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Inbreeding, Coancestry, and Founding Clones of Sweet Cherries from North America

Cheol Choi[1] and Frank Kappel
Agriculture and Agri-Food Canada, Pacific Agri-Food Research Centre, Summerland, BC V0H 1Z0, Canada

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ABSTRACT. **Inbreeding and coancestry coefficients were calculated for 66 sweet cherry (*Prunus avium* L.) selections released from four breeding programs in North America (HRIO, Vineland, Ont., IAREC, Prosser, Wash., NYSAES, Geneva, N.Y., and PARC, Summerland, B.C.). Highly used founding clones were 'Black Heart', 'Emperor Francis', 'Empress Eugenie', 'Napoleon' and 'Windsor'. Coefficients of coancestry between all selections and these clones averaged 0.038, 0.045, 0.060, 0.091, and 0.033, respectively. In these five founding clones, coefficients of coancestry in self-compatible selections were over twice as much as those in self-incompatible selections except 'Windsor'. In the analysis of coefficients of coancestry between self-incompatible and self-compatible sweet cherry, almost 20% of self-incompatible selections represent more than a half-sib relationship (0.125) to self-compatibles. Increasing and maintaining genetic diversity is needed in sweet cherry breeding program in North America for continued breeding progress.**

In North America, cherry was introduced as seeds by early settlers in the northeastern United States and was later brought into the Midwest and Pacific West Coast (Hedrick, 1915). Sweet cherry (*Prunus avium* L.) improvement was initiated in North America by the Lewelling family in Oregon (Brown et al., 1996). 'Lambert' and 'Bing' were first selected from the seed of 'Napoleon' in about 1848 and 'Republican' in 1875, respectively (Hedrick, 1915). Early institutional sweet cherry breeding programs began at the New York State Agricultural Experiment Station, Geneva, in 1911; Horticultural Research Institute of Ontario, Vineland Station, Ont., Canada, in 1915; and Agriculture Agri-Food Canada, Summerland, B.C., in 1936 (Kappel and Lay, 1997; Wellington and Lamb, 1950).

Although most sweet cherries are self-incompatible and outbreeding diploids, inbreeding is increased when parents have common ancestors. The repeated use of a limited number of parents and their progeny as parents may decrease genetic diversity and increase inbreeding depression in future generations. Previous studies using molecular marker analysis showed a low degree of genetic diversity in sweet cherry cultivars (Gerlach and Stosser, 1998; Shimada et al., 1999; Zhou et al., 2002).

Although different regions have different breeding objectives, sweet cherry breeding in North America has recently mainly focused on self-compatibility, tolerance to rain-induced cracking, fruit size, fruit firmness, and disease resistance. The first self-compatible sweet cherry seedlings were produced by a cross that was a result of 'Emperor Francis' seed donor and X-irradiation of 'Napoleon' pollen (Lewis and Crowe, 1954) at the John Innes Institute in the United Kingdom. After that, the first commercial self-compatible sweet cherry, 'Stella'('Lambert' X 'JI 2420'), was introduced from the Pacific Agri-Food Research Centre (PARC), Summerland, B.C. (Lapins, 1970). All self-compatible selections released have been derived from 'Stella'. The data presented describes the level of inbreeding, coancestry and genetic contribution of founding clones among sweet cherry selections in

Table 1. Parentage of 66 sweet cherry selections from four North American breeding programs.

Selection	Parentage	Breeding programs[z]
2N-39-05	Van x Stella	PARC
2N-60-07	Bing[y] x Stella	PARC
2N-61-18	Star x Van	PARC
2N-63-20	Bing[y] x Salmo	PARC
Benton	Stella x Beaulieu	IAREC
Blackgold	Stark Gold x Stella	NYSAES
Cashmere	Stella x Early Burlat	IAREC
Celeste	Van x Newstar	PARC
Chelan	Stella x Beaulieu	IAREC
Chinook	Gil Peck x Bing[y]	IAREC
Cristalina	Star x Van	PARC
Gil Peck	Napoleon x Giant	NYSAES
Glacier	Stella x Early Burlat	IAREC
Hartland	Windsor x unknown	NYSAES
Hudson	Oswego x Giant	NYSAES
Index	Stella x unknown	IAREC
Kristin	Emperor Francis x Gil Peck	NYSAES
Lapins	Van x Stella	PARC
Newmoon	Van x Stella	PARC
Newstar	Van x Stella	PARC
NY1725	Giant x Emperor Francis	NYSAES
Olympus	Lambert[y] x Van	IAREC
P8-79	Rainier x Bing[y]	IAREC
Rainier	Bing[y] x Van	IAREC
Royalton	NY1725 x unknown	NYSAES
Salmo	Lambert[y] x Van	PARC
Sam	V1060140 x unknown	PARC
Sandra Rose	2N-61-18 x Sunburst	PARC
Santina	Stella x Summit	PARC
Selah	P8-79 x Stella	IAREC
Simcoe	Stella x unknown	IAREC
Skeena	2N-38-22[y] x 2N-60-07[y]	PARC
Sodus	Napoleon x Giant	NYSAES
Somerset	Van x Vic	NYSAES
Sonata	Lapins x 2N-39-05	PARC
Sparkle	Empress Eugenie x unknown	PARC
Staccato	Sweetheart x unknown	PARC
Star	Deacon x unknown	PARC

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[1] Department of Horticulture, Hankyong National University, Ansung-city, Kyonggi-do, 456-749, Korea. To whom reprint requests should be addressed; e-mail choic@agr.gc.ca

Table 1 (continued). Parentage of 66 sweet cherry selections from four North American breeding programs.

Selection	Parentage	Breeding programs[z]
Stardust	2N-63-20 x Stella	PARC
Stella	Lambert[y] x JI2420[y]	PARC
Sue	Bing[y] x Schmidt	PARC
Summer Jewel	2N-61-18[y] x 2S-28-30[y]	PARC
Summit	Van x Sam	PARC
Sunburst	Van x Stella	PARC
Sweetheart	Van x Newstar	PARC
Sylvia	Van x Sam	PARC
Symphony	Lapins x Bing[y]	PARC
Tehranivee	Van x Stella	HRIO
Tieton	Stella x Early Burlat	IAREC
Ulster	Schmidt x Lambert[y]	NYSAES
V1060140	Windsor x unknown	HRIO
V35024	Hedelfingen x Bing[y]	HRIO
V35029	Hedelfingen x Bing[y]	HRIO
Valera	Hedelfingen x Windsor	HRIO
Van	Empress Eugenie x unknown	PARC
Vandalay	Van x Stella	HRIO
Velvet	Windsor x unknown	HRIO
Venus	Hedelfingen x Windsor	HRIO
Vernon	Windsor x unknown	HRIO
Vic	Bing[y] x Schmidt	HRIO
Victor	Windsor x unknown	HRIO
Viscount	V35024 x V35029	HRIO
Vista	Hedelfingen x Victor	HRIO
Viva	Hedelfingen x Windsor	HRIO
Vogue	Hedelfingen x Windsor	HRIO
Whitegold	Emperor Francis x Stella	NYSAES

[z] Irrigated Agriculture Research and Extension Center (IAREC), Prosser, Wash.; Horticultural Research Institute of Ontario (HRIO), Vineland Station, Ont., Canada; New York State Agricultural Experiment Station (NYSAES), Geneva; Pacific Agri-Food Research Centre (PARC), Summerland, B.C., Canada.

[y] 2N-38-22 = 'Van' x 'Stella'; 2N-60-07 = 'Bing' x 'Stella'; 2S-28-30 = 'Van' x 'Stella'; 'Bing' = 'Black Republican'[x] x Unknown; JI2420 = 'Emperor Francis' x 'Napoleon' (mutated pollen); 'Lambert' = 'Napoleon' x 'Black Heart'.

[x] Black Republican was assumed to be the result of 'Napoleon' x 'Black Tartarian' (Hedrick, 1915).

North American breeding programs as previous studies in other fruit species (Byrne, 1989; Hancock and Siefker, 1982; Lansari et al., 1994; Noiton and Alspach, 1996; Scorza et al., 1985).

Materials and Methods

Pedigrees of 66 sweet cherry cultivars and breeding selections released from four breeding programs (15 from HRIO, Vineland, Ont., 12 from IAREC, Prosser, Wash., 11 from NYSAES, Geneva, N.Y., and 28 from PARC, Summerland, B.C.) in North America were collected from breeding records, published sources (Bargioni, 1996; Brooks and Olmo, 1972, 1997; Hedrick, 1915; Kappel and Lay, 1997), and via direct communication (R.L. Andersen and G. Lang, personal communication) (Table 1). 'Black Republican' was considered the result of 'Napoleon' by 'Black Tartarian' in this analysis (Hedrick, 1915). All parents of unknown origin were assumed to be noninbred and unrelated and also all open pollinations were assumed to be noninbred and unrelated to the pollen parent. These assumptions were based on the self-incompatibility in sweet cherry, may underestimate possible inbreeding and would give lower inbreeding coefficients. All 66 selections were classified into two groups by self-compatibility (42 self-incompatible and 24 self-compatible).

As with previous studies (Byrne, 1989; Scorza et al., 1985), the SAS procedure INBREED (Barr, 1983) was used to calculate inbreeding and coancestry coefficients. In this analysis, the inbreeding coefficient of an individual is the probability that a pair of alleles carried by the gametes that produced it are identical by descent (Falconer and Mackay, 1996) and is equal to the coancestry between its parents (Barr, 1983). The coancestry coefficient of prospective progeny of two individuals is equal to one half the covariance of the parents. Since the inbreeding coefficient of an individual is equal to the coancestry coefficient of its parents, the coancestry coefficient of two selections was calculated as the inbreeding coefficient of their prospective progeny (Lansari et al., 1994).

The inbreeding coefficients were calculated for all 66 sweet cherry selections, and the degree of relationship of these 66 selections with the five founding clones, 'Black Heart', 'Emperor Francis', 'Empress Eugenie', 'Napoleon', and 'Windor' was analyzed by calculation of coefficients of coancestry. Coefficients of coancesty

Table 2. Inbreeding coefficients and coancestry coefficients with 'Black Heart', 'Emperor Francis', 'Empress Eugenie', 'Napoleon' and 'Windsor' of 66 sweet cherry selections released from North American programs.

		Coefficient of coancestry[y] with				
Selection	Inbreeding coefficients	Black Heart	Emperor Francis	Empress Eugenie	Napoleon	Windsor
Self-incompatible						
2N-60-07	0.063	0.063	0.063	---	0.188	---
2N-61-18	---[z]	---	---	0.125	---	---
2N-63-20	0.031	0.063	---	0.063	0.125	---
Chelan	---	0.063	0.063	---	0.125	---
Chinook	---	---	---	---	0.188	---
Cristalina	---	---	---	0.125	---	---
Gil Peck	---	---	---	---	0.250	---
Hartland	---	---	---	---	---	0.250
Hudson	---	---	---	---	---	---
Kristin	---	---	0.250	---	0.125	---
NY1725	---	---	0.250	---	---	---
Olympus	---	0.125	---	0.125	0.125	---
P8-79	0.250	---	---	0.063	0.094	---
Raininer	---	---	---	0.125	0.063	---
Royalton	---	---	0.125	---	---	---

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Table 2 (continued). Inbreeding coefficients and coancestry coefficients with ‘Black Heart’, ‘Emperor Francis’, ‘Empress Eugenie’, ‘Napoleon’ and ‘Windsor’ of 66 sweet cherry selections released from North American programs.

		Coefficient of coancestry^{y} with				
Selection	Inbreeding coefficients	Black Heart	Emperor Francis	Empress Eugenie	Napoleon	Windsor
Salmo	---	0.125	---	0.125	0.125	---
Sam	---	---	---	---	---	0.125
Simcoe	---	0.063	0.063	---	0.125	---
Sodus	---	---	---	---	0.250	---
Somerset	---	---	---	0.125	0.031	---
Sparkle	---	---	---	0.250	---	---
Star	---	---	---	---	---	---
Sue	---	---	---	---	0.063	---
Summer Jewel	0.125	0.031	0.031	0.125	0.063	---
Summit	---	---	---	0.125	---	0.063
Sylvia	---	---	---	0.125	---	0.063
Tieton	---	0.063	0.063	---	0.125	---
Ulster	---	0.125	---	---	0.125	---
V1060140	---	---	---	---	---	0.125
V35024	---	---	---	---	0.063	---
V35029	---	---	---	---	0.063	---
Valera	---	---	---	---	---	0.250
Van	---	---	---	0.250	---	---
Velvet	---	---	---	---	---	0.250
Venus	---	---	---	---	---	0.250
Vernon	---	---	---	---	---	0.250
Vic	---	---	---	---	0.063	---
Victor	---	---	---	---	---	0.250
Viscount	0.250	---	---	---	0.063	---
Vista	---	---	---	---	---	0.125
Viva	---	---	---	---	---	0.250
Vogue	---	---	---	---	---	0.250
Mean	*0.144*	*0.017*	*0.022*	*0.042*	0.058	*0.063*
Self-compatible						
2N-39-05	---	0.063	0.063	0.125	0.125	---
Benton	---	0.063	0.063	---	0.125	---
Blackgold	---	0.063	0.063	---	0.125	---
Cashmere	---	0.063	0.063	---	0.125	---
Celeste	0.250	0.031	0.031	0.188	0.063	---
Glacier	---	0.063	0.063	---	0.125	---
Index	---	0.063	0.063	---	0.125	---
Lapins	---	0.063	0.063	0.125	0.125	---
Newmoon	---	0.063	0.063	0.125	0.125	---
Newstar	---	0.063	0.063	0.125	0.125	---
Sandra Rose	0.125	0.031	0.031	0.125	0.063	---
Santina	---	0.063	0.063	0.063	0.125	0.031
Selah	0.047	0.063	0.063	0.031	0.172	---
Skeena	0.156	0.063	0.063	0.063	0.156	---
Sonata	0.266	0.063	0.063	0.125	0.125	---
Staccato	---	0.016	0.016	0.094	0.031	---
Stardust	0.109	0.094	0.063	0.031	0.188	---
Stella	0.125	0.125	0.125	---	0.250	---
Sunburst	---	0.063	0.063	0.125	0.125	---
Sweetheart	0.250	0.031	0.031	0.188	0.063	---
Symphony	0.031	0.031	0.031	0.063	0.125	---
Tehranivee	---	0.063	0.063	0.125	0.125	---
Vandalay	---	0.063	0.063	0.125	0.125	---
Whitegold	0.125	0.063	0.313	---	0.125	---
Mean	*0.148*	*0.059*	*0.068*	*0.077*	*0.124*	*0.002*
Grand Mean	0.146	0.038	0.045	0.060	0.091	0.033

[z] Dashes indicate no inbreeding or coancestry of known parents.

[y] Mean coefficients of coancestry calculated with dashes = zero.

Table 3. Coefficient of coancestry of self-incompatible sweet cherry selections released from North American breeding programs[z].

Selection	1[y]	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1) 2N-60-07	531	---[w]	188	156	188	---	94	---	---	78	31	94	211	141	16	94	---	156	94	70	---	---	141	78
2) 2N-61-18		500	63	---	---	250	---	---	---	---	---	125	63	125	---	125	---	---	---	125	63	250	---	313
3) 2N-63-20			516	55	164	63	63	---	---	31	---	141	230	195	---	266	---	55	63	129	31	---	133	90
4) Chelan				500	47	---	63	---	---	63	31	78	23	16	16	78	---	141	63	8	---	---	16	70
5) Chinook					531	---	281	---	63	141	63	47	211	141	31	47	---	47	156	70	---	---	141	23
6) Cristalina						500	---	---	---	---	---	125	63	125	---	125	---	---	---	125	63	250	---	188
7) Gil Peck							500	---	125	250	125	63	47	31	63	63	---	63	250	16	---	---	31	31
8) Hartland								500	---	---	---	---	---	---	---	---	63	---	---	---	---	---	---	---
9) Hudson									500	63	125	---	---	---	63	---	---	---	125	---	---	---	---	---
10) Kristin										500	188	31	23	16	94	31	---	63	125	8	---	---	16	31
11) NY1725											500	---	---	---	250	---	---	31	125	---	---	---	---	16
12) Olympus												500	86	141	---	250	---	78	63	133	63	---	16	164
13) P8-79													625	375	---	86	---	23	47	156	31	---	188	74
14) Rainier														500	---	141	---	16	31	188	63	---	125	133
15) Royalton															500	---	---	16	63	---	---	---	---	8
16) Salmo																500	---	78	63	133	63	---	16	164
17) Sam																	500	---	---	---	---	---	---	---
18) Simcoe																		500	63	8	---	---	16	70
19) Sodus																			500	16	---	---	31	31
20) Somerset																				500	63	---	125	129
21) Sparkle																					500	---	---	63
22) Star																						500	---	125
23) Sue																							500	8
24) Summer Jewel																								563
25) Summit																								
26) Sylvia																								
27) Tieton																								
28) Ulster																								
29) V1060140																								
30) V35024																								
31) V35029																								
32) Valera																								
33) Van																								
34) Velvet																								
35) Venus																								
36) Vernon																								
37) Vic																								
38) Victor																								
39) Viscount																								
40) Vista																								
41) Viva																								
42) Vogue																								
Mean																								

[z] Coefficients of coancestry values × 1000.
[y] Numbers across top of table refer to selection numbers at far left of table.
[x] Mean coefficient of coancestry excluding selfing.
[w] Mean coefficient of coancestry calculated with dashes = 0.

were also calculated among the 42 self-incompatibles, among 24 self-compatibles and among the 66 sweet cherries together.

Results and Discussion

Of the 66 selections analyzed, 15 (5 and 10 from self-incompatible and self-compatible selections, respectively) had an inbreeding coefficient other than zero (Table 2). The overall mean inbreeding coefficient was 0.146 for all selections and cultivars, where their parentages were known. If we assumed an inbreeding coefficient for selections of unknown parentage to be zero (nonrelated with known parentage), the overall mean inbreeding coefficients would be lowered (0.033). The mean for self-compatible and self-incompatible selections were 0.148 and 0.144, respectively. These figures are high considering that a value of 0.063 would result from first cousin mating of noninbred, nonrelated diploids, 0.125 from half-sib mating, 0.250 from full-sibs, and 0.500 from selfing. Compared to other fruit species, the inbreeding level of sweet cherry is not as high as peach (0.26 to 0.35) (Scorza et al., 1985), but higher than blueberry (0.13) (Hancock and Siefker, 1982), raspberry (0.12) (Dale et al., 1993), plum (0.02 to 0.05) (Byrne, 1989), and apple (0.01 to 0.04) (Noiton and Alspach, 1996). It can be expected that the inbreeding level of future self-compatible selections will be elevated unless self-compatible genes other than S4' (mutation from 'Napoleon' pollen) are utilized in sweet cherry breeding programs.

Sixty-four selections (out of a total of 66) released from four sweet cherry breeding programs in North America were found to be descended from only five founding clones: 'Black Heart', 'Emperor Francis', 'Empress Eugenie', 'Napoleon', and 'Windsor'. These results suggest that these five founding clones have formed an exceptionally narrow germplasm base in the North American sweet cherry breeding program. Two cultivars, 'Hudson'(= 'Oswego' x 'Giant') and 'Star' (= 'Deacon' x unknown) were not related to these five clones.

'Black Heart', one of the oldest cherries under cultivation, contributed to 9 of the 42 self-incompatible selections and 100% of the self-compatible selections. Along with 'Black Heart', 'Emperor Francis', and 'Napoleon' have also contributed to all of the self-compatible selections. The extensive use of 'Emperor Francis'

25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	Mean[x]
---	---	156	94	---	141	141	---	---	---	---	---	141	---	141	---	---	---	67
125	125	---	---	---	---	---	---	250	---	---	---	---	---	---	---	---	---	48
63	63	55	78	---	133	133	---	125	---	---	---	133	---	133	---	---	---	70
---	---	141	78	---	16	16	---	---	---	---	---	16	---	16	---	---	---	35
---	---	47	47	---	141	141	---	---	---	---	---	141	---	141	---	---	---	61
125	125	---	---	---	---	---	---	250	---	---	---	---	---	---	---	---	---	45
---	---	63	63	---	31	31	---	---	---	---	---	31	---	31	---	---	---	47
31	31	---	---	125	---	---	125	---	125	125	125	---	125	---	63	125	125	28
---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	13
---	---	63	31	---	16	16	---	---	---	---	---	16	---	16	---	---	---	35
---	---	31	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	25
125	125	78	125	---	16	16	---	250	---	---	---	16	---	16	---	---	---	60
63	63	23	23	---	188	188	---	125	---	---	---	188	---	188	---	---	---	72
125	125	16	16	---	125	125	---	250	---	---	---	125	---	125	---	---	---	73
---	---	16	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	15
125	125	78	125	---	16	16	---	250	---	---	---	16	---	16	---	---	---	63
250	250	---	---	250	---	---	63	---	63	63	63	---	63	---	31	63	63	31
---	---	141	78	---	16	16	---	---	---	---	---	16	---	16	---	---	---	32
---	---	63	63	---	31	31	---	---	---	---	---	31	---	31	---	---	---	41
125	125	8	70	---	63	63	---	250	---	---	---	250	---	63	---	---	---	60
63	63	---	---	---	---	---	---	125	---	---	---	---	---	---	---	---	---	18
---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	15
---	---	16	141	---	125	125	---	---	---	---	---	250	---	125	---	---	---	43
125	125	70	39	---	8	8	---	250	---	---	---	8	---	8	---	---	---	60
500	250	---	---	125	---	---	31	250	31	31	31	---	31	---	16	31	31	52
	500	---	---	125	---	---	31	250	31	31	31	---	31	---	16	31	31	52
		500	78	---	16	16	---	---	---	---	---	16	---	16	---	---	---	32
			500	---	16	16	---	---	---	---	---	141	---	16	---	---	---	34
				500	---	---	125	---	125	125	125	---	125	---	63	125	125	37
					500	250	125	---	---	125	---	125	---	375	125	125	125	59
						500	125	---	---	125	---	125	---	375	125	125	125	59
							500	---	125	250	125	---	125	125	188	250	250	49
								500	---	---	---	---	---	---	---	---	---	63
									500	125	125	---	125	---	63	125	125	28
										500	125	---	125	125	188	250	250	49
											500	---	125	---	63	125	125	28
												500	---	125	---	---	---	46
													500	---	250	125	125	33
														625	125	125	125	62
															500	188	188	40
																500	250	49
																	500	49
																		45

and 'Napoleon' can be explained by the original creation of self-compatibility in sweet cherry. 'Emperor Francis' contributed to 8 of the 42 self-incompatible selections. 'Napoleon' also known as 'Royal Ann', grown in Europe in the early 18th century, was most frequently found in the pedigree of self-incompatible selections in North America (21 of 42). Although 'Napoleon' has less desirable traits such as susceptibility to brown rot and cracking, it has outstanding breeding material characteristics, including firm flesh, large size, and attractive appearance of the fruit, along with good productivity of the trees (Hedrick, 1915). This cultivar has been grown largely for processing (Bargioni, 1996). 'Empress Eugenie' was found in the development of many cultivars from PARC, Summerland, B.C. However, none of the cultivars directly used 'Empress Eugenie' as a parent except 'Sparkle' and 'Van'. Due to its good fruit characteristics (i.e., fruit size, firmness, and flavor) and tree hardiness (Lapins et al., 1977), 'Van' ('Empress Eugenie' × unknown) was used extensively in North American breeding programs and was an intermediate parent in 80% of the cultivars and selections developed at Summerland, B.C. 'Windsor' was almost exclusively used in the cherry breeding program at HRIO (9 of 15), the region where the cultivar originated (Hedrick, 1915).

The average coancestry within self-incompatible sweet cherry is 0.045 and mean coefficients range from 0.013 to 0.073 (Table 3). These values were comparable with coancestry of apples in the 50 world main-stream cultivars (average 0.052; range 0.006 to 0.090) and *Vf*-carrier (average 0.051; range 0.017 to 0.088) groups (Noiton and Alspach, 1996). Coefficients of coancestry among self-compatible selections range from 0.102 to 0.256 (Table 4), and these values were much higher than coancestry in self-incompatible sweet cherry selections (0.013 to 0.073) or plums (0.069 to 0.080) (Byrne, 1989) and comparable with average coancestry reported for peaches (0.023 to 0.208, 0.034 to 0.330) (Scorza et al., 1985). In the case of peaches, some cultivars were reported or assumed to be the result of self-pollinations; however, there are no reports that sweet cherry selections were the result of self-pollination. Without any self-pollination, the average coancestry within self-compatible selections is 0.179 and it is considered quite high (0.125 = half-sib relationship). Only one out of 22 self-compatible selections had coefficients of

Table 4. Coefficient of coancestry of self-compatible sweet cherry selections released from North American breeding programs[z].

Selection	1[y]	2	3	4	5	6	7	8	9	10	11	12
1) 2N-39-05	500	141	141	141	258	141	141	266	266	266	195	203
2) Benton		500	141	141	70	141	141	141	141	141	70	141
3) Blackgold			500	141	70	141	141	141	141	141	70	141
4) Cashmere				500	70	266	141	141	141	141	70	141
5) Celeste					625	70	70	258	258	375	223	164
6) Glacier						500	141	141	141	141	70	141
7) Index						500	141	141	141	70	141	152
8) Lapins								500	266	266	195	203
9) Newmoon									500	266	195	203
10) Newstar										500	195	203
11) Sandra Rose											563	133
12) Santina												500
13) Selah												
14) Skeena												
15) Sonata												
16) Staccato												
17) Stardust												
18) Stella												
19) Sunburst												
20) Sweetheart												
21) Symphony												
22) Tehranivee												
23) Vandalay												
24) Whitegold												
Mean coefficent of coancestry												

[z]Coefficients of coancestry values X 1000.

[y]Numbers across top of table refer to genotype numbers at far left of table.

[x]Mean coefficient of coancestry excluding selfing.

coancestry less than a half-sib relationship (0.125). 'Stella', the first commercial self-compatible cultivar, recorded the highest coefficient of coancestry value (0.256), which is greater than a parent–offspring relationship (0.250).

The coefficients of coancestry between self-incompatible and self-compatible sweet cherry range from 0 to 0.168 with an overall mean of 0.060 (Table 5). In the self-compatible selections, all selections were quite consistently related to self-incompatible selections (0.035 to 0.077). Eight out of 42 self-incompatible selections were more closely related to self-compatible groups (i.e., coancestry >0.125; half-sib relationship). These numbers may be underestimated because we assumed unknown or open pollinated parents were not related with the known parent.

The inbreeding problem and potential genetic limitations have been raised for numerous other fruit species (Lansari et al., 1994; Noiton et al., 1994). Our results suggest the repeated use of five founding clones and one genetic source for self-compatibility has narrowed the genetic base of sweet cheery breeding in North America. As the gene pool gets narrower and narrower so does the genetic gain. A lack of diverse germplasm may limit long-term progress in sweet cherry breeding programs.

In sweet cherry breeding programs, redundant use of the same parents and their progeny can greatly limit prospects for continued success (Andersen, 1998). For continued improvement of commercial traits in sweet cherry genetic diversity should be maximized and loss of diversity minimized. Possible methods to accomplish this include using more diverse parents in crossing, using the other self-compatible sweet cherry allele(s) that the John Innes Institute developed (Tehrani and Brown, 1992), and searching for naturally occurring self-compatible mutants in sweet cherry such as in sour cherry (Yamane et al., 2003) and Japanese apricot (Tao et al., 2002). Maximizing genetic diversity is important, since it enhances the potential gain from selection (Lansari et al., 1994). Unexposed (wild) germplasm should be collected and introduced in future sweet cherry breeding programs. To minimize the loss of genetic diversity, one could adopt a modified backcross design to avoid inbreeding (Crosby et al., 1992) or a recurrent selection for combining ability as in an apple breeding population (Noiton and Shelbourne, 1992).

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13	14	15	16	17	18	19	20	21	22	23	24	Mean[x]
184	211	383	129	199	281	266	258	148	266	266	172	214
152	148	141	35	168	281	141	70	86	141	141	172	134
152	148	141	35	168	281	141	70	86	141	141	172	134
152	148	141	35	168	281	141	70	86	141	141	172	139
123	168	258	188	131	141	258	375	137	258	258	86	185
152	148	141	35	168	281	141	70	86	141	141	172	139
148	141	35	168	281	141	70	86	141	141	172	134	
184	211	383	129	199	281	266	258	266	266	266	172	219
184	211	266	129	199	281	266	258	148	266	266	172	209
184	211	266	188	199	281	266	375	148	266	266	172	221
107	137	195	111	115	141	313	223	105	195	195	86	148
168	180	203	82	184	281	203	164	117	203	203	172	173
523	223	184	62	237	305	184	123	201	184	184	184	172
	578	211	84	225	297	211	168	184	211	211	180	186
		633	129	199	281	266	258	207	266	266	172	221
			500	65	70	129	313	68	129	129	43	102
				555	336	199	131	182	199	199	199	184
					563	281	141	172	281	281	344	256
						500	258	148	266	266	172	214
							625	137	258	258	86	191
								516	148	148	102	139
									500	266	172	209
										500	172	209
											563	162
												179

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Table 5. Coefficient of coancestry of 66 selected sweet cherry selections released from North American breeding programs.

Selection	2N-39-05	Benton	Blackgold	Cashmere	Celeste	Glacier	Index	Lapins	Newmoon	Newstar	Sandra Rose	Santina	Selah
2N-60-07	156	156	156	156	78	156	156	156	156	156	78	156	262
2N-61-18	125	---[y]	---	---	188	---	---	125	125	125	313	63	31
2N-63-20	117	55	55	55	121	55	55	117	117	117	90	86	170
Chelan	141	266	141	141	70	141	141	141	141	141	70	141	152
Chinook	47	47	47	47	23	47	47	47	47	47	23	47	152
Cristalina	125	---	---	---	188	---	---	125	125	125	188	63	31
Gil Peck	63	63	63	63	31	63	63	63	63	63	31	63	86
Hartland	---	---	---	---	---	---	---	---	---	---	---	16	---
Hudson	---	---	---	---	---	---	---	---	---	---	---	---	---
Kristin	63	63	63	63	31	63	63	63	63	63	31	63	74
NY1725	31	31	31	31	16	31	31	31	31	31	16	31	31
Olympus	203	78	78	78	227	78	78	203	203	203	164	141	121
P8-79	86	23	23	23	105	23	23	86	86	86	74	55	336
Rainier	141	16	16	16	195	16	16	141	141	141	133	78	203
Royalton	16	16	16	16	8	16	16	16	16	16	8	16	16
Salmo	203	78	78	78	227	78	78	203	203	203	164	141	121
Sam	---	---	---	---	---	---	---	---	---	---	---	125	---
Simcoe	141	141	141	141	70	141	141	141	141	141	70	141	152
Sodus	63	63	63	63	31	63	63	63	63	63	31	63	86
Somerset	133	8	8	8	191	8	8	133	133	133	129	70	86
Sparkle	63	---	---	---	94	---	---	63	63	63	63	31	16
Star	---	---	---	---	---	---	---	---	---	---	125	---	---
Sue	16	16	16	16	8	16	16	16	16	16	8	16	109
Summer Jewel	195	70	70	70	223	70	70	195	195	195	254	133	107
Summit	125	---	---	---	188	---	---	125	125	125	125	250	31
Sylvia	125	---	---	---	188	---	---	125	125	125	125	125	31
Tieton	141	141	141	266	70	266	141	141	141	141	70	141	152
Ulster	78	78	78	78	39	78	78	78	78	78	39	78	90
V1060140	---	---	---	---	---	---	---	---	---	---	---	63	---
V35024	16	16	16	16	8	16	16	16	16	16	8	16	109
V35029	16	16	16	16	8	16	16	16	16	16	8	16	109
Valera	---	---	---	---	---	---	---	---	---	---	---	16	---
Van	250	---	---	---	375	---	---	250	250	250	250	125	63
Velvet	---	---	---	---	---	---	---	---	---	---	---	16	---
Venus	---	---	---	---	---	---	---	---	---	---	---	16	---
Vernon	---	---	---	---	---	---	---	---	---	---	---	16	---
Vic	16	16	16	16	8	16	16	16	16	16	8	16	109
Victor	---	---	---	---	---	---	---	---	---	---	---	16	---
Viscount	16	16	16	16	8	16	16	16	16	16	8	16	109
Vista	---	---	---	---	---	---	---	---	---	---	---	8	---
Viva	---	---	---	---	---	---	---	---	---	---	---	16	---
Vogue	---	---	---	---	---	---	---	---	---	---	---	16	---
Mean	71	46	35	37	72	37	35	71	71	71	64	66	77

[z] Coefficients of coancestry values X 1000.

[y] Mean coefficient of coancestry calculated with dashes = 0.

Skeena	Sonata	Staccato	Stardust	Stella	Sunburst	Sweetheart	Symphony	Tehranivee	Vandalay	Whitegold	Mean
344	156	39	250	313	156	78	219	156	156	188	168
63	125	94	31	---	125	188	63	125	125	---	85
152	117	61	313	109	117	121	191	117	117	55	112
148	141	35	168	281	141	70	86	141	141	172	140
117	47	12	129	94	47	23	164	47	47	47	60
63	125	94	31	---	125	188	63	125	125	---	79
78	63	16	94	125	63	31	63	63	63	63	62
---	---	---	---	---	---	---	---	---	---	---	1
---	---	---	---	---	---	---	---	---	---	---	0
70	63	16	78	125	63	31	47	63	63	188	65
31	31	8	31	63	31	16	16	31	31	156	34
148	203	113	148	156	203	227	117	203	203	78	152
148	86	53	139	47	86	105	230	86	86	23	88
141	141	98	113	31	141	195	195	141	141	16	108
16	16	4	16	31	16	8	8	16	16	78	17
148	203	113	211	156	203	227	117	203	203	78	155
---	---	---	---	---	---	---	---	---	---	---	5
148	141	35	168	281	141	70	86	141	141	172	134
78	63	16	94	125	63	31	63	63	63	63	62
102	133	96	72	16	133	191	129	133	133	8	91
31	63	47	16	---	63	94	31	63	63	---	38
---	---	---	---	---	---	---	---	---	---	---	5
78	16	4	82	31	16	8	133	16	16	16	29
137	195	111	115	141	195	223	105	195	195	86	148
63	125	94	31	---	125	188	63	125	125	---	85
63	125	94	31	---	125	188	63	125	125	---	79
148	141	35	168	281	141	70	86	141	141	172	145
86	78	20	117	156	78	39	55	78	78	78	76
---	---	---	---	---	---	---	---	---	---	---	3
78	16	4	82	31	16	8	133	16	16	16	29
78	16	4	82	31	16	8	133	16	16	16	29
---	---	---	---	---	---	---	---	---	---	---	1
125	250	188	63	---	250	375	125	250	250	---	154
---	---	---	---	---	---	---	---	---	---	---	1
---	---	---	---	---	---	---	---	---	---	---	1
---	---	---	---	---	---	---	---	---	---	---	1
78	16	4	82	31	16	8	133	16	16	16	29
---	---	---	---	---	---	---	---	---	---	---	1
78	16	4	82	31	16	8	133	16	16	16	29
---	---	---	---	---	---	---	---	---	---	---	0
---	---	---	---	---	---	---	---	---	---	---	1
---	---	---	---	---	---	---	---	---	---	---	1
74	71	36	75	69	71	72	73	71	71	46	60