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Evaluation of American (*Sambucus canadensis*) and European (*S. nigra*) Elderberry Genotypes Grown in Diverse Environments and Implications for Cultivar Development

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Abstract*. American (*Sambucus canadensis* L.) elderberry genotypes were evaluated at multiple locations, whereas European (*S. nigra* L.) elderberry genotypes were evaluated at a single location to assess genotypic differences and, for genotypes evaluated at multiple locations, to determine genotype × environment interactions (G × E). Seventeen *S. canadensis* genotypes were planted in replicated trials at Missouri State University (Mountain Grove, MO) and at the University of Missouri (Mt. Vernon, MO) or at the U.S. Department of Agriculture–Agricultural Research Service in Oregon (Corvallis). 'Johns', 'Netzer', 'Adams II', and 'Gordon B' were in common at all locations. In addition, three genotypes of *S. nigra*, which are not winter-hardy in Missouri, were planted in Oregon. All plants were established in 2003 and evaluated in 2004, 2005, and, for some traits, in 2006. Plants were evaluated for phenology (e.g., dates of budbreak, first flowering, full flowering, and first ripening), vegetative growth (e.g., number of shoots and plant height), yield components (e.g., total yield, number of cymes, cyme weight, and berry weight), and for pest incidence (e.g., eriophyid mites). For the genotypes in common to all locations, there were significant differences resulting from genotype, location, year, and the interactions for various traits. Although the trend was for Corvallis to have the highest and Mt. Vernon the lowest yield, there was no significant location effect. The significant genotype × environment interaction appeared to be primarily the result of the differential performance of 'Johns', which was generally high-yielding in Corvallis and low-yielding at both Missouri locations. The significant G × E suggests that as the Missouri institutions develop new cultivars, it will be important to test them individually at other locations and not rely on their relative performance compared with standards in Missouri. For the genotypes in common to the two Missouri sites, there was significant variation for many traits. Although there were no differences among genotypes for yield across the locations, there was a significant G × E. Although there were some small changes in performance among the sites for yield, the most dramatic changes were for 'Wyldewood 1' that was the second highest yielding genotype at Mountain Grove and the second worst at Mt. Vernon. Plant growth in Oregon was 40% and 60% greater than at Mountain Grove and Mt. Vernon, respectively, when the plants were first measured. In Oregon, the two *Sambucus* species behaved differently. Phenologically, although the *S. nigra* genotypes flowered ≈3 weeks earlier than the *S. canadensis* genotypes, they ripened at the same time, thereby shortening their exposure to potential biotic and abiotic stress. 'Johns', 'York', 'Golden', and 'Gordon B' were the highest yielding *S. canadensis* genotypes and 'Korsør' the highest of the *S. nigra* genotypes. Although 'Korsør' is considered high-yielding in Denmark, it did not yield as well as the highest yielding *S. canadensis* cultivars.

The American (*Sambucus canadensis*) and the European (*S. nigra*) elderberry are closely related species in the *Adoxaceae* [also placed in *Caprifoliaceae* and *Sambucaceae* (USDA, ARS, National Genetic Resources Program, 2008)] that, although separated in the USDA-ARS National Genetic Resources Program (2008), are sometimes combined as two subspecies of *S. nigra* (Bolli, 1994). Although they have naturalized throughout much of the world, *Sambucus* species are predominantly native to the northern hemisphere. Their seeds are spread rapidly by birds to colonize forest edges and disturbed areas along roads and railroad lines. Although the focus of this research is on these species as fruit crops, they are popular ornamentals, particularly *S. nigra*, displaying a range of foliage colors as well as cut-leaf forms. The bark, roots, stems, flowers, and fruit of both species historically have been used by native people as medicine (Moerman, 1998) and this aspect of these species recently has received significant attention (Thomas et al., 2008).

Commercial elderberry production is scattered across Denmark, Italy, Hungary, and Austria in Europe and in central Chile. Historically, Oregon was a major producer in the United States, but production has rapidly declined in the past few years. However, wild harvested fruit is sold commercially in a number of areas, particularly the midwestern United States. Although the European industry primarily relies on *S. nigra* genotypes and the United States on *S. canadensis* genotypes, commercial production practices are similar. The morphological and reproductive characteristics of these species are similar; however, *S. nigra* tends to be a single or few trunked large shrub/small tree, whereas *S. canadensis* can have many stems and can aggressively spread by underground rhizomes. The fruit chemistry of the two species is different, most notably in that the major anthocyanins of *S. canadensis* are acylated (Lee and Finn, 2007). Although all processed elderberry samples that have been tested as a juice, concentrate, natural colorant, and as dietary supplements in the literature were produced from *S. nigra*, *S. canadensis* should be a better choice as a result of its acylated anthocyanins.

Most of the *S. canadensis* cultivars were developed decades ago either at the New York Agricultural Experiment Station or at Agriculture and Agri-Food Canada in Nova Scotia (e.g., 'Adams I', 'Adams II', 'Johns', 'York', 'Nova') (Table 1). Although the Danish developed the *S. nigra* cultivars Allesø, Korsør, Sambu, and Sampo (Kaack, 1989, 1997), the origin of 'Haschberg', the main *S. nigra* cultivar grown in Europe, is uncertain.

Most of the horticultural literature on American elderberry is geared toward

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Table 1. Origin of *Sambucus canadensis* and *S. nigra* genotypes and where they were in replicated trial among locations at the Missouri State University–Mountain Grove, MO, the University of Missouri Southwest Center, Mt. Vernon, MO, and the USDA-ARS Horticultural Crops Research Laboratory, Corvallis, OR.

Genotype	USDA-ARS NCGR PI number/accession number[z]	Species	Origin	Corvallis, OR	Mountain Grove and Mt. Vernon, MO
Adams I	652808/CSAM 75	*S. canadensis*	Named wild selection, W. W. Adams, Union Springs, NY, 1926	x	
Adams II	652809/CSAM 76	*S. canadensis*	Named wild selection, W. W. Adams, Union Springs, NY, 1926	x	x
Barn	652807/CSAM 72	*S. canadensis*	Wild selection, E. Meader, NH	x	
Competition 5	—	*S. canadensis*	Wild selection, Wooley Farms, Competition, MO		x
Golden	652799/CSAM 49	*S. canadensis*	Uncertain	x	
Gordon B	652856/CSAM 168	*S. canadensis*	Named wild selection, R. Gordon/C. Cooper, Collins, MO	x	x
Gordon E	—	*S. canadensis*	Wild selection, R. Gordon/C. Cooper, Collins, MO		x
Harris 4	—	*S. canadensis*	Wild selection, G. Harris, Golden City, MO		x
Hwy O	—	*S. canadensis*	Wild selection P. Byers/A. Thomas, Pierce City, MO		x
Johns	652814/CSAM 82	*S. canadensis*	Named wild selection from Ontario released in NS, 1954	x	x
Maxima	652812/CSAM 80	*S. canadensis*	Named cultivar of uncertain Nova Scotia origin	x	
Netzer	652857/CSAM 169	*S. canadensis*	Wild selection, R. Netzer/C. Netzer, Springfield, MO	x	x
Scotia	652815/CSAM 83	*S. canadensis*	Named cultivar, Adams II open pollinated, E. Eaton, Agriculture and Agri-Foods Canada, Kentville, NS, 1959	x	
Votra	652850/CSAM 162	*S. canadensis*	Wild selection, D. Votra, Wheatland, MO		x
Walleye	652852/CSAM 164	*S. canadensis*	Wild selection P. Byers/A. Thomas, Wentworth, MO		x
Wyldewood 1	—	*S. canadensis*	Named wild selection, M. Millican, Eufaula, OK		x
York	652810/CSAM 77	*S. canadensis*	Named cultivar. Adams II × Ezyoff, N.Y. Agr. Expt. Stat., Geneva, NY, 1964	x	
Haschberg	652825/CSAM 103	*S. nigra*	Named wild selection, Austria	x	
Korsør	652856/CSAM 104	*S. nigra*	Named cultivar, Denmark	x	
S. nigra	314807/CSAM 14	*S. nigra*	Wild selection made in Montana by N. Callan in seed accession from The Netherlands	x	

[z]PI and accession numbers used by U.S. Department of Agriculture, Agricultural Research Service, National Clonal Germplasm Repository, Corvallis, OR.

production practices and was published in the mid-20th century (Craig, 1978; Ritter, 1958; Ritter and McKee, 1964; Skirvin and Otterbacher, 1977; Way, 1957, 1967, 1981). To our knowledge, other than Waźbińska et al. (2004), who evaluated *S. nigra* production on two soils at the same location, no studies have been carried out to examine genotype × environment (G × E) interactions or seasonal effects or that compared the two species for horticultural characteristics. The main objective of this study was to determine the G × E interaction for yield and phenological traits for four *S. canadensis* genotypes (‘Adams II’, ‘Gordon B’, ‘Johns’, and Netzer) grown at three locations, two in Missouri and one in Oregon. Separately, each state had secondary interests. In Missouri, a replicated comparison of a large number of genotypes was important to help determine which selections of *S. canadensis* should be advanced in their development program. In Oregon, because it is possible to grow *S. nigra*, the primary commercial European species, it was of interest to see how cultivars of *S. nigra* compared with those of *S. canadensis*.

Materials and Methods

The plantings were established in 2003 at the University of Missouri’s Southwest Research Center at Mt. Vernon (lat. 37°4′ N, long. 93°53′ W, alt. 378 m), Missouri State University’s State Fruit Experiment Station at Mountain Grove (lat. 37°13′ N, long. 92°26′ W, alt. 434 m), and the USDA-ARS North Farm, in the Willamette Valley near Corvallis, OR (lat. 44°30′ N, long.123°28′ W, alt. 72 m). The two Missouri sites are 140 km apart, whereas the Oregon site is quite distant. The two Missouri sites are in USDA hardiness zone 6 (mean annual minimum –23.3 to –17.8 °C), whereas the Oregon site is in zone 8 (mean annual minimum –12.2 to –6.7 °C). Annual precipitation averages 1103 mm at Mt. Vernon, 1148 mm at Mountain Grove, with rainfall distributed fairly evenly throughout the year, and 1041 mm at Corvallis with most precipitation at Corvallis falling between November and May. The soil at Mt. Vernon was a Hoberg silt loam (fine-loamy, siliceous, mesic Mollic Fragiudalfs); at Mountain

Grove, a Viraton silt loam (fine-loamy, siliceous, mesic Typic Fragiudalfs); and at Corvallis, a Blachly-Kilowan sandy loam complex (fine, isotic, mesic Typic Dystrudepts).

Cuttings from each genotype were rooted and then transplanted to all three sites in May 2003. Originally, 36 *S. canadensis* genotypes were planted either in a completely randomized design or in single observation plots; however, data from only the 17 genotypes included in replicated trials in more than one location are presented (Table 1). Additionally, three genotypes of *S. nigra*, which are not reliably hardy in Missouri, were planted in Corvallis. Of the 17 genotypes studied, Adams I, Adams II, Johns, Kent, Maxima, Scotia, York, Haschberg, and Korsør are cultivars that have been planted commercially. The remaining genotypes are selections from the wild, predominantly from Missouri, that are part of a long-term evaluation program by Missouri State University in collaboration with the University of Missouri (Thomas and Byers, 2000).

In Missouri, plants were 1.2 m apart within rows with 3.3 m between rows, and in Oregon, they were 1.8 m apart within rows and 3 m between rows. Although four replications were planted in Missouri, only three were planted in Oregon. All plantings were fertilized each spring with 56 $kg \cdot ha^{-1}$ N and irrigated by drip lines (Missouri) or overhead sprinklers (Oregon) as needed. At all sites, weeds were managed with mulch, glyphosate herbicide, or hoeing, and no insecticides or fungicides were used.

The plants were evaluated for phenological traits, including date of first flowering, date of full flowering (greater than 50% of cymes in bloom), first ripe date, and full ripe date (greater than 50% of cymes with colored fruit). Fruit was harvested as the plants reached full ripe by clipping entire cymes. Yield-related traits included total yield per plant, total number of cymes, and weight per cyme. Damage from a bacterial leaf spot [tentatively identified as *Pseudomonas viridiflava* Burkholder (Dowson)] and eriophyid mites (*Eriophyes* spp.) were recorded in Missouri. The occurrence of an unidentified blossom blight that caused blossoms to turn brown before they opened was evaluated in Oregon. Fruit from this study was also used for separate fruit chemistry analysis in which Lee and Finn (2007) compared fruit from *S. nigra* and *S. canadensis*. Thomas et al. (2008) evaluated a subset of the *S. canadensis* genotypes in this trial for the occurrence of rutin and chlorogenic acid in the leaves, flowers, and stems.

Statistical analyses were conducted using SAS (SAS Institute Inc., 1990). For analysis of variance (ANOVA) construction, GLM procedure was used and means were calculated using TABULATE. In all three sets of ANOVAs (Missouri and Oregon sites together; only Missouri sites; only Oregon site), factors were considered as random; therefore, random effect models were used. The significance of each factor was tested by relevant error term.

Results and Discussion

The elderberry plants remained healthy and vigorous at all three locations during this study; however, there were differences in arthropod/disease pressure, phenology, and fruit yield traits in the various groups of plants across the three locations.

The first ANOVA examined the differences across all three locations for the four *S. canadensis* genotypes in common in replicated trial (‘Adams II’, ‘Gordon B’, ‘Johns’, and Netzer) (Table 2). The ANOVA indicated that although the main factors of E and year (Y) were not statistically significant for any of the variables tested, the elderberry genotypes (‘Adams II’, ‘Gordon B’, ‘Johns’, and Netzer) grown in Mountain Grove, Mt. Vernon, and Corvallis differed significantly in first and full flowering dates (Table 2). Netzer had later first and full flowering dates in both years when compared with the other cultivars (Table 3). The G × Y interaction was only significant for the date of first ripening (Table 2). Although ‘Adams II’ and ‘Johns’ ripened earlier in 2004, ‘Gordon B’ and Netzer had earlier ripening dates in 2005 (Table 3). At all three locations, ‘Gordon B’, ‘Adams II’, and Netzer had a similar order of first ripening, full flowering, and first ripening; however, ‘Johns’ was different and likely is responsible for the significant G × E interaction for full flowering and first ripening dates. ‘Johns’ flowered earliest in Oregon but was the third of the four to flower at both Missouri sites and similarly; although it ripened early in Oregon, it was the last to ripen in Missouri (Table 3). G × E interactions were significant or highly significant for all traits except number of harvests and cyme weight, and G × E × Y interactions were significant for all variables tested except date of full flowering (Table 2). Although the trend was for Corvallis to have the highest and Mt. Vernon the lowest yield, there were no significant differences among locations (Table 3). The significant G × E interaction for yield reflects the different performance of the various cultivars at each location. At the two Missouri locations, ‘Johns’ typically had the lowest yield and ‘Gordon B’ the highest. At the Corvallis location, ‘Johns’ was the highest yielder in both years but had a very high yield in 2005. The lack of significant year effect was surprising because the mean number of cymes in 2006 was much less at both Missouri locations than in either of the previous years.

The two Missouri locations had 12 genotypes in common in replicated trial that were compared in the second ANOVA (Table 4). The variability resulting from E was only significant for eriophyid mite damage and berry weight with mite damage being worse at Mountain Grove and with berries being larger at Mt. Vernon (Tables 4 and 5).

There was a significant Y effect for dates of first flowering, full flowering, and first ripening as well as for cyme weight and mite damage (Table 4). Although the flowering and ripening dates were fairly similar for 2004 and 2005, they were much later in 2006 (Table 5). The mite damage was scored lowest in 2005 and highest in 2004. Typically the scores at Mountain Grove were ≈0.5 lower (worse) and, although numerically small, the differences in symptoms were clearly visible (Table 5). The interaction between Y and E was significant for all variables except date of first ripening and cyme weight indicating a differential genotypic performance over the years the data were collected for the majority of traits (Tables 4, 5, and 6).

The genotypes varied significantly for the various phenological characteristics (Table 4). The difference between the first and last to break bud was nearly a month, with ‘Adams II’ the earliest and Walleye and Highway O the latest (Table 5). There was a 14- to 18-d difference from the first genotype to flower or ripen fruit to the last with ‘Adams II’

Table 2. Mean squares and their significances for four elderberry (*S. canadensis*) cultivars grown at Missouri State University–Mountain Grove, MO, University of Missouri Southwest Center, Mt. Vernon, MO, and USDA-ARS Corvallis, OR, in 2004 and 2005.

Source	df	Date of first flowering	Date of full flowering	Date of first ripening	Number of harvests	Yield (g)/plant	Number of cymes/plant	Cyme wt (g)/cyme
Environment (E)	2	860.0	1,378.5	1,792.6	20.5	132,038,728	250,296	3,089
Year (Y)	1	16.6	300.4	16.8	3.2	7,734,268	72,324	10,302
E × Y	2	160.0	72.9*	3.6	4.5	16,512,321	32,165	2,632*
Rep (E, Y)	18	6.5	6.2	23.8*	0.6*	2,842,992	2,317*	139
Genotype (G)	3	1,047.7*	780.3*	806.9	10.6	28,754,692	26,264	675
G × E	6	266.8*	217.0**	526.6**	8.6	36,920,679*	28,557*	693
G × Y	3	80.1	6.7	157.3*	1.1	2,730,544	1,333	298
G × E × Y	6	32.7**	9.9	30.4*	2.4**	6,356,908**	4,916**	302*
Error	50	5.9	7.6	12.9	0.3	1,583,511	1,244	115

*, **Significant at 5% and 1%, respectively.

Table 3. Mean values for four elderberry (*S. canadensis*) cultivars grown at Missouri State University–Mountain Grove, MO, University of Missouri Southwest Center, Mt. Vernon, MO, and USDA-ARS Corvallis, OR in 2004 and 2005.

Source	Date of first flowering[z]		Date of full flowering[z]		Date of first ripening[z]		Number of harvests		Yield (g)/plant		Number of cymes		Cyme wt (g)/cyme	
	2004	2005	2004	2005	2004	2005	2004	2005	2004	2005	2004	2005	2004	2005
Corvallis, OR														
Adams II	159	158	172	167	213	215	6	4	3,385	4,438	102.8	163.3	33.0	28.0
Gordon B	162	156	174	170	211	212	6	6	5,493	5,223	232.0	324.3	26.0	16.3
Johns	153	150	166	160	197	204	7	6	6,128	12,935	176.5	401.5	34.2	30.9
Netzer	188	174	195	185	228	222	2	3	260	1,907	14.7	195.3	16.7	9.7
Mean	164	159	176	169	211	213	5	5	3,951	6,491	132.6	272.7	28.4	22.4
Mountain Grove, MO														
Adams II	144	151	158	159	196	196	4	4	2,660	2,166	45.6	84.4	58.6	26.8
Gordon B	144	152	160	159	196	191	4	5	3,332	3,170	54.4	95.6	63.6	33.5
Johns	154	153	160	159	201	214	4	2	1,362	66	15.1	4.7	91.7	15.0
Netzer	159	159	167	165	206	204	4	3	1,735	1,044	32.8	67.1	52.5	15.9
Mean	150	154	161	161	200	201	4	4	2,272	1,611	37.0	62.9	66.6	22.8
Mt. Vernon, MO														
Adams II	148	152	160	156	187	194	3	5	396	379	14.1	33.3	30.1	11.5
Gordon B	150	152	163	158	187	186	3	5	700	1,324	16.2	47.4	45.3	28.7
Johns	161	155	168	162	206	211	1	3	65	203	1.0	4.8	65.0	34.7
Netzer	161	161	169	167	206	199	3	3	446	633	10.1	17.1	51.7	39.6
Mean	155	155	165	160	195	198	3	4	479	663	12.5	27.0	44.1	28.2
Overall														
Mean	156	156	167	163	202	203	4	4	2,277	2,814	60.7	116.2	47.3	24.5
SD	11	6	10	7	11	11	2	1	2,099	3,860	72.9	130.1	22.5	12.9

[z]Days from 1 Jan.

typically the first and 'Wyldewood 1' among the last to reach these stages (Table 5). Genotypes differed for the number of harvests required to pick the crop (Table 4). Most of the genotypes took three harvests, whereas 'Johns' more often required only two and Votra, Gordon E, 'Adams II', and 'Gordon B' took four harvests to get the crop picked (data not shown). Surprisingly, there were no differences among genotypes for yield or number of cymes in Missouri, although there were G × E interactions for both traits (Table 4). Although there was some shuffling in order from best to worst for yield among the genotypes at each location, the most dramatic was for 'Wyldewood 1', the second highest yielding genotype at Mountain Grove and second worst at Mt. Vernon (Table 6). The G × Y interaction for yield is difficult to dissect because the cultivars did not change order dramatically over the years (Tables 4 and 6). Highway O was in the top half of the producers in 2004 and 2006 but was among the lower yielders in 2005. Harris 4 had a similar pattern, although it was only in the middle of the group for production in 2004 and 2006. Votra had among the lowest yields in the first year but built to the second highest by 2006. Additionally, yields at Mountain Grove decreased each year, whereas they increased at Mt. Vernon.

The genotypes differed for berry weight and there was a G × E interaction (Table 4). Although most of the genotypes had berries that averaged between 0.08 and 0.10 g, 'Adams II' had berries that only averaged 0.06 g (data not shown). Although the genotypes varied among location for berry size, Netzer was among the largest in Mt. Vernon and among the smallest at Mountain Grove (Table 6).

Plant height was measured in Corvallis only in 2005 and in each year at the other locations. In the year in common, there was a significant location effect with Oregon plants being 40% taller than those at Mountain Grove and 60% taller than those at Mt. Vernon (data not shown). The difference in height between the Oregon and the two Missouri locations is likely the result of the moderate climate in Oregon. There were no differences in plant height among genotypes in Corvallis. In Missouri, over the 3 years measured, there was no G × E, but there were differences among the genotypes and there was a significant G × Y interaction for number of shoots and plant height (Table 4). There was also significant variability resulting from G and resulting from E × Y for number of shoots and plant height. The mean heights among genotypes ranged from 217 to 229 cm tall, which, although statistically significant, would not appear to be horticulturally significant. However, they did produce mean ranges of 41 to 58 shoots per plant, with Gordon E producing 5.6 more shoots than the next highest genotype, Netzer. 'Adams II' had a moderate production of shoots in 2005 and had the fewest shoots in 2006, whereas Eridu 1 and 'Gordon B', which were the low and moderate shoot producers in 2005, were much greater producers in 2006.

There were no significant E, G, or Y effects for damage from bacterial leaf spot, but there was significant variability resulting from interactions (Table 4). Although the differences between mean scores for all genotypes at the two Missouri location were 1.2 and 1.6 in 2004 and 2005, respectively, they were only 0.3 in 2006 as a result of a decline in the disease symptoms in Mountain Grove in 2006. The G × E appears to be primarily the result of the differential performance of 'Wyldewood 1' and Harris 4. 'Wyldewood 1' had the lowest disease incidence at Mountain Grove and the highest in Mt. Vernon, whereas Harris 4 had severe symptoms at Mountain Grove but much less intense symptoms at Mt. Vernon (Table 5). 'Wyldewood 1' also had a similar yield response over locations; whether weak plants were more susceptible to disease that in turn led to low yield or whether the disease weakened the plants leading to low yield at Mt. Vernon is impossible to discern.

Although the number of cymes per plant was greater in 2005 than 2004, the weight per cyme decreased the second year, and therefore the overall yield was comparable across the 2 years (Table 4). The first harvest was earlier in 2005 than 2004. The genotypes had significant differences for the flowering-, ripening- and harvest-related traits but not for yield, number of cymes, mites, and bacterial leaf spot. Although yields were not significantly different among the genotypes, 'Adams II' had a numerically higher yield than 'Johns', which may be comparable to a previous study in the Midwest, where 'Adams II' was significantly higher-yielding than 'Johns' (Skirvin and Otterbacher, 1977). Similar to the first analysis, the only significant G × Y interactions were for the date of budbreak and number of cymes per plant. G × E interactions were significant for yield, number of cymes per plant, damage from bacterial leaf spot, and berry weight. G × E × Y interactions were significant for all the traits tested except date of budbreak, yield, cyme weight, plant height, and berry weight. The mean values for genotypes separated by E and Y are presented in Table 5. In general, yields rose at Mt. Vernon from 2004 to 2005 and although they declined at Mountain Grove, they were still greater than at Mt. Vernon. We believe the yield decline at Mountain Grove in 2005 was the result of eriophyid mite damage to flowering

Table 4. Mean squares and their significances for elderberry (*S. canadensis*) cultivars grown at Missouri State University–Mountain Grove, MO, and University of Missouri Southwest Center, Mt. Vernon, MO in 2004 to 2006.

Source	df	Date of budbreak	Date of first flowering	Date of full flowering	Date of first ripening	Number of harvests	Yield (g)/plant	Number of cymes	Cyme wt (g)/cyme	Date of first harvest	Number of shoots	Plant ht (cm)	Damage from eriophyid mites	Damage from bacterial leaf spot	Berry wt (g)
Environment (E)	1	1,070	62.8	384.8	3.8	2.0	110,961,909	33,265	644	1,919*	4,399	6,747	17.3*	72.5	804.30**
Year (Y)	2	10,704	4,751.1**	5,436.4*	36,817.8**	11.8	20,931,417	18,194	116,491**	10,325**	99,556	51,675	11.9**	9.3	20.23
E × Y	2	7,927**	249.9*	464.2*	223.9	26.6*	35,908,234**	6,695**	4,806	199	50,733**	11,543**	0.4	10.1*	27.08
Rep (E, Y)	18	19	25.7**	21.6	34.5	0.4	202,993	106	2,011	25	557**	460*	0.3	0.4*	6.71**
Genotype (G)	11	1,001**	462.6**	519.2**	780.5**	8.9**	4,405,445	2,330	13,134*	367**	6,229**	36,340*	2.5	2.6	31.48**
G × E	11	104	24.8	75.9	141.9	3.0	2,834,740**	708*	2,336	102	871	712	1.7	4.3**	7.82**
G × Y	22	114**	23.4	52.6	75.5	1.7	964,345	736**	3,947	66	1,445	872	1.0	1.1	2.76
G × E × Y	21	162	13.9*	36.8**	72.4**	2.7**	868,260	255**	1,129	88**	761**	406	0.6*	0.9**	2.30
Error	190	16	8.3	14.3	22.8	0.4	188,793	82	1,258	21	237	229	0.3	0.2	2.04

*, **Significant at 5% and 1%, respectively.

Table 5. Mean values for phenological, plant growth, and pest-related traits for elderberry (*S. canadensis*) cultivars grown at Missouri State University Mountain Grove, MO, and University of Missouri Southwest Center, Mount Vernon, MO, in 2004 to 2006.

	Date of budbreak[z]		Date of first flowering[z]			Date of full flowering[z]			Date of first ripening[z]			Number of shoots/plant		Plant ht (cm)	Damage from eriophyid mites[y]			Damage from bacterial leaf spot[y]		
Source	2005	2006	2004	2005	2006	2004	2005	2006	2004	2005	2006	2005	2006	2004–06	2004	2005	2006	2004	2005	2006
Mountain Grove, MO																				
Adams II	29	36	144	151	160	158	159	167	196	196	234	56.7	33.7	219	2.1	1.6	2.3	2.9	2.5	4.3
Competition 5	35	68	154	162	170	165	168	179	200	214	234	62.8	41.3	221	2.6	2.5	4.0	2.8	3.0	2.8
Eridu 1	38	74	156	162	172	166	171	180	202	208	234	52.2	42.5	224	3.8	1.9	2.3	2.6	3.5	1.8
Gordon B	37	71	144	152	166	160	159	178	196	191	234	56.7	47.6	217	2.0	1.6	1.3	2.4	3.0	1.8
Gordon E	37	74	148	153	171	158	159	177	196	196	234	64.2	55.5	219	2.9	2.0	1.8	3.0	4.0	1.8
Harris 4	37	74	154	155	170	164	167	178	204	199	234	60.8	34.9	223	3.9	2.6	2.0	2.9	4.3	1.3
Highway O	50	74	154	155	169	166	170	177	199	211	234	53.9	37.3	222	2.6	2.8	3.0	2.9	3.8	1.8
Johns	48	70	154	153	168	160	159	179	201	214	239	48.6	34.9	225	2.5	1.6	2.8	1.8	3.0	1.3
Netzer	47	76	159	159	175	167	165	182	206	204	237	64.5	44.9	222	2.0	1.4	1.5	1.9	2.8	1.0
Votra	35	71	154	157	170	160	165	180	196	196	234	52.2	42.5	220	3.1	1.3	3.0	3.4	3.5	2.8
Walleye	55	74	154	157	171	159	162	179	204	200	234	57.6	32.2	221	3.4	3.0	2.5	2.5	3.3	1.8
Wyldewood 1	27	53	161	165	174	167	171	180	207	210	234	64.0	53.6	221	2.0	1.0	1.0	2.0	1.5	1.0
Mean	39	67	153	157	170	162	165	178	200	203	235	58.0	41.7	221	2.7	1.9	2.3	2.6	3.2	1.9
Mt. Vernon, MO																				
Adams II	37	36	148	152	160	156	164	-	187	194	220	53.3	37.7	217	1.9	1.4	2.1	2.8	1.8	2.5
Competition 5	46	41	165	160	174	177	171	184	209	199	238	55.5	46.8	225	2.0	1.9	2.3	1.0	1.5	1.8
Eridu 1	49	62	167	163	171	174	169	177	209	204	235	37.3	39.2	231	2.4	1.6	1.5	1.3	1.8	1.3
Gordon B	46	40	150	152	163	163	158	173	187	186	221	48.5	48.3	217	1.8	1.0	1.6	1.0	1.3	1.1
Gordon E	48	56	152	152	164	165	158	173	193	191	231	58.0	53.8	221	2.4	1.6	1.9	1.3	1.3	1.6
Harris 4	46	41	155	155	163	167	163	175	203	199	245	53.6	45.7	228	2.3	1.5	1.7	1.0	1.0	1.3
Highway O	53	65	158	155	169	172	168	183	205	206	239	46.6	42.5	229	2.3	1.8	1.5	1.8	2.0	1.8
Johns	53	63	161	155	165	167	162	182	206	212	243	42.3	38.3	234	2.5	1.5	1.8	1.0	1.3	1.2
Netzer	53	56	161	161	174	168	167	187	206	199	251	54.6	44.9	231	2.0	1.0	2.0	1.3	1.8	1.1
Votra	45	39	156	152	167	166	158	175	196	191	230	45.7	40.2	221	2.3	1.0	2.1	1.0	1.3	1.3
Walleye	53	63	156	154	169	181	158	175	206	202	246	39.6	39.4	233	2.0	1.5	1.9	1.5	1.3	1.6
Wyldewood 1	44	40	164	167	177	176	178	192	203	210	246	49.7	38.7	230	1.6	2.3	2.0	2.3	3.3	3.0
Mean	48	50	158	156	169	170	164	178	199	199	237	48.7	43.0	226	2.1	1.5	1.9	1.4	1.6	1.6
Overall mean	44	58	155	156	169	166	164	178	200	201	236	53.3	42.3	224	2.4	1.7	2.1	2.0	2.4	1.8
SD	8.5	15	6.4	5	5.5	6.9	6.2	7.1	6.9	8.8	8.8	8.5	8.0	7	0.8	0.7	0.8	0.8	1.1	0.9

[z]Days from 1 Jan.
[y]Subjective score in which 1 = severe damage; 5 = no injury.

cymes. 'Johns', although low-yielding in 2004, had almost no yield in 2005 at Mountain Grove.

The Corvallis location had additional *S. canadensis* genotypes as well as genotypes of the less winter-hardy *S. nigra* in the planting that were analyzed separately (Tables 7 and 8). The date of full flowering, the number of harvests, and the incidence of blossom blight did not differ significantly between years, whereas the rest of the variables tested were significantly different (Table 7). Although the first flowering date was earlier in 2005 compared with 2004, first ripening date was ≈3 d later (Table 8). *Sambucus nigra* ripened 5 to 6 weeks earlier in Oregon than has been reported for similar cultivars in Denmark (Kaack, 1997). The number of cymes and total yield were greater in the second year, although the weight of each cyme was less. The increased yield was not surprising because the plants were maturing. The two species were different for flowering traits with *S. nigra* flowering over 3 weeks earlier than *S. canadensis*; however, they ripened at the same time. Although *S. nigra* flowered very early in Corvallis, it still flowered well after danger of frost. However, an important advantage of the shorter flower to ripening period for *S. canadensis* would be the decreased chance of fruit being injured by biotic or abiotic stress. The Y × species (S) interactions were not significant, whereas Y × G/S were significant for first flowering, full flowering, and the number of harvests (Table 7). The highest-yielding cultivars were Johns, York, Golden, and Gordon B for *S. canadensis* and Korsør for *S. nigra* (Table 8). The same genotypes also had the highest number of cymes. Cyme weight was highest in 'Maxima' and Barn, both *S. canadensis*, and 'Korsør' (*S. nigra*). The ideal genotype would be high-yielding and inexpensive to harvest by producing fewer very large cymes rather than many smaller cymes (Kaack, 1989; Waźbińska et al., 2004). Unfortunately, for the genotypes in this study, by and large, as the cyme number increased, the yield increased. 'Korsør' is considered high-yielding among *S. nigra* cultivars grown in Denmark, although recently developed cultivars are even more productive (Kaack, 1989, 1997). 'Korsør' was also higher-yielding than 'Haschberg', the traditional industry standard in Europe. The highest-yielding *S. canadensis* cultivars produced significantly more fruit than the highest-yielding *S. nigra* cultivars. The only incidence of blossom blight was on Netzer in 2004 (data not shown). This "blight" may very well have been eriophyid mite damage, but we were not able to identify the causal organism.

Table 6. Mean values for yield related traits for elderberry (*S. canadensis*) cultivars grown at Missouri State University–Mountain Grove, MO and University of Missouri Southwest Center, Mt. Vernon, MO, in 2004 to 2006.

	Number of harvests			Number of cymes			Cyme wt (g/cymes)			Berry wt (g)			Yield (g/plant)		
Source	2004	2005	2006	2004	2005	2006	2004	2005	2006	2004	2005	2006	2004	2005	2006
Mountain Grove, MO															
Adams II	4.0	4.0	3.0	45.6	84.4	15.9	58.6	26.8	24.6	0.055	0.051	0.052	2,660	2,166	377
Competition 5	4.0	3.0	3.0	31.3	65.5	8.7	112.1	30.9	90.5	0.072	0.064	0.051	3,495	1,967	798
Eridu 1	3.5	2.5	3.0	27.1	20.9	4.9	125.9	43.0	117.5	0.078	0.066	0.059	3,318	852	559
Gordon B	3.8	5.0	3.0	54.4	95.6	10.0	63.6	33.5	103.9	0.080	0.066	0.091	3,332	3,170	938
Gordon E	4.0	4.3	2.8	22.9	47.5	10.4	123.5	46.2	91.6	0.074	0.062	0.080	2,780	2,211	894
Harris 4	3.5	2.8	3.0	29.3	22.9	9.1	94.8	15.6	121.3	0.089	0.067	0.072	2,710	367	1,100
Highway O	3.5	3.0	3.0	34.1	25.2	11.2	103.5	22.8	97.3	0.078	0.061	0.070	3,219	547	1,105
Johns	3.8	2.3	2.0	15.1	4.7	2.6	91.7	15.0	49.0	0.082	0.054	0.076	1,362	66	147
Netzer	3.8	3.3	2.5	32.8	67.1	5.2	52.5	15.9	72.7	0.071	0.058	0.046	1,735	1,044	397
Votra	3.8	3.8	2.8	22.8	62.4	6.1	111.5	34.8	137.6	0.074	0.065	0.069	2,349	2,172	844
Walleye	3.5	4.0	3.0	28.9	44.3	10.2	132.2	23.9	64.7	0.107	0.062	0.081	3,442	1,077	661
Wyldewood 1	4.0	3.0	3.0	67.1	93.2	16.0	90.7	36.3	108.1	0.069	0.063	0.052	5,674	3,427	1,729
Mean	3.8	3.4	2.8	34.3	52.8	9.2	96.7	28.7	89.9	0.077	0.062	0.067	3,006	1,589	796
Mt. Vernon, MO															
Adams II	3.0	5.0	7.0	14.1	33.3	15.3	30.1	11.5	27.1	0.066	0.070	0.066	396	379	440
Competition 5	1.8	4.3	2.8	2.5	17.6	4.8	126.2	46.9	144.6	0.102	0.102	0.085	299	833	778
Eridu 1	1.5	3.8	2.8	1.6	6.3	3.9	202.2	52.2	170.4	0.095	0.108	0.083	210	345	649
Gordon B	3.0	4.5	6.8	16.2	47.4	14.1	45.3	28.7	134.3	0.107	0.109	0.097	700	1,324	1,890
Gordon E	3.0	4.3	4.3	6.0	21.2	7.1	100.0	42.8	118.9	0.107	0.100	0.089	511	888	858
Harris 4	2.5	3.5	2.0	7.0	9.5	3.1	69.2	27.4	132.5	0.130	0.135	0.128	533	286	331
Highway O	2.0	4.0	2.8	4.7	10.5	7.8	107.0	43.9	91.1	0.098	0.102	0.099	288	450	723
Johns	1.0	2.7	2.0	1.0	4.8	2.2	65.0	34.7	57.5	0.106	0.110	0.083	65	203	174
Netzer	2.8	3.3	1.3	10.1	17.1	1.5	51.7	39.6	57.0	0.102	0.112	0.114	446	633	81
Votra	3.0	4.3	4.0	5.9	20.0	6.3	76.6	37.6	172.9	0.115	0.124	0.101	466	711	1,114
Walleye	1.5	3.8	1.8	1.7	9.8	6.2	71.3	46.6	89.4	0.131	0.117	0.117	158	435	608
Wyldewood 1	3.0	3.8	1.8	7.6	15.3	1.4	42.0	30.9	58.1	0.088	0.111	0.091	346	428	90
Mean	2.4	3.9	3.3	6.9	18.0	6.1	83.4	36.9	104.5	0.104	0.108	0.096	388	584	644
Overall mean	3.1	3.7	3.0	21.0	35.6	7.6	90.3	32.8	97.2	0.090	0.085	0.081	1,740	1,092	720
SD	0.9	0.9	1.5	19.2	30.3	5.0	56.5	14.6	52.8	0.022	0.029	0.028	1,581	992	557

Table 7. Mean squares and their significances for elderberry cultivars from two species (*S. canadensis*, *S. nigra*) grown at USDA-ARS in Corvallis, OR, in 2004 and 2005.

Source	df	Date of first flowering	Date of full flowering	Date of first ripening	Number of harvests	Yield (g)/plant	Number of cymes	Cyme wt (g/cyme)	Incidence of blossom blight
Year (Y)	1	459.2**	438.6	245.5*	3.9	139,936,363*	550,882**	2,322.0**	0.1
Rep/Y	6	9.5	0.6	23.6	1.3*	20,290,018**	17,944**	80.6	1.4
Species (S)	1	11,718.6**	11,671.1**	17.4	15.8	32,878,534	53,818	47.0	0.1
Genotype (G)/S	11	909.4**	622.6**	497.3**	9.3**	35,884,638*	48,112*	630.4**	0.4
Y × S	1	6.8	15.9	63.4	0.0	5,944,650	443	8.0	0.1
Y × G/S	11	43.0**	34.0*	61.5	1.2*	8,582,489	15,942	101.0	0.4
Error	62	12.6	17.2	52.5	0.5	4,451,118	4,179	60.4	1.5

*, **Significant at 5% and 1%, respectively.

Table 8. Mean values for elderberry cultivars from two species (*S. canadensis* and *S. nigra*) grown at USDA-ARS in Corvallis, OR, in 2004 and 2005.

Source	Date of first flowering[z]	Date of full flowering[z]	Date of first ripening[z]	Number of harvests	Yield (g)/plant	Number of cymes/plant	Cyme wt (g)/cyme
Year							
2004	150.6	162.9	209.6	5.0	3,215.5	99.1	33.2
2005	146.2	157.8	212.5	4.5	5,565.3	262.7	22.5
S. canadensis							
Adams I	157.8	168.2	215.0	4.3	4,323.3	132.3	34.4
Adams II	158.3	169.5	213.9	4.8	3,911.3	133.0	30.5
Barn	160.8	172.8	217.2	3.5	1,961.7	52.3	37.3
Golden	134.6	152.6	216.5	6.4	5,303.8	262.9	26.9
Gordon B	158.8	172.3	211.8	5.8	5,358.3	278.2	21.1
Johns	151.3	162.6	200.5	6.5	9,531.3	289.0	32.5
Maxima	157.3	167.5	212.6	4.4	4,813.8	108.0	44.1
Netzer	181.2	190.0	226.3	2.5	1,083.3	105.0	13.2
Scotia	148.0	158.5	199.9	5.4	3,436.3	274.8	14.9
York	147.7	160.5	197.7	6.0	6,183.3	273.5	25.1
Mean	154.8	166.7	210.8	5.0	4,706.1	194.1	28.3
S. nigra							
Korsør	136.9	147.0	207.9	4.6	5,395.0	153.5	35.1
CSAM 14	119.3	134.6	209.6	3.8	2,100.0	122.1	24.0
Haschberg	133.3	143.5	218.3	3.8	2,913.8	151.6	20.8
Mean	129.8	141.7	211.9	4.0	3,469.6	142.4	26.6
Overall							
Mean	148.4	160.3	211.1	4.8	4,390.4	180.9	27.8
SD	15.7	14.7	10.3	1.4	3,367.9	137.4	12.7

[z]Days from 1 Jan.

Conclusions

This study provides some insight into the performance of genotypes of young elderberry plants at three locations. The lack of significant G × E interactions for the phenological traits and the significant G × E interaction for yield was unfortunate. The Missouri institutions have a long-term commitment to elderberry research and the Pacific Northwest is a fantastic place to grow berries. We had hoped that performance, particularly for yield in Missouri, would reflect performance in Oregon, but this was not reliably the case. As new cultivars are developed in Missouri, it will be necessary to trial them in the Pacific Northwest to determine whether they have sufficient yield to be commercially viable there.

Across the locations in Missouri, although there were differences among genotypes for the phenological traits, there were no differences resulting from location. Yield differences were not seen resulting from location, year, or genotype, but there were significant interactions. Although the yields at Mt. Vernon were numerically lower than those at Mountain Grove, there was enough variability overall to obscure differences that might have been real. Several selections in replicated trials in Missouri such as 'Gordon B', Gordon E, Competition 5, and Votra were numerically among the highest-yielding cultivars and are probably worthy of further evaluation. A study that looked just at these genotypes in comparison with the current standard cultivars might expose more subtle differences not apparent in this study that included so many genotypes. Although *S. nigra* can be grown quite successfully in Oregon, *S. canadensis* cultivars could be selected that are higher-yielding and that have acylated anthocyanins in their fruit (Lee and Finn, 2007). If a grower can successfully manage *S. canadensis* with its multiple shoots, it would probably be a better commercial choice. Although several of these *S. canadensis* genotypes are likely to do well in Oregon, 'Johns' and 'York' offer the most promise based on yield, and the selections 'Gordon B' and the ornamental 'Golden' are probably worthy of further evaluation. Although 'York' looks promising from a yield perspective, it was one of three cultivars that Lee and Finn (2007) could not recommend as a result of its low level of polyphenolics.

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