The results of this study indicate that high levels of resistance to leaf curl are available in peach germplasm, particularly in germplasm not currently commercially utilized. If resistance is highly heritable, as has been suggested (3), the development of leaf curl resistant cultivars is a viable goal for peach breeding programs.

Factors such as climate, particularly during leaf development in the spring, and inoculum density may affect field evaluation of leaf curl resistance requiring multiple years of observation. The development of controlled inoculation procedures would aid in the evaluation of resistance in both exotic germplasm and seedling progeny and reduce the time necessary to develop resistant cultivars.

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Breeding Apples for Scab Resistance: 1945-1990

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Abstract

The breeding of apples resistant to scab incited by *Venturia inaequalis* (Cke.) Wint. is a genetically-based strategy for the control of this major fungal fruit pathogen. A concerted breeding effort began with three cooperating Agricultural Experiment Stations in the late 1940s and early 1950s. Soon afterwards collaboration was extended to research workers in Canada and Europe, and later to other continents. The effort that continues today in at least 17 breeding programs throughout the world was based on a modified backcross program to combine genes for resistance to apple scab from *Malus floribunda* 821, and other species with commercially-accepted traits. Since 1970, 48 scab-resistant cultivars have been released worldwide of which 37 purportedly carry the V_f gene from *M. floribunda* 821, one of which ('Freedom') carries additional polygenic resistance from 'Antonovka,' one ('Imrus') with V_f from *M. atrosanguinea* 804: five with other genes [one ('Rouville') with the V_m gene from *M. atrosanguinea* 804; one ('Nova Easygro') with the V_r gene from a Russian apple seedling from the Caucasas Mountains (R#12740-7A); one ('Murry') with V_m and/or V_f from *M. micromalus;* and three ('Romus 2,' 'Gavin' and 'Generos') with polygenic resistance only. There now exists a wide range of genotypes containing the V_f gene ranging in maturity from 75 days to 180 days or longer after flowering, with large fruits, crisp flesh, good storage behavior, and a wide range in flavor and skin color. A number of selections have been identified that contain varying degrees of resistance to other diseases and pests.

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1. Introduction

A breeding program to produce apple cultivars resistant to scab incited by *Venturia inaequalis* (Cke.) Wint. was initiated in 1945 by J. R. Shay at Purdue University and L. F. Hough, then at the University of Illinois but later at Rutgers, The State University of New Jersey. This collaboration led to a cooperative breeding program between Purdue University, Rutgers University and the University of Illinois, known by the acronym PRI.

The major source of scab resistance used in this program was first identified by Dr. L. F. Hough. Newly appointed as assistant professor in 1942, he was responsible for evaluating a collection of *Malus* species and hybrids previously assembled by Professor C. S. Crandall at the University of Illinois in the beginning of this century. Unusually cool, wet weather in the spring of 1943 resulted in a severe epidemic of apple scab which defoliated all susceptible, unsprayed apple trees. One progeny derived from the cross (*Malus floribunda* 821 x 'Rome Beauty') x (*M. floribunda* 821 x 'Rome Beauty') approximated a segregation ratio of 1 scab resistant : 1 scab susceptible. Further crosses with two resistant selections from this cross indicated that resistance was conferred by a single qualitative dominant gene, or by a block of closely linked quantitative genes, that was subsequently named V_f (*Venturia* resistance from *floribunda*). The 1:1 ratio apparently resulted from the following cross:

$$V_f v_f \times v_f v_f \longrightarrow 1\ V_f v_f : v_f v_f$$

It was later demonstrated that intercrossing plants heterozygous for resistance would produce the classic ratio of 3 resistant : 1 susceptible (21).

Resistance conferred by V_f had many desirable attributes: (1) it showed no evidence of being violated by new fungal races, (2) it was not linked to any undesirable effects, (3) it acted as a true dominant in the diploid, triploid or tetraploid condition, and (4) it was found in two selections, F_2 26829-2-2 and F_2 26830-2, that were horticulturally advanced over the original species (*M. floribunda* 821, which has fruit about 1 cm in diameter). These two selections formed the basis of the present scab-resistant program in apples.

Dominant genes for scab resistance were transferred by a repeated series of hybridizations of genotypes heterozygous for resistance with adapted, high quality genotypes, which are homozygous for scab susceptibility. In these modified backcrosses, half of the progeny contained dominant resistance in the heterozygous condition and were clearly identified in the seedling stage when inoculated with spores of the fungus (21). During the first three or four generations of crossing, the scab-resistant genotype was usually the pollen parent because the resistant selections were often small trees with limited flowering.

Seed from controlled pollination crosses made each spring were sent to Purdue University where they germinated after stratification and were screened for scab resistance in the seedling stage each winter in the greenhouse. This phase of the program was long under the direction of Dr. E. B. Williams of the Department of Botany and Plant Pathology. Resistant plants were moved directly to permanent positions in the field for tree and fruit evaluations; promising selections provided parents for the next breeding cycle.

The crossing process was repeated with the most horticulturally desirable of each generation of scab-resistant seedlings. After 3-4 generations this process, in essence, captured the dominant scab resistant gene from *M. floribunda* 821, replacing most of its other genes with those of the horticulturally desirable but scab-susceptible parents. To avoid inbreeding (backcrossing is equivalent to selfing in bringing about homozygosis), the high quality scab

susceptible genotypes (equivalent to the recurrent parent in a classical backcross program) were varied each generation. This protocol recombined traits of the different high-quality susceptible parents. In 1990, the Purdue, Rutgers, Illinois program may be summarized as follows:

Crosses	3468
Seeds produced	~617,000
Seedlings screened	~380,000
Seedlings planted	~100,000
Seedlings evaluated	~60,000
Selections	~1500
Co-op releases	31
Cultivars named	9

2. Stability of Resistance

The possibility of development of races of the fungus that would overcome an individual source of resistance was recognized very early in the program (38). Efforts were undertaken to find and characterize additional sources of resistance.

Subsequent studies by J. R. Shay, E. B. Williams, and D. F. Dayton identified 25 different *Malus* species and selections possessing high levels of genetic resistance to apple scab (19, 45). Through a series of intercrosses (tests of allelism) it was established that 11 of the 25 sources were due to the same V_f gene (45). Six loci for qualitative resistance (defined gene pools) were identified as follows:

Symbol	Original Source
V_f	*M. floribunda*
V_m	*M. micromalus*
V_r	*M. pumila* R12740-7A (Dayton et al., 1953)
V_{bj}	*M. baccata jackii*
V_b	Hansen's baccata #2
V_a	Antonovka PI 172623

Five different virulent races of *Venturia inaequalis* have been identified, four of which infect and overcome certain genes for resistance. Thus, race 5 of *V. inaequalis* was found at the John Innes Institute, Norwich, England (44) that overcame V_m, the Micromalus pit type resistance found in *M. micromalus* and *M. atrosanguinea* 804. Resistance in the original species sources of V_m consisted of two qualitative loci for resistance. When the two loci were separated in segregating progeny, it was found that V_m by itself was vulnerable to race 5.

Race 1 is the race commonly encountered throughout the world. Race 2, collected in South Dakota, successfully attacks: *M. baccata* 'Dolgo,' 'Alexis,' and 'Bittercrab'; certain segregates of the Russian seedling R12740-7A (but not V_r); and 'Geneva' (*M. pumila* var. *niedzwetzkyana* o.p.). Race 3, collected in Nova Scotia, Canada, overcomes the resistance found in 'Geneva.' Race 4, found in a scab resistant seedling block in Lafayette, Indiana, successfully attacks certain segregates of the Russian seedling R12740-7A, suggesting a third locus for qualitative resistance different from that overcome by race 2 or V_r (45).

Although V_f is traditionally considered to be a simply inherited, dominant factor conditioning qualitative resistance, it is often associated with any number of quantitative resistance factors (22, 45), which make it less vulnerable to attack by new races of the fungus. Progeny segregation ratios and the frequency distributions of leaf reaction classes suggest the complexity of the genetic basis of resistance derived from V_f sources.

Reaction classes for leaf inoculations under greenhouse conditions were established early in the program: 0 = no macroscopic evidence of infection; 1 = pin point pits and no sporulation; 2 = irregular chlorotic or necrotic lesions and no sporulation; 3 = few restricted sporulating lesions; M = mixture of necrotic, nonsporulating and sparsely sporulating lesions; and 4 = extensive abundantly sporulating lesions (20, 37, 45).

Modified backcross progenies from V_f parents exhibit resistant reaction classes ranging from 2 to M to 3 after inoculation in the greenhouse (E. B.

Williams, unpublished data). When reaction classes 2, M, and 3 were considered resistant and class 4 susceptible, ratios approximating 1 resistant:1 susceptible were observed in backcross progenies. When sporulation, however slight, is considered susceptible, a much lower ratio of resistant: susceptible is observed. In this case, rarely do the resistant fraction of the backcross progenies approach as much as a third (29). Additionally, the original *M. floribunda* 821 resistance was expressed as a class 1 reaction and F_2 26829-2-2 and F_2 26830-2 were class 2 reaction types. From these observations it is hypothesized that V_f is a simply inherited gene that confers a class 3 reaction type, and that additional genes enhance or augment the effect of V_f to give class 1, 2, and M reactions. It is very likely that these additional or modifier genes are complexly inherited quantitative factors. Hough et al. (22) interpreted V_f resistance as "the result of a hypersensitive reaction and that the intensity of the hypersensitivity is reinforced by quantitative genes inherited in a cumulative manner."

H. S. Aldwinkle (1989, unpublished) reported that resistant reactions exhibited by plants inoculated in the greenhouse showed a continuous gradation from hypersensitive to restricted sporulation and then on to susceptible, rather than as discrete reaction classes. This observation confirms that the qualitative resistance conditioned by V_f is genetically complex and is almost always fortified by a number of quantitative resistance factors even in seedlings identified as Class 3 reaction type.

The performance of V_f scab resistance in the field, attests to the usefulness of this gene and its genetic complexity. After over 40 years of widespread testing, in humid apple production regions around the world, V_f resistance has not been overcome by new races of *V. inaequalis*. All occurrences of reported breakdown of resistance have been attributed to mislabeling of apple propagules. Hough et al. (22) has documented published accounts.

We do not consider reports of low levels of scab infection on PRI resistant selections in Europe (2, 26, 41) as a breakdown of resistance. Originally reaction classes M and 3 exhibited limited sporulation in the greenhouse. 'Prima,' the first scab-resistant cultivar (8) which carries V_f, exhibits only a class 3 reaction type. Limited leaf sporulation of *V. inaequalis* may be seen occasionally on 'Prima' and a few other Co-op selections under optimal conditions for infection with rare minor infection on fruits—yet, they have maintained a high level of field resistance wherever they have been grown. Class 2 reaction types have always remained field immune. Except for 'Prima,' the reaction class of the Co-op series of selections is unknown.

3. Co-op Selections

In the 1960s, cooperators in the PRI breeding program felt that scab resistant germplasm had progressed to the point where various high-quality selections were ready for widespread testing. In response, the "Co-op" series of releases was introduced as a mechanism to focus attention on deserving selections and to emphasize the cooperation and joint effort of the three universities behind the releases.

From 1967 to 1990, 31 Co-op selections were released for advanced testing and distributed for testing throughout the world (6, 25, 43, 47, 49, 51). During the period 1970 to 1988, seven of these selections were named, and offered to the nursery industry for propagation: 'Prima' (Co-op 2) (8); 'Priscilla' (Co-op 4) (46); 'Sir Prize' (Co-op 5) (48); 'Jonafree' (Co-op 22) (7); 'Redfree' (Co-op 13) (50); 'Dayton' (Co-op 21) (24), and 'Williams' Pride' (Co-op 23) (23). In addition, two other selections made at Purdue University

and sent to other locations for testing were named: 'Priam' in cooperation with the Station d'Arboriculture Fruitiere, INRA, Angers, France (10); and 'McShay' in cooperation with Oregon State University (32). A scab-susceptible escape was named 'Viking' by F. H. Gilbert at the Wisconsin Agricultural Experiment Station in 1969.

A description and evaluation of each of the Co-op selections is summarized in Table 1. Co-op selections 1 - 26, released prior to 1985, have been evaluated sufficiently to establish their potential. The information for this evaluation was gathered from many different sources, including a comprehensive worldwide survey of cooperators made by J. A. Crosby in 1985-86. Most of the information on growth and fruiting comes from ongoing evaluations in Indiana, Illinois, and New Jersey. Relative disease resistance is based on observation of natural field infection in these states as well as from cooperators in other states and countries. A few recently published reports give good indication of disease incidence under epidemic conditions (26, 40, 41, 42). Information on longevity in refrigerated storage is based on data collected at Purdue University from 1984 to 1991.

Although it is unlikely that any of the currently unnamed releases in Co-op 1 through 26 will be named or widely grown, several have been and will continue to be valuable as parents for breeding. Co-op 8 and Co-op 14, recently evaluated by EMBRAPA in Rio Grande do Sul, Brazil, have proven to have low-chilling requirements, inherited from 'Mollie's Delicious.' Interest has been expressed in the release of both selections in Brazil. The Bålsgard Department of Horticultural Plant Breeding Sweden has recently evaluated Co-op 12 and found it to be well adapted to Swedish conditions. Interest has been expressed in recommending Co-op 12 as an early apple for home garden in Sweden. Co,-op 15, recently evaluated in western Oregon, exhibits promise for utility in the Pacific Northwest, west of the Cascades, due to its field immunity to scab, high level of resistance to powdery mildew, and good fresh fruit quality. Goonewardine and Williams (1988) identified Co-op 17 as the most resistant of 360 PRI selections screened for different insect pests including apple maggot, *Rhagoletis pomonella* (Walsh), plum curculio *Conotrachelus nenuphar* (Herbst), and the redbanded leafroller *Argyrotaenia velutinana* (Walker) (15). When crossed with 'Golden Delicious,' it yielded several outstanding selections with promising fruit quality and excellent keeping ability. Co-op 17 is recommended for use in breeding as a potential source of insect resistance, firm flesh type, smooth, yellow fruit finish, and long-term retention of quality in storage. After ten years of evaluation, Co-op 25 stands out as one of the longest keeping, highest quality selections to originate from the PRI program. The fruit are sweet with a fragrant, fruity flavor, blushed red to orange, hard, and dense with very firm, crisp and breaking texture. Harvested with 'Delicious' in Lafayette, Indiana (Sept. 20 to Oct. 1), Co-op 25 can keep until the following June in refrigerated storage, and in 1990 compared favorably in quality to 'Fuji' in April and May. Co-op 25 has not been named for release because of its marked susceptibility to fire blight. We are encouraging the testing of Co-op 25 only in areas where fire blight is not a problem.

Co-ops 27 to 31 differ from the six previous series of releases from the PRI program in that all five selections mature relatively late in the harvest season. These selections have fruited as grafted trees at West Lafayette, Indiana and/or Urbana, Illinois from 8 to 11 seasons, and are only now beginning to fruit at other sites in the U.S. All five selections show promise based on good flavor, firm, crisp flesh

type, and good retention of texture and quality in storage. The utility of Co-op 28 may be limited by its susceptibility to fire blight.

4. Cultivar Releases

'Prima,' 'Priscilla,' and 'Sir Prize' have been widely distributed since 1967 and evaluated under many environmental and cultural conditions. 'Prima' currently has some utility as a roadside market or commercial early fresh market substitute for 'Jonathan' in the mid-western U.S. and eastern Europe, essentially in areas where 'Jonathan' is grown. 'Prima' is somewhat susceptible to winter cold injury and to sun scald on exposed bark. It is not suitable for cropping in far northern areas. More than 70,000 'Prima' trees have been sold in the U.S. from 1974-1990, and some commercial plantings of 800 to 1000 trees exist in the U.S. Midwest. 'Prima' has been used extensively as a parent in breeding programs worldwide and has been of special interest in eastern Europe. It appears that 'Prima' will have little utility in western Europe other than as parental germplasm or a pollinator. The sole licensee in western Europe reported that sales did not support the maintenance cost of varietal protection in France and Germany, and protection was discontinued. 'Prima' continues to have varietal protection in the U.S. and Denmark, and is used as a pollinizer in solid blocks of other cultivars. The U.S. Plant Patent (Reissue No. 28,435) expires in June of 1992.

'Priscilla' has been planted on a small scale as a specialty apple for home or road-side fresh market use. More than 40,000 'Priscilla' trees have been sold in the U.S. from 1974-1990. During the early 1980s its reputation was damaged due to a mix-up in a scion orchard of a major U.S. licensee, resulting in the substitution of Co-op 3, an inferior scab resistant selection, for 'Priscilla' in six or more years of sales. 'Priscilla' has very good fresh fruit quality with firm, crisp flesh texture but the sweet, aromatic, somewhat licorice-like flavor is disliked by some consumers. The cultivar's most significant problem is its lack of quality retention in storage, but if handled properly, 'Priscilla' can maintain adequate flavor and texture in refrigerated storage for 3 months. 'Priscilla' is highly resistant to fire blight. It has rivaled or surpassed 'Liberty' and 'Prima' in observations of fire blight epidemics in North Carolina (40) as well as 'Liberty,' 'Prima,' and 'Williams' Pride' in severe epidemics in Vincennes, Indiana in 1989 and 1990. Its unique quality and high level of overall disease resistance should allow it to survive for local markets in the U.S. In Europe, 'Priscilla' currently has plant varietal protection only in Denmark. In the 1970s, the main licensee in Europe fruited 'Priscilla' and 'Sir Prize' for the first time, and displeased with them, opted not to procure varietal protection for France or Germany. Few trees were ever sold. 'Priscilla' will have little utility in Europe other than as a backyard apple. The U.S. Plant Patent (No. 3,488) expires in February of 1991.

'Sir Prize,' a triploid seedling from a progeny of tetraploid 'Golden Delicious,' was released with an overwhelming flaw: the fruit are too tender and susceptible to bruising. Despite good quality, attractive appearance, and high productivity, this one flaw has doomed 'Sir Prize' as a commercial cultivar. Although easily bruised, the flesh is not soft, the tree is very productive, and quality is usually ranked quite high. More than 6000 trees of 'Sir Prize' were sold in the U.S. from 1976-1990. 'Sir Prize' is not being propagated in the U.S. except on a per order basis. Plant varietal protection was never enacted in Europe and few trees were sold. 'Sir Prize' will have little utility in Europe or the U.S. other than as a home apple. The U.S. Plant Patent (No. 3,988) expires in December 1993.

'Priam,' named in cooperation with INRA, Angers, France, was reported

Table 1. Summary of fruit and tree characteristics of Co-op 1 through 31, scab resistant apple selections released for advanced testing.

Co-op 1 (PRI 1235-101 = PRI 47-147 x N.J. 123249) (Williams *et al.* 1967)
Fruit-64 to 70 mm (2-1/2 to 2-3/4 in.); round oblate; pale yelow to cream ground color; bright finish; slightly striped, 70% medium to pale red; fine-grained, cream colored, firm to slightly crisp flesh; spicy, spritely acid, slightly aromatic flavor; moderately juicy. **Season of Maturity**-Six weeks before 'Delicious.' **Tree**-Limber, bare-wooded branches; unreliable cropping. **Disease Resistance**-Field immune to apple scab; moderate resistance to powdery mildew; field immune to cedar-apple rust; susceptible to fire blight. **Problems**-Acidic, small fruit size, uneven ripening, heavy fruit drop, inadequate storage life. **General Recommendation**-Problems too severe for further consideration. Discarded at Lafayette.

Co-op 2 (PRI 1225-100 = PRI 14-510 x N.J. 123249) Introduced as 'Prima' (Dayton *et al.* 1970) U.S. Plant Patent No. Reissue 28,435, 1975
Fruit-67 to 76 mm or more (2-1/2 to 3 in.); round to short conic and irregular; green yellow to yellow ground color; bright finish; slightly striped, 50 to 90% medium to dark red; medium grained, cream colored, crisp and breaking flesh at harvest, reduced firmness after 3 to 4 weeks in storage; slightly spicy, moderately to spritely acid, and rich in flavor, juicy; very good dessert quality. Moderate to large fruit size. Early 'Jonathan' type fruit. Retains quality for one month or more in refrigerated storage. Fruit hangs on tree until over-ripe. **Season of Maturity**-Four to five weeks before 'Delicious.' **Tree**-Semi-vigorous, spreading. Moderately large in size. **Disease Resistance**-Highly resistant to scab in the field. Good resistance to powdery mildew. Moderate to good resistance to fire blight. Susceptible to cedar-apple rust. **Problems**-Sensitive to cold and prone to winter injury; susceptibility to cedar-apple rust is a problem in some areas; fruit colors poorly inside canopy; storage longevity often considered inadequate; prone to bitter-pit, uneven ripening, requiring two or more pickings. **General Recommendation**-Suggested for commercial plantings for early entry into fresh market, in areas where 'Jonathan' is grown, and especially for reduced input production. Only suggested where winter injury is not a severe problem.

Co-op 3 (PRI 1686-1 = N.J. 8 x PRI 558-1) (Williams *et al.* 1967)
Fruit-57 to 70 mm (2-1/4 to 2-3/4 in.); round to short conic; green yellow to yellow ground color; bright finish; slightly striped, 60 to 80% medium red; medium grained, white to cream colored, slightly crisp yet tender flesh at harvest, softening after 3 weeks in storage; bland, spritely acid; moderately juicy. **Season of Maturity**-Five weeks before 'Delicious.' **Tree**-Semi-vigorous, spreading. **Disease Resistance**-Field immune to apple scab; good resistance to powdery mildew; susceptible to fire blight; highly resistant to cedar-apple rust. **Problems**-Insufficient flavor; tender flesh; small fruit size; uneven ripening; tendency for fruit drop; very short storage life; susceptibility to secondary diseases. **General Recommendation**-Problems too severe for further consideration. Discarded at Lafayette.

Co-op 4 (PRI 1659-1 = 'Starking Delicious' x PRI 610-2) Introduced as 'Priscilla' (Williams *et al.* 1972) U.S. Plant Patent No. 3,488
Fruit-64 to 76 mm (2-1/2 to 3 in.); oblate conic to short conic with pointed calyx; green yellow to pale yellow or cream ground color; very bright finish, slightly striped, splashed, 70 to 95% medium red; medium grained, pale yellow colored, unusually crisp and breaking flesh at harvest; moderately aromatic, licorice aroma, moldly acid to sweet, and rich in flavor; moderately juicy; very good dessert quality. Moderate fruit size. Annual cropping. Fruit hangs on the tree until over-ripe. Retains quality for two to three months or more in refrigerated storage if properly handled. **Season of Maturity**-Two weeks before 'Delicious.' **Tree**-Moderate vigor; standard bearing habit, somewhat thin branched; medium size. **Disease Resistance**-Field immune to apple scab; high level of resistance to fire blight; high level of resistance to cedar-apple rust; good level of resistance to powdery mildew. **Problems**-Small fruit size if not properly thinned; overcropping; does not color well inside canopy; licorice aroma; longevity in storage variable, inadequate in some years, short shelf life out of storage; tendency for caylx end cracking when over-mature; varietal mix-up caused major nursery to supply an inferior scab resistant cultivar as 'Priscilla' for six years during the early 1980s. Although scab resistant, the bogus 'Priscilla' significantly damaged the cultivar's image. **General Recommendation**-Suggested for small scale commercial plantings and for specialty markets where the unique flavor can be used as an advantage and fruit is not stored for extended periods.

Co-op 5 (PRI 673-20 = tetraploid 'Golden Delicious' x PRI 14-152) Introduced as 'Sir Prize' (Williams *et al.* 1975) U.S. Plant Patent No. 3,988
Fruit-70 to 76 mm or more (2-3/4 to 3+ in.); short conic to long conic with calyx points; bright finish, 100% green yellow to lemon yellow with an occasional slight red blush; fine grained, lemon yellow colored crisp yet very tender flesh; moderately to spritely acid, and rich in flavor with distinctive aroma; very juicy; very good dessert quality. Large fruit size. Smooth, conic shaped, very attractive

Table 1. (Continued).

fruit with limited russet. Annual cropping. Retains quality for 6 months in refrigerated storage. Fruit hangs on the tree very well. **Season of Maturity**-With 'Delicious.' **Tree**-Vigorous, spreading growth habit, moderately spurry, 90 degree crotch angles, moderately large size tree. **Disease Resistance**-Field immune to apple scab; good level of resistance to powdery mildew; moderately susceptible to cedar-apple rust; susceptible to fire blight. **Problems**-Tender (yet crisp) flesh is extremely sensitive to bruising, which makes it unacceptable as a commercial cultivar, although fruit size, finish, and fine quality make it ideal for the home garden; susceptibility to cedar-apple rust is a problem in some areas; susceptibility to fire blight is a problem in some areas; triploid with unviable pollen so it requires an additional pollinizor. **General Recommendation**-Suggested for limited use in pick-your-own operations and as a home grower cultivar. 'Sir Prize' is currently the only widely available, yellow scab resistant apple in 'Golden Delicious' season.

Co-op 6 (PRI 1500-101 = PRI 558-1 x 'Mollie's Delicious') (Williams *et al.* 1972)
Fruit-70 to 76 mm (2-3/4 to 3 in.); conic to long conic; green-yellow to yellow ground color; bright finish; slightly striped 75% light to medium red; fine grained, tough skin; cream colored, moderately tough, tender flesh; spritely acid, bland; juicy. **Season of Maturity**-Five and one-half weeks before 'Delicious.' **Tree**-Vigorous, somewhat lanky and bare wooded branches. **Disease Resistance**-Field immune to apple scab; good level of resistance to powdery mildew; susceptible to cedar-apple rust; susceptible to fire blight. **Problems**-Acidic, insufficient flavor; tender flesh; poor coloring; uneven ripening; heavy fruit drop; inadequate storage life; growth habit; and susceptibility to secondary diseases. **General Recommendation**-Problems too severe for further consideration. Discarded at Lafayette.

Co-op 7 (PRI 2023-1 = PRI 1018-9 x N.J. 154955) (Williams *et al.* 1972)
Fruit-70 to 76 mm or more (2-3/4 to 3+ in.); round to short conic; yellow ground color; bright finish; heavily splashed, slightly striped, mottled in some years, 70 to 90% medium red, attractive; medium grained; cream colored crisp and breaking flesh; sweet to mildly sub-acid and slightly aromatic in flavor; moderately juicy. Large fruit size. Fruit hangs on the tree until over-ripe. **Season of Maturity**-Five weeks before 'Delicious.' **Tree**-Vigorous, highly vegetative and branching, moderate tendency for biennial bearing. **Disease Resistance**-Field immune to apple scab; susceptible to powdery mildew; highly resistant to cedar-apple rust; moderately resistant to fire blight. **Problems**-Bland sweet, insufficient flavor; poor color development in shaded canopy; growth habit; and susceptibility to secondary diseases. **General Recommendation**-Problems too severe for further consideration. Discarded at Lafayette.

Co-op 8 (PRI 1326-1 = PRI 558-1 x 'Mollie's Delicious') (Williams *et al.* 1972)
Fruit-76 mm or more (3+ in.); round to conic with distinctive, strongly pointed, narrow calyx end; green-yellow to pale-yellow ground color; very bright finish; blushed 60 to 85% light to medium red, very attractive; medium grained, cream colored, firm to crisp and slightly breaking flesh; mildly sub-acid, bland; juicy. Some tendency to drop when ripe. **Season of Maturity**-Two and one-half weeks before 'Delicious.' **Tree**-moderate vigor, spreading branches with 90 degree crotch angles, uniformly distributed, large fruit; annual light to moderate cropping. **Disease Resistance**-Field immune to apple scab; good level of resistance to powdery mildew; highly resistant to cedar-apple rust; moderately resistant to fire blight. **Problems**-Bland insufficient flavor, inadequate storage life for season, sparse cropping, tendency to drop. **General Recommendation**-Problems too severe for further consideraton. Discarded at Lafayette. Brazilian reports indicate low chilling requirement. Suggested for further testing in regions with moderate winter chilling.

Co-op 9 (PRI 1677-2 = Starking 'Delicious' x PRI 877-2) (Williams *et al.* 1972)
Fruit-76 mm or more (3+ in.); variable, short conic to round or slightly oblate; green-yellow to yellow ground color; bright finish; striped 90 to 100% medium to dark, red to purple-red, very attractive; coarse grained, cream colored, firm to crisp, moderately tough flesh; sweet to mildly sub-acid, bland, slightly aromatic flavor; juicy. Flavor and quality similar to, but less than 'Delicious.' Fruit hangs on the tree until over-ripe. **Season of Maturity**-One to one-half week before 'Delicious.' **Tree**-Moderate vigor, spreading branches with 90 degree crotch angles, strongly biennial. **Disease Resistance**-Field immune to apple scab; good level of resistance to powdery mildew; susceptible to cedar-apple rust; moderately resistant to fire blight. **Problems**-Bland insufficient flavor; astringent at harvest; tough flesh; alternate bearing, unreliable cropping. **General Recommendation**-Problems too severe for further consideration. Discarded at Lafayette.

Co-op 10 (PRI 1659-10 = 'Starking Delicious' x PRI 610-2) (Williams *et al.* 1972) U.S. Plant Patent No. 4,321
Fruit-70 to 76 mm or more (2-3/4 to 3+ in.); conic with pronounced calyx end points; very bright finish; bright red blushed 100% self yellow to pale-yellow, very attractive; very smooth, non-russeted skin; totally inconspicuous lenticels; medium grained, cream to pale yellow colored, firm to crisp, slightly tender flesh; sweet to mildly sub-acid, bland, slightly spicy flavor; juicy. Flavor

Table 1. (Continued).

and quality similar to, but less than 'Delicious.' Softens and becomes mealy in storage. **Season of Maturity**-With 'Delicious.' **Tree**-Moderately vigorous, strong, thick, heavily spurred branches with 90 degree crotch angles, excellent growth habit. **Disease Resistance**-Field immune to apple scab; moderately resistant to powdery mildew; highly resistant to cedar-apple rust; moderately resistant to fire blight. **Problems**-Bland insufficient flavor; tender flesh, alternate bearing, extremely heavy fruit drop, inadequate storage life for the season. Highly susceptible to leaf bronzing damage by the European red mite *Panonychus ulmi* (Koch.). **General Recommendation**-Problems too severe for further consideration. Discarded at Lafayette.

Co-op 11 (PRI 1947-104 = Ill.#2 ('Winesap' o.p.) x PRI 1042-100) (Williams *et al.* 1972)
Fruit-70 to 76 mm (2-3/4 to 3 in.); conic to long conic with pronounced calyx end points; yellow ground color; bright finish; slightly striped, slightly splashed, 75 to 95% medium red, attractive; medium grained, pale yellow colored, crisp and breaking tough flesh; mildly sub-acid, slightly spicy and full rich flavor; juicy. Flavor is fair at harvest, maturing to good after a month of storage. Fruit hangs on the tree very well. **Season of Maturity**-Two weeks after 'Delicious.' **Tree**-Moderately vigorous, slightly upright, thin branched, very sparse cropping. **Disease Resistance**-Field immune to apple scab; moderately susceptible to powdery mildew; highly resistant to cedar-apple rust; resistant to fire blight. **Problems**-Sparse cropping; tough flesh texture; thin but tough skin; astringence and slight bitterness at harvest; susceptible to fruit storage scald. **General Recommendation**-Problems too severe for further consideration. Discarded at Lafayette.

Co-op 12 (PRI 2175-25 = 'Raritan' x PRI 1018-101) (Williams *et al.* 1975) U.S. Plant Patent No. 4,359
Fruit-70 to 76 mm or more (2-3/4 to 3+ in.); round with wide, open calyx; cuticle covered with pronounced glaucous, waxy, bloom; green yellow to pale yellow ground color; very bright, glossy finish; moderately striped, 60 to 90% light to medium red, attractive; medium grained, light cream colored, crisp and slightly breaking flesh; mildly to moderately acid, slightly spicy, with full rich flavor; very juicy. Flavor breaks down and is unpalatable after one month in refrigerated storage. Uniformly shaped, large fruit evenly distributed throughout tree canopy. **Season of Maturity**-Eight weeks before 'Delicious.' **Tree**-Moderately vigorous, somewhat weeping growth habit, some tendency for tip bearing. In 1978, Co-op 12 showed minimal damage in a test winter at St. Jean-sur-Richelieu, Quebec, Canada, when the majority of the apple collection showed significant winter damage. **Disease Resistance**-Field immune to apple scab; moderately resistant to powdery mildew; susceptible to cedar-apple rust; moderately resistant to fire blight. **Problems**-Short storage-life, uneven ripening, some tendency to drop when ripe, little color develops inside tree canopy, develops full color only when over-mature (see also—Tree and Degree of Resistance to Disease). **General Recommendation**-Discarded at Lafayette. Resistant to winter ocld injury and expected to be well adapted in the North Central U.S., Southern Canada, and similar cilmates. After initial observations, The Swedish University of Agricultural Sciences, Balsgård, has concluded tht Co-op 12 is well adapted under Swedish conditions, and recommends the cultivar for home grower use.

Co-op 13 (PRI 2175-7 = 'Ratitan' x PRI 1018-101) Introduced as 'Redfree' (Williams *et al.* 1981) U.S. Plant Patent No. 4,322
Fruit-64 to 76 mm (2-1/2 to 3 in.); slightly oblate to round, regular; light green to pale yellow ground color; washed and faintly striped, very bright finish; 70 to 95% medium red; medium grained, light yellow to cream colored, firm, crisp and breaking yet slightly tender flesh; mildly acid to sweet, slightly rich and pleasant flavor; juicy; very mild, good dessert quality. Moderate fruit size. Annual cropping. Retains quality for 1 month or more in refrigerated storage. Fruit hangs on the tree until well over-ripe. **Tree**-Vigorous, spreading growth habit, 90 degree crotch angles, moderately spurry. Slightly leggy branches with a limited basal portion of the branches bare-wooded. Moderately large sized tree. In 1978, 'Redfree' showed minimal damage in a test winter at St. Jean-sur-Richelieu, Quebec, Canada, when the majority of the apple collection showed significant winter damage. Other reports from North Dakota, Minnesota, and Canada indicate that 'Redfree' is resistant to winter cold injury. **Season of Maturity**-Seven weeks before 'Delicious.' **Disease Resistance**-Field immune to apple scab; field immune to cedar-apple rust; moderate level of resistance to powdery mildew; good level of resistance to fire blight. **Problems**-Powdery mildew may warrant control only under severe disease pressure; some feel that the flavor is too mild and bland; uneven ripening, requiring two or more pickings; slight tendency toward biennial bearing habit after heavy fruit set; some tendency to set heavy crops, resulting in reduced fruit size if not properly thinned; somewhat leggy growth habit with manageable amount of undesirable bare wood. **General Recommendation**-Suggested for commercial use, as well as small scale and home grower plantings. Produces relatively high quality, low-acid fruit, with pronounced color and adequate storage-life for early entry into the summer apple market. Resistant to winter cold injury and expected to be well adapted in the North Central U.S., Southern Canada, and similar climates.

Table 1. (Continued).

Co-op 14 (PRI 1325-101 = PRI 10-147 x 'Mollie's Delicious') (Williams *et al.* 1975) U.S. Plant Patent No. 4,320
Fruit-64 to 76 mm (2-1/2 to 3 in.); long conic; yellow ground color; bright finish; slightly striped, splashed, 75% medium red to slightly orange, attractive; fine grained, pale yellow colored, very firm, crisp and breaking flesh at harvest, softening and becoming mealy after one and one-half months in storage; sweet to mildly sub-acid, bland flavor; moderately juicy. Heavy cropping with slight tendency for bienniel bearing. Fruit hangs on the tree until over-ripe. Tendency to soften on the tree when over-ripe. **Season of Maturity**-Six weeks before 'Delicious.' **Tree**-Moderately vigorous, moderately spurred, slightly upright branches. **Disease Resistance**-Field immune to apple scab; highly resistant to powdery mildew; field immune to cedar-apple rust; moderately resistant to fire blight. **Problems**-Bland, insufficient flavor; slightly astringent and/or bitter flesh; heavily splashed or mottled color pattern; stem end fruit cracking; tendency to overcrop with small fruit size. **General Recommendation**-Discarded at Lafayette. Brazilian reports indicate low chilling requirement. Suggested for further testing in regions with moderate winter chilling.

Co-op 15 (PRI 1569-100 = N.J. 27 x PRI 612-1) (Williams *et al.* 1975)
Fruit-64 to 70 mm (2-1/2 to 2-3/4 in.); short conic to long conic; pale yellow ground color; bright finish, slightly striped, blushed, 80 to 95% bright medium red, attractive; thin, somewhat tough skin, occasionally with large white or russeted conspicuous lenticels; moderate grained, pale yellow colored, firm, crisp and breaking flesh at harvest, becoming tender after storage; mildly to moderately sub-acid, spicy, full rich flavor; juicy. Moderate cropping with tendency for biennial bearing. Retains quality into December in refrigerated storage. **Season of Maturity**-Two and one-half weeks before 'Delicious.' **Tree**-Moderately vigorous, slightly upright, moderately spurred branches, with some bare wood at their base; very desireable growth habit; tendency for fruit to drop when ripe. **Disease Resistance**-Field immune to apple scab; highly resistant to powdery mildew; moderately susceptible to cedar-apple rust; moderately resistant to fire blight. **Problems**-Moderate to small fruit size; limited storage-life for season; somewhat tender flesh after one month in storage; tendency for fruit drop. **General Recommendation**-Suggested for advanced testing in the Pacific Northwestern U.S., west of the Cascade Mountains.

Co-op 16 (PRI 2174-3 = PRI 764 x PRI 672) (Williams *et al.* 1975) U.S. Plant Patent No. 4,499
Fruit-70 to 76 mm or more (2-3/4 to 3+ in.); conic, classic 'Golden Delicious' shape; moderately bright finish; occasionally red blushed 100% self yellow with small yet conspicuous russeted lenticels, very attractive; fine grained, pale yellow colored, firm, very crisp and breaking flesh; mildly sub-acid, slightly spicy, full rich flavor; very juicy. Uniformly shaped, large fruit distributed evenly throughout the canopy. Flesh texture is maintained for 5 months or more in refrigerated storage. Fruit hangs on the tree very well. **Season of Maturity**-With 'Delicious.' **Tree**-Moderately vigorous, thin branched and somewhat bushy. **Disease Resistance**-Field immune to apple scab; highly susceptible to powdery mildew; susceptible to cedar-apple rust; moderately susceptible to fire blight. **Problems**-Inadequate storage life for season. Even though crisp breaking flesh texture is maintained for more than three months in refrigerated storage, the sugar and flavor in the fruit are converted into starchy, "potato-like" flavor after storage, and develop an extremely greasy cuticle. If harvested only slightly over-ripe, the apple becomes greasy and "potato-like" after one or two months in storage. Poor growth habit and susceptibility to secondary diseases. **General Recommendation**-Problems too severe for further consideration. Discarded at Lafayette.

Co-op 17 (PRI 1689-110 = Ill.#2 ('Winesap' o.p.) x PRI 668-100) (Williams *et al.* 1975)
Fruit-70 to 76 mm (2-3/4 to 3 in.); short conic to slightly oblate-conic; bright, smooth, russet-free finish; burnt-orange blushed 100% self pale yellow with inconspicuous lenticels, attractive; thick tough skin; fine grained, pale yellow colored, very firm, moderately tough, crisp flesh; sweet to mildly sub-acid, slightly aromatic, bland flavor; juicy. Heavy annual cropping. Fruit hangs on the tree extremely well. Retains quality for six months or more in refrigerated storage. Fruit tend to be too small with a heavy crop, unless thinned. **Season of Maturity**-Three and one-half weeks after 'Delicious.' **Tree**-Moderately vigorous; smaller than average tree size; moderately spurry with some tendency for branches to weep; some tendency for tip bearing, some bare wood on branch bases. **Disease Resistance**-Field immune to apple scab; moderately resistant to powdery mildew; susceptible to cedar-apple rust; moderately resistant to fire blight. **Problems**-Bland, insufficient flavor; tough skin; tough flesh texture; undesireable growth habit. (also see Degree of Resistance to Disease). **General Recommendation**-Problems too severe for further consideration. Discarded at Lafayette. Goonewardene and Williams (1988) showed that Co-op 17 possesses resistance to three different insect pests.

Co-op 18 (PRI 1983-207 = N.J. 60837 x PRI 669-205 (669NJ5)) (Williams *et al.* 1975)
Fruit-64 to 70 mm (2-1/2 to 2-3/4 in.); short conic to round; cream to pale yellow ground color; bright finish, washed, 50 to 80% light to medium red; moderate grained, cream to pale yellow colored, firm, crisp flesh; fair to good quality; very juicy. Heavy annual cropping. Quality retained

Table 1. (Continued).

in refrigerated storage. Fruit hangs well on the tree. Cooked apple slices are firm, translucent, and gold in color. **Season of Maturity**-One week after 'Delicious.' Storage-life believed to be three months but conclusive data unavailable. **Tree**-Moderately vigorous; spreading; wide crotch angles; thick, semi-spur type branches. **Disease Resistance**-Field immune to apple scab; moderately resistant to powdery mildew; moderately resistant to cedar-apple rust; very susceptible to fire blight. **Problems**-Moderate to small fruit size; moderate appearance and quality; susceptibility to fire blight. **General Recommendation**-Problems too severe for further consideration. Discarded at Lafayette.

Co-op 19 (PRI 2318-104 = N.J. 57249 x PRI 854-100) (Dayton *et al.* 1977)
Fruit-70 to 76 mm (2-3/4 to 3 in.); oblate-round; cream to pale yellow ground color; very smooth, glossy finish, slightly striped, washed, 50 to 95% light red to pink, attractive; fine grained, pale yellow colored, somewhat crisp yet tender flesh at harvest, softening after storage; mildly sub-acid, spicy, full rich flavor; very juicy. Light cropping. Retains quality for three to four weeks in refrigerated storage. **Season of Maturity**-Eight weeks before 'Delicious.' **Tree**-Vigorous, slightly upright, weeping downward from the top. Strong tendency to bear clustered fruit on the tips of branches; tendency for fruit to drop when ripe. **Disease Resistance**-Field immune to apple scab; highly resistant to powdery mildew; highly resistant to cedar-apple rust; moderately resistant to fire blight. **Problems**-Tender to soft flesh texture; limited storage-life; poor color development; uneven ripening; tendency for fruit drop; and poor growth habit. **General Recommendation**-Problems too severe for further consideration. Discarded at Lafayette.

Co-op 20 (PRI 2318-104 = 'Crandall' x PRI 688-100) (Dayton *et al.* 1977)
Fruit-64 to 70 mm (2-1/2 to 2-3/4 in.); oblate-round; pale yellow to deep canary yellow ground color; smooth, glossy finish; striped, washed, 50 to 80% medium to light red or orange, unique; fine grained, deep yellow colored, firm, very crisp and breaking flesh at harvest, retaining this texture up to one and one-half months in storage; mildly to moderately sub-acid, spicy, very full rich flavor; juicy. Retains quality for two months or more in refrigerated storage. Extremely sparse cropping with biennial tendency. **Season of Maturity**-Six to seven weeks before 'Delicious.' **Tree**-Moderately vigorous slightly upright, very thin branches with prolific branching producing a very brushy, undesirable tree; strong tendency for fruit to drop when ripe. **Disease Resistance**-Field immune to apple scab; susceptible to powdery mildew; very susceptible to cedar-apple rust; moderately resistant to fire blight. **Problems**-Sparse bearing, uneven ripening; tendency for fruit drop; poor growth habit; and susceptibility to secondary diseases. **General Recommendation**-Problems too severe for further consideration. Discarded at Lafayette.

Co-op 21 (PRI 2259-100 = N.J. 123249 x PRI 1235-100) Introduced as 'Dayton' (Korban *et al.* 1988) U.S. Plant Patent No. 5,584
Fruit-67 to 76 mm or more (2-1/2 to 3+ in.); slightly oblate to round or short-conic; green to pale yellow ground color; washed, extremely bright and shiny, 75 to 95% medium red; fine grained, pale yellow to cream colored, firm, crisp yet somewhat tender flesh, texture similar to 'Jonathan'; slightly spicy, mildly to moderately acid, and moderately rich in flavor; flavor resembles 'Prima'; juicy; very good dessert quality. Large fruit size. Attractive, "commercial" looking fruit. Retains quality for six weeks or more in refrigerated storage, longer than 'Prima.' **Season of Maturity**-Four to five weeks before 'Delicious.' **Tree**-Vigorous, moderately upright, moderately spreading tree. Standard bearing habit. Moderately large sized tree. **Disease Resistance**-Field immune to apple scab; moderate resistance to powdery mildew; moderate resistance to fire blight; moderately susceptible to cedar-apple rust. **Problems**-Susceptibility to cedar-apple rust is a problem in some areas. Powdery mildew may warrant control in some seasons. Fruit does not color well inside canopy. Some consider longevity in storage to be inadequate, but it keeps longer than 'Prima.' Prone to bitter-pit under appropriate conditions. Uneven ripening, requiring two pickings. Moderate cropping; unsure about the cropping potential in some areas; we have observed better cropping on deep, loamy, fertile soils. **General Recommendation**-Suggested for advanced commercial testing, as well as small scale and home grower plantings. Produces relatively high quality, moderately acid fruit, with pronounced color and adequate storage-life for early entry into the fall apple market. Develops more color and less acid than 'Prima,' ripening in approximately the same season, a slightly more tender flesh texture and slightly longer storage-life.

Co-op 22 (PRI 2016-100 = PRI 855-102 x N.J. 31) Introduced as 'Jonafree' (Dayton *et al.* 1979) U. S. Plant Patent No. 4,633
Fruit-64 to 76 mm (2-1/2 to 3 in.) averaging 70; round, regular; green yellow to pale yellow ground color; washed without stripes, very bright, 75 to 95% medium red; medium grained, light yellow to cream colored, firm, crisp and slightly breaking flesh, slightly tough until full ripe; slightly spicy, moderately acid, and moderately rich in flavor; juicy; very good dessert quality. Less susceptible to powdery mildew, fire bilght, and cedar-apple rust than 'Jonathan.' Not prone to bitter-pit or

Table 1. (Continued).

'Jonathan' spot. Higher percent red color than 'Jonathan.' Flavor similar to 'Jonathan,' but less acid. Moderate fruit size. Annual cropping. Quality retention in storage similar to 'Johathan,' better in some years. Develops flavor breakdown to objectionable aldehyde in some years, after 2 and ½ to 3 months of storage. **Season of Maturity**-With 'Jonathan,' one week before 'Delicious.' **Tree**-Moderately vigorous and spreading, somewhat upright, leggy branches with a significant basal portion of the branches bare-wooded. Medium sized tree. **Disease Resistance**-Field immune to apple scab; moderately susceptible to powdery mildew; moderately susceptible to cedar-apple rust; moderately susceptible to fire blight. **Problems**-Susceptibility to cedar-apple rust, mildew, and fire blight are all problems in some areas; somewhat bushy growth habit, with significant lengths of bare wood. Somewhat difficult to train and manage; usually requires two pickings; small fruit size if not properly thinned. **General Recommendation**-Recommended for commercial use as a disease resistant substitute for 'Jonathan' in areas where this cultivar is grown, as well as small scale and home grower plantings. Produces high quality, 'Jonathan'-type fruit with more red color, less acid, firmer texture, and no 'Jonathan' spot.

Co-op 23 (PRI 2845-1 = PRI 1018-101 x NJ 50) Introduced as 'Williams' Pride' (Janick *et al.* 1988) U.S. Plant Patent No. 6268

Fruit-67 to 76 mm or more (2-1/2 to 3+ in.); variable size; round to conic, variable shape; lime green to pale yellow ground color; washed and faintly striped, bright, 70 to 99% medium to dark red or purple-red; conspicuous, slightly sunken lenticels; medium to coarse grained, cream colored, firm, very crisp and breaking flesh; moderately to mildly sub-acid, slightly spicy, full rich flavor; juicy; excellent summer dessert quality. Moderate to large fruit size. Fall quality in the middle of the summer. Annual cropping, with slight bienniel tendencies. Retains quality and crisp flesh texture for 6 weeks or more in refrigerated storage. **Season of Maturity**-Seven to eight weeks before 'Delicious.' **Tree**-Vigorous, spreading, 90° crotch angles, very spurry wood. Similar in growth habit to 'Empire,' but not quite as spurry. Moderately large tree size. **Disease Resistance**-Field immune to apple scab; field immune to cedar-apple rust; high level of resistance to fire blight; good level of resistance to powdery mildew. **Problems**-Severe watercore may be a significant problem in some seasons. Slight bitter pit observed in a few seasons. Severe bitter pit was observed on young trees with their first crop on MM-111 rootstock, on very sandy soil, under heavy nitrogen and irrigation. Fruit borne in clusters on short spurs, may tend to be pushed off as they swell, giving some loss to dropped fruit. Slightly coarse flesh texture. Uneven ripening will require two or more pickings. **General Recommendation**-Suggested for advanced commercial testing on soils where nutrient deficiencies do not predispose trees to bitter-pit. as well as small scale and home grower plantings. Produced large, high quality fruit, ripening with the earliest red apple cultivars and relatively long storage-life for early entry and extended use in the summer apple market. Not recommended on MM-111 rootstock, on bitter-pit prone soils, or under high nitrogen fertilization.

Co-op 24 (PRI 2058-2 = N.J. 125355 x 'Prima') (Williams *et al.* 1984)

Fruit-64 to 70 mm (2-1/2 to 2-3/4 in.); variable, oblate-round or short-conic and slightly lobed, wide calyx cavity with open calyx; green-yellow to pale yellow ground color; bright glossy finish; washed 75 to 95% medium to dark, red to purple-red, very attractive; fine grained, pale yellow to cream colored, firm, very crisp and breaking flesh; mildly sub-acid, slightly spicy. slightly aromatic, moderately rich flavor at peak; juicy. Fruit hangs on the tree until over-ripe. Annual, moderate cropping. **Season of Maturity**-One-half to one week before 'Delicious.' **Tree**-Moderate vigor, slightly upright, spreading to rangy growth habit with limber branches; semi-spur type bearing habit with some bare wood at branch base. **Disease Resistance**-Field immune to apple scab; highly resistant to powdery mildew; susceptible to cedar-apple rust; moderately resistant to fire blight. **Problems**-Insufficient storage for season; although flesh texture is maintained for many months, after one and one-half to two months in refrigerated storage, flavor breaks down to undesirable aldehyde and becomes unpalatable; with a large crop, fruit tend to be small and flavor tends to be bland and insufficient; flavor peaks only after two to four weeks in refrigerated storage. **General Recommendation**-Problems too severe for further consideration. Discarded at Lafayette.

Co-op 25 (PRI 2712-4 = PCF 2-134 x PRI 669-205 (669NJ5)) (Williams *et al.* 1984)

Fruit-76 mm or more (3+ in.); round to short-conic; green-yellow to yellow ground color; moderate to bright finish; slightly splashed, washed 75 to 90% light to medium red to orange; moderate grained, pale yellow to cream colored, extremely firm, very crisp and breaking flesh; sweet to mildly sub-acid, slightly spicy, fruity, rich, pleasant flavor; juicy. Open calyx tube. Somewhat bland at harvest, flavor improves greatly after one to two months in storage. Retains quality in refrigerated storage for seven months or more. Co-op 25 pme of the longest storing selections to originate from the PRI program. Fruit hangs on the tree very well. Observed to be susceptible to apple maggot in late-season unsprayed blocks. **Season of Maturity**-One to one-half week before 'Delicious.' **Tree**-Moderate vigor, spreading with 90 degree crotch angles, somewhat thin, slightly

Table 1. (Continued).

weeping branches with moderately bare-wooded bases; fruit tend to be borne on long spurs, with some slight tendency for tip-bearing, and some tendency for fruit to be borne in clusters; slight biennial tendency. **Disease Resistance**-Field immune to apple scab; moderately resistant to powdery mildew; highly resistant to cedar-apple rust; highly susceptible to fire blight. **Problems**-Mediocre growth habit (partially overcome by ability of fruit to hang very well); tendency for reduced fruit size and reduction in flavor with a heavy crop; high fire blight susceptibility. Low level of moldy-core observed under the absence of fungicidal sprays. **General Recommendation**-Suggested for advanced testing in Oregon, Washington, U.S.; British Columbia, Canada; and other areas where fire blight is not a major concern.

Co-op 26 (PRI 1659-100 = 'Starking Delicious' x PRI 610-2) (Williams *et al.* 1984)
Fruit-Variable size and shape: 64 to 76 mm (2-1/2 to 3 in.); round or short-conic to long-conic; green-yellow to pale-yellow ground color; very bright, glossy finish; washed 75 to 100% medium red, very attractive; fine grained, cream colored, firm to crisp, yet slightly tender flesh, texture varies from year to year; sweet to mildly sub-acid, somewhat bland, pleasant flavor; very juicy. Quality peaks soon after harvest. Fruit hangs on the tree well. Annual heavy cropping. Initial tests on dwarfing rootstocks have shown tendency for watercore. **Season of Maturity**-With 'Delicious.' **Tree**-Moderate vigor, slightly upright with wide, strong crotch angles, and thick, heavily spurred branches; semi-spur type, desirable growth habit. **Disease Resistance**-Field immune to apple scab; highly resistant to powdery mildew; highly resistant to cedar-apple rust; highly resistant to fire blight. Shown to be sensitive to Stem Pitting and Chlorotic Leaf Spot viruses. Prone to "measles" caused by boron deficiency/acid soil conditions. **Problems**-Mediocre flavor, variable fruit size, shape, and year to year quality; insufficient storage-life for season: in most years becoming tender, mealy, and unpalateable by mid-December in refrigerated storage; poor color development inside tree canopy. **General Recommendation**-Problems too severe for further consideration. Discarded at Lafayette.

Co-op 27 (PRI 1947-105 = Ill.#2 ('Winesap' o.p.) x PRI 1042-100) (Korban *et al.* 1990)
Fruit-64 to 76 mm (2-1/2 to 3 in.); round to oblate-round; pale yellow ground color; moderate to bright finish; splashed and occasionally mottled, 90% medium to dark red, attractive; fine grained, cream colored, firm to crisp flesh and slightly tough at harvest, mellowing to firm and moderately crisp in storage; moderately to sprightly sub-acid, spicy, full, rich, flavor; juicy. Very good quality. Open calyx. Retains flesh texture and quality for six months or more in refrigerated storage. Fruit hangs on the tree very well. Moderate to heavy annual cropping. Uniformly moderate to large size. Winter, storage apple with uniform ripening and single harvest. **Bloom Period**-Early-midseason. **Season of Maturity**-One week after 'Delicious.' **Tree**-Moderate vigor, moderately upright, full spur-type, with strong branches. Bears fruit in short spurs. **Disease Resistance**-Field immune to apple scab; moderately resistant to powdery mildew; field immune to cedar-apple rust; highly resistant to fire blight. **Problems**-Slightly tough flesh at harvest; sprightly acid; occasional mottled color; thick, stiff stem. **General Recommendation**-Strongly suggested for advanced testing.

Co-op 28 (PRI 2929-104 = PRI 1982 x 'Prima') (Korban *et al.* 1990)
Fruit-60 to 70 mm (2-1/4 to 2-3/4 in.); variable shape-round to oblate-conic; green-yellow to yellow ground color; bright finish; slightly striped, washed, 75 to 90% medium red; occasionally conspicuous lenticels; medium grained, white to cream colored, firm, crisp and breaking flesh; mildly sub-acid, slightly spicy, full, rich, flavor; moderately juicy. Retains flesh texture and quality for up to four months in refrigerated storage. Fruit hangs on the tree very well, retaining quality and texture for several weeks on tree. Heavy cropping with strong biennial tendency. **Bloom Period**-Early to midseason. **Season of Maturity**-One to one and one-half weeks before 'Delicious.' **Tree**-Vigorous, upright and spreading, somewhat limber, with blind wood in basal portion of branches. Fruit borne on short to moderate length spurs. **Disease Resistance**-Field immune to apple scab; moderately resistant to powdery mildew; moderately resistant to cedar-apple rust; highly susceptible to fire blight. **Problems**-Limber wood (partially overcome by ability of fruit to hang very well); tendency for reduced fruit size and reduction in flavor with a heavy crop; susceptibility to fire blight. **General Recommendation**-Suggested for advanced testing in areas where fire blight is not a problem.

Co-op 29 (PRI 2050-4 = 'Golden Delicious' x PRI 1050-201 (1050NJ1)) (Korban *et al.* 1990)
Fruit-70 to 76 mm or more (2-3/4 to 3+ in.); round to short-conic; moderate to bright finish; occasional mottled, pink to orange blush, 100% pale yellow, attractive; moderate stem-end russet, occasionally conspicuous, russeted lenticels; medium to coarse grained, cream colored, very firm, very crisp and breaking flesh; moderately to sprightly sub-acid, mellowing in refrigerated storage; spicy, full, rich, flavor; juicy. Very good quality. Retains flesh texture and quality for five months or more in refrigerated storage. Fruit hangs on the tree until over ripe. Moderate to heavy cropping. Winter, storage apple. **Season of Maturity**-Two and one-half weeks after 'Delicious.' **Tree**-

Table 1. (Continued).

Moderate to high vigor, slightly upright, branches with lengths of bare-wood at their bases; some slight tendency for fruit to be borne in clusters; slight biennial tendency. **Disease Resistance**-Field immune to apple scab; moderately resistant to powdery mildew; highly resistant to cedar-apple rust; highly resistant to fire blight. **Problems**-Some tendency for fruit to be borne in clusters; leggy, bare-wooded branches may make training somewhat difficult; stem end russet and mottled blush detract from appearance. **General Recommendation**-Strongly suggested for advanced testing.

Co-op 30 (PRI 2693-1 = PRI 1661-2 x PRI 1661-1) (Korban *et al.* 1990)
Fruit-64 to 76 mm (2-1/2 to 3 in.); round to elongate and occasionally oblong; green yellow to deep yellow ground color; very bright, glossy finish; washed 80 to 100% medium red to slightly orange, very attractive; inconspicuous lenticels; fine grained, pale yellow to cream colored, firm, crisp and breaking flesh; moderately thick, tough skin; sprightly sub-acid at harvest mellowing to moderately sub-acid in storage; spicy, very full, rich, flavor; juicy, Very good quality. Retains flesh texture and quality for six months or more in refrigerated storage. Fruit hangs on the tree very well. Uniformly moderate to large size. Winter, storage apple with uniform ripening, moderate to heavy annual cropping, and single harvest. Flavor peaks after one or two months in refrigerated storage. **Bloom Period**-Late season. **Tree**-Moderate to high vigor, spreading, round top. Fruit borne singly on moderate length spurs distributed uniformly throughout canopy. **Season of Maturity**-two and one-half weeks after 'Delicious.' **Disease Resistance**-Field immune to apple scab; moderately resistant to powdery mildew; highly resistant to cedar-apple rust; highly resistant to fire blight. **Problems**-Sprightly acid at harvest; quality only becomes exceptional after storage. **General Recommendation**-Strongly suggested for advanced testing.

Co-op 31 (PRI 2463-101 = Rock 41-112 x PRI 841-103) (Korban *et al.* 1990)
Fruit-Variable size 60 to 76 mm (2-1/4 to 3 in.); round; green yellow to yellow ground color; appearance varies from year to year, performs best under hot, dry conditions (excellent performance in 1988 and 1990 droughts); dull to moderate or bright finish; splashed and striped, mottled with green in some seasons, 80 to 100% dark purple-red; tendency for heavy scarf-skin; medium to coarse grained, cream colored, firm, very crisp and breaking flesh; relatively thin, palatable skin; mildly sub-acid; spicy, full, rich, flavor; juicy. Very good quality. Retains flesh texture and quality for six months or more in refrigerated storage. In the 1989 storage season, fruit quality was still very good after eights months in refrigerated storage. Some tendency to drop when ripe. Winter, storage apple with uniform ripening, moderate to heavy cropping, and single harvest. Biennial tendency after heavy cropping. Flavor peaks after one month in refrigerated storage. **Bloom Period**-Midseason. **Season of Maturity**-Two weeks after 'Delicious.' **Tree**-Moderate vigor, spreading, round top. **Disease Resistance**-Field immune to apple scab; moderately resistant to powdery mildew; moderately susceptible to cedar-apple rust; good resistance to fire blight; susceptible to Botryosphaeria rots in storage. **Problems**-Unattractive in most seasons; dull, scarfy skin promotes dehydration and shrivelling in storage; some tendency to drop when ripe; strong biennial habit and variable fruit size indicates thinning is required. **General Recommendation**-Suggested for testing.

to have utility in the Loire Valley, the Massif Central Valley, and the east of France. The fruit is quite acid and was originally intended to fill a specific niche in production in France and Belgium as a late, red, markedly-acid apple. Limited in adaptation, it was released as a stopgap cultivar. Originally selected in Indiana, it had been discarded in the second test block at Purdue because it was too highly acid for American tastes and was markedly susceptible to powdery mildew. 'Priam' continues to be tested by cultivar evaluation programs in Europe and is suggested for use in the home garden. It was never patented and is currently unavailable in the U.S.

'Jonafree' and 'Redfree' are gaining in popularity in the U.S. Productivity, good red color, competitive fruit quality, and adequate fruit storage life are factors expressed repeatedly in reports by growers. Expressions of interest by nurseries, the appearance of fruit in small scale in Indiana supermarkets and roadside markets, and the first overseas shipment of 'Redfree' apples to market in Europe in 1990 offer encouraging signals for the future. In the 5 year period 1986-1990, 22,000 trees of 'Jonafree' and 14,000 of 'Redfree' have been sold. 'Jonafree' may find a niche as a scab-resistant substitute for 'Jonathan,' ripening in the same season, with attributes such as lower acidity,

redder fruit color, and similar storage life. Although 'Jonafree' has better resistance to powdery mildew, cedar-apple rust, and fire blight than 'Jonathan,' its moderate susceptibility to these diseases will require control measures. 'Redfree,' an early, sweet, summer apple, is somewhat earlier than 'Paulared' and later than 'Vista Bella.' Its mild, pleasantly-sweet flavor and four-week retention of firm-ness in storage make this apple very competitive in a season filled with tart to acid, short-lived or early 'McIntosh'-like cultivars. 'Jonafree' and 'Redfree' are under evaluation in Europe. 'Jonafree' was licensed in Yugoslavia in 1979. Both cultivars are protected by plant patent in the U.S. The U.S. Plant Patent (No. 4,322) for 'Redfree' expires in October of 1995, and (No. 4,633) for 'Jonafree' expires in January of 1998.

'Dayton,' 'Williams' Pride,' and 'McShay' are too new to have established a reputation for adaptation or acceptance. 'Williams' Pride' was named in honor of E. B. Williams, long-time leader of the breeding program at Purdue. It offers potential as an early summer, mildly acid, full flavored dessert apple, maturing just before 'Redfree,' that will store for up to 6 weeks. It has excellent fall quality for a summer apple but has shown excessive water core and bitter pit in some years. 'Dayton,' named in honor of D. F. Dayton, long-time coordinator of the project at the University of Illinois, may offer an alternative to or replacement for 'Prima' with more red color, more uniform fruit size and shape, and less susceptibility to rust. 'McShay' was named in honor of the late J. R. Shay, originator of disease resistant apple breeding at Purdue and former Assistant Dean of Research at Oregon State University. 'McShay,' originally selected at Purdue, was named in cooperation with Oregon State University, after many years of evaluation at Corvallis. It performs well as a scab-resistant substitute for 'McIntosh' in Oregon's Williamette Valley. 'Dayton,' 'Williams' Pride' and McShay' are all protected by U.S. Plant Patents.

5. Conclusions

The scab-resistant apple breeding program was conceived to increase grower efficiency by reducing fungicidal sprays. The impact of the environmental movement and ever-rising costs of energy have greatly increased the relevance of this program. Widespread adoption of disease-resistant cultivars could impact food safety, groundwater purity, protection of nontarget organisms, applicator exposure to pesticides, and also lower the cost of production.

The success of the modified backcross program to confer scab resistance in apple was due to a number of additional factors which should be underscored:

1). A distinct advantage over standard susceptible cultivars was immediately conferred to any seedling that possessed the V_f gene.
2). A serendipitous transfer of other desirable characters of *Malus floribunda* such as attractive fruit finish.
3). Indirect selection for precocity by the continual crossing of selections which fruit in the early years after planting.
4). Selection for whole or partial resistance to other diseases. Disease resistance was easily recognized because scab resistance made it possible to grow seedlings without fungicide protection.

Equally important has been the bonus achieved by the coordination of apple breeding that this cooperative program engendered. In 1963 an informal organization known as the Apple Breeders Cooperative was formed which coordinates research efforts among apple breeders with special attention to disease resistance. The program is now cooperative between 16 active apple breeding

programs throughout the world. These include: New York State Agricultural Experiment Station, Geneva, and the University of Minnesota, Excelsior, U.S.A.; Summerland Agricultural Research Station, Summer-land British Columbia, and Agriculture Canada Research Station, Kentville, Nova Scotia, Canada; EMPASC, Cacador and Sao Joaquim, Santa Catarina, and at EMBRAPA, Vacaria, Rio Grande de Sul, Brazil; INRA, Angers, France; Granite Belt Horticultural Research Station, Applethorpe, Queensland, Australia; DSIR, New Havelock, New Zealand; Orlovskaja Plodovo-Jagodnaja Opitnaja Stanzija, Zhilina, Orel, USSR; Swedish University of Agricultural Sciences, Bålsgard-Department of Horticultural Plant Breeding, Kristianstad, Sweden; SCPP Voinesti, Judetul Dimbovita, SCPP Bistrita, ICPP Pitesti, and SCPP Cluj, Romania; Research Institute of Pomology and Floriculture, Skierniewice, Poland; IVT, Wageningen, the Netherlands; Research and Breeding Institute of Pomology, Holovousy, Institute of Experimental Botany and O. Louda (private breeder), Prague, Czechoslovakia; and Horticulture Research International, East Malling, Kent, England.

Scab-resistant selections for advanced or intensive testing have been identified by many of these programs. Recent reports by breeders at the respective stations have identified the promising selections listed below:

Brazil

EMPASC, Cacador, Santa Catarina. A number of selections from crosses with 'Gala' and 'Fuji,' deriving resistance from *M. floribunda* 821.

Czechoslovakia

Breeding Institute of Pomology, Holovousy. Eight advanced selections given to the State Variety Trials. All derive resistance from *M. floribunda* 821 and quality characters from 'Britemac,' 'Golden Delicious,' 'Cox's Orange Pippin,' and Red 'Delicious.' Two other selections with polygenic resistance from 'Antonovka' (second generation offspring crossed with 'Golden Delicious'), HL 362 ('Angold') and HL 369, are promising in trials.

Institute of Experimental Botany and O. Louda, Prague. 'Harmonie' is a working name for selection 163-3, a seedling of 'Prima' x 'Sampion.' UEB 1679/4, UEB 1740/5, and UEB 1173/1 are other advanced selections currently under test in Czechoslovakia. These derive resistance from *M. floribunda* 821 and quality from 'Lord Lambourne' and 'Golden Delicious' as seed or pollen parents.

England

Horticulture Research International, East Malling, Kent. A272/5, A720/7, E11/20, and SA15/4 are all advanced selections introduced into grower trials in England. Seed or pollen parents include: 'James Grieve,' 'Cox Orange,' 'Michaelmas Red,' 'Falstaff,' and 'Starkspur Golden Delicious.' Resistance sources include V_f and V_r. A92/23, A172/2, and A567/19 have shown promise in trials in Switzerland. Seed or pollen parents include: 'James Grieve,' 'Cox Orange,' and 'Tydeman's Late Orange.' These derive resistance from *M. floribunda* 821.

France

INRA, Angers. X 3191, X 3189, X 3177, P6 R28-6, P6 R28-39, and P22 R17-66 are currently under test in the U.S. Seed or pollen parents include: 'Idared,' 'Winesap,' 'Florina Querina,' 'Gala,' 'Prima,' and 'Jonamac.' All derive resistance from *M. floribunda* 821.

The Netherlands

IVT, Wageningen. IVT 78039-8, IVT 78039-18, IVT 78039-20, IVT 78039-26, and IVT 78039-27. All are seedlings of 'Elstar' x 'Prima'; some seedlings of 'Priscilla' are also promising.

Poland

Research Institute of Pomology and Floriculture, Skierniewice. V-136-D2, V-144-D2, V-151-D2, V-142-D2, and VI-17-D2. Seed or pollen parents include: 'Primula' and 'Bancroft.' Resistance sources include V_f and V_r.

Romania

SCPP, Voinesti, Bistrita, and Cluj. 126 selections from crosses with 'Prima'; 2 selections from crosses with 'Priam.'

Russia

The Research Institute of Fruit Breeding, Orel. Elita 18-13-27 ('Antonovka' x PRI 240-57), selected as an elite seedling in 1988, contains V_f resistance from *M. atrosanguinea* 804. Elita 18-11-43 ('Skrizhapel' x 1924), Elita 18-52-13 ('Korichnoye Polosatoye' x 'Priam'), Elita 18-62-57 (814 open pollinated), and Elita 23-14-123 (814 open pollinated) were selected as elite seedlings beteen 1988 and 1990 and contain V_f resistance from *M. floribunda* 821.

United States of America

New York State Agriculture Experiment Station. NY 65707-19, NY 66305-139, NY 73334-35, NY 74828-12, NY 74840-1, NY 75413-30, NY 75414-1, and NY 75441-67, offered for widespread testing in the U.S. through the New York Fruit Testing Association. Seed or pollen parents include: 'Spartan,' 'Liberty,' 'Delicious,' 'Jonamac,' 'Empire,' 'Prima,' and 'MacSpur.' Most of the above selections derive resistance from *M. floribunda* 821.

Purdue, Rutgers, Illinois. Co-op series 27, 28, 29, 30, and 31. The process is underway to patent Co-op 30. Other promising selections to be released in an upcoming series of Co-op releases include: HFRow 34, HER4T16, CLR13T45, TNR10T11, and CLR13T40. Seed or pollen parents include: 'Golden Delicious' and 'Prima.' All of the above selections derive resistance from *M. floribunda* 821.

The cultivar releases of all programs are presented in Table 2. Other ongoing efforts to utilize scab resistance exist in China.

Although none of the cultivars released are currently of widespread commercial importance, a number show promise. 'Liberty' and 'Prima' are at present the most widely planted scab-resistant cultivars in the U.S. 'Redfree' and 'Jonafree' are quickly gaining favor and in our estimation will become important. 'Florina Querina' (31) appears promising in Europe and initial evaluations in the U.S. are encouraging.

Most important, the V_f gene has not been overcome by the development of virulent new races of *V. inaequalis* and no negative pleiotropic effects of this gene have been observed. Reports of *V. inaequalis* infection of various Co-op selections in Moldavia have been attributed to mislabeling (I. P. Turcan, personal communication). Low levels of scab infection reported on various Co-op selections in Europe under optimal conditions for disease development are consistent with original phenotypic expressions of resistance determined in the greenhouse inoculation trials. Class 3 reaction types would allow for a low level of leaf infection in the field under optimal conditions.

There now exists a wide range of genotypes containing the V_f gene, ranging in maturity from 75 to 180 days after flowering, with large size, crisp flesh types, good storage behavior, and a wide range in flavor and skin color (red, orange, yellow, and green). A number of selections contain varying resistance to other diseases including fire blight (*Erwinia amylovora* (Burr.) Winslow), powdery mildew (*Podosphaera leucotricha* (Ell & Ev.) Salm), and cedar-apple rust (*Gymnosporangium juniperi-virginianae* Schw.). A few selections (e.g., 'Liberty' 'Williams' Pride' and Co-op 26) exhibit high levels of resistance to

all four of these major diseases. These results indicate that traditional breeding will continue to be an effective strategy for controlling some of the major diseases of apple.

The future objectives of apple breeding must be to combine scab resistance with resistance to other diseases, the most important being cedar-apple rust, powdery mildew, fire blight, and various summer diseases. Tolerance for many insect pests exists in the scab-resistant germplasm (12, 14, 15, 16) and insect resistance will become an objective in the future. Current programs are under way in California to add the Bt gene from *Bacillus thurengensis* to scab resistant genotypes by genetic transformation. The University of Illinois Cornell University have begun to use molecular techniques to investigate the transfer or induction of resistance on the molecular level, including the genetic transformation of apple by *Agrobacterium* spp. and other techniques (34). Despite all efforts on pest resistance it is clear that resistance must be combined with superior fruit quality for these improved genotypes to gain acceptance in the marketplace.

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Table 2. Worldwide scab-resistant apple releases 1970-1990. All releases contain V_f resistance derived from *M. floribunda* 821 except were noted.

Country of origin	Cultivar name	Year of release	Pedigree	Reference
Brazil	Primicia	1988	(PRI 1986-201 x PRI 1983)	Denardi *et al.* 1988
Canada	Nova Easygro[a]	1971	('Spartan' x PRI 565)	Crowe 1971
	Macfree	1974	('McIntosh' x PRI 48-177)	Spangelo *et al.* 1974
	Moira	1978	('McIntosh' x PRI 47-77)	Heeney 1981
	Trent	1978	(McIntosh' x PRI 48-173)	" "
	Britegold	1978	('Sandel' x O-522 ['Red Melba Platts' x PRI 11-151])	" "
	Murray[b]	1978	('McIntosh' x 52-05-26 ['Red Melba Platts' x PRI 69-52])	" "
	Novamac	1978	('McIntosh' x PRI 1018-3)	Crowe 1978
	Rouville[c]	1983	({'Red Melba Platts' x ['Wolf River' x *M. atrosanguinea* 804]} x 'McIntosh')	Rouselle 1983
	Richelieu	1983	(O-521['Melba' x PRI 11-51] x O-541['McIntosh' x PRI 47-77])	Rouselle 1983
	Nova Spy	1986	('Nova Easygro' x NY 44411-1 ['RedSpy' x 'Golden Delicious'])	Crowe 1986
Czechoslovakia	Jolana	1985	('Spartan' x PRI 370-15)	J. Blazek pers. comm.
	Melodie[d]	1989	('Sampion' x PRI 370-15)	" " " "
	Imuna	1990	('Jolana' x 'Early Red Bird')	" " " "
	Karmîna	1990	('Karmen' x UEB 1725/6 [PRI 370-15 x 'Spartan'])	" " " "
	Katka	1990	('Jolana' x 'Rubin')	" " " "
	Rosana	1990	('Jolana' x 'Lord Lambourne')	" " " "
	Selena	1990	('Britemac' x 'Prima')	" " " "
	Vanda	1990	('Jolana' x 'Lord Lambourne')	" " " "
England	Gavin[e]	1977	('Merton Worcester' x D920-9)	F. Alston pers. comm.
France	Priam	1974	(PRI 370-16)	DeCourtye *et al.* 1974
	Florina Querina	1977	('Jonathan' x PRI 612-1)	Lespinasse *et al.* 1985
	Judeline	1986	('Golden Delicious' x 'Priam')	Lespinasse 1989
	Judaine	1986	('Reinette du Mans' x 'Priam')	" "
	Baujade	1989	('Granny Smith' x P5R42-52 [PRI 672-3 x 'Reinette du Mans'])	" "
Poland	Primula[f]	1974	(PRI 1255-100)	A. Czynczyk pers. comm.
	Witos	?	('Fantazja' x 'Primula')	A. Rejman pers. comm.

Table 2. (Continued).

Country of origin	Cultivar name	Year of release	Pedigree	Reference
Romania	Generos[g]	1972	('Frumos de Voinesti' x [{'Golden Pearmain' x *M. kaido*} x 'Jonathan'])	L. Serboiu, pers. comm.
	Pionier	1983	(55-109-149 Voinesti x 'Prima')	" " " "
	Romus 1	1984	?	" " " "
	Romus 2[h]	1984	?	" " " "
	Romus 3	1984	?	" " " "
	Voinea	1985	('Frumos de Voinesti' x 'Prima')	" " " "
U.S.S.R.	Imrus[i]	1989	('Antonovka' x PRI 240-57)	Sedov *et al.* 1989
	Chistotel[j]	1989	('Antonovka' x SR0523)	" " "
	Orlovim[k]	1990	('Antonovka' x SR0523)	" " "
	Orlovski Pioner[l]	1989	('Antonovka Krasnobochka' x SR0523)	" " "
	Pervinka[m]	1990	('Antonovka Krasnobochka' x SR0523)	" " "
U.S.A.	*New York Agricultural Experiment Station, Geneva.*			
	Liberty	1979	(PRI 54-12 x 'Macoun')	Lamb 1979
	Freedom[n]	1985	(NY 18492['Macoun' x Antonovka] x NY 49821-46 ['Golden Delicious' x PRI $F_2$26829-2-2])	Lamb *et al.* 1985
	PRI (Purdue University, Rutgers University, University of Illinois):			
	Prima	1970	(PRI 14-64 x N.J. 123249)	Dayton *et al.* 1970
	Priscilla	1972	('Starking Delicious' x PRI 610-2)	Williams *et al.* 1972
	Sir Prize	1975	(tetraploid 'Golden Delicious' x PRI 14-152)	Williams *et al.* 1975
	Jonafree	1978	(PRI 855-102 x N.J. 31)	Dayton *et al.* 1978
	Redfree	1980	('Raritan' x PRI 1018-101)	Williams *et al.* 1980
	Dayton	1988	(N.J. 123249 x PRI 1235-100)	Korban *et al.* 1988
	Williams' Pride	1988	(PRI 1010-101x N.J. 50)	Janick *et al.* 1988
	McShay	1988	('McIntosh x PRI 612-4)	Mehlenbacher *et al.* 1988

[a]Contains V_r scab-resistance from Russian seedling R#12740-7A.
[b]Contains scab-resistance from *M. micromalus*; unknown susceptibility to Race 5.
[c]Contains V_m scab-resistance from *M. atrosanguinea* 804; susceptible to Race 5.
[d]Incompletely resistant; may carry V_f at reaction class 3 level or only a high level of polygenic resistance.
[e]The observation of a high percentage of scabby fruit in The Netherlands in 1985 (van der Scheer 1988) suggests that 'Gavin' only contains a high level of polygenic resistance and not V_f.
[f]Reports of minor scab infection on 'Primula' in Poland (A. Rejman pers. comm.) are consistent with a class 3 reaction in greenhouse inoculations. However, reports in Moldavia, U.S.S.R. indicate scab susceptibility; yet 'Primula' produced some progeny with high levels of field resistance. It is unclear to us if 'Primula' contains the V_f gene.
[g]Significant scab infection observed; carries a high level of polygenic resistance only.
[h]Scab infection observed (L. F. Hough and Y. Lespinasse pers. comm.); it may have only polygenic quantitative resistance or V_f at reaction class 3 level.
[i]Contains V_f resistance from *Malus astrosanguinea* 804.
[j,k,l,m]Contains V_m resistance from *Malus atrosanguinea* 804. Susceptible to Race 5 of *Venturia inaequalis* (Cke.) Wint.
[n]Contains V_f resistance as well as polygenic resistance from 'Antonovka.'

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An Autotetraploid of the Key Lime, *Citrus aurantifolia*

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Abstract

The origin of an autotetraploid plant of Key Lime, *Citrus aurantifolia* (Christm.) Swing. is recorded. Some of the phenotypic effects of autotetraploidy are described. The discovery of this autotetraploid occurred as a result of research to obtain tetraploid forms of *Citrus* that could be used as potential parents in crosses with diploid forms to produce triploid seedless cultivars. The fruit of the autotetraploid is more than twice as large as comparably grown diploid Key Lime fruit and is a useful improvement over the original diploid form. Container-grown plants of the autotetraploid are attractive ornamentals that produce fruit year-round with true Key Lime flavor and aroma.

Polyploid plants have been of interest to horticulturists and plant breeders concerned with plant improvement. The interest of plant breeders in autotetraploid forms has generally been in their genetic potential for combining with other tetraploids to create improved allotetraploids and/or for combining with diploids to produce triploids with superior traits. Horticulturists have had an interest in autotetraploids because of the phenotypic effects of polyploidy on existing diploid cultivars that might enhance the horticultural usefulness of known cultivars. Autotetraploids may arise spontaneously, usually at low frequencies, or they may be induced by various techniques including the most commonly used one, treatment of dividing cells of appropriate plant parts with the alkaloid colchicine. The origin of the autotetraploid form of Key Lime, *Citurs aurantifolia* (Christm.) Swing., is recorded here for the first time. Some of the phenotypic effects of autotetraploidy in Key Lime that distinguish this clone and also endow it with possible horticultural usefulness are described.

Origin

In 1973 a spontaneous autotetraploid seedling was selected from a population of 30 nucellar seedlings of diploid Key Lime. The diagnosis of autotetraploidy in the seedling was made by an adaptation of the technique developed by Barrett (1) to induce polyploid citrus cultivars by colchicine treatment of apical meristems. The seedling was propagated the following year on potted seedling rootstocks of trifoliate orange, *Poncirus trifoliata* (L.) Rafinesque, and grown in the glasshouse for observation. Repropagations were made at intervals and grown as potted plants in the glasshouse to the present time.

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