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The USDA-ARS/Cornell University Apple Rootstock Breeding and Evaluation Program

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INTRODUCTION

The Cornell apple rootstock breeding project was initiated in 1968 with the original objective to develop rootstock genotypes with improved nursery and orchard characteristics that are much better adapted to the abiotic stresses of New York and surrounding areas. During this era interest in high density planting systems developed in New York because they dramatically increased precocity and productivity. Partly because of this change in the direction of the industry, the primary constraints facing growers in the northeastern US changed from the abiotic stresses such as drought and cold tolerance to biotic stresses such as crown rot and fire blight. Therefore the focus of the program also changed to the factors that were exacerbated by the weaker root systems and higher plant densities of dwarfed tree plantings. Improved productivity and precocity, combined with resistance to critical diseases and tree size control, remained the goals of the project through the tenure of Dr. Jim Cummins, who retired in 1993. From 1994-1997 the project was maintained at a reduced level by Dave Gill, who retired in 1997. Cornell University was experiencing financial difficulties during this time, and few faculty positions were being reinstated, so during this interim period there was a great deal of uncertainty about whether the program would continue or be terminated. Preliminary trial data with some of the earliest genotypes from the program generated strong interest among apple growers, particularly those from regions where fire blight is a major problem. Because the genotypes developed from the program had strong appeal throughout the nation, members of the apple industry began to seek ways to resurrect the program.

As a result of industry encouragement, the United States Department of Agriculture–Agricultural Research Service (USDA-ARS) decided to look for ways to support the program. In 1997 the USDA-ARS and Cornell University developed a Specific Cooperative Agreement, mobilizing the resources for the continued operation of the program. In February 1998 the ARS hired Dr. William Johnson as a research geneticist for apple rootstock breeding and evaluation and as an adjunct Assistant Professor for the Department of Horticultural Sciences at Cornell University. Todd Holleran was hired in April 1998 as the research technician for the project. Because the breeder is an ARS employee, the ARS was able to significantly modify the responsibilities of the position compared to the job description of Dr. Cummins. In addition to breeding of new varieties, the program now has an important new focus: the evaluation of rootstock genotypes from other breeding programs. During the first year of the program we have begun incorporating many new rootstock cultivars from Germany, Poland, Russia, the Czech Republic, and France.

Through the Specific Cooperative Agreement (SCA) the USDA-ARS provides the salary for a full-time scientist and a portion of the salary for a full-time technician as well as the use of some

ARS facilities. Cornell provides the remainder of the salary for the technician as well as full access to the university resources of germplasm, fields, laboratories, vehicles, and libraries. Cornell provides a small operating budget for the program, but the primary source of funds will be from competitive research grants. The royalty revenues have not yet begun to flow back into the program, but over time this will be a source of funding for the project. Prior to the SCA Cornell University managed the business end of plant breeding programs through the Cornell Research Foundation (CRF). CRF will continue to oversee the licensing and sales of Geneva series apple rootstocks, but the agreement grants a sliding scale share of 0-50% of the proceeds to the ARS. The fraction allocated to the ARS is determined on a cultivar basis, where royalties from the previously released cultivars disburse none to ARS, and cultivars made from crosses performed in the future disburse 50% of royalty proceeds to ARS. Of these royalty revenues a small fraction of the Cornell side is invested back into the research program, while the entire federal portion goes directly back into breeding and research. We expect that within 20 years this will represent a major source of funding to conduct research so that the project will approach self-sufficiency.

ROOTSTOCK BREEDING OVERVIEW

The apple rootstock breeding program functions like any breeding program, but with a few added complications. The fundamental method employed by plant breeders is to generate large populations of novel genotypes and then to progressively make the population size smaller by removing the genotypes that are not commercially desirable. The complication that makes apple rootstock breeding more of a challenge is that the final evaluations of the genotypes are as a part of a compound system with both a rootstock and a scion genotype. Because the most expensive phase of the breeding program is orchard trials, we attempt to reduce the population sizes as much as possible in the seedling and initial stoolbed phases of the breeding program before new rootstock genotypes are entered into orchard trials. Our final goal is to identify a group of rootstock genotypes that are superior to the commercially available lines. After making crosses between rootstock genotypes with complementary characteristics (e.g., a disease-resistant genotype crossed by a size-controlling commercially important rootstock cultivar) a large group of seedlings from these crosses is then inoculated with a series of pathogens. Drs. Cummins and Aldwinckle typically inoculated all seedlings first with a mixture of strains of the fire blight bacterium, killing the majority of the plants in the process. The survivors were then placed in waterlogged soils with *Phytophthora cactorum* cultures, and again a majority of the plants were killed in the process. The survivors from these two screenings were then placed in the field and grown as single tree stool plants. Woolly apple aphid populations were established in the fields by chemically suppressing their natural enemies. After a few years to establish the single tree stools, small numbers of liners from the plants with the best stoolbed characteristics are collected from each plant. These are used to produce finished trees in the nursery that then go on to their first orchard trial.

Rootstock cultivars require extensive evaluation through stoolbed trials, biotic and abiotic stress screenings, and multiple orchard performance tests. Rootstock breeding programs are operated only by public agencies due to the long development period (25 to 30 years minimum) required to evaluate ultimate tree size and productivity in each breeding cycle, a time scale that precludes commercial breeding projects. All rootstock genotypes will be assigned to a specific stage in this more formalized program. The breeding program will continue to capitalize on its historic strength in the development of novel, precocious rootstock genotypes with higher production efficiencies and improved resistance to biotic and abiotic stresses. We will continue to develop varieties with a range of vigor from fully dwarfing to near standard size, but there will be a renewed emphasis on the traits of nursery propagability, lodging resistance, tolerance to extreme temperatures, resistance to the soil pathogens of the sub-temperate regions of the US, and tolerance to apple replant disorder.

APPLE ROOTSTOCK BREEDING AND EVALUATION PROTOCOL

Outlined below is the multi-stage process used to create rootstock genotypes and then evaluate them to identify those most promising for commercial release. The stages, plant numbers, and time frames presented describe how we expect the project to work ideally, without unanticipated setbacks. In reality genotypes may sometimes require more time than is scheduled to move from stage to stage, and any particular genotype could move more slowly through the breeding program. It would be difficult, however, to move a genotype through the program more rapidly than is described and still obtain adequate levels of testing. There are approximately 5000 rootstock genotypes presently in stages 2-9 (see below), and these will continue to be evaluated by the program and to move through the appropriate stages. New rootstock genotypes will be added annually to stage 1 through hybridizations and to stages 4 or 8 through introduction from other breeding programs. Promotions to higher stages will be contingent upon desirable characteristics that exceed commercially available cultivars. *Updates on progress in the current year and plans for the coming year are presented in italics.*

STAGE 1

Parental selection, hybridization, disease screenings and stool tree establishment are carried out in years 1-3 (5000 seedlings). Pairs of parents are carefully chosen for hybridization that have complementary characteristics (for example, an easily propagated dwarfing parent might be crossed with an exceptionally disease resistant parent). Seeds are collected from the fruit of these crosses, and the seeds are germinated. We then attempt to infect seedlings with fire blight bacteria (*Erwinia amylovora*) and crown rot fungus (*Phytophthora* spp.), the rootstock diseases that cause the most difficulty for US apple producers. We expect only 20% of our seedlings will survive these screens, and we plant these populations in our fields to establish single plant stool tree populations with enhanced disease resistance.

Thirty rootstock genotypes were chosen as potential parents for a crossing block. Each of these will be grown for controlled pollinations beginning in 2001.

STAGE 2

Stool plant selection, nursery liner establishment and nursery tree growth occur in years 4-6 (1000 stool trees). Genotypes are propagated as single tree stool plants, and nursery liners are harvested from genotypes that show adequate rooting, few spines, and non-brittle wood. Liners are moved to a nursery for years 5 and 6, where finished trees are produced after budding with a vigorous, non-precocious scion (Crispin). In years 5 and 6 stool trees are again evaluated for resistance to fire blight and for infestation levels with woolly apple aphids, and susceptible genotypes are discarded from the nursery and from the stool tree fields. Only approximately 100 genotypes per year move on to actual orchard tests.

We are presently evaluating (fall 1998) approximately 2000 unique genotypes of individual stool trees for spines, brittleness, and rooting ability. An additional ~1000 genotypes will be evaluated in 1999 or 2000.

STAGE 3

Initial test orchard establishment, precocity evaluation and selection are carried out in years 7-9 (100 rootstock genotypes). Three finished trees on each rootstock genotype are planted in an initial test orchard. In addition to the test genotypes, size standard rootstock varieties are included (M.27, M.9, M.26, MM.106, MM.111). Trees are trained to develop an open branching pattern, but pruning is minimized to allow an accurate assessment of size control. Data are collected annually for yield, yield efficiency, suckering, anchorage, timing of bud break, and response to any unique stress events.

In April we planted an initial test orchard with 174 new rootstock genotypes. Trunk cross-sectional area, suckering, yield, and fruit size data were collected on all initial test orchard trees planted in 1996. Fruit number data were collected in the 1997 planted orchard on highly precocious rootstocks.

STAGE 4

Initial test orchard evaluation and selection and elite stoolbed establishment occur in years 10-12 (50 rootstock genotypes). Promising rootstock genotypes are stooled during year 10. Elite stoolbeds of 1-3 m (3 to 10 feet) are established in year 11 using liners or, if necessary, root cuttings from orchard trees. In year 12, liners of rootstock genotypes that continue to perform well in initial test orchards are collected. The most promising genotypes evaluated from other breeding programs may join the evaluation portion of the Cornell/USDA program as stage 4 genotypes if they have not yet been commercially successful internationally.

Trunk cross-sectional area, suckering, yield, and fruit size data were collected on all initial test orchard trees planted in 1992-1995. A large new intermediate stage testing stoolbed was layered to begin medium-scale liner production of promising rootstock genotypes for testing beginning in 1999.

STAGE 5

Liner production, stoolbed evaluation and nursery tree growth occur in years 13-15 (25 rootstock genotypes). Liners in the nursery are budded with a minimum of 2 commercially attractive scion cultivars, with a goal of producing 30 finished trees. Initial test orchards are removed after harvest in year 15 (after 9th leaf). Liners are also collected from elite stoolbeds and subjected to evaluations of disease resistance and stress tolerance (extreme temperature soil tests, replant soil tests, fire blight tests, crown rot tests, latent virus tests, anchorage tests, graft union strength tests).

Biotic and abiotic stress tolerance tests for intermediate stage rootstocks are planned for 1999. Tests for fire blight tolerance, midwinter chilling injury, and high soil temperature stress are planned for 1999. Fifteen intermediate and advanced stage selections were budded in 1998 with 3 latent virus-infected genotypes to characterize their reactions during nursery growth.

STAGE 6

Intermediate stage orchard establishment and early evaluation occur in years 16-18 (10 rootstock genotypes). Intermediate stage orchards are planted beginning in year 16 in New York and Washington environments. Each orchard includes 3 commercial standard genotypes (M.9, M.26, MM.106) and approximately 10 elite rootstock genotypes that have shown promise in elite stoolbed liner production, initial test orchard performance, and biotic and abiotic stress resistance screens. Orchard trees are evaluated for precocity in years 17-18.

No new intermediate stage orchard trials were established in 1998. In 1999 we established a central Washington (WSU Tree Fruit Research and Extension Center, Wenatchee) intermediate stage test with 10 new rootstock genotypes, 10 single tree replications per rootstock, and Malling series standard check varieties. Trunk cross-sectional area, suckering, yield, and fruit size data were collected on all existing intermediate stage test orchard trees in New York.

STAGE 7

Intermediate stage orchard evaluation and commercial stoolbed trials occur in years 19-21 (5 rootstock genotypes). Intermediate stage orchard trial data collection continues. Biotic and abiotic stress screenings of rootstock liner trees are completed. The most promising rootstock genotypes (a maximum of 5 per year) from the Cornell/USDA program are distributed to cooperating nurseries for commercial stoolbed trials beginning in year 19. Liners are collected from stoolbed trials and budded to produce finished trees for NC-140 and/or on-farm trials. Most promising Geneva rootstock genotypes are submitted for pathogen-free status certification (NRSP5, Prosser, WA) to enable international distribution.

We will be implementing the new commercial stoolbed trial procedure beginning in 1999 by distributing 5 promising rootstock clones to 2 cooperating commercial nurseries (TRECO in Oregon and Willow Drive in Washington). In 1999 the rootstocks distributed for stoolbed trials will be CG.935, CG.041, CG.179, CG.707, and CG.210. Rootstock selections from foreign programs will be included in stress screenings as material is available.

STAGE 8

NC-140 and on-farm trials and distribution to all cooperators occur in years 22-24 (1-2 rootstock genotypes). Intermediate stage orchard trial data collection continues. For outstanding rootstock genotypes from the intermediate stage orchard trials and commercial nursery stoolbed trials, liner production from cooperating nurseries is used to propagate trees for NC-140 and/or on-farm trials. NC-140 trials and on-farm trials are established. Best rootstock genotypes are distributed to domestic cooperating nurseries for propagation and to international cooperating nurseries and institutions for propagation and local evaluation trials. Rootstock genotypes that are commercially successful internationally join the evaluation program as stage 8 materials following biotic and abiotic stress screenings.

Recommendations for rootstock selections to include in NC-140 plantings will be made based on intermediate stage orchard, commercial stoolbed cooperator, and biotic and abiotic stress screening trials.

STAGE 9

Final evaluations and selections, commercial ramp-up and patent applications occur in years 25-27 (<1 rootstock genotype). Plant material for rootstock genotypes demonstrating marked improvement over commercially available varieties is increased in commercial stoolbeds. Intermediate stage evaluation orchards are removed after 10th leaf. Patent and UPOV protection applications are filed on the best Geneva series rootstock genotypes. Additional on-farm trials are planted.

We have no plans for domestic patents on CG series rootstocks in 1999.

STAGE 10

First commercial sale of Geneva rootstocks, elimination of all unreleased genotypes from trials, years 28-30. NC-140 and on-farm trial data collection continues. Unreleased genotypes that showed promise but were not demonstrably superior to commercially available rootstocks are eliminated from the program.

G.16 and G.30 are available for limited commercial plantings in 1999, G.11 and G.65 may be commercially available in 2002.

CHALLENGES

Because of the extensive and ambitious scope of the USDA-Cornell rootstock breeding program, and because of past problems with misidentified rootstock genotypes released from the program, there is concern about the record-keeping in the project. The current focus of the program is to verify the correct identity of elite selections from the program, to implement a modern record-keeping system, and to improve the transparency of the program so that the clients (nursery operators and apple producers) have a clear understanding of program operations and easy access to the information available for elite rootstock genotypes.

STRENGTHS

This program is unique among apple rootstock programs around the world because of the focus on disease resistance and orchard performance. The program has drawn heavily upon the genetic resources of the newly acquired apple germplasm at the Plant Genetic Resources Unit in Geneva and has screened over 700 accessions of wild and cultivated *Malus* spp. as potential parents. More than 100 genotypes have been used as parents in the breeding program, providing a broad genetic base for potential future cultivars. All seedlings are subjected to rigorous screening programs to eliminate disease-susceptible individuals prior to planting in the field. Rootstock genotypes are selected on the basis of abiotic stress tolerance, disease resistance, productivity, and precocity in orchard tests. This breeding protocol contrasts sharply with those of other breeding programs which have concentrated effort on improving the stoolbed and nursery performance of rootstock cultivars and have employed the much narrower range of traditional rootstock genotypes as parents of breeding populations. As a result, the USDA-Cornell rootstock breeding program is recognized worldwide as a promising source of new, disease-resistant and productive rootstock genotypes for the future.

Jim Cummins' general strategy through the mid-1970s and early 1980s was to make hybridizations between established rootstock cultivars with desirable horticultural characteristics (e.g., M.9, B.9, P.2) and wild relatives of cultivated apples (e.g., *Robusta 5, Malus floribunda*) that showed strong resistance to the fire blight bacteria (*Erwinia amylovora*). These crosses led to the first generation of Geneva series rootstocks including G.30 (a *Robusta 5* crabapple by M.9) and G.16 (Ottawa 3 by *Malus floribunda*). While these genotypes show great promise in the orchard, nursery operators often dislike Geneva series rootstocks because, like G.30 and G.65, they can be difficult to propagate. To address these problems Dr. Cummins initiated a second series of crosses in 1992-1994 that use the first generation cultivars with improved fire blight and *Phytophthora* spp. resistance as parents crossed again to cultivars with the horticultural characteristics appreciated by nursery operators (e.g., M.26, P.2). The cultivars from this second series of crosses are still in a very early stage of the breeding program and have not yet moved to the orchard evaluation stage, but should prove very interesting. These genotypes "in the pipeline" are what will become commercially available probably in the 2020s.