ripen later because of their reduced seed numbers (Coville, 1921; Harrison et al., 1993; Meader and Darrow, 1947; Morrow, 1943).

This study evaluated the self- and cross-fertility of seven recently released highbush blueberry cultivars to determine their relative pollination requirements. These cultivars were compared with 'Bluecrop' and 'Rubel', established commercial clones, which were used as standards.

Materials and Methods

In 1995 and 1996, 3-L pots containing 3-year-old blueberry plants were brought into a screened, insect-free greenhouse in late January for pollination studies. The cultivars used (seven to nine plants each) were 'Bluegold', 'Duke', 'Legacy', 'Nelson', 'Sierra', 'Sunrise', and 'Toro', all of which have been released since 1985. 'Bluecrop' was included as a standard because it is the most widely grown and broadly adapted cultivar, and 'Rubel' because it has a reputation as being self-fruitful (Merrill, 1936; White and Clark, 1938).

Pollen was collected each day from one plant of each cultivar, which had been brought in earlier to serve as a pollen donor. Pollinations were made on nonemasculated, open flowers that were exhibiting stigmatic exudate. Closed flowers in the selected inflores-

cences were removed, and pollen was liberally applied to the open flowers using a pencil tip. Selfs and outcrosses were randomly distributed among inflorescences on each plant, and all plants had both selfed and outcrossed inflorescences. For cross-pollination, all cultivars except 'Bluecrop' were pollinated with 'Bluecrop' pollen; 'Bluecrop' was pollinated with 'Rubel' pollen.

Inflorescences were tagged to indicate number and date of pollinations. In 1995, an effort was made to make a minimum of 100 pollinations per cross (Table 1). In 1995, this number was reached for all cultivars except 'Legacy', which had poor budset the previous year. In 1996, 'Nelson' had fewer than 100 pollinations for outcrosses, and 'Sunrise' had fewer than 100 pollinations in both categories. Fruit was allowed to ripen (at ≈ 24 °C), and were collected three times a week until all had been harvested. Date of harvest was noted for all fruit in 1996 to allow calculation of ripening time (i.e., days between pollination and harvest). Seed was extracted by hand, and fruit weight and seed number were recorded for each individual fruit, except for the crosses of 'Duke' in 1995, in which the seed were accidentally bulked following extraction.

Means for fruit weight, seed per fruit, and ripening time in each year were evaluated for significant differences using *t* tests with $\alpha = 0.05$. Correlation analyses and *t* tests were performed using MSTAT-C (Plant and Soil Science Dept., Michigan State Univ., East Lansing).

Results and Discussion

The expected trends of reduced fruit set and fruit weight, and longer ripening times following self-pollination were generally observed in the newer cultivars. However, response varied among cultivars, and some exceptions were observed (Table 1). These trends are best examined cultivar-by-cultivar.

'Bluecrop' had a high percentage of fruit set, and was notable among all cultivars in having a higher set for self- than for cross-pollinations in both years (avg. 77% vs. 67%). This observation should, however, be treated with some caution because 'Bluecrop' was outcrossed to 'Rubel', whereas the other cultivars were outcrossed to 'Bluecrop'. Cross-pollination yielded significantly higher fruit weights than did selfing, averaging 25% higher across 2 years, and consistently increased seed number. Selfing significantly delayed ripening (3 d).

In 'Rubel', cross-pollination increased fruit set 29%, but did not affect fruit weight. This supports, at least partially, the belief that 'Rubel' does not require cross-pollination. Despite the weight uniformity, the yield increase makes cross-pollination desirable, although the amount of increase may vary under field conditions. Cross-pollination increased seed per fruit significantly in 1995, but not in 1996, and had no effect on ripening time.

The effect of cross-pollination in 1995 and 1996 varied most in 'Bluegold'. In 1995, selfing resulted in only 13% set vs. 58% for cross-

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Table 1. Number of pollinations, percentage of fruit set, fruit weight, seed number, and ripening time following self- and cross-pollination of nine highbush blueberry cultivars in 1995 and 1996.

Cultivar	Year	No. of pollinations		Fruit set (%)			Fruit wt (g)			No. of seed/fruit			Ripening interval (d)		
		Self	Cross	Self	Cross	% Inc. ^z	Self	Cross	% Inc.	Self	Cross	% Inc.	Self	Cross	% Dec.
Bluecrop	1995	158	114	60	55		1.69	2.04*		5.5	36.0*		---	---	
	1996	206	205	94	78		1.41	1.82*		13.4	37.0*		61	58*	4
	Avg			77	67	-13	1.55	1.93	25	9.5	36.5	284			
Rubel	1995	114	114	39	62		0.76	0.83 ^{ns}		12.0	32.4*		---	---	
	1996	213	185	59	64		0.97	0.93 ^{ns}		18.5	16.8 ^{ns}		65	63 ^{ns}	3
	Avg			49	63	29	0.87	0.85	-2	15.3	24.7	61			
Bluegold	1995	188	106	13	58		0.98	1.05 ^{ns}		8.3	47.6*		---	---	
	1996	189	170	86	99		1.32	1.56*		13.0	36.0*		69	61*	12
	Avg.			50	79	58	1.15	1.31	14	10.7	41.8	291			
Duke	1995	213	208	---	---	(4) ^y	1.51	1.51 ^{ns}		16.0	14.4 ^{ns}		---	---	
	1996	207	205	31	53	71	1.33	1.58*		13.4	26.6*		46	48 ^{ns}	-3
	Avg			---	---		1.42	1.55	9	14.7	20.5	39			
Legacy	1995	19	32	74	100		1.71	2.15 ^{ns}		13.9	31.6*		---	---	
	1996	224	256	82	79		1.47	1.62*		13.0	28.6*		65	62*	4
	Avg			78	90	15	1.59	1.89	19	13.5	30.1	123			
Nelson	1995	167	166	66	70		1.59	1.82*		11.5	17.3*		---	---	
	1996	111	64	62	67		1.38	1.59*		13.7	16.8 ^{ns}		59	55*	7
	Avg			64	69	8	1.49	1.71	15	12.6	17.1	36			
Sierra	1995	116	114	58	78		1.14	1.83*		6.6	32.1*		---	---	
	1996	249	223	24	59		1.05	1.55*		3.1	26.1*		63	53*	16
	Avg			41	69	68	1.10	1.69	54	4.9	29.1	494			
Sunrise	1995	211	114	64	91		1.57	1.81*		12.4	31.5*		---	---	
	1996	43	55	58	87		1.04	1.63*		7.4	22.6*		52	51 ^{ns}	3
	Avg			61	89	46	1.31	1.72	31	9.9	27.1	174			
Toro	1995	93	152	34	68		1.52	2.55*		4.8	38.6*		---	---	
	1996	232	285	71	71		1.06	1.30 ^{ns}		4.9	35.7*		68	61*	10
	Avg			53	70	32	1.29	1.93	50	4.9	37.2	659			
Avg for new cultivars other than Bluecrop and Rubel						43			27			259			7

^zPercentage of increase for cross-pollination as compared with self-pollination.

^yCount of numbers of fruit from these two sets of crosses was lost, but calculations based on seed number and seed per fruit suggest that set was not affected, and averaged 48% and 50%, respectively, for self- vs. cross-pollination.

^{ns}, *Nonsignificant or significant at $P \leq 0.05$, respectively.

pollination. In 1996, the same values were 86% and 99%, respectively. Cross-pollination significantly increased fruit weight in 1996 and increased seed number in both years. Cross-pollination accelerated ripening by 8 d; this was one of the largest changes observed in ripening time.

'Duke' was nearly as fertile with self-pollination as with cross-pollination. In 1995, counts of fruit set were lost, but calculations based on total seed number and seed per fruit suggest that set for self- and cross-pollinations were 48% and 50%, respectively. Fruit weight and seed per fruit were also nearly identical in 1995. This agrees with field observations of 'Duke' that suggest that it is highly self-fertile in solid plantings. In 1996, however, cross-pollination increased fruit set 22% (31% with self-pollination vs. 53% with cross-pollination) and also increased fruit weight and seed number. Only in 'Duke' was the mean ripening time for self-pollinated fruit slightly shorter (2 d) than that for cross-pollinated fruit; however, the difference was nonsignificant.

'Legacy' was notable for its high percentages of fruit set, both with self- and cross-pollination, averaging 78% and 90%, respectively, for 1995 and 1996. Cross-pollination increased fruit weight in 1996, but not in 1995, and increased seed number per fruit in both years, and accelerated of ripening (3 d).

Cross-pollination had little effect on fruit set of 'Nelson', but increased fruit weight in both years. 'Nelson' was notable in having

among the lowest seed numbers following cross-pollination, averaging 17.1 seed per fruit. Cross-pollination increased seed number in 1995, but not in 1996, and accelerated ripening by 4 d. 'Bluecrop' is a parent of 'Nelson', and this factor may contribute to its low seed set with cross-pollination; a less closely related pollen source might have improved fruit set and fruit weight.

Cross-pollination affected all parameters in 'Sierra'. It increased fruit set 68% (41% vs. 69%) over 2 years. Fruit weight and seed per fruit were also increased significantly in both years. Seed number per fruit was very low following self-pollinations, suggesting low self-fruitfulness. This may be the result of a genetic background that includes both *V. darrowi* Camp and *V. ashei* (Brooks and Olmo, 1997). The large difference in seed set is also reflected in the significant 10-d reduction in time of ripening following cross-pollination.

Cross-pollination increased fruit set in 'Sunrise' by 46%, averaged across 2 years, increased fruit weight and seed number in both years (averaging 31% and 174%, respectively), but did not significantly affect ripening time.

Like 'Sierra', 'Toro' appeared to have very low self-fertility. All parameters, and seed number in particular, were affected by cross-pollination. Fruit weight was increased upon cross-pollination in 1995, and number of seed per fruit in both years. Ripening time was significantly hastened (7 d) in 1996.

Regressions of ripening time on seed number indicate whether seed number affects ripening time. These regressions were all highly significant (Table 2), with r^2 values ranging from 0.10 for selfs of 'Legacy' to 0.64 for outcrosses of 'Nelson'. Regression coefficients ranged from -0.2 to -0.4 for the majority of both the selfs and outcrosses. Regression coefficients (i.e., slopes) for the self-crosses were generally steeper than were those for outcrosses, with certain exceptions. Notably different were selfs of 'Rubel', 'Sierra', 'Sunrise', and 'Toro', all of which had coefficients of less than -0.7. The lower coefficients in these particular selfs suggest that increases in seed number have a greater effect on ripening time. Note, however, that for three of these cultivars, low coefficients are associated with very low mean seed numbers. The mean seed numbers for selfs of 'Sierra', 'Sunrise', and 'Toro' (in 1996) were 3.1, 7.4, and 4.9, respectively. Apparently when seed set is very low, changes in seed number have a relatively large effect on ripening. Crosses with just slightly higher mean seed numbers had coefficients similar to those of most other crosses. 'Rubel' and 'Duke' were notable in that seed per fruit and ripening time were nearly identical in both the selfs and the outcrosses (Table 1).

The evaluations here provide data only on exclusively self- vs. cross-pollinated flowers. Under field conditions both self- and cross-pollination are likely. Harrison et al. (1993) examined yield parameters from pollinations

Table 2. Effects of self- vs. cross-pollination on coefficients of determination (r^2) and regression coefficients (b) for: 1) fruit weight vs. seed number; and 2) ripening time vs. seed number for nine highbush blueberry cultivars in 1995 and 1996.

Cultivar	Year	Fruit wt vs. seed no.				Ripening time vs. seed no.			
		Self		Cross		Self		Cross	
		r^2	b	r^2	b	r^2	b	r^2	b
Bluecrop	1995	0.08*	0.18	0.35**	0.06	---	---	---	---
	1996	0.24**	0.12	0.30**	0.05	0.14**	-0.4	0.26**	-0.2
Rubel	1995	0.55**	0.05	0.14**	0.04	---	---	---	---
	1996	0.49**	0.03	0.48**	0.04	0.49**	-1.1	0.12**	-0.4
Bluegold	1995	0.05	0.25	0.24**	0.04	---	---	---	---
	1996	0.48**	0.06	0.27**	0.05	0.18**	-0.4	0.46**	-0.3
Duke	1995	0.38**	0.08	0.31**	0.09	---	---	---	---
	1996	0.53**	0.06	0.46**	0.05	0.28**	-0.3	0.20**	-0.4
Legacy	1995	0.25	0.12	0.08	0.24	---	---	---	---
	1996	0.46**	0.07	0.13**	0.07	0.10**	-0.3	0.14**	-0.2
Nelson	1995	0.36**	0.10	0.41**	0.11	---	---	---	---
	1996	0.36**	0.08	0.08	0.14	0.23**	-0.3	0.64**	-0.4
Sierra	1995	0.18**	0.17	0.25**	0.07	---	---	---	---
	1996	0.24**	0.34	0.30**	0.06	0.18**	-1.7	0.41**	-0.2
Sunrise	1995	0.37**	0.07	0.27**	0.06	---	---	---	---
	1996	0.53**	0.09	0.55**	0.04	0.41**	-0.8	0.50**	-0.3
Toro	1995	0.40**	0.24	0.41**	0.05	---	---	---	---
	1996	0.46**	0.18	0.48**	0.04	0.29**	-2.1	0.18**	-0.2

*,**Significant at $P \leq 0.01$ and 0.001 , respectively.

of half-high blueberry cultivars with varying ratios of self and outcross pollen. For most cultivars the relationship between the measured parameters and the percentage of outcross pollen was linear, with fruit set, fruit weight, and seed number decreasing with percentage of outcross pollen. In most cases, 50:50 mixes gave results, which, although lower than those of 100% outcross pollinations, would still be considered acceptable. Values for 100% self-pollination did not align with the trend of values from various pollen mixes, reflecting the severe effect of inbreeding on fertilization.

The results suggest which cultivars might be more productive in solid plantings, and which cultivars would benefit most from some degree of cross-pollination. Although several of the newer cultivars, notably 'Duke', 'Nelson', and 'Legacy', appear to have good levels of self-fertility, cross-pollination still appears desirable to optimize fruit set and fruit weight, and to hasten maturity. 'Duke', which has been widely planted is reasonably self-fertile in solid plantings. The 1995 data support this, but the 1996 data demonstrate that 'Duke' will benefit from cross-pollination in some years. 'Legacy' and 'Nelson', neither of which have been widely planted, also appear to be promising for planting in solid blocks.

'Nelson', like 'Duke', is adapted to northern areas. 'Legacy', which has *V. darrowi* germplasm in its ancestry, is less well-adapted to northern climates, but has great promise for more southern areas.

'Bluecrop' was unique in this study in that fruit set decreased with cross-pollination when 'Rubel' pollen was used. This may be a general reaction of 'Bluecrop' or may represent a specific interaction with this pollen source. If it is a general reaction, it would represent a means of compensation that would provide a measure of yield stability. This is an aspect of 'Bluecrop' development deserving of further examination. 'Rubel' was unusual in that fruit weight was not increased by cross-pollination. This characteristic undoubtedly has contributed to the reputation of 'Rubel' as being highly self-fertile; however, the data also show that fruit set in 'Rubel' benefits from cross-pollination, as do most cultivars.

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