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Blueberry Hybrids with Complex Genetic Backgrounds Evaluated on Mineral Soils: Flowering, Fruit Development, Yield and Yield Components as Influenced by Parental Species

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Abstract

A blueberry (*Vaccinium* subsection Cyanococcus) population consisting of 15 blueberry cultivars and 39 interspecific hybrid selections resulting from combinations of nine *Vaccinium* species were evaluated in 1995 for flowering and fruit development parameters, yield and yield components after three years of growth on mineral soils. Substantial variation was uncovered among individuals for bloom date (7 May-22 May), date of first harvest (7 July-7 Aug.), ripening interval (54-90 days), harvest interval (6-23 days), yield (51-1324 g/plant), berry weight (0.52-2.24 g/fruit) and fruit number/plant (35-1390). Superior yielding individuals with interspecific hybrid backgrounds, 'Bluetta,' 'Northland,' 'Patriot', 'Sierra,' 'Sunrise,' US 625, US 644, US 645, US 652, US 654, US 665 and US 693 yielded in excess of I kg fruit/plant. When genotypes were grouped according to their genetic constitutions, significant effects of heritage were uncovered for bloom date, harvest date, ripening interval, harvest interval and fruit wt. Flowering and fruiting performance was also monitored to identify interspecific hybrids exhibiting the combined traits of positive mineral soil adaptation, high yield, large fruit size, high numbers of fruit/plant, late flowering, shortened ripening intervals, early ripening, and shortened harvest intervals. Although none of the individuals within the mineral soil-adapted hybrid group possessed all possible positive traits for flowering, fruit development, yield and yield components, most contained two or more characteristics which might be useful in further breeding efforts. Within this group US 645, US 665 and US 693 were considered to be superior based upon an early-fruiting fresh-market ideotype.

Introduction

Primary and secondary feral gene pools of the cultivated blueberry (*Vaccinium* subsection *Cyanococcus*) contain a wealth of genetic diversity for traits of current and future importance to the blueberry industry, including those which affect flowering, fruit development, yield and yield components (1, 6, 8, 12, 13, 18, 23). Traits such as late or delayed blooming, potentially important in areas where spring frosts after budbreak often damage floral buds or flowers, have been reported in feral populations of the southern-adapted species *V. constablaei* Gray, *V. darrowi* Camp and *V. myrsinites* Lamarck. Conversely, genes for early ripening have been uncovered in *V. angustifolium* Ait., diploid *V. corymbosum* L., V. *elliottii* Chapman and *V. myrtilloides* Michx. According to Ballington and coworkers (2) time of harvest may be one of the most economically important traits of blueberry. Fruit marketed early or extremely late in the season when supply is limited command higher prices in the marketplace. Shortened fruit development periods (ripening intervals) and concentrated harvest intervals may also be advantageous, especially when mechanical harvesting procedures are employed. The introgression of *V. constablae*i germplasm has been

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found to shorten the ripening interval of cultivated rabbiteye blueberry, *V. ashei* Reade. Variability in yield potential undoubtedly exists among and within blueberry species. To date, yield improvements in highbush blueberries, tetraploid *V. corymbosum,* have resulted through breeding for increased fruit size within the species (18). Considerable variation in fruit size has been uncovered within species (e.g., *V. angustifolium, V. darrowi* and *V. myrsinites*).

Fortunately, homoploid blueberry species are predominantly interfertile and crosses among species of different ploidy levels are possible (1, 6, 13, 18, 22, 23). Historically, breeders have employed interspecific hybridization most successfully to extend the climatic adaptation of the highbush blueberry crop (11, 21). However, Draper along with colleagues have created an extensive interspecific hybrid germplasm pool in order to broaden the cultivated blueberry germplasm base and to capture traits of commercial interest, specifically mineral soil adaptation, from over a dozen native *Vaccinium* species (7). Individual genotypes within this pool are typically composed of a complex blend of genes from both northern and southern biotypes (7, 14, 15, 25). In previous papers we have described the performance of a core of elite selections from the Draper gene pool which were cultured in a mineral soil environment. Cold tolerance was addressed and cold tolerant selections within the population were identified (14, 15) and growth, vigor, fruiting capacity and mineral soil adaptation were described (25). Gas exchange and water potentials, fruit quality and keeping quality as well as root development will be addressed in companion papers (9, 26). The objectives of this paper were to: describe diversity in flowering, fruit development periods, yield and yield components among Draper's elite hybrids; uncover trends in performance with respect to their heritage; and identify those individuals within the population that demonstrated both mineral soil adaptation and superior fruiting behavior, yield, fruit size and fruit number/plant.

Materials and Methods

The population evaluated in this experiment consisted of 15 blueberry cultivars and 39 of Draper's elite interspecific hybrid selections resulting from combinations of nine *Vaccinium* species. The identity and genetic constitution of all genotypes within the study, as well as the experimental design of the plot and cultural procedures used were discussed in Scheerens et al. (25, see Table 2). The planting was maintained throughout the 1993-1998 growing seasons, but fruiting behavior, yield, fruit weight and fruit number/plant of all genotypes were comprehensively evaluated only during 1995. Subjective evaluations of these parameters obtained in other years were in general agreement with the 1995 data and therefore, they are not presented herein.

Flowering, fruit development, yield and yield component measurements: Flowering was monitored in May 1995 on a three day observational cycle and evidence of anthesis (first bloom) was recorded for each plant as a Julian date. As fruit ripened, plants were netted in order to limit bird predation. During the peak fruiting season, individual plants were harvested on approximately a three day picking cycle. An individual was first harvested when approximately 75% of fruit were blue colored. Julian dates of first and subsequent harvests were also recorded for each plant. Ripening (first bloom to first harvest) and harvest intervals (first harvest to last harvest) were calculated by subtraction. For each plant, yield was recorded cumulatively over harvests, whereas berry wt. was determined at first harvest (one 25-berry sample/plant). Berry number/plant was estimated as the ratio of yield/berry weight. The method of Himelrick and Galletta (17) was used to estimate accumulated growing degree days from last frost date (22 April. 1995) through harvest.

Data analysis: For all parameters, variability among genotypes and differences among genotypic means were deter-

mined by analysis of variance using SAS PROC GLM (24). Genotypic means (four field replicates) were separated by the Duncan's Multiple Range option (data not shown). Relationships among variables were ascertained by linear correlation (SAS PROC CORR). In order to assess parental effectiveness and the role native species in hybrid performance, genotypes within the study were clustered in heritage groups (25, see Table 2). Thereafter, for each parameter, the genotypic means of member genotypes were considered to be replicates within the group. To ascertain statistical differences among groups, group means were subjected to the non-parametric Kruskal-Wallis procedure (5).

Results and Discussion

Previous reports (14, 15, 25) documented a high level of variability for cold tolerance, growth rate, vigor, yield balance, fruit yield/volume and nutrient deficiency symptoms among individual cultivars and elite hybrids studied during this project. In this study, we uncovered substantial variation among these genotypes for bloom date, fruit development parameters (ripening interval, date of first harvest and harvest duration), yield, and yield components (berry weight and fruit number/plant) (Table 1). F-values were very highly significant for genotype; genotypic means within the lowest 10% cluster were significantly different (P = 0.05) from those in the highest 10% cluster.

Flowering: US 645 and 'Northcountry' were the earliest blooming genotypes in 1995 (Table 1), both exhibiting a mean bloom date of 7 May; the mean bloom dates of all additional cultivars and hybrids within the study fell within three weeks of this initial date. Physiologically, date of flowering in blueberry is conditioned by the satisfaction of chilling requirements and additionally, by the accumulation of an obligatory number of heat units (growing degree days) necessary for bud development (2, 4). As 74% of the individuals within the population studied are first or second generation hybrids of northern and southern biotypes, it is not surprising that we observed a significant variation in chilling requirements among genotypes. Variation in bloom date and accumulated growing degree days also occurred (18 and 235 growing degree days for the earliest and latest blooming clones respectively) even among entries with similar genetic backgrounds (e.g., US 645 and US 659 which are both offspring of US 75 and US 226, Fig 1).

US 723, US 729 and US 734 exhibited the latest mean flowering dates in 1995. Delayed or late flowering blueberries were thought to be advantageous for production because of the frequency of damaging spring frosts (2, 4, 10, 16, 20); flowering delays of a week or longer may be sufficient to protect later-blooming genotypes. For instance, the early-flowering genotypes, US 621, US 645 and US 717, flowered fully in 1995, when sub-freezing temperatures were recorded on 26 April, eleven days prior to the first recorded bloom. However in 1994, when the last frost occurred on 2 May, moderate to severe bud destruction was recorded for these individuals (15).

During mild winters, low chilling requirements in blueberry might also be detrimental to yield in northern production regions. Unseasonably warm temperatures in February and March 1997 resulted in a March bloom date and after subsequent freezes, a significant crop loss (up to 100%) for many of the cultivars and hybrids with southern heritage (data not shown).

Bloom date in blueberries has been reported to be highly heritable (4, 10, 18, 20). While studying progenies of *V. angustifolium* and *V. corymbosum* parents, Finn and Luby (10) uncovered significant levels of general and specific combining ability (GCA and SCA, respectively) and a narrow sense heritability of 0.54 associated with a 50% bloom date, with *V. angustifolium* parents generally transmitting genes for early flowering to their offspring. Due to its relatively low chilling requirement, *V. ashei* was also described as early flowering (4, 20), although the bloom period of *V. ashei* progenies was

found to be highly dependent on parental genotype (i.e., high levels of SCA) and few progenies bloomed as early as those derived from *V. corymbosum*. Conversely, because of its relatively high chilling and subsequent heat unit requirements, introgression of *V. constablaei* germplasm with that of *V. ashei* resulted in offspring which bloomed late (4).

To examine the effects of heritage on bloom date and other traits, individual mean performances were clustered in 13 heritage groups based on parental genotypes (25, Table 2) and then reanalyzed using group means. Highly significant differences in first bloom date with respect to heritage were uncovered (Table 2, herein), and in general group behavior followed that described above. The *V. angustifolium-V. corymbosum* containing cultivars and interspecific hybrids of Groups 4 and 11 tended to bloom very early. First bloom dates of US 226 selfed (Group 8) and members of Group 2 also exhibited early bloom dates, perhaps acquired from their *V. myrtilloides* grandparent. In contrast, progeny of NJUS 11 (i.e., Groups 3, 6 and 7, containing 30% *V. ashei* genes) were among the latest to bloom, generally flowering after the *V. corymbosum* standards. Interestingly, 'Little Giant' (the *V. ashei* X *V. constablaei* hybrid comprising Group 13) bloomed late, but not significantly later than that of other *V. ashei* hybrids in this study.

Fruit development periods: In 1995, fruit harvest commenced on 7 July and continued until 28 August, corresponding to 1054 and 2413 growing degree days, respectively. Variability for harvest dates and ripening intervals was significant among cultivars and interspecific hybrids (Table 1).

Because of market advantage, early ripening has been considered to be an economically important blueberry trait in some production areas (2, 4, 10, 20), whereas in others fruit of late ripening cultivars command superior prices. Fortunately, substantial among and within species variation for ripening interval (i.e., 5-56 days and 16-26 days for fruit development stages 2 and 3, respectively) has also been described (10). In this study, early first harvest dates were loosely associated with early bloom dates ($r = +0.47$) and strongly correlated with short ripening intervals ($r = +0.83$). These relationships were similar in strength and direction to those reported previously by Hancock and coworkers (16) for *V. corymbosum* cultivars, by Lyrene (20) for *V. ashei* and *V. corymbosum* cultivars and by Finn and Luby (10) for seedlings of *V. angustifolium* and *V. corymbosum*. Ripening intervals were not significantly associated with bloom dates in our study or in two of the previous reports (10, 20). Relationships among fruit development parameters suggested the possibility of developing late blooming, early ripening cultivars by simultaneous selection for appropriate flowering dates and ripening intervals. Indeed, there were individuals within our population that exhibited these traits (Fig 1). Of those individuals that were harvested on 7 or 8 July, 1995, 'Sunrise' and US 642 bloomed 11 days after 'Northcountry' and US 645, the earliest blooming/ripening genotypes. US 693 also exhibited a bloom date advantage of 7 days without substantially affecting an early harvest date.

Conversely, seven individuals, G 344, 'Jersey,' US 612, US 673, US 675, US 679 and US 696, matured fruit late in the season and were first harvested after 1 Aug. 1995 (Fig. 1). These late maturing genotypes all exhibited long ripening intervals, but varied in bloom date. US 675 and US 696 were nearly as late fruiting as a single-plant observational entry of 'Elliott' (Julian date of first harvest = 228) growing within the same plot. These two genotypes may be useful as parents when developing cultivars to produce for the late market.

For populations studied previously, variance for harvest dates and ripening intervals was found to be primarily genetic in origin (4, 8, 10, 20); the activity of both GCA and SCA were reported, but the relative importance of these components dif-

fered depending on the population studied. Moreover, in a study by Ballington and coworkers (2), ploidy level was a significant factor in determining harvest timing among seedlings derived from various *Vaccinium* species. Diploid seedlings from *V. corymbosum* (2X), *V. myrtilloides* and *V. elliottii* generally ripened fruit earlier than those of tetraploid *V. corymbosum*, and fruit of most hexaploid *V. ashei* seedlings were latest to ripen. However, the effect of ploidy on these traits was not absolute, as seedlings from *V. angustifolium* (4X) were among the first to ripen fruit and progeny from *V. darrowi* (2X) and *V. tenellum* (2X) ripened fruit later than those of tetraploid *V. corymbosum* or simultaneously with those of *V. ashei* (6X), respectively. Regardless of ploidy level, substantial genetic variability also existed for ripening date among seedlings within a species and among *V. corymbosum* cultivars. The prolonged ripening interval of *V. ashei* was said to result from protracted flowering periods within individual inflorescences or from uneven inflorescence development due to irregular bud break (6). The introgression of *V. constablaei* (6X) genes often corrected this defect, resulting in progeny with short ripening intervals. Although they are relatively late blooming, seedlings of *V. ashei* X *V. constablaei* often ripen fruit simultaneously with *V. ashei* (4, 20).

Herein, both harvest date and ripening intervals were significantly related to heritage (Table 2). US 226 selfed (Group 8) and interspecific hybrids of US 226 (Groups 2 and 5) were among the earliest to be harvested and displayed relatively short ripening intervals. US 226 contains 50% *V. myrtilloides* genes, which is the probable source for the expression of these traits. *V. angustifolium-V. corymbosum* (half high) cultivar standards (Group 11) also exhibited very early ripening dates and relatively short ripening intervals. Although they were among the latest to bloom, hybrids containing *V. elliottii* (Group 9) had intermediate harvest dates due to their short ripening intervals. The behavior of *V. corymbosum* standard cultivars (Group 10) was intermediate for both traits; *V. corymbosum-V. darrowi* cultivars and hybrids (Groups 1 and 12) had slightly shorter ripening periods and earlier harvest dates than Group 10 cultivars, but these differences were not statistically significant. Hybrids in Groups 3 and 7, progeny of NJUS 11 (predominantly *V. ashei*), matured fruit very late in the season due to prolonged ripening periods, but these results were not significantly different from those obtained for the *V. corymbosum* cultivars. As expected, the *V. ashei-V. constablaei* hybrid, 'Little Giant' (Group 13), exhibited a very short ripening period. Patterns in our data agreed closely with those found in previous studies (2, 4, 8, 20). Moreover, Erb and coworkers (8), studying seedling populations from which most of Draper's elite interspecific hybrids were derived, reported highly significant GCA effects for both harvest dates and ripening intervals, suggesting that the heritability for these traits was largely additive. The GCA effects associated with parents NJUS 11, US 75, G 362 and US 226 of the seedling population predicted well, the behavior of the elite selections in Groups 1-8.

Concentrated harvest intervals may improve the mechanical harvestability of blueberries (6, 12, 19). In this study, harvest intervals varied substantially among genotypes (Table 1); US 659 and US 734 exhibited the shortest harvest interval (6 days) whereas G 344 displayed ripe fruit over a prolonged period (23 days). Harvest intervals were not closely correlated with bloom dates, harvest dates or ripening intervals. Both Luby and Finn (19) and Erb et al. (8) reported large GCA components for harvest interval associated with parents of *V. angustifolium-V. corymbosum* hybrids and with the parents of Draper's elite hybrids, respectively, suggesting the possibility for genetic improvement through breeding. Herein, the heritage of cultivars and hybrids did have a significant effect upon harvest intervals (Table 2); discernable patterns among heritage groups were few, but generally followed those suggested by the data of Erb

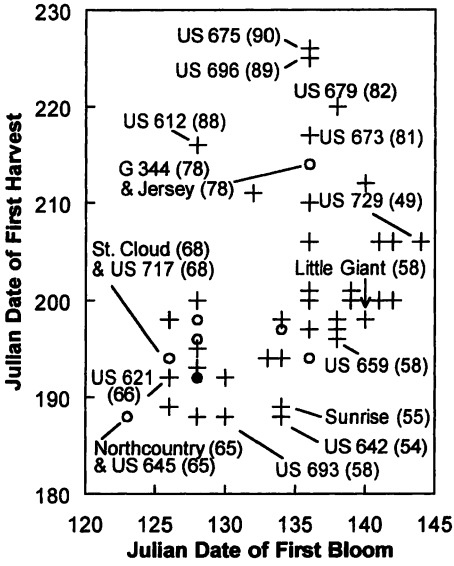


Figure 1. Relationship between Julian dates of first bloom and first harvest for 54 *Vaccinium* cultivars or interspecific hybrids; + represents values of individual clones, O represents two clones with identical values, ● represents three clones with identical values; numbers in parentheses following clone designations report associated ripening intervals. Julian dates of first bloom, 120, 125, 130, 135, 140 and 145 correspond with cumulative growing degree days of 10, 28, 86, 132, 191 and 249, respectively. Julian dates of first harvest, 180, 190, 200, 210, 220 and 230 correspond with cumulative growing degrees of 960, 1181, 1445, 1730, 1992 and 2285, respectively.

and coworkers (8). The *V. ashei*-containing progeny of NJUS 11, especially those of Group 3, tended to have somewhat prolonged harvest intervals, whereas the harvest intervals of US 75 hybrids (e.g., Groups 1 and 5) tended to be short. Contrary to the negative GCA effect for US 226 reported by Erb et al. (8), ripe fruit were harvested over an 18 day period on the individual representative of Group 8 (US 226 selfed). Additionally, Group 9 hybrids with *V. elliottii* backgrounds (not studied by Erb et al.) exhibited short harvest intervals.

Yield and yield components: Fruit yields varied widely among trial entries (Table 1), with widely adapted *V. corymbosum* cultivars such as 'Spartan' and 'Bluecrop' generally outperforming interspecific hybrids. Although 'Spartan' exhibited the highest mean yield in 1995 (1323 g/plant), several cultivars with interspecific backgrounds (i.e., 'Bluetta,' 'Northland,' 'Patriot,' 'Sierra' and 'Sunrise') and several interspecific hybrid clones (i.e., US 625, US 644, US 645, US 652, US 654, US 665 and US 693) were higher yielding than 'Bluecrop' (980 g/plant). These cultivars and hybrids were thought to be superior yielding, considering their culture in a mineral soil environment. However, poor adaptation to mineral soils undoubtedly limited yield for some genotypes. For example, 'Blueridge,' the lowest yielding entry in the study (50 g/plant), failed to grow adequately throughout the study (25) and when unearthed in 1998, its roots had not extended beyond the volume of its original container. Yield estimates for members of the population were loosely associated with their bloom dates ($r = -0.40$), but were not significantly related with their ripening intervals, harvest dates or harvest intervals. The lack of strong relationships among these parameters suggested the possibility of identifying high yielding, late blooming genotypes with short ripening intervals and/or short harvest intervals. Among the highest yielding cultivars and hybrids (i.e., those with yields $\geq$ 1000 g/plant), seven genotypes were considered to offer a late blooming advantage (Fig. 2a). US 693 flowered one week later than 'Northcountry' and US 645, the earliest blooming clones and 'Sierra,' 'Spartan,' 'Sunrise,' US 644 and US 652 bloomed as much as 6 days after US 693. However, only 'Sunrise' and US 693 appeared to couple late bloom and high yield with early dates of first harvest and short ripening intervals (Fig. 2b). The lack of clones exhibiting these combined traits was not surprising, as in a previous study, prolonged fruit development was found to have positively effected fruit wt. per plant, primarily through its effect on fruit size (20). Unfortunately 'Sunrise'

Table 1 Variation among *Vaccinium* cultivars and interspecific hybrid genotypes for flowering, fruit development periods, yield, berry wt. and fruit/plant.

Characteristic	Range among genotype means[1]	Genotypic performance extremes[2]	
		Lowest 10%	Highest 10%
1st bloom (J. date)[3,4]	123 - 144	N'country, N'land, St. Cloud, US 621, 645, 647, 717	US 720, 723, 729, 734, 848
Ripening interval (days)[4,5]	54 - 90	L' Giant, Sunrise, US 607, 643, 693, 734, 846	US 612, 673, 675, 679, 696
1st harvest (J. date)[3,4]	188 - 226	B'tta, N'country, US 643, 645, 693	US 612, 673, 675, 679, 696
Harvest interval (days)[4,6]	6.3 - 22.5	US 658, 659, 675, 734, 847	G 344, Spartan, US 612, 676, 730
Yield (g/plant)[4]	51 - 1324	B'ridge, L' Giant, US 675, 729, 847	Spartan, US 625, 645, 654, 665
Berry wt. (g)[4]	0.52 - 2.24	L' Giant, US 612, 675, 702, 714	US 508, 607, 647, 657, 659
Fruit/plant[7]	35 - 1390	B'ridge, L' Giant, US 657, 659, 729	N'land, US 654, 693, 702, 845

[1]Range of genotypic means calculated over four replications.
[2]B'--, C', L' and N'-- are contractions for Blue--, Cape, Little and North--, respectively; clusters contain 5 genotypes each, except where ties in genotypic means occurred; all means for genotypes within the lowest 10% cluster are significantly different ($P = 0.05$) from those in the highest 10% cluster as determined by Duncan's New Multiple Range Test (full data set not shown).
[3]J. date = Julian date; J. dates 127-142 and 188-219 correspond to 7 May 1995-22 May 1995 and to 7 July 1995-7 Aug. 1995, respectively.
[4]F-values for genotype are significant at $P = \leq 0.001$.
[5]Ripening interval = 1st harvest J. date - 1st bloom J. date.
[6]Harvest interval = last harvest J. date - 1st J. date.
[7]Fruit/plant = yield (g)/berry wt. (g).

and US 693 did not exhibit concentrated fruit ripening (short harvest intervals) (Fig. 2c), but the high yielding genotype, 'Sierra' had fruit which were harvestable within an 8 day period. 'Sierra's short harvest interval may be advantageous in cultural regimes where mechanical harvest predominates.

Among genotypes within heritage groups, yield per plant was highly variable and the effect of heritage on yield was not significant (Table 2). For instance, among hybrids containing background from *V. elliottii*, yields ranged from 111 to 882 g/plant. Group 5 seedlings (progeny of US 75 and US 226) and Group 11 individuals (*V. angustifolium-V. corymbosum* hybrids) did predominate among high yielding clones and cultivars, but counterparts within these groups (e.g., US 657 and US 659 in Group 5 and 'Northcountry' and 'St. Cloud' in Group 11) exhibited very low yields, depressing group means. Except for US 676 and US 679, members of Groups 3, 6 and 7 also exhibited low fruit weights per plant, perhaps resulting from some degree of chromosomal imbalance [i.e., one of their parents, NJUS 11, is putatively a hexaploid hybrid of *V. ashei* (6X) and a colchiploid of *V. atrococcum* (4X)]. The sole *V. ashei-V. constablaei* cultivar in the study ('Little Giant,' Group 13) also failed to fruit well in the mineral soil environment.

Yield improvements in *V. corymbosum* have resulted primarily through breeding for increased fruit size within the species (18). The current high yielding highbush blueberry cultivars often display average fruit wts. (>1 g/berry) that are approximately 3 X larger than those typically found among wild tetraploid *V. corymbosum* populations (3, 12). Large fruit are more efficiently harvested by hand for the fresh market, are easier to handle after harvest, have greater consumer appeal and command a premium price in the marketplace (13). Average fruit wts. of 1 g may be suitable for new mechanically-harvested processing cultivars, whereas continued genetic improvement in berry size is expected to produce future fresh market cultivars with mean fruit wts. approaching 2 g or even greater, depending on cluster architecture (10, 13). Fortunately, herein, and in other studies (8, 18) fruit wt. was not tightly correlated with yield, and the lack of compensation among yield components suggested the possibility for continued improvement by increasing both wt./berry and number of fruit/plant.

Among cultivars and interspecific hybrids in this study, mean fruit wts. ranged

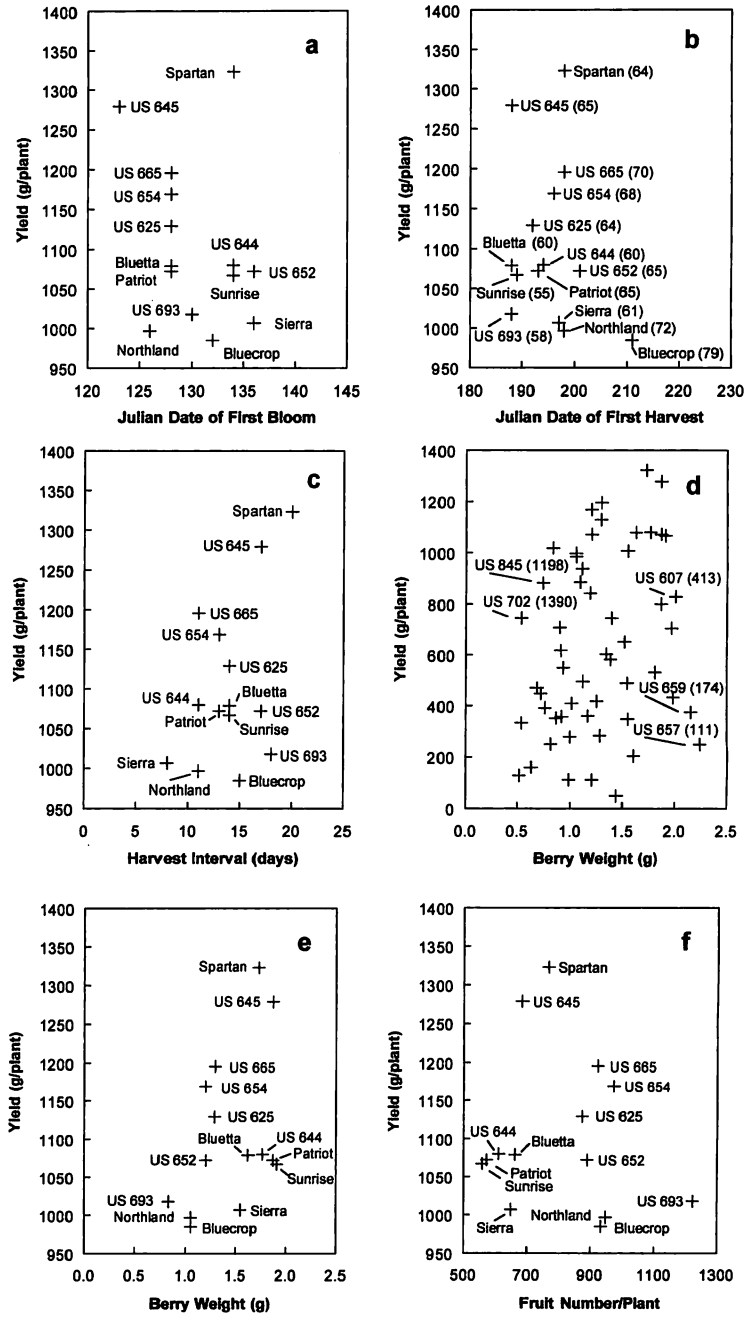


Figure 2. Relationship between yield and flowering, fruit development parameters or yield components for 54 *Vaccinium* cultivars or interspecific hybrids (d) or 14 *Vaccinium* cultivars or interspecific hybrids comprising a cluster of high yielding genotypes (a, b, c, e, f); numbers in parenthesis report associated ripening intervals (b) or fruit numbers per plant (d).

Table 2. Heritage group means for bloom, harvest, ripening and yield parameters of *Vaccinium* cultivars and interspecific hybrids.

Gp	Heritage	Number in gp	1st bloom (J. date)[1]	Ripening interval	1st harvest (J. date)[1]	Harvest interval (days)	Yield (g/plant)	Fruit wt. (g)	Fruit/plant
1	G 362, US 75	4	132 cd[2]	65 b-d	196 d-g	11.0 b	802	1.54 ab	567
2	G 362, US 226	2	127 d	65 b-d	192 fg	13.5 ab	965	1.54 ab	651
3	G 362, NJUS 11	4	136 ab	82 a	218 a	16.3 a	584	0.92 cd	579
4	G 362, NJUS 64	4	130 cd	74 ab	204 a-d	14.5 ab	568	0.79 cd	793
5	US 75, US 226	9	132 cd	62 d	193 e-g	12.1 b	765	1.67 a	474
6	US 75, NJUS 11	4	142 a	64 cd	205 a-c	15.3 ab	375	1.14 b-d	321
7	US 226, NJUS 11	2	138 ab	81 ab	219 a	14.5 ab	375	0.84 cd	485
8	US 226 selfed	1	130 cd	58 d	188 g	18.0 a	1019	0.83 cd	1224
9	Ell hybrids[3]	7	137 ab	60 d	197 c-f	9.6 b	460	1.00 cd	490
10	Cor cultivars	3	134 bc	73 a-c	208 ab	16.7 a	975	1.23 b-d	794
11	Cor-Ang cultivars	8	128 d	64 cd	192 fg	15.1 ab	754	1.43 a-c	529
12	Cor-Dar cultivars/hybrids	5	134 bc	66 b-d	200 a-e	13.4 ab	547	1.52 ab	397
13	Ash-Con cultivar	1	140 ab	58 d	198 b-e	15.0 ab	128	0.52 d	248
Kruskal-Wallis *T*[4]			32.20**	30.64**	35.08***	25.20*	14.86[ns]	28.47**	15.92[ns]

[1]J date = Julian dates; J. dates 127-142 and 188-219 correspond to 7 May 1995 - 22 May 1995 and 7 July 1995 - 7 Aug 1995, respectively.

[2]Multiple comparisons between means accomplished by the Kruskal-Wallis procedure; means with similar letter designations are not significantly different ($P = 0.05$).

[3]Species designations as follows: Ang = *V. angustifolium;* Ash = *V. ashei,* Con = *V. constablaei;* Cor = *V. corymbosum;* Dar = *V. darrowi;* Ell = *V elliottii.*

[4]Significance of *T* based on comparisons with the X^2 distribution; [ns], ** and *** indicate probability levels of >0.05, ≤0.05 and ≤0.001, respectively.

from 0.52 in 'Little Giant' to 2.24 g in US 657 (Table 1). The mean fruit wts. of US 607 and US 659 also exceeded the benchmark of 2 g, but US 659, like its sibling, US 657 matured few fruit (Fig. 2d). Berry wts. among the highest yielding clones averaged 1.5 ± 0.1 g, and all but one individual displayed average fruit wts. in excess of 1 g (Fig. 2e). Fruit wt. was negatively correlated with harvest date (r = –0.53) and ripening interval (r = –0.43), suggesting that early harvest dates and to short ripening intervals resulted in larger fruit. However, there were some obvious outliers. For instance, mean fruit wts. averaged 1.9 and 0.8 g, respectively, for 'Sunrise' and US 693, the two late blooming, early ripening, high yielding genotypes. Likewise, in a study of *V. angustifolium-V. corymbosum* populations, early ripening dates were strongly related to small fruit size (10). Short fruit development periods have also been reported to be negatively correlated with fruit wt. (10) and conversely, long fruit development periods have been shown to positively effect both yield and fruit wt. (20). The inclusion of NJUS 11 (*V. ashei* X *V. atrococcum*) progeny in this study may have accounted for the disagreement between correlation estimates among fruit size, ripening date and ripening interval found herein and those previously reported. Individuals with NJUS 11 in their genetic background tended to bloom late, ripen late and produce small-sized fruit.

Obviously, yield is a function of both wt./fruit and fruit number/plant. Fruit number/plant was highly correlated with yield (r = +0.74), but independent of berry wt. Although yield improvement in highbush blueberry, *V. corymbosum,* has been focused upon increased fruit wt., the development of high yielding clones of lowbush blueberry, *V. angustifolium,* has progressed also by selection for greater fruit numbers/upright (18). Because fruit number/plant was strongly related to yield and unrelated to berry wt., both yield components should be considered when selecting of parental material from among the interspecific hybrids studied. Genotypes

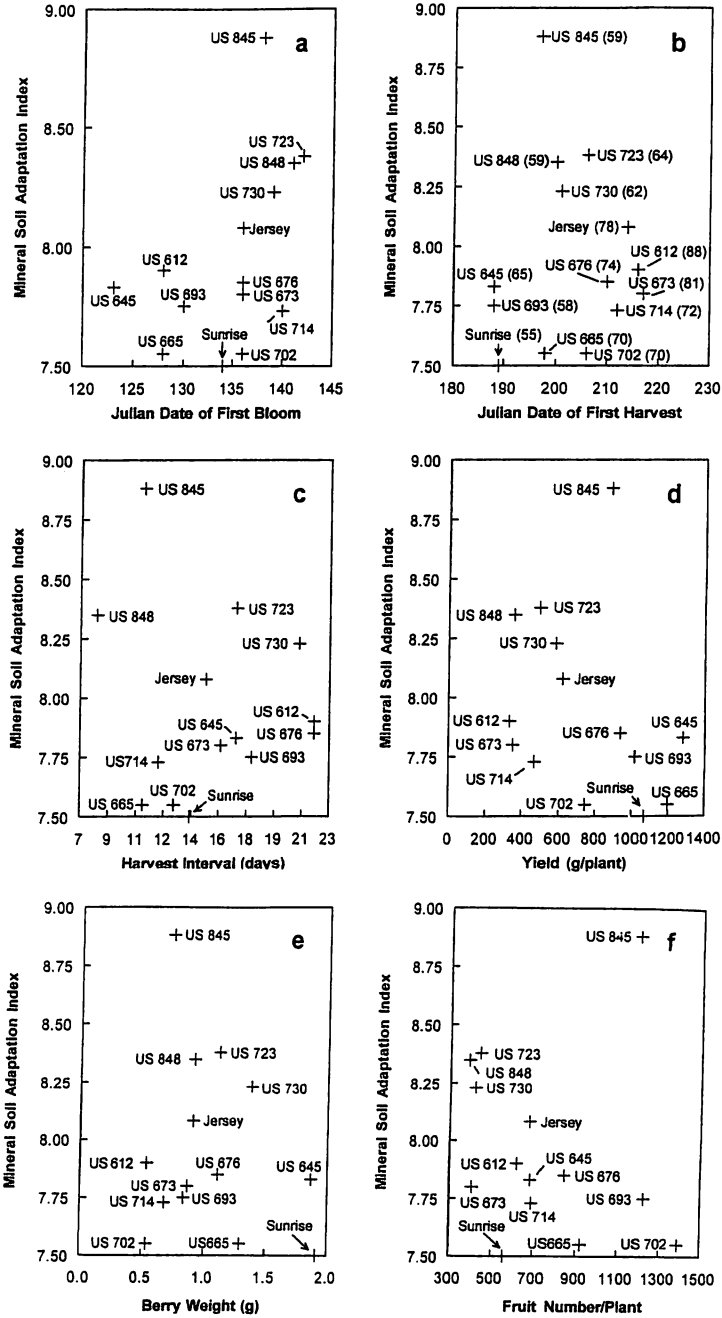


Figure 3. Yield and flowering, fruit development parameters yield or yield components for 14 *Vaccinium* cultivars or interspecific hybrids comprising a cluster of mineral soil adapted genotypes; numbers in parenthesis report associated ripening intervals (b). Description of the mineral soil adaptation index was previously reported (25).

with adequate to exceptional yields, high fruit numbers/plant, but with relatively small fruit size, such as US 693, US 702 and US 845 (Fig. 2d, f) may provide an avenue for increased yields when crossed with large-fruited parents.

Fruit size is determined primarily by genotype (8, 10, 12). Finn and Luby (10) calculated a narrow sense heritability estimate of $h = 0.78$ for fruit wt. whereas Erb and coworkers (8) reported a large GCA component associated with this trait. Although these parameters indicated a predominance of additive genetic variance for berry size, both groups cited the work of others in which dominant genes for small fruit were evident. Among *Vaccinium* species, fruit size is loosely related to chromosome number (3, 6); diploids often exhibit smaller fruit wts. than their polyploid counterparts. However, considerable variation in fruit size has been uncovered within species. Luby and coauthors (18) cited evidence for variation in fruit size in *V. angustifolium, V. darrowi* and *V. myrsinites,* whereas, in a study by Ballington et al. (3), wild strains of *V. ashei* and tetraploid *V. corymbosum* were found to exhibit "reasonable" variation in fruit size. Moreover, there is a strong potential for combining desirable traits in feral species with increased fruit size through interspecific hybridization with *V. corymbosum* (18). Berry wt. was significantly related to heritage, but fruit/plant was not (Table 2). Groups 1, 2 and 5, containing offspring of US 75 (*V. darrowi* X 'Bluecrop') and/or G 362 (*V. corymbosum*) typically bore large fruit averaging greater than 1.5 g/berry. Conversely, members of Group 3, 4, 6, 7 and 8, (progeny of NJUS 11, NJUS 64 or US 226) bore fruit which often weighed less than 1 g. Erb and colleagues (8) reported positive GCA components for G 362 and US 75 and negative GCA components for NJUS 11 and US 226. Fruit wt. means of Draper's elite hybrids in this study agree with these predictions and were very similar to progeny means of similar crosses reported by Erb et al. (8). Even though they contained as much as 25% *V. angustifolium* or *V. darrowi* genes, respectively, individuals within Groups 11 and 12 possessed average fruit wts. slightly in excess of the *V. corymbosum* cultivar standards. Consistent with selection criteria of its breeder, 'Little Giant' (Group 13), a machine-harvestable, processing cultivar had the smallest fruit. Group trends not withstanding, substantial variability existed in fruit wt. for specific genotypes within groups. Relatively large-fruited segregates were found in groups with low mean fruit wts. (e.g., US 717 in Group 4 and US 846 in Group 9), indicating that traits of importance may be captured through interspecific hybridization without necessarily conferring small fruit size on progeny.

Fruit development parameters, yield, fruit weight and mineral soil adaptation: Previously, we developed an index based upon subjective ratings of vigor, yield balance (transformed fruit/foliage ratios) and nutrient deficiency symptoms in order to identify individuals among is cultivars and Draper's elite hybrids that exhibited some degree of mineral soil adaptation (25). Along with 'Jersey' and 'Sunrise,' interspecific hybrids that appeared to function well on mineral soils (i.e., those that obtained index scores ≥ 7.5) included US 612, US 645, US 665, US 673, US 676, US 693, US 702, US 714, US 723, US 730, US 845 and US 848. Many of these genotypes are currently being propagated for further testing as potential cultivars or breeding stock (25). However, their value as such will depend not only on their mineral soil adaptation response, but upon other traits of commercial importance as well.

In order to further assess the performance of mineral soil-adapted hybrids, their bloom dates, ripening intervals, harvest dates, harvest intervals, yields, berry wts. and fruit numbers/plant were arrayed according to their mineral soil adaptation scores in Fig. 3 a-f. Yield capacity is thought to be a prime measure of overall performance, and fortunately, three interspecific hybrids with adaptability to min-

eral soils, US 645, US 665 and US 693, were also among the group of high yielding genotypes discussed above. The high yield associated with US 645 resulted primarily from its superior average berry wt. US 645 was one of the earliest genotypes to mature fruit, but unfortunately, it was also one of the earliest to flower, which may be of concern if it is cultured where late spring frosts are common (15). The ripening and harvest intervals of US 645 were considered to be intermediate. The high yields of US 665 and, especially, US 693 were derived primarily from large numbers of fruit/plant. US 665 ripened fruit 10 days later than US 645. Like US 645, US 665 bloomed relatively early, and its ripening interval was intermediate, but it displayed a relatively short harvest interval. US 693, was the only hybrid in the mineral soil adapted cluster to couple a late bloom date advantage with an early ripening date and a short ripening interval. The harvest interval of US 693 was relatively prolonged.

Moderate yielding genotypes included US 676 and US 845. The yield of US 676 was similar to that of 'Bluecrop' (Figs. 2, 3d), and it flowered almost two weeks later than US 645. However it was also harvested late, displaying both long ripening and harvest intervals. US 845 also bloomed late, but due to its short ripening interval, ripe fruit were harvested concurrent with US 665. Six mineral soil-adapted genotypes, US 612, US 673, US 714, US 723, US 730 and US 848, exhibited relatively low yields (<600 g/plant, Fig. 3d). Among these individuals, only US 848 developed berries averaging greater than 1.0 g (Fig. 3e). Although none of the individuals within the mineral soil adaptability possessed all possible positive traits for flowering, fruit development, yield and yield components, most contained two or more characteristics which might be useful in further breeding efforts.

Conclusions

The wealth of genetic diversity extant in feral blueberry germplasm has created opportunities for breeding advancement with respect to a variety of important economic traits. However, as wild relatives are not necessarily suited for direct agricultural use, their use in breeding schemes may also pose some limitations to advancement, especially if deleterious traits are highly heritable, or if relationships among variables are particularly strong. In a previous report (25), we described the diversity within a population of cultivars and elite interspecific hybrids for parameters associated with growth, vigor, fruiting balance and nutrient deficiency and identified individuals within that population that exhibited positive mineral soil adaptation responses. Herein, we have characterized these genotypes further by exploring the performance of individuals and among heritage groups for flowering, fruit development, yield and yield component traits. We were able to identify genotypes with a degree of mineral soil adaptation that approached a fresh market cultivar ideotype, exhibiting the combined traits of high yield, large fruit size, high numbers of fruit/plant, late flowering (for frost avoidance), shortened ripening intervals and early ripening (for market advantage in some areas) and shortened harvest intervals (for eventual mechanical harvestability).

Substantial variability was evident for all traits studied, among individuals within the general population and among genotypes comprising the mineral soil-adapted cluster. Individual performance with respect to bloom date, ripening interval, date of first harvest, harvest interval and berry wt. was significantly affected by heritage. The heritage patterns uncovered were very similar to those reported by previous authors (2, 3, 4, 6, 8, 10, 18, 19, 20, 23) who determined these traits to be largely controlled by additive genetic variance. However, some variability among genotypes within heritage groups was also evident for most traits, and, in the case of yield per plant, this variation was extensive (i.e., the effect of heritage on yield was not significant). Weak or insignificant correlations among bloom

date, fruit development and yield parameters, and the strong correlation between ripening interval and date of first harvest also supported the possibility of identifying high yielding, late blooming genotypes with short ripening intervals and/or short harvest intervals.

Although the ideotypical genotype was not recovered during this study, the data did illustrate and reaffirm the usefulness of interspecific hybridization within a blueberry breeding program. Several mineral soil-adapted, high-yielding individuals (e.g., US 645, US 665 and US 693) did possess advantageous flowering and fruit development characteristics. Moreover, within the general population, five cultivars with complex genetic backgrounds and seven of Draper's interspecific hybrids averaged yields greater than 1000 g/plant in this mineral soil environment and many of these genotypes also displayed one or more positive flowering or fruit development attributes. As fruit number/plant was strongly related to yield but independent of fruit weight, high and intermediate yielding genotypes maturing the greatest number of fruits (e.g., US 693, US 717, and US 845) may be extremely useful as parents when crossed with large-fruited genotypes. Admittedly, the data in this study was evaluated with respect to a single ideotype. Darrow and Camp (6) described the folly in attempting to breed an "all-purpose" blueberry cultivar, as variability in cultural conditions and/or end-product uses demand the development of cultivars with differing characteristics. Had our discussion considered alternate or additional ideotypes (e.g., cultivars suitable for processing), genotypes within the population may also have been identified which closely approximated the optimum characteristics of those ideotypes.

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Susceptibility to Leaf Curl in Peach Germplasm

The susceptibility of 1103 peach genotypes (738 dessert, 168 clings, 197 nectarines) and 152 unselected seedlings to leaf curl was assessed. No cultivar rated 0 or immune, only 6 rated 1 while 62% had the highest susceptibility rating. There was a loss of resistance to leaf curl during selection for improved horticultural characters. From Roselli et al. 1997. J. Hort. Sci. 72(6):863-872.

Picking and Storage Affect Apple Texture

Early picked apples maintained higher firmness during 0°C and CA storage with CA having better quality than 0° C. Later picked 'Cox' apples tend to lose firmness faster during post harvest storage. More cell wall breakup was observed from early picked apples indicating a less mealy texture than late picked apples. Apple firmness related to extractable juice content and cell wall breakage. From Tu et al. 1997. J. Hort. Sci. 72(6):971-980.