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The Cornell University Apple Breeding Program: Past, Present, and Future

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Cornell's apple breeding program at Geneva has had a long history of accomplishments since its initiation in 1892. While well known for its cultivars, it has also been a source of information about cultivars. "Apples of New York" remains a valued reference on apples (4). Subsequent publications continue to provide important information on cultivars to growers and researchers. During the course of our program, apple breeders included Drs. Roger Way and Robert Lamb who were precede by Drs. Klien, Einset, Wellington, Howe, Hedrick, and Beach.

The apple breeding program at Geneva has always had the goal of developing superior apple cultivars to meet the needs of the growers of New York State. Cultivars are now being bred that perform well in New York but are international in appeal so that export markets are possible. Quality (flavor, texture, firmness, juiciness, storage and shelf life) is of highest priority. Where possible, genes for resistance to fungal and bacterial diseases are also incorporated. Cooperative research is a strength of the Cornell program, with collaboration among many departments at Geneva and Ithaca.

Germplasm preservation and utilization: Cornell's apple breeders have long recognized the importance of trying to predict future needs. Fruit breeders at Geneva initiated plans for the development of a repository for preservation of apple germplasm (22). The establishment of the USDA National Clonal repository for apples and grapes at Geneva in 1983 provides researchers with access to over 3,000 accessions representing a range of *Malus* species and cultivars (13). Germplasm collected from the center of origin in the republics of Kazakhstan and Kyrgystan in central Asia will ensure adequate representation and preservation of species from this area (11).

Cultivars Developed: 63 cultivars have been named from the Cornell program (36). Familiar cultivars such as 'Lodie,' 'Burgundy,' 'Monroe,' 'Redfield,' 'Redford,' 'Spigold,' and 'Spijon' at one time were important cultivars in New York State. They aided the local economy by being good quality cultivars, well adapted to the region, that provided growers with a competitive advantage in the marketplace. From 1918 to 1994, the Fruit Testing Association provided a means of distributing trees of advanced selections for testing by growers, researchers and home orchardists (23). The association was awarded the Wilder medal from the American Pomological Society for its accomplishments.

'Macoun,' 'Jonagold,' 'Cortland,' and 'Empire' are four well known cultivars from Geneva. New York production figures for 1995 for these cultivars accounted for 5, 10, 80, and 95 million pounds, respectively. 'Cortland,' released in 1915, was one of the first cultivars released by a public breeding program, and it is still an industry standard. 'Macoun' (1923) is still very popular and often commands a premium price. The 'Empire' apple provided growers and consumers with an apple of widespread appeal (37). This apple performs well for our industry and is also grown extensively in Michigan. It is a valuable export cultivar prized by English consumers.

A highly colored limb sport of 'Empire' was discovered by a family of fruit growers, the Teeples, in Wolcott, NY.

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The Teeples decided to co-release 'Royal Empire' with Cornell Univevsity and share the royalty funds (6). This was an expression of their appreciation for cultivars such as 'Empire,' 'Jonagold' and 'Jonamac' that had benefited the fruit industry, but because they had not been patented did not generate funds for the breeding program. This show of support is an excellent example of the close relationship between the breeding program and growers.

'Jonagold' released in 1968 represents an apple known as a standard quality and having international appeal (39). An informal poll of 19 apple experts from around the world rated 'Jonagold' as the world's best commercial dessert apple (35). 'Jonagold' is an important cultivar in Belgium, The Netherlands, Germany, France, Switzerland, Italy, the United Kingdom, Japan, the United States and Canada. Its prominence in western Europe stimulated testing in the US.

Both 'Jonagold' and 'Empire' received th outstanding fruit cultivar award from the Fruit Breeding working group of the American Society for Horticultural Sciences recognizing them as "modern fruit introductions having a significant impact on the fruit industry."

'Jonamac' released in 1972 is a hybrid of 'McIntosh' x 'Jonathan.' It has gained market acceptance as a high quality 'McIntosh' type, but there is a marketing problem because in some states, including New York, it cannot legally be sold as a 'McIntosh.' This raises the question of whether it is best to create cultivars that resemble existing commercial standards or new distinct types that require marketing on their own merits.

'Fortune,' originally designated and tested as NY 429, is the latest release from our program (7). Favorable grower comments in the Pacific Northwest Fruit Tester's Association newsletter stimulated great interest in this selection before it was named. 'Fortune' is a good dual use cultivar for both fresh consumption and for processing.

Disease Resistance Breeding: Our disease resistance breeding program was initiated in 1949 by Dr. Robert Lamb. Drs. Aldwinckle and Norelli in the Department of Plant Pathology are key collaborators and have developed excellent screening methods to ensure that resistance ratings in the greenhouse correspond to resistance in the field. This program has resulted in the release of cultivars with resistance to several disease, but it has also had impact by its contributions to our knowledge of the genetics and mechanisms involved in resistance.

In developing new cultivars with resistance to apple scab *(Venturia inaequalis),* our program is distinct in that it uses a more stringent definition of resistance. Even slight sporulation is considered to be susceptible. Lamb and Hamilton (26) determined that environmental and genetic factors have a great influence on reaction to inoculation with scab. Aldwinckle et al. (2) developed a method for early determination of genotypes for apple scab resistance by forced flowering of test cross progenies.

Research at Geneva also helped to establish screening methods and to elucidate the nature and inheritance of resistance to cedar apple rust, *Gymnosporangium juniperi-virginianae,* (3). For powdery mildew, small-fruited *Malus* cultivars were determined to be sources of resistance (14). Norelli et al. (34) studied the effects of virulence of *Erwinia amylovora* on evaluation of fire blight resistance and determined that a mixture of 5 strains would mask the differential response of specific cultivar by strain interactions.

Two multiple disease resistant cultivars have been released, 'Liberty' (24) and 'Freedom' (25). 'Liberty' is recognized as one of the best of the scab resistant cultivars, and both 'Liberty' and 'Freedom' are being used as parents in breeding programs throughout the world. There are many advanced selections being evaluated for potential release. Development of subsequent generations of disease resis-

tant apples will be aided by molecular marker assisted selection. This research area is detailed below.

Concerns about food safety and danger to the environment, whether real or perceived, have stimulated interest in reduction of chemical inputs through the use of resistant cultivars. The USDA Sustainable Agriculture Research and Education (SARE) program has funded an extensive study on disease resistant apples that was reviewed by Merwin et al. (32).

Processing industry: Processors were quite concerned about governmental regulations that "prevent establishment of a residue tolerance for a processed food for any pesticide found to cause cancer in man or animals" and its implications relative to the use of registered fungicides on apple. Such concerns prompted interest in testing disease resistant cultivars for the processing market. Fruit breeders at Geneva have always examined the processing potential of advanced breeding material. Way and McLellan (41) reviewed collaborative research on developing apple cultivars for the processing market, Currently, we emphasize the development of cultivars with dual usage, fresh and processed, to offer access to both markets. Cultivars are being developed that might be suitable for the expanding markets of hard cider, apple wine, and apple brandy.

Industry support: The New York Apple Research and Development Program and the New York Apple Association are grower and processor organizations that fund apple research. They have funded quality assessment evaluations for advanced selections and new cultivars of commercial interest as well as research on molecular improvement. They funded the establishment of demonstration plantings of advanced breeding selections in commercial orchards throughout fruit growing regions in New York. These plantings are all in cooperation with Cornell Cooperative Extension personnel.

National impact: The interest in new apple cultivars is evident by examination of nursery catalog listings, fruit testing organization newsletters, and conference talks on new cultivars for testing. The development of the NE-183, a 26 state regional testing program for cultivars, modeled after the NC-140, is further evidence of the strong research interest.

Information: There have been numerous articles and bulletins from Geneva breeders that have reached growers and researchers. While most have concentrated on cultivars and advanced selections, there have been genetic studies such as those on pale green lethals (17, 40). Reviews on fruitfulness and productivity (42) and on *Malus* germplasm (38) also have provided important information. Current genetic studies are detailed below.

Studies of the inheritance of plant form: The reduced branching sport of 'McIntosh,' 'Wijcik McIntosh,' has been used as a source of the dominant *Co* (columnar) gene (27) in breeding for modification of plant form (16). 'Wijcik McIntosh' and hybrid populations segregating for columnar habit were used to study the effects of exogenous plant growth regulators and pruning on columnar form (15). Lawson et al. examined the use of cages on columnar forms to exclude insects (29) and determined their effect on plant performance (30). Many hybrid populations are being studied to determine the effect of *Co* and its interaction with other genes controlling plant form.

Molecular markers: Research on molecular markers and mapping is an area of collaboration initiated by Dr. Norman Weeden and enhanced by the research of Drs. Hemmat and Cheng, students, and visiting scientists. In 1985, Weeden and Lamb (43) used six isozyme systems to characterize 54 apple cultivars. They then analyzed the polymorphism of nine enzyme systems in 7 progenies (44), and received the American Society for Horticultural Sciences Best Fruit Publication award. In 1994, the first linkage map for apple was published by Hemmat et al. (21). Lawson et al. (28) used molecular markers to ana-

lyze the inheritance of morphological and developmental traits in apple and found genes influencing branching habit and time of reproductive budbreak.

Finding markers linked to the V_f gene conferring resistance to apple scab has been a high priority (19, 31). Markers for scab resistance genes other than V_f have also been identified and will allow effective pyramiding of genes for resistance (8). A bacterial artificial chromosome (BAC) library is being developed as the next step towards cloning resistance genes (10).

Co-dominant RAPD markers tightly linked to fruit skin color were also identified (9). Hemmat et al. (20) found a DNA marker for columnar growth habit that contains a simple sequence repeat. Conner (11, 12) created genetic linkage maps for 'Wijcik McIntosh' and for two advanced selections of interest to the breeding program and performed quantitative trait loci (QTL) analysis of traits related to tree and fruit morphology. Significant QTLs were identified for fruit shape and weight and a single gene appeared to account for most of the variation in acidity. These studies aid our understanding of the inheritance of important traits, help to develop breeding strategies, and offer prospects for marker assisted selection at the seedling stage.

Biotechnology: Drs. Herb Aldwinckle and Jay Norelli in the Department of Plant Pathology have in intensive program for improving specific apple cultivars by biotechnology. Norelli et al. (33) transformed M.7 rootstock with lytic peptides (attacin E) to confer resistance to fire blight. Transgenics of 'Royal Gala' have also been produced (Aldwinckle and Norelli, personal communication). There is active collaboration between our programs, with plant breeding and pomology majors conducting research in their laboratories. Recent student projects include examination of factors affecting transformation of 'McIntosh' by *Agrobacterium tumefaciens* (5) and assessment of chimeric transgenic M.7 apple rootstock lines (18). Field testing of transgenics will also be in important area of collaboration.

International impact: We have developed, and will continue to develop, varieties with international appeal, but we have also had a positive effect in our interactions with researchers from the US and other countries. The exchange of germplasm and ideas enhances collaboration. The training of students and visiting scientists is an area of current and future impact, because these individuals will be the fruit breeders of the future.

Future: The Cornell program will continue to emphasize the development of superior apple varieties of excellent quality. Reduced reliance on chemical control will be possible through the incorporation of resistance genes. The progress we have made in cultivar development, genetic studies, molecular markers, genetic maps, and biotechnology holds great promise for the development of new cultivars by marker assisted selection and for the improvement of existing cultivars by molecular techniques. The Cornell program is characterized by a high degree of collaboration among many researchers. This collaboration has helped to make Geneva a center for apple improvement and allows apple to serve as a model crop for temperate fruit genetic studies. Our goal is to produce new superior cultivars, but also to obtain information and develop new techniques to maximize further genetic improvement of apple. Our new cultivars will benefit the fruit industry and the consumer by establishing new standards for apple quality.

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The United States Department of Agriculture Strawberry Breeding Program

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Abstract

The comprehensive USDA strawberry breeding program was started by George Darrow In Maryland In 1919-20. It continues today at three of six former federal locations: Beltsville, Maryland; Corvallis, Oregon; and Poplarville, Mississippi (breeding has been discontinued at Glenn Dale MD, Carbondale, IL, and Cheyenne, WY). Cooperating scientists, growers and nurseries are presently located in 24 states, three Canadian provinces and five countries. The Beltsville portion of the program originates strawberry cultivars intended for one or more of five broad eastern U.S. regions. Its emphasis is on combining disease and stress resistance with superior fruit quality and productivity for the market outlets of each region. The Corvallis emphasis is on breeding productive, well-colored and fine-flavored procewsing cultivars for the Pacific Northwest. The Poplarville program concentrates on producing shipping cultivars highly resistant to anthracnose crown and fruit rots and adapted to winter and early spring production areas. Seventy-four cultivars and four anthracnose-resistant parent germplasm clones have been Introduced by the USDA and its cooperators. The program has freely shared cultivar and parental germplasm and/or seed progenies worldwide during its entire history.

History

The noted physician, horticulturist, plant hybridist, and renowned rose specialist, Dr. Walter Van Fleet, introduced four strawberries from his private breeding efforts prior to and just after becoming associated with the United States Department of Agriculture (11, 16). Van Fleet also produced an interspecific raspberry hybrid later named for him (1) while stationed at the Chico, California Plant Introduction Garden in 1910. Van Fleet's four strawberry introductions (16), 'Early Jersey Giant,' 'Late Jersey Giant' 'Edmund Wilson,' and 'John H. Cook' are described by Hedrick (12). Van Fleet also acted as advisor to the early USDA strawberry breeding work from 1920 until his death in early 1922 (5).

The present strawberry breeding effort was preceded by a comprehensive series of small fruit industry surveys throughout the United States conducted by George Darrow prior to America's entry into

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