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Evaluation of Scab (*Venturia inaequalis*) Severity on 54 Cultivars of Apple in an Unsprayed Common Planting

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Abstract

Seventy apple (*Malus* × *domestica* Borkh.) genotypes were evaluated in a common planting to identify clones with partial resistance to apple scab [*Venturia inaequalis* (Cke.) Wint.] that could be used in a durable scab resistance breeding program. Fifty-four cultivars and 14 breeding selections of cultivated apple, and one clone each of *Malus floribunda* and *Malus sikkimensis* were evaluated. Two to ten replicate trees per genotype were propagated on dwarf rootstocks and planted into raised beds covered with black plastic at Agassiz, BC, Canada, a site with severe annual scab epidemics. No fungicides were applied. Field resistance to natural scab infection was rated on a 0 to 5 scale for each plant for three consecutive years. Scab-susceptible standards such as 'Delicious', 'McIntosh', 'Royal Gala' and 'Idared' had severe annual infection. Genotypes carrying V_f, V_m or V_r scab resistance genes were free of leaf and fruit scab, as was *Malus floribunda* 821, indicating that scab races 5, 6 and 7 were absent from the plot. 'Regine', 'Rebella', 'Resi', 'Rewena' were notable for the absence of all visible leaf disease symptoms. Among cultivars with presumed polygenic resistance, 'Akane', 'Anis Aily', 'Antonovka', 'Bramley's Seedling', 'Chehalis', 'Discovery', 'Generos', 'Golden Reinette', 'Golden Russett', 'Margil', 'Peypring Cerueuko' and 'Wolf River' were free of sporulating scab every year. 'Frumos de Voinesti', 'Lord Lambourne', 'Spartan', 'Gravenstein' and 'Lodi' were less susceptible than 'McIntosh', but some trees had moderate to high infection (ratings 3 to 4) in some years. 'Goldgelbe' and 'Gladstone' initially appeared resistant, but became infected in the third year, and may not have durable resistance. Summerland apple introductions 'Sinta', 'Stirling', 'Silken', 'Chinook', '8S6923'(Aurora Golden Gala™), and advanced selection BC 8S-26-50 were highly susceptible to scab, 'Creston' was moderately susceptible, and 'Golden Sentinel' and 'Scarlett Sentinel' were resistant. Several breeding selections of 'Akane' × 'Discovery' parentage originally selected for their fruit quality also appeared to be resistant to scab.

Introduction

Apple scab is a disease of major importance to production worldwide. Most scab-resistant cultivars carry the V_f gene, originally introduced from *Malus floribunda* 821. In 1993, a new race of scab (race 6) was discovered in Germany that attacked some, but not all, V_f-carrying cultivars, but not *Malus floribunda* 821 itself (31,32). Race 7, discovered in the UK, overcomes the resistance of *Malus floribunda* 821, but does not infect 'Golden Delicious' (3,29). Races 6 and 7 have since been found in several European countries, but have not yet been documented in North America. Although it is now possible to transform existing susceptible cultivars such as 'Gala' with a single gene to confer scab resistance (2), single-gene resistance is unlikely to be durable.

These events have spurred efforts to develop apples with more durable scab resistance. DNA markers can be used to pyramid major genes for resistance, in order to forestall or prevent resistance breakdown. Markers now exist for V_m (10), V_r and V_x (16), in addition to V_f (17,37,40). Minor-gene resistance may also be combined with major-gene resistance by traditional breeding. Evaluation of partially resistant (presumed polygenic) cultivars is proceeding in Europe (24,27).

The expression of partial resistance varies with the concentration and pathotype composition of the inoculum, and with climatic conditions and the physiological state

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of the plant. Polygenic resistance is frequently assumed to be more durable than major-gene vertical resistance. In fact, cultivars such as 'Antonovka' and 'Discovery' have shown general field resistance for a long time in many geographic areas (8), although some new races can overcome Antonovka-derived resistance (13,18,31). Cases of short-lived partial resistance have also been recorded. For example, in the UK where 'Bramley' is widely grown, it is highly susceptible to scab, whereas it is considered highly resistant in the USA (29). Presumably a pathotype overcoming the resistance of 'Bramley' has evolved in the UK in response to selection pressure. In contrast, severe scab has occurred in some years on 'Baldwin' apple in New York State, but that strain did not become widespread (29). Lindhout (28) contends, "Estimations about the durability of polygenic, quantitative resistance are still academic, as there is hardly any experience with large-scale usage of quantitative resistance over a longer period." Most likely, durable scab control in the future will require a combination of the deployment of resistant cultivars, vigilant cultural control, and avoidance of monoculture (15). Simulation models suggest that deployment of a mixture of cultivars with partial innate resistance (even genes that have been overcome by some pathotypes) can reduce the number of scab lesions in an orchard by 65-80% (15). Accounting for cultivar resistance may also reduce the number of sprays needed in scab control programs based on Mills' table calculations (12).

Common plantings are useful for identifying sources of partial genetic resistance to wild-type scab in a region. Ideally, the trials should be repeated at different locations to reveal genotypes with widespread general resistance. 'Discovery' appears to be one such cultivar (21,24).

Our immediate objective was to evaluate the relative resistance to wild-type scab of a number of old and new cultivars, including many with presumed polygenic resistance, in a common planting at a site with high disease pressure. The cultivars were chosen based on published or anecdotal reports of scab resistance, and availability of scion wood. Several additional clones were included to begin characterizing the race composition of the scab population at the site. Finally, several selections or cultivars were tested as part of the apple breeding effort at Agriculture and Agri-Food Canada in Summerland, B.C., Canada. The long term objective of these studies is to identify clones with useful levels of field resistance for progeny testing. Those with good general combining ability could be used as parents in a recurrent mass selection scheme to increase the frequency of favorable alleles of minor-effect scab resistance genes in a breeding population.

Materials and Methods

Cultural care. All plots were located at the Pacific Agri-Food Research Centre (PARC)-Agassiz. Agassiz is in the Fraser River valley of southwestern British Columbia (BC), and experiences a cool, wet climate. Monthly temperature and precipitation data for the main growing season during the study are in Table 1. The soil was a Monroe series silt loam, eluviated eutric brunisol.

The trees were propagated on virus-free dwarf rootstock (specified below under individual experiments) and planted in offset double rows in raised beds (0.8 m wide) covered with 2.25 mil black polyethylene plastic. Tree spacing was about 0.5 m apart on the diagonal. No irrigation or tree support was provided. Walkways (0.6 m wide) between raised beds were kept free of vegetation with herbicides (glyphosate, pendimethalin and princep) applied as needed with a backpack sprayer. Weeds growing in the planting holes were removed by hand. No fungicides or insecticides were applied, except for some *Bacillus thuringiensis* in the year after planting to curtail leafroller damage in the young trees. Low branches were removed to facilitate walkway herbicide treatments, and any fire blight strikes were pruned out. Dormant pruning was used to keep the trees within their allotted space and to reduce their height. Some trees produced fruit after the first year; these were hand thinned just enough to prevent limb breakage. The cultivars and selections assessed are described in Table 2.

Non-randomized experiments. Experiment A: Two or three replicate trees of 9 genotypes were budded in place in 1999 onto M.27 rootstock. Scab was assessed for three years starting in 2001. Experiment B: Two to four

Table 1. Monthly averages for maximum and minimum temperature and total precipitation during the growing season at the experimental site in Agassiz, BC, Canada, 2000-2003.

	2000			2001			2002			2003		
Month	Max. temp. (°C)	Min. temp. (°C)	Precipitation (mm)	Max. temp. (°C)	Min. temp. (°C)	Precipitation (mm)	Max. temp. (°C)	Min. temp. (°C)	Precipitation (mm)	Max. temp. (°C)	Min. temp. (°C)	Precipitation (mm)
March	10.1	3.2	146.1	11.5	3.2	145.3	7.2	0.3	122.7	10.1	2.4	281.9
April	15.5	6.1	134.8	14.1	4.8	102.7	14.5	4.9	140.0	13.6	5.8	121.6
May	16.5	8.6	163.1	18.7	7.1	107.9	16.7	7.6	107.7	18.0	8.0	74.8
June	21.9	11.8	121.1	19.4	10.8	122.1	22.6	12.1	132.8	23.1	12.2	43.1
July	23.1	13.3	70.6	23.3	11.7	30.9	24.6	13.3	44.0	26.2	13.2	19.8
August	23.0	11.9	48.8	24.0	13.6	111.4	25.1	12.3	16.2	26.5	10.9	7.3
September	20.1	10.9	117.3	21.1	10.8	54.1	21.3	9.4	81.7	23.7	10.8	56.2
October	15.3	7.3	139.2	13.5	7.0	220.9	15.5	6.2	24.6	16.1	7.7	426.1

replicate trees of 6 genotypes were budded in place in 2000 onto M.27 rootstocks. Scab was assessed in 2002 and 2003. Only the data from the three named cultivars are presented here. (The others were Summerland breeding selections.) Experiment C: Three replicate trees of 13 genotypes were budded in place onto M.27 rootstock in 1999. Only the data from the five named cultivars are presented here. Scab was assessed for three years beginning in 2001. 'Liberty' and 'McIntosh' were resistant and susceptible controls, respectively. Experiment D: Two to four replicate trees of 10 cultivars were budded onto M.9 rootstock in 1998 and transplanted in 2000. 'Gala' was the susceptible control. Scab was assessed for three years beginning in 2001. In Experiments A through D, genotypes were planted consecutively in the row (not randomized).

Randomized experiments. Experiments E through J were each planted in a randomized complete block design. Experiment E: Ten replicate trees of each of 10 cultivars were budded in place onto M.27 rootstock in 1999. Scab was assessed for three years beginning in 2001. 'McIntosh' and 'Antonovka' were the susceptible and resistant controls, respectively. Experiment F: Five replicate trees of 10 cultivars were propagated on M.9 rootstock in 1998 and transplanted in spring of 2000. Scab was assessed for three years beginning in 2001. 'McIntosh' and 'Antonovka' were the susceptible and resistant controls, respectively. Experiment G: Six replicate trees of 13 cultivars were budded in place in 1999 onto M.27 rootstock. These selections were chosen for fire blight tests but scab was also assessed for three years beginning in 2001. Experiment H: Five replicate trees of 14 genotypes were budded in place in1999 onto M.27 rootstock. Only the data from the 5 named cultivars are presented here. Scab was assessed for three years starting in 2001. Experiment I: Three to four replicate trees of 12 genotypes propagated on M.9 rootstock were transplanted in 1999. Only the data for the named cultivars are presented here. Scab was rated for three years beginning in 2000. Experiment J: Four to five replicate trees were propagated onto M.9 rootstock in 1998 and transplanted in spring of 2000. Data for 17 genotypes are presented here. Scab was assessed for three years beginning in 2001.

Scab assessment. Although scab is endemic in the Fraser Valley, the plot was some distance from any host trees. Scab was therefore introduced to the plot in 1999 by inoculating with mixed virulent strains of scab collected in the Okanagan Valley. Scabbed leaves from a tree fruit nursery in the Fraser Valley were also scattered in the plots in autumn of 2000. Thereafter the disease self-perpetuated. The race composition of the original inoculum was unknown, but race 1 is common, and races 6 and 7 are unknown in the area. Scab severity was rated once annually by one or more pairs of recorders experienced in rating scab. In the first year, ratings were done in late August, but because some of the lower infected leaves had abscised by then, ratings were done in late July thereafter.

Categorical ratings of leaf scab were assigned for each tree as follows: 0=no visible

Table 2. Clones of *Malus x domestica* tested at Agassiz for field resistance to scab.

Name	Remarks[1]
Akane	Breeding program, Aomori, Japan 1970; Jonathan × Worcester Pearmain
Ambrosia	Chance seedling from Cawston, BC, Canada, early 1980s; parentage unknown
Anis Aliy	Origin former USSR; parentage unknown
Antonovka	From at least 1826 in Russia; parentage unknown; sub-clones exist
Beacon	Breeding program, Univ. of Minnesota, USA, 1936; Malinda × unknown
Bramley's seedling	Origin UK, 1809 to 1813, triploid
Chehalis	Chance seedling from Oakville, WA, USA, 1965; parentage unknown
Chinook	Breeding program Summerland, BC, Canada 1997; Splendour × Gala
Co-op 11	Breeding program Purdue Univ., Indiana, USA; Illinois # 2 × PRI 1042-100; V_f
Co-op 25	Breeding program Purdue Univ., Indiana, USA; PFC 2-134 × PRI 669-205; V_f; Scarlet o'Hara™
Creston	Breeding program Summerland, BC, Canada 1997; Golden Delicious x NJ381049; triploid
Delicious, Starkrimson	High colour spur-type strain found by R. Bisbee, WA, 1951
Discovery	Chance seedling, UK, named in 1962; Worcester Pearmain × possibly Beauty of Bath
Frumos de Voinesti	Breeding program Romania; Jonathan × Belle de Boskoop
Gala, Royal	Color sport of Gala, 1974
Generos	Breeding program in Romania, 1972; Frumos de Voinesti × SCP[2]
Gladstone	Origin UK c. 1780, parentage unknown
Golden Reinette	Origin Europe in mid 1600s; parentage unknown
Golden Russett	Probably England mid 1700s
Golden Sentinel	Breeding program, Summerland, BC, Canada 1997; Discovery × (Wijcik × Illinois #1), columnar
Goldgelbe	Origin France as early as 1628; also called Reinette Jaune Hâtive
Gravenstein	Known before 1669; origin believed to be Germany or Italy; triploid
Hudson's Golden Gem	Chance seedling from Oregon, USA, introduced 1931; parentage unknown
Idared	Breeding program in Idaho, USA, 1942; Jonathan × Wagener
Liberty	Breeding program, Geneva, NY, USA, 1978; Macoun × PRI 54-12; V_f
Lodi	Breeding program, Geneva, NY, USA 1924; Montgomery × Yellow Transparent
Lord Lambourne	Origin UK, introduced 1923; James Grieve × Worcester Pearmain
Maigold	Breeding program, Wadenswil, Switzerland, 1964; Fraurotacher × Golden Delicious
Margil	Origin Europe before 1750; parentage unknown
McIntosh	Chance seedling from Ontario, Canada, 1796; parentage unknown
Murray	Breeding program, Ottawa, ON, Canada, 1980; McIntosh × 52-05-26; V_f
Northern Spy	Chance seedling, USA, c. 1840; parentage unknown
Peypring Cerueuko	Origin Romania; parentage unknown
Primevère	Breeding program, St-Jean-sur-Richelieu, QC, Canada 1997; Graham × 597NJ1; V_f
Rebella	Breeding program, Dresden, Germany, 1998; complex parentage; V_f

Table 2. Continued Clones of *Malus x domestica* tested at Agassiz for field resistance to scab.

Name	Remarks[1]
Reglindis	Breeding program, Dresden, Germany, 1990; James Grieve × SCP[2]; V_a
Remo	Breeding program, Dresden, Germany, 1990; James Grieve × SCP[2]; V_f; processing cultivar
Remura	Breeding program, Dresden, Germany, 1991; (Cox × Oldenburg) × SCP[2]; V_r
Resi	Breeding program, Dresden, Germany, 1996; Clivia × SCP[2]; V_f
Rewena	Breeding program, Dresden, Germany, 1991; (Cox × Oldenburg) × SCP[2]; V_f; processing cultivar
Richelieu	Breeding program, St-Jean-sur-Richelieu, QC, Canada 1990; Ottawa 521 × O-541; V_f
Rosana	Breeding program, Czech Republic; Jolana × Lord Lambourne; V_f
Rosu de Cluj	Breeding program, Romania
Rouville	Breeding program, St-Jean-sur-Richelieu, QC, Canada 1983; 52-05-26 × 69-52; V_m
Scarlett Sentinel	Breeding program, Summerland, BC, Canada 1997; Discovery × (Wijcik × Illinois #1), columnar
Silken	Breeding program, Summerland, BC, Canada 1997; Honeygold × Sunrise
Sinta	Breeding program, Summerland, BC, Canada 1970; Golden Delicious × Grimes Golden
Spartan	Breeding program, Summerland, BC, Canada 1936; parentage McIntosh × unknown
Spartan B	Gamma-irradiated buds of Spartan c. 1960s, Summerland, BC, Canada
Stirling	Breeding program, Summerland, BC, Canada, 1936; open-pollinated seedling of Yellow Newtown
Voinea	Breeding program, Romania, 1985; Frumos de Voinesti × Prima; V_f
Wolf River	Origin USA, 1875; said to be Alexander × unknown
11W-54-12	Breeding program, Summerland, BC, Canada; Akane × Discovery
11W-54-19	Breeding program, Summerland, BC, Canada; Akane × Discovery
11W-54-55	Breeding program, Summerland, BC, Canada; Akane × Discovery
11W-55-11	Breeding program, Summerland, BC, Canada; Akane × Discovery
11W-55-12	Breeding program, Summerland, BC, Canada; Akane × Discovery
11W-55-59	Breeding program, Summerland, BC, Canada; Gala × (Akane × Discovery)
11W-55-75	Breeding program, Summerland, BC, Canada; Gala × (Akane × Discovery)
11W-57-17	Breeding program, Summerland, BC, Canada; Gala × (Akane × Discovery)
11W-57-32	Breeding program, Summerland, BC, Canada; Gala × (Akane × Discovery)
8S-26-50	Breeding program, Summerland, BC, Canada; Splendour × Gala
8S6923	Breeding program, Summerland, BC, Canada 1997; Splendour × Gala; Aurora Golden Gala™
8SE-09-39	Breeding program, Summerland, BC, Canada; Akane × Discovery
8SE-09-48	Breeding program, Summerland, BC, Canada; Akane × Discovery
8SE-09-70	Breeding program, Summerland, BC, Canada; Akane × Discovery
8SE-15-72	Breeding program, Summerland, BC, Canada; Discovery × Akane

[1]References MacHardy, 1996; Smith, 1971; Brooks and Olmo, 1997; Bultitude, 1983; Fischer and Fischer, 1999; Koch et al., 2000

[2] SCP: numbered selection of complex parentage

scab symptoms; 1=a few necrotic flecks but no evidence of sporulation, 1-10% of leaves affected; 2=sporulating lesions, 1-25% of leaves affected; 3=sporulating lesions, 26-40% of leaves affected; 4=sporulating lesions, 41-60% of leaves affected; 5=over 60% of leaves with sporulating lesions. The flecks in rating 1 were presumed to be caused by scab, but may have been from other diseases or physiological conditions in some instances. If trees had fruit, fruit scab was rated as follows: 0=no scab; 1=slight infection; 2=moderate infection; 3=severe infection. Powdery mildew [*Podosphaera leucotricha* (Ellis & Everh.) E.S. Salmon] incidence was only recorded if symptoms were marked, as the site was not especially favorable for this disease. Recorders assigned a 0 to 9 rating for mildew severity, with each increment signifying 10% of leaves showing symptoms. For example, a rating of 9 would indicate that 91-100% of leaves showed mildew symptoms.

Statistical analysis. The categorical data were discontinuous and not normally distributed. Furthermore the intervals of the scale did not represent equal increments of scab expression. Parametric statistics could not be used. Therefore the mode and range are presented. In cases of a tie for modal score, the figures were averaged. For example, if the mode was either 1 or 2, it is listed as 1.5 in the tabulated results.

Results and Discussion

A low incidence of tree loss occurred. Causes of mortality included trunk cankers, unsuccessful bud take (for trees budded in place) and fire blight. A few tree labels were lost during a flood one winter, so these trees were dropped from the data set. For this reason, tabulated data show the number of trees per genotype at the beginning and end of the trial.

Data are presented in Tables 3 to 5. Although parametric statistical analysis was not possible, the difference between susceptible and very resistant clones is readily seen. Year-to-year differences in scab severity were observed. The disease was well-established before we began our ratings, but weather was more favorable for scab epidemics in some years than others (number and frequency of infection periods). Susceptible control cultivars were infected annually. Year-to-year differences may also reflect changes in pathotype composition of the scab population over time. Scab isolates often most successfully infect the cultivar from which they were isolated (35), and the population of resistance genes in the host trees will exert selection pressure on the scab population over time (27).

Race composition of the scab population. We were not able to acquire a complete set of race indicators, but some conclusions may be drawn. All the V_f-carrying genotypes and *Malus floribunda* 821 were free from scab throughout the experiments, suggesting that races 6 and 7 were absent (Table 3). 'Rouville' (V_m) and 'Remura' (V_r) were also free of scab, indicating that race 5 was also absent. Some chlorotic mottling occurred on 'Rouville' leaves, but no sporulation. The absence of scab on 'Beacon' and *Malus sikkimensis* suggests that pathogenicity genes p-2 and p-12 respectively, were not in the scab population (6). The absence of infection in these cultivars is unlikely to signify escape, because all were in close proximity to heavily infected plants. Race 1 is prevalent in the Okanagan Valley and was probably present in the initial inoculum, but no conclusions can be drawn about races 2, 3 or 4. It is possible that only race 1 occurred in the plot.

Cultivars with major-gene resistance. All the V_f-carrying cultivars (Expts. A, B, C, D, Table 3), and one each carrying V_m (Expt. B, Table 3), or V_r (Expt. D, Table 3) were scab-free, but not all were free from other leaf diseases. Powdery mildew and various unidentified leaf spotting symptoms were seen in the plot each year. Although powdery mildew severity was generally low, 'Primevére' had comparatively heavy infection (modal score 3, range 1-3 in 2001, modal score 3.3, range 2-5 in 2002, compared to modal scores of 1 or less for other genotypes in the same experiment). 'Primevére' has suffered severe powdery mildew in research plots under conventional management in Summerland (unpublished data). Powdery mildew was also observed in one or more years on 'Remo' and 'Rosana', and to a lesser extent 'Co-op 11' and 'Remura'. The other Dresden "Re-" cultivars were remarkable for their freedom from all leaf disease symptoms. These cultivars were bred for multiple disease resistance, and

Table 3. Mode and range of leaf scab severity scores (0 to 5) for various clones of apple, number of replicate trees at the beginning (n_1) and end (n_2) of the experiment, and range for fruit scab severity score (0 to 3) over the combined years.

		2001		2002		2003			Fruit scab range
Cultivar or clone	n_1	mode	range	mode	range	mode	range	n_2	(all years)
Experiment A									
Beacon	3	0	-	0	-	1	0-1	3	0
Generos	2	0	-	0	-	0	-	1	0
Golden Reinette	2	0	-	0	-	1	-	2	0
Hudson's Golden Gem	2	1	0-2	0	-	2	-	1	0
Malus floribunda 821	2	0	-	0	-	0	-	2	0
Malus sikkimensis	3	0	-	0	-	0	-	3	nf[z]
Margil	3	0	-	0	-	1	-	1	0
Voinea	1	0	-	0	-	0	-	1	0
Wolf River	3	0	-	0	-	0	0-1	3	0
Experiment B									
Murray	4	nd[y]	nd[y]	0	-	0	-	4	0
Richelieu	4	nd[y]	nd[y]	0	-	0	-	4	0
Rouville	2	nd[y]	nd[y]	0	-	0	-	2	nf[z]
Experiment C									
Co-op 11	3	0	-	0	-	0	-	3	0
Co-op 25	3	0	-	0	-	0	-	3	0
Liberty	3	0	-	0	-	1	-	3	0
McIntosh	3	2	1-2	5	4-5	4	-	3	nf[z]
Primevère	3	0	0-1	0	-	0	-	3	0
Experiment D									
Gala, Royal	4	1	1-3	2	1-2	3.5	3-4	4	1-3
Gladstone	4	0	-	0	-	2	1-3	4	0-4
Rebella	2	0	-	0	-	0.5	0-1	2	0-1
Regine	2	0	-	0	-	0	-	2	0
Reglindis	2	0	-	0	-	0.5	0-1	2	0
Remo	2	0	-	0.5	0-1	1	0-2	2	0
Remura	2	0	-	0	-	0.5	0-1	2	0
Resi	2	0	-	0	-	1	-	2	0
Rewena	2	0	-	0	-	0.5	0-1	2	0
Rosana	2	0	-	0.5	0-1	0.5	0-1	2	0
Experiment E									
Akane	10	0	0-1	0	0-1	0	0-1	10	0
Anis Aily	9	0	-	0	0-1	0	-	6	0
Antonovka, subclone 1	4	0	-	nd[y]	nd[y]	0	-	3	0
Antonovka, subclone 2	8	0	-	0	-	0	0-1	6	0
Discovery	9	0	-	0	-	0	-	7	0
Frumos de Voinesti	10	1	0-2	1.5	0-3	1	1-3	10	0-2
Lord Lambourne	9	1.5	0-3	1	1-3	1	1-4	9	0-3
McIntosh	9	3	2-3	4	2-4	3	1-4	9	0-2
Rosu de Cluj	10	0	0-1	1	0-2	0.5	0-2	9	0-3
Spartan	10	1	0-2	2	1-2	1	1-3	10	1-2
Experiment F									
Akane	4	0	-	0	-	0	0-1	4	0-1
Antonovka, subclone 2	5	0	-	0	-	0	-	4	0
Chehalis	4	0	-	0	-	0	-	4	0
Goldgelbe	5	0	0-1	1	0-2	2.5	1-3	5	0-2
Golden Russett	5	1	0-1	0	-	1	0-1	4	0-2
McIntosh	5	3	2-4	2.5	1-4	4	3-4	5	0-2
Northern Spy	5	4	1-2	1	0-1	0	0-2	5	0
Sinta	5	3	0-3	2	2-3	3.5	2-4	5	0-2
Spartan	5	1	0-1	1	1-2	1.5	1-2	4	0-1
Stirling	5	3	1-3	1	0-1	1	0-3	5	0-2

Table 3. Continued Mode and range of leaf scab severity scores (0 to 5) for various clones of apple, number of replicate trees at the beginning (n_1) and end (n_2) of the experiment, and range for fruit scab severity score (0 to 3) over the combined years.

		2001		2002		2003			Fruit scab range
Cultivar or clone	n_1	mode	range	mode	range	mode	range	n_2	(all years)
Experiment G									
Ambrosia	6	1	1-2	5	3-5	4	3-5	6	0-1
Bramley's seedling	6	0	-	0.5	0-1	1	-	6	0
Delicious, Starkrimson	6	0	0-3	3	2-5	3	1-5	6	1-5
Golden Sentinel	6	0	-	0	-	0	0-1	6	0-1
Gravenstein	5	0	0-1	2	2-3	1	-	5	nf[z]
Idared	6	1	1-2	2	1-4	5	3-5	5	0-4
Lodi	6	1	0-2	3	2-4	2	1-2	6	0-1
Maigold	6	1	0-2	2	2-5	2	1-4	6	nf[z]
McIntosh	5	3	2-3	5	4-5	5	4-5	5	nf[z]
Peypring Cerueuko	6	0	-	0	0-1	1	0-1	6	0
Scarlett Sentinel	6	0	-	0	-	0	0-1	6	0
Spartan	5	1	0-1	3.5	1-4	2	2-4	5	nf[z]
Spartan B	6	1	0-2	3	1-4	2	2-5	6	nf[z]
Experiment H									
8S-26-50	5	nd[y]	nd[y]	1	0-1	4	2-4	4	0
Creston	5	nd[y]	nd[y]	0	0-1	2	2-3	5	nf[z]
Delicious, Starkrimson	4	nd[y]	nd[y]	2	0-2	3.5	3-4	4	1
Gala, Royal	5	nd[y]	nd[y]	2	0-2	4.5	3-5	5	1
Lodi	5	nd[y]	nd[y]	1	0-1	5	2-5	5	nf[z]
McIntosh	5	nd[y]	nd[y]	2	2-3	5	4-5	5	1

[z]nf=no fruit were produced
[y]nd=no data

Table 4. Mode and range of leaf scab severity scores (0 to 5) for various clones of apple, number of replicate trees at the beginning (n_1) and end (n_2) of Experiment I, and range for fruit scab severity score (0 to 3) over the combined years.

		2000		2001		2002			Fruit scab
Cultivar or clone	n_1	mode	range	mode	range	mode	range	n_2	(all years)
8S-26-50	4	2	-	1	0-2	4	3-5	3	0-2
8S6923	4	2	-	1	0-2	5	3-5	4	1-3
Chinook	4	5	4-5	5	2-5	5	-	3	3
Gala, Royal	3	3	2-4	2	-	5	-	3	3
McIntosh	3	3	3-5	2	2-3	5	-	3	2
Silken	4	4	-	4	2-5	5	-	4	2-3

they may be suited to commercial organic production if their fruit finds acceptance in North American markets. They may also be suited to homeowner use.

Other named cultivars. 'Antonovka', 'Akane', 'Anis Aily', and 'Discovery', all reportedly carrying polygenic resistance (8,18,24,30,33), were scab-free in these experiments (Table 3). 'Antonovka', 'Discovery' and 'Akane' were also free from scab in a previous study (33), but only 'Antonovka' and 'Discovery' appeared capable of effectively passing resistance on to their progeny. The 'Antonovka' trees used as male and female parents by Quamme et al. (33) were both thought to be 'Antonovka monasir', but we have since obtained molecular marker data showing that they are different, and that the clone used as a female parent is Antonovka debnicki (Naik, Hampson and Bakkeren, unpublished data). The 'Antonovka' clones in that study also appeared to carry a major gene, possibly the same V_a that was reported from 'Antonovka' PI 172623 by Lespinasse (26). The polygenic nature of scab resistance in 'Discovery' has recently been confirmed (27).

'Akane' has been considered tolerant to scab (5) and is resistant to race 6 (31). Bengtsson et al. (4) state that it is susceptible to races 2 to 5, but unfortunately do not provide a citation. If this is the case, our wild scab population may not have contained these races. 'Akane', 'Discovery' and 'Lord Lambourne' all share 'Worcester Pearmain' as a common parent (Table 2).

Other cultivars not known to carry major-gene resistance were tested. In Expt. A, 'Wolf River', 'Margil', 'Generos' and 'Golden Reinette' scored 0 or 1; 'Hudson's Golden Gem' seemed to be partially resistant but some sporulation was observed in two of three years. 'Wolf River' and 'Hudson's Golden Gem' were considered partially resistant by Norton and King (30). 'Generos' had red blotches on its leaves, but the cause was not identified and may have been physiological. No sporulation was seen. 'Reglindis', with V_a resistance originally from 'Steinantonovka', had no scab (Expt. D, Table 3). In Expt. E, 'Frumos de Voinesti', 'Lord Lambourne', 'Rosu de Cluj' and 'Spartan' all had lower modal scab scores than 'McIntosh', but individual trees of all but 'Rosu de Cluj' scored as high as 3 or 4 in one or more years. Some of these clones have been reported previously to show some resistance to scab (12,30). The resistance of 'Lord Lambourne' decreased over time in two European studies (23,39), where up to 74% of the fruit had scab damage after several years, confirming that polygenic resistance cannot be assumed to be durable (4,25).

In Expt. F, 'Antonovka', 'Akane', 'Chehalis' and 'Golden Russett' were all free from sporulating scab for three years. 'Golden Russet' also showed a high level of partial resistance in greenhouse tests (12). Resistance greater than in 'McIntosh' was again observed in 'Spartan' (and also in Expt. G), as found by Norton and King (30) and Dewdney et al. (12), but not Aldwinckle (1). 'Stirling' and 'Sinta', both older cultivars from the Summerland breeding program, had scab scores similar to 'McIntosh' in one or more years. 'Stirling' and 'Chehalis' appeared partially resistant in previous work (30). 'Goldgelbe' was free from sporulating scab in 2001 and 2002, but not 2003. A similar situation occurred with 'Gladstone' in Expt. D. The resistance of these cultivars may not be durable.

In Expt. G, 'Bramley', 'Golden Sentinel', 'Scarlett Sentinel' and 'Peypring Cerueuko' were all free from sporulating scab. 'Golden Sentinel' and 'Scarlett Sentinel' are columnar releases from the Summerland program, targeted for home gardener usage. Both appear to have inherited useful levels of scab resistance from their 'Discovery' parent, but unfortunately not its resistance to powdery mildew, especially 'Scarlett Sentinel', which had a modal score of 3 for mildew in 2001. As expected, 'Delicious', 'McIntosh', 'Idared' and 'Maigold' were all highly susceptible to scab, as commonly reported (1,15). In contrast, 'Delicious' and 'Idared' showed partial resistance in Quebec (12). This difference may reflect the inoculum source used (lesions from 'McIntosh'). The new cultivar 'Ambrosia' was highly susceptible. 'Gravenstein' and 'Lodi' had scores as high as 3 or 4 respectively in 2002. Mixed results for 'Gravenstein' were reported in previous tests (1,30).

With the exception of 'Golden Sentinel' and 'Scarlett Sentinel', none of the Summerland apple cultivars was bred for scab resistance.

Table 5. Mode and range of leaf scab severity scores (0 to 5) for various selections from the apple breeding program in Summerland, number of replicate trees at the beginning (n_1) and end (n_2) of Experiment J, and range for fruit scab severity score (0-3) over the combined years.

		2001		2002		2003			Fruit scab
Cultivar or clone	n_1	mode	range	mode	range	mode	range	n_2	(all years)
Akane × Discovery									
11W-54-12	5	0	-	0	-	0	-	4	0
11W-54-19	5	0	0-1	1	0-1	0	0-2	4	0-1
11W-54-55	3	1	-	0	-	0	0-1	3	0
11W-55-11	5	0	0-1	0	0-1	0	0-1	5	0-1
11W-55-12	5	0	0-1	0	0-2	0	0-1	4	0-1
8SE-09-39	5	0	0-1	0	0-1	0	-	3	0
8SE-09-48	5	0	-	0	-	0	-	4	0
8SE-09-70	4	0.5	0-1	0.5	0-1	0	-	3	0-1
Discovery × Akane									
8SE-15-72	4	0	0-1	1	-	0	0-2	3	0
Gala x (Akane × Discovery)									
11W-55-59	5	0	0-1	0	0-2	0	0-1	4	0-1
11W-55-75	5	2	2-3	4	3-4	3	3-4	5	1-3
11W-57-17	5	0	-	0	-	0	-	5	0-1
11W-57-32	5	0.5	0-2	0	0-1	0	-	3	0-1
Controls									
Discovery	5	0	-	0	-	0	-	5	0
Gala, Royal	4	0	0-1	2.5	2-3	2	1-3	3	1-3
McIntosh	5	2	-	3	2-3	3	2-3	4	1-2

'Silken', 'Chinook', '8S6923' (Aurora Golden Gala™) and BC 8S-26-50 (Table 3 Expt. H and Table 4) were all highly susceptible to scab. BC 8S-26-50 is an advanced selection included in the USDA NE-183 project trials. Modal scores for 'Creston' were a little lower (Table 3, Expt. H), but it was not resistant. Scab incidence on 'Creston' was low or moderate in trials in CT, MA, NY, VA and WV, but high in MI (11,19,41).

Progeny of 'Discovery'. A number of 'Akane' × 'Discovery' or 'Discovery × Akane' progeny from the Summerland breeding program were tested (Expt. J, Table 5). These selections were not random samples of the seedlings from this cross, because they had previously been selected for acceptable tree vigor, resistance to powdery mildew in the nursery and field, and fruit quality, but without regard to scab resistance. Scab ratings of selections of 'Akane' × 'Discovery' parentage were not more than 1 in most cases, compared to 2 or 3 for the susceptible control cultivars 'Royal Gala' and 'McIntosh' in the same experiment (Table 5). One of these selections, 8SE-09-70, had also been crossed with 'Gala' in previous years; some of these selections also showed high levels of scab resistance, but not all (e.g. 11W-55-75).

The proportion of offspring with useful levels of field resistance to scab that can be expected from this cross could not be estimated from our data. However, Liebhard et al. (27) noted that some of the resistance loci in 'Discovery' appear to be homozygous, and that 'Discovery' resistance appears to be highly heritable. High heritability of resistance from 'Discovery' was also reported by Quamme et al. (33). Although 'Akane' did not show positive general combining ability for scab resistance (33), it was itself resistant to scab, and so may also have contributed some favorable alleles. It is well-known that even a "susceptible" parent carries some resistance genes (e.g. V_g in 'Golden Delicious') and can influence the level of resistance in its progeny (20,38). 'Sansa' ('Gala' × 'Akane') is another example of a scab-resistant offspring of 'Akane' (11,19,34). However if 'Akane' is susceptible to races 2 to 5 (4), these selections may also be. More study is required to answer this question.

Relation between leaf and fruit scab. In our tests, not all trees fruited, and many did not fruit annually. In cases where fruit were produced, scab scores for fruit usually reflected leaf scab scores for the named cultivars. 'Rouville' (V_m) did not fruit. None of the V_f cultivars showed any fruit scab. Likewise fruit scab was absent on cultivars with presumed polygenic resistance where leaf scab was absent, but on cultivars that had sporulating leaf scab in one or more years, fruit scab was frequently seen too (e.g. 'Frumos de Voinesti', 'Lord Lambourne', 'Rosu de Cluj', 'Spartan', 'Goldgelbe'). Neither 'Akane' nor 'Discovery' had fruit scab, but a few of their offspring had fruit scab scores of 1, including some with no signs of sporulating leaf scab (Table 5). Different quantitative trait loci were reported for fruit and leaf scab (27).

Although our objective was to acquire information for our breeding program, the results may be of interest to organic, pick-your-own, or home growers who desire a scab resistant tree. The horticultural quality of these cultivars was not studied. A recent Danish report (23) found that only one of 14 old cultivars tested combined acceptably low disease susceptibility with adequate yield, fruit size and fruit eating quality.

Further study of the genetics of minor-gene resistance is needed. It is likely that genes conferring pathogen recognition can be overcome by new pathotypes of scab wherever sufficient selection pressure is imposed (27). Resistance based on other modes of action may prove to be more durable on its own or in combination with pyramided pathogen-recognition genes. Recently, Kemp et al. (21) successfully screened genotypes in the greenhouse with race-specific scab isolates as a new way to estimate the durability of their resistance. If this method proves to predict field resistance accurately, it would save considerable time and plot space over field screening. In secure controlled conditions, one could use races that do not yet occur in a given region, or probe genotypes for as-yet undiscovered resistance genes that have been overcome. Meanwhile, the methods used here were simple and effective.

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