

Tugan (*C. reticulata*) is a semi-dwarfing rootstock for 'Xianfeng' orange with a compact type of growth. The root system is well developed. Tugan is resistant to drought and adaptable to soils of low fertility. Fruit production and quality of the orange scion are satisfactory. The fruit of Tugan contains many seeds, which are necessary in propagation.

Tangerine (*C. reticulata*) is a commonly used rootstock for 'Xianfeng' sweet orange. The tree grows vigorously and has a well-developed root system, adaptable to soils of low fertility. Since it is late bearing, the fruit is low in sugar and high in acid content producing poor quality fruit and it should be used in limited areas.

## Rootstock Development Screening and Selection for Disease Tolerance and Horticultural Characteristics

D. J. HUTCHISON<sup>1</sup>

The propagation of citrus trees by budding began in Florida in the 1830's. By the 1940's approximately 80% of the citrus trees were propagated on rough lemon (*Citrus jambhiri* Lush.) and sour orange (*C. aurantium* L.) rootstocks. Over the 11-year period of 1973-1983, 24,425,100 registered and validated nursery trees were sold in Florida (Table 1). Of these trees, 30.2% were propagated on sour orange, 0.6% on rough lemon, 9.5% on Cleopatra (*C. reticulata* Blanco), 39.5% on Carrizo citrange (a hybrid of *C. sinensis* (L.) Osb. X *Poncirus trifoliata*

(L.) Raf.), 8.1% on Swingle citrumelo (a hybrid of *C. paradisi* Macf. X *P. trifoliata*), 6.2% on Milam and 4.2% on miscellaneous rootstocks. Significantly, these statistics reveal that 45.7% of the citrus trees in Florida were propagated on two hybrid rootstocks, Carrizo citrange and Swingle citrumelo, originated and developed by the United States Department of Agriculture in Florida. Disease susceptibility is the reason for this change in rootstock usage. Sour orange is susceptible to the citrus tristeza virus and rough lemon is susceptible to blight

**Table 1. Rootstocks used to propagate registered and validated nursery trees in Florida, 1953-1983.<sup>z</sup>**

	Percent			Overall
	1953-1962	1963-1972	1973-1983	
Sour orange	42.0	36.8	30.2	33.9
Rough lemon	41.0	37.5	0.6	18.9
Cleopatra	8.0	12.3	9.5	10.4
Carrizo citrange	0.3	6.7	39.5	22.9
<i>Poncirus trifoliata</i>	1.6	2.8	1.7	2.1
Milam lemon		1.9	6.2	3.9
Swingle citrumelo			8.1	4.2
Miscellaneous	9.6	2.0	4.2	3.7
Number of trees — total	5,292,000	17,594,800	24,425,100	47,311,900

<sup>z</sup>Data furnished by Citrus Budwood Registration Program, Division of Plant Industry, Florida Department of Agriculture, Winter Haven, Florida.

<sup>1</sup>U.S. Department of Agriculture, Agricultural Research Service, Orlando, FL 32803.

and foot rot (*Phytophthora parasitica* Dastur). Both are susceptible to citrus nematode (*Tylenchulus semipenetrans* Cobb.) and the burrowing nematode (*Radopholus similis* (Cobb) Thorne). Therefore, the objective of the USDA, Orlando, Florida, citrus rootstock improvement program is to develop rootstocks that combine resistance to these aforementioned diseases and nematodes with desired horticultural characteristics.

In order to develop a rootstock breeding program, one has to characterize the available parental material and the ensuing progenies for the traits desired. Table 2 lists the characteristics evaluated in the citrus rootstock screening program. Every single citrus plant has the potential of being utilized as a rootstock; therefore, one must eliminate undesirable cultivars. The preliminary phase of the disease screening program is to eliminate susceptible germplasm. To accomplish this task, *P. parasitica* resistance is used as the preliminary screening procedure (3), because one can screen approximately 300 seedling selections/year. *P. parasitica* causes plant loss due to infection of the fibrous root system and the trunk or stem. The

**Table 2. Characteristics evaluated in the citrus rootstock screening program.**

---

<i>Phytophthora parasitica</i> resistance
a. tank test (feeder roots)
b. pot test (stem lesions)
Citrus tristeza virus resistance
a. regular test (severe strain)
b. strain test (mild moderate, and severe strains)
Nematode resistance
a. <i>Radopholus similis</i>
b. <i>Tylenchulus semipenetrans</i>
c. <i>Pratylenchus coffeae</i>
Cold hardiness
Seedbed and nursery
Horticultural field performance

---

first screening test is on the root system. Six control cultivars are included with each group of selections screened. These control cultivars range from susceptible to resistant in their reaction to the disease organism. They furnish a measure on the pathogenicity of each test and give a basis for comparison ratings between different tests and within a single test.

Carrizo citrange is used as a commercial cultivar that is moderately resistant to *P. parasitica*, and any selection that is more susceptible than Carrizo is eliminated at this stage of screening. The remaining selections are then given a stem lesion test for resistance to *P. parasitica*. Selections more resistant than Carrizo are then entered into further screening programs. Approximately 95% to 98% of the original selections have been eliminated at this point. Most have been eliminated due to *P. parasitica* susceptibility, but some also were eliminated due to stunted growth, unthriftness and nonuniform populations.

Various selections of *Poncirus trifoliata*, *C. grandis* (L.) Osb., *C. medica* L., *C. macrophylla* Wester and *C. macroptera* Montr. have repeatedly demonstrated resistance to *P. parasitica*. These germplasm sources have been utilized in the rootstock breeding program.

Since 1960 more than 5,000 hybrids consisting of more than 150 different parental combinations have been produced in the USDA citrus rootstock program. Some parental types have produced disappointing hybrid populations. For example, rootstocks such as sour orange and rough lemon have produced populations with inferior characters such as sterility, seedlessness, nonuniformity, and stunted and chlorotic plants. This is probably because they are heterozygous hybrids and not true species. At present, 44 rootstock selections resistant to *P. parasitica* are undergoing further screening and field testing. Thirty-nine se-

lections have *P. trifoliata* in their parentage, 1 is a rough lemon type, 3 are mandarins, and 1 is a hybrid of *C. paradisi* X *C. reticulata*. In the *P. trifoliata* parentage group, 1 is 'Flying Dragon,' which is probably not a true *P. trifoliata* but may have been introgressed with *C. reticulata* over generations of time, 32 are first-generation *P. trifoliata* hybrids (Table 3), and 6 are second-generation *P. trifoliata* hybrids (Table 4). The parentages were: 11 selections of *C. reticulata* X *P. trifoliata*, 3 selections of *C. grandis* X *P. trifoliata*, 12 selections of *C. paradisi* X *P. trifoliata*, 4 selections of *C. sinensis* X *P. trifoliata*, and 2 selections of (*C. aurantium* X *C. paradisi*) X *P. trifoliata*. The parentages of the second-generation *P. trifoliata* hybrids were 2 selections of *C. reticulata* X (*C. sinensis* X *P. trifoliata*), 2 selections of (*C. aurantium* X *C. paradisi*) X (*C. paradisi* X *P. trifoliata*), and 2 selections of (*C. paradisi* X *P. trifoliata*) X *C. sinensis*. After screening for *Phytophthora* has been completed and promising selections have been made, these selections are entered into the citrus tristeza virus and nematode screening programs and propagated with scions for field evaluation of horticultural characteristics.

The tristeza screening program consists of inoculating seedlings and scion-propagated rootstocks with the virus, and growing these plants in the

field along with uninoculated plants. Tree-size measurements are made after 2 years in the field and determinations of reduction in plant size are made. Visual observations for stem pitting caused by the virus are made in comparison with the uninoculated controls. *P. trifoliata*, *C. reticulata* and *C. sinensis* have shown resistance to tristeza. Tristeza resistance screening has been completed for 5 rootstock selections. One *C. reticulata* and 4 *P. trifoliata* selections were evaluated as tristeza resistant.

The nematode screening program is concerned with 3 species of nematodes, namely *Pratylenchus coffeae* (Zimmerman) Filipjev and Shuurmans Stekhoven, *Radopholus similis*, and *Tylenchulus semipenetrans*. Preliminary screening is done under controlled greenhouse conditions in concrete-block tanks and/or clay pots containing nematode-infested soil. Resistant or tolerant selections are further evaluated in the field for nematode resistance. *P. trifoliata* is resistant to *T. semipenetrans* (1), and *Microcitrus australasica* (F. Muell.) Swing has shown resistance to *R. similis* (unpublished data). No resistance to *P. coffeae* has been found (6).

Inheritance studies in citrus are practically nonexistent due to generation time (7 to 10 years), sterility, heterozygosity, and type of reproduction. However, inferences can be made in

**Table 3. First-generation *poncirus trifoliata* hybrids resistant to *phytophthora parasitica*.**

Parentage	Selections No.
( <i>Citrus aurantium</i> X <i>C. paradisi</i> ) X <i>P. trifoliata</i>	2
<i>C. grandis</i> X <i>P. trifoliata</i>	3
<i>C. paradisi</i> X <i>P. trifoliata</i>	12
<i>C. reticulata</i> X <i>P. trifoliata</i>	11
<i>C. sinensis</i> X <i>P. trifoliata</i>	4

**Table 4. Second-generation *poncirus trifoliata* hybrids resistant to *phytophthora parasitica*.**

Parentage	Selections No.
( <i>Citrus aurantium</i> X <i>C. paradisi</i> ) X ( <i>C. paradisi</i> X <i>P. trifoliata</i> )	2
( <i>C. paradisi</i> X <i>P. trifoliata</i> ) X <i>C. sinensis</i>	2
<i>C. reticulata</i> X ( <i>C. sinensis</i> X <i>P. trifoliata</i> )	2
<i>Fortunella margarita</i> X ( <i>C. sinensis</i> X <i>P. trifoliata</i> )	1

most instances (Table 5). The recovery of 44 selections out of 5,000 hybrids that are resistant to *P. parasitica* gives a yield of approximately 1%. The inference in this case would be that *Phytophthora* resistance is controlled by several genes and is probably not a simply inherited character. We also recognize that another characteristic, the ability of a plant to regenerate new roots, (2) can influence the damage of a root system by *Phytophthora*. This regeneration of new roots is rapid enough in some instances to surpass the ability of the organism to infest the root system. This is known to occur in *C. jambhiri*, *C. limon* (L.) Burm. f., and *C. medica*, all of which contain root primordia in the stem. *Citrus grandis* also has the ability to regenerate roots.

Resistance to the citrus tristeza virus by *P. trifoliata* is practically complete (immunity). This resistance has been recovered in first, second, and third generation *P. trifoliata* hybrids, leading one to the inference that tristeza resistance is a simple dominant factor controlled by 1 or 2 genes.

Resistance to the citrus nematode has been easily recovered in first-generation *P. trifoliata* hybrids and is probably a dominant factor controlled by one or two genes. One linkage group has been observed in our breeding work; if a plant is resistant to *T. semipenetrans*, it is also resistant to *P. parasitica*. However, all *P. parasitica*-resistant plants are not necessarily resistant to *T. semipenetrans*.

Another factor of great importance in rootstock improvement is that of polyembryony. This type of repro-

duction is essential to production of genetically uniform plants. An arbitrary, practical figure of 70% polyembryony is realistic in selecting a commercial rootstock. Approximately 15% of our hybrids have a 70% or more polyembryonic reproduction rate. This is not a limiting factor in our citrus rootstock improvement program.

The most limiting factor in producing a new commercial rootstock is the long field-evaluation period required to ascertain a rootstock's horticultural characteristics. The time required from pollination to selection of disease-resistant hybrids is approximately 7-10 years. Subsequently, another 10 to 15 years of field evaluations are necessary before a rootstock can be released for widespread grower use. Major horticultural characteristics that are influenced by rootstocks include yield, fruit quality, tree size, cold hardiness, and salt tolerance.

Fruit yield is probably the most important economic factor in rootstock selection. Though high yield is usually associated with large trees, probably of more importance is the yield per unit of tree. The measurement of unit of tree is usually expressed as tree volume or canopy size, and is an expression of tree efficiency in regard to fruit production. There are many factors that make up fruit quality and all can be influenced by selection of rootstock. These factors are: size, rind color and thickness, oil, juice content, vitamin content, total soluble solids, and total acids.

Tree size influences tree hedging and topping needs, ease of harvesting, and production per acre. Tree size is

**Table 5. Probable inheritance of selected rootstock characters.**

Character	Probable inheritance
Citrus tristeza virus resistance	Simple dominance, 1 or 2 genes
<i>Phytophthora parasitica</i> resistance	Complex dominance, multiple genes
<i>Tylenchulus semipenetrans</i> resistance	Simple dominance, 1 or 2 genes
Polyembryony	Complex dominance, multiple genes
Cold hardiness	Simple dominance, 2 genes

influenced by parental combinations. Hybrids of *P. trifoliata* as one parent and various species as the other parent control tree size from largest to smallest in the following order: *C. grandis*, *C. paradisi*, *C. cinensis*, and *C. reticulata* (5).

Cold hardiness as influenced by rootstock is a controversial subject. Most seedlings of *P. trifoliata* and its hybrids and *C. reticulata* express cold hardiness; however, this situation changes when a scion is propagated on the rootstock. The answer to this problem probably will be in selecting scions and rootstocks that mature their fruit early and exhibit a semideciduous to deciduous character that aids in forcing the tree into dormancy during the cold season.

Salinity is becoming a problem of worldwide importance. One of the limiting factors in determining the ability of rootstocks to exclude salts is that of a reliable screening technique. Selections of *C. grandis* and *C. reticulata* have exhibited some degree

of salt exclusion and further development of this line of research is underway.

### Literature Cited

1. Baines, R. C., W. P. Bitters, P. F. Clarke. 1960. Susceptibility of some species and varieties of citrus and some other rutaceous plants to the citrus nematode. *Plant Dis. Repr.* 44:281-285.
2. Carpenter, J. B. 1961. Occurrence and inheritance of preformed root primordia in stems of citron (*Citrus medica* L.) *Proc. Amer. Soc. Hort. Sci.* 77:211-218.
3. Grimm, G. R. and D. J. Hutchison. 1973. A procedure for evaluating resistance of citrus seedlings to *Phytophthora parasitica*. *Plant Dis. Repr.* 57:669-672.
4. Grimm, G. R. and D. J. Hutchison. 1977. Evaluation of *Citrus* spp., relatives, and hybrids for resistance to *Phytophthora parasitica* Dastur. *Proc. Int. Soc. Citriculture* 3:863-865.
5. Hutchison, D. J. 1977. Influence of rootstock on the performance of 'Valencia' sweet orange. *Proc. Int. Soc. Citriculture* 2:523-525.
6. O'Banon, J. H. and R. P. Esser. 1975. Evaluation of citrus, hybrids, and relatives as hosts of *Pratylenchus coffeae* with comments on other hosts. *Nematologia Mediterranea* III:113-122.

## Book Review

**The Apple Tree Physiology and Management.** D. L. Abbott, Long Ashton Research Station, University of Bristol, England. Published by Grower Books, 50 Doughty Street, London, WC1N 2LP. 80 pages. Price £4.00 which includes surface mail postage. (They cannot accept other currencies.)

This excellent paperback book summarizes 20 years of experimentation designed to gain an understanding of apple tree behaviour. The book examines a year in the life of an apple tree from 3 viewpoints. First orchard performance over a 9 years period, followed by detailed analysis of specific aspects of growth and development and completed by an overview

of the annual cycle.

The differences in growth and yield of 12 cultivars (mostly English) is shown with performance differences related to air temperature, flower density and fruit set. Factors that influence bud break and fruit set are related to tree performance with the tying together of many aspects usually treated singularly. The use of many graphs and diagrams help immensely in clarifying the relationship of one growth factor to another. Following presentation of the results of many experiments the author relates mechanisms of controlling tree vigor, maintaining balance of growth and fruiting, rejuvenating senescent trees and optimum cropping.