Commercial Citrus Rootstocks in the United States[1]

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Introduction

Fresh and processed citrus products are an important component of the diet of many Americans, yet, citrus fruit are produced primarily in only four states. The scale of citrus production in each area, however, is quite unlike that of other fruit-producing regions.

Florida is the major producer. A wide variety of cultivars, including sweet oranges, grapefruit, mandarins, mandarin hybrids and some lemons and limes are grown on about 850,000 acres. A large part of the sweet orange and grapefruit crop is processed each year to produce frozen concentrate and other products.

California has a smaller industry, about 260,000 acres of citrus, and fewer cultivars, with emphasis placed on fresh fruit, most notably lemons and navel and valencia oranges. The 100,000 acres of citrus in Texas are used primarily for the production of Redblush or Ruby grapefruit for the fresh market.

The smallest industry among the major citrus-producing states is located in Arizona where the prominent variety is the lemon. Some fruit is also grown in Louisiana. The four major states contributed a total of 16,491,000 tons of fruit to the United States' economy in the 1979-80 season, an amount which was more than twice the production of all deciduous tree fruits combined (U.S. Department of Agriculture, 1981 statistics).

Propagation and Nucellar Embryony

Citrus trees, as most fruit trees, consist of a scion and rootstock, with citrus being budded rather than grafted. Nearly all citrus trees are propagated in commercial nurseries. Approximately 5 million trees have been produced annually in the United States in recent years with almost 80% of those raised in Florida.

Briefly, a typical nursery operation involves 3 steps, all traditionally conducted outdoors. The first step is the collection and sowing of seed. The rootstock seedlings are then removed from the seedbed and lined out in field rows. In the final step, the rootstock seedling is budded with the scion variety using an upright or inverted 'T' bud, and the tree is grown. The time required to complete all these steps is usually 2 to 3 years. There is an interest among commercial nurserymen in reducing this time by producing trees indoors in containers (8) and several nurseries have adopted all or part of the process.

There are two particularly significant differences in the propagation of citrus when compared to that of other fruit trees. First, the rootstock can be, and normally is, propagated from seed because the seeds of citrus are polyembryonic, the multiple embryos arising through nucellar embryony, a form of apomixis. Thus, a large percentage of the seedlings are genetically identical to the mother tree. The degree of nucellar embryony varies among rootstocks with some species of citrus being monoembryonic and producing only zygotic seedlings. Nucellar embryony provides the citrus nurserymen with a distinct advantage in that he can readily and easily reproduce many rootstocks true-to-type from seed. Also, seed propagation per se, as com-

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pared to vegetative propagation, has certain well-known advantages.

Second, several viruses that plague citrus are not ordinarily transmitted through seeds. Thus, nucellar embryony is a means by which clean scion material of virus-infected old lines can be obtained as well as insuring that rootstock seedlings are also virus-free. It enables virus-infected old-lines to be rejuvenated simply by sowing seed and selecting nucellar seedlings. However, many years are often required before such a nucellar line becomes a commercially acceptable budwood source because of a long period of juvenility. Today, old-line and nucellar budwood sources are available for many cultivars.

Nucellar embryony also has an important disadvantage. Attempts to breed new rootstocks are frequently thwarted by the difficulty in identifying hybrid seedlings. If the female parent is polyembryonic and not distinctly different in some readily identifiable characteristic from the male parent, identifying the hybrid seedling when nucellar seedlings arise from the same seed is an obstacle.

Commercial Rootstocks

Citrus trees can be own-rooted (i.e., cuttings or seedlings) or can be budded. Citrus first arrived in the United States as seed or seedlings. Some of the oldest commercial trees (100 or more years of age) are seedlings. Eventually, though, the use of rootstocks predominated.

Choosing a rootstock for commercial use is a very important and difficult decision because rootstocks vary greatly in their soil adaptability, tolerance to various pests, diseases, and environmental conditions, and can markedly affect scion performance.

In selecting a rootstock, the following characteristics are generally considered:

(1) **Climate.** Drought and cold tolerance are particularly meaningful.

(2) **Tree vigor.** Large, vigorous trees were generally desired because of their high productivity as mature trees. Now, they may not be as desirable as progress in growth control leads to a greater interest in high density plantings. Also, vigorous scions, such as lemon, are best suited to propagation on less vigorous rootstocks if yield is not affected.

(3) **Fruit yield.** A primary factor in successful fruit farming, it is strongly influenced by rootstock.

(4) **Fruit quality.** This is a factor which affects the value of fresh market fruit and fruit for processing and involves the external (peel) and internal (juice) quality of the fruit as well as fruit size. In Florida, where over 75 percent of the fruit is processed, there are legally established maturity standards which govern several factors including the juice, acid, and total soluble solids (Brix) content.

(5) **Disease tolerance.** There are several rootstock-related viruses including xyloporosis, exocortis (a viroid which can be transmitted mechanically) and tristeza (aphid transmitted) as well as a soil-borne fungus, *Phytophthora nicotianae* var. parasitica (Dast.) Waterhouse which causes serious root and crown rot problems, that must be considered in selecting a rootstock.

(6) **Nematodes.** The burrowing nematode [*Radopholus similis* (Cobb) Thorne] and citrus nematode (*Tylenchulus semipenetrans* Cobb) attack most citrus rootstocks with a few important exceptions.

The common commercial rootstocks are rough lemon (*Citrus jambhiri* Lush.), sour orange (*C. aurantium* L.), sweet orange [*C. sinensis* (L.) Osb.], Cleopatra mandarin (*C. reticulata* Blanco) and Carrizo and Troyer citrange, [*C. sinensis* × *Poncirus trifoliata* (L.) Raf.].

These rootstocks and others of lesser importance, can easily be divided into several groups according to their general effects on scion performance.

Rough lemon represents one group which also includes Palestine Sweet Lime (*C. limettioides* Tan.) and Rangpur Lime (*C. limoniya* Osbeck). Trees on these stocks are usually vigorous and produce large crops of poor internal quality fruit.

Rough lemon has only been important in Florida where it has been used for many scions and is well-adapted to the sandy soils. It develops an extensive root system which provides a high level of drought tolerance (7, 9, 10). Rough lemon is tolerant of the three viruses mentioned above but is considered relatively more susceptible to footrot and cold as compared to the other common stocks.

Rough lemon has been a popular rootstock in Florida primarily because of its soil adaptability and yield. Fruit in Florida used for processing is sold on the basis of the total soluble solids (TSS) content of the juice. The juice quality of fruit grown on rough lemon is relatively poor, but the high yield of these trees usually more than compensates for this factor. Also, the juice has a relatively low acid content and the fruits, therefore, mature earlier than those on other stocks. This allows the grower to extend his season for a particular cultivar simply through his choice of rootstock.

Milam, another rootstock of special significance in the rough lemon group is probably a rough lemon hybrid. Trees on this rootstock seem to behave similarly to those on rough lemon under Florida conditions (6). Milam, however, is resistant to the burrowing nematode and is used essentially only in Florida where this nematode is a problem.

Sour orange is largely in a category by itself. There are 3 or 4 recognized groups of sour oranges and certain representatives are used as scions to provide fruit for the manufacture of marmalade or flowers for an oil used as a perfume base.

The fruit from trees on sour orange is noted for its excellent internal quality, the juice being very high in TSS and acid. The trees are cold tolerant, but are very susceptible to tristeza virus which can be a limiting factor in citrus production. The desirable attributes of sour orange have resulted in it being a rootstock of worldwide distinction, but its susceptibility to tristeza has reduced its use primarily to the Mediterranean area and some areas of the United States.

Sour orange is an attractive rootstock because of its effect on fruit quality. This explains its importance in Florida as a stock for fresh market grapefruit and its virtual exclusive use in Texas where the dominant scion is a red grapefruit. It was also a popular California rootstock until tristeza became widespread.

Cleopatra mandarin has been a consistently popular rootstock, mainly in Florida, for early and midseason oranges and mandarin and mandarin hybrid cultivars. Fruit quality is comparable to that of fruit from trees on sour orange. The disadvantages usually cited are small fruit size and poor yield particularly with nucellar sources of Valencia. The trees are moderately vigorous, as are those on sour orange, and cold tolerant, but, they may not begin bearing substantially until 15 years of age especially with nucellar scions.

Sweet orange and the citranges constitute an intermediate group. Trees on these rootstocks would be moderately vigorous, not as fruitful as those on rough lemon, nor would fruit quality be quite as good as that of fruit from trees on sour orange.

Sweet orange is a very old rootstock, attaining early prominence as a commercial scion variety, first as seedling trees and later as a scion or as a rootstock for budded trees. Sweet orange does not have the range of soil adaptability of rough lemon, being better suited for well-drained loam soils. It is probably the most drought susceptible of the common rootstocks and also the most susceptible to footrot, which was the main reason for abandoning sweet orange in California. Both factors have also limited the use of sweet orange in Florida. However, despite these disadvantages, sweet orange remains a rootstock of persistent interest. Trees on this stock are moderately vigorous and can produce good crops of fine quality fruit.

Carrizo and Troyer citrange are, perhaps, the most widely used rootstocks, at present, in the United States. They combine advantages of sweet orange and trifoliate orange. Troyer replaced sour orange in California because Troyer is tolerant to tristeza and footrot and has acceptable tree vigor, yield and fruit quality. In Florida, Carrizo has replaced rough lemon as the most commonly used rootstock because trees on rough lemon have declined in large numbers in many groves from blight, a disorder of undetermined cause. Neither citrange rootstock is important in Texas.

Carrizo and Troyer are rootstocks that purportedly have a common origin but were later named separately (12). They are virtually indistinguishable, except that Carrizo has sometimes shown greater resistance to the citrus nematode. Troyer also has some resistance, a trait acquired in both citranges from the trifoliate orange parent.

The citranges seem to be finding wide acceptance throughout the world, perhaps, because their attributes offer a compromise between those of rough lemon and sour orange. Grapefruit and oranges perform satisfactorily on the citrange rootstocks, but certain lemons and mandarins suffer from an apparent incompatibility (3, 14).

Poncirus trifoliata (trifoliate orange) is a deciduous citrus relative and a rootstock of minor consequence in the United States. Nevertheless, it is used commercially in Florida and California, commonly in areas where the threat of cold damage is greatest. Trees on trifoliate orange are sometimes small, but, productive with small fruit of excellent quality. Trees on this rootstock seem to grow well in clay soils but notably poor in calcareous or saline soils. Its limited, shallow root system precluded its wide use on the deep sands of central Florida (9).

Trifoliate orange has been particularly valuable as a parent in rootstock breeding programs. Its trifoliate leaf characteristic is a dominant trait which greatly assists in the quick and reliable differentiation of hybrid from nucellar seedlings. It is resistant to tristeza virus, footrot, cold, and the citrus nematode, traits which are transmitted to some extent to its hybrid offspring. The main undesirable characteristic of trifoliate orange, also perpetuated in the citranges, is intolerance to the exocortis viroid. The use of viroid-free budwood normally eliminates this problem but trees may become infected by mechanical means. Furthermore, the presence of exocortis may not be entirely undesired since it is being purposely introduced into trees on sensitive rootstocks to test its potential for controlling tree vigor (1).

C. volkameriana, C. macrophylla (Alemow) are other rootstocks of potential importance which belong in the rough lemon group. The first rootstock is similar to rough lemon in all respects except it seems to be slightly but consistently superior in many characteristics based on field trials in Florida. Trees on this stock are vigorous with a commensurate yield. *C. macrophylla* is sensitive to tristeza and xyloporosis viruses, but it is highly resistant to footrot. It is used for lemon cultivars in California and Arizona. Trees on *C. macrophylla* are usually precocious but the fruit is of very poor quality. These factors combined with cold susceptibility have limited its use primarily to lemons.

Swingle citrumelo is another relatively new rootstock with commercial promise. It is a trifoliate orange hybrid but is different from the citranges in that one parent is the grapefruit (11). There are other citrumelos but Swingle has received the greatest attention. Its merits include cold and virus tolerance, resistance to footrot and good fruit quality. It has been extensively tested in Texas with red grapefruit and other scions (14) but is only now developing commercial interest in California and Florida.

Additional details regarding these and other rootstocks can be found in a recent review (14).

Rootstock Research

Rootstock development tends to reflect local conditions and the particular needs of a citrus-growing region. Rootstocks are selected because they are the best adapted for the area. Nevertheless, there is a continuing need for rootstock research because all rootstocks have certain disadvantages. Although the choice of a rootstock is an essentially permanent decision by an individual grower, change does occur within an industry. The introduction and acceptance of a new rootstock is a gradual process. Sometimes, however, a new rootstock may be needed overnight when a catastrophe strikes. Losses of trees on sour orange from tristeza in Africa, South America and California required the rapid development and changeover to new rootstocks.

Rootstock research is a never-ending international activity. Much work has been, and remains, oriented toward pest problems especially virus and virus-like diseases. Tristeza is a worldwide threat and is a significant force motivating research in California, Texas and Florida.

Tree size control has become a contemporary citrus rootstock research goal and several approaches are being explored. W. P. Bitters, at the University of California, Riverside, has reported the successful use of interstocks using plant material obtained from genera of the orange subfamily other than *Citrus* such as *Citropsis, Feronia, Clymenia, Microcitrus* and *Hesperethusa* (4). Lemon trees with these sources as interstocks and in some instances as rootstocks, were considerably less vigorous than lemon trees on conventional rootstocks. Similar studies have been initiated in Florida where size control is receiving emphasis; however, the use of interstocks has been expanded to include species of *Citrus* as well and to explore the effects on other scion characteristics such as yield and fruit quality. Furthermore, the possibility of achieving an interstock effect by removing a ring of bark from the scion portion of the trunk on a budded tree while in the nursery and substituting a ring of bark from another species of *Citrus* or a citrus relative, is being studied.

Dwarfing rootstocks are also being evaluated and one candidate, Flying Dragon trifoliate orange, appears very promising. It has been suggested that trees on this stock may be planted at 1200 to the acre (5).

Citrus viruses may be undesirable but they may also be useful. Exocortis, a viroid, exists in several forms which can cause severe to mild symptoms with a given rootstock. The milder forms seem to decrease tree vigor without additional adverse effects where susceptible rootstocks are employed (1). Experiments are in progress to evaluate this rare opportunity to exploit a beneficial use of a plant virus, and to determine how tristeza may also be used. Tristeza also apparently exists in a range of forms and trees may be inoculated with a mild strain which may protect the plant from infection by more severe ones.

Sometimes potential rootstocks are field tested but do not develop commercial acceptance because of a single limiting factor, for example, Morton citrange. This rootstock has been tested in California and Texas with favorable results (13, 14). However, this cultivar produces few seed, a disadvantage which may be overcome with the advent of tissue culture techniques for propagation.

Attempts to produce new rootstocks through breeding have met with limited success. Nucellar embryony and the long reproductive cycle are major hindrances. Nevertheless, the U.S.D.A. in California and Florida have been involved in hybridizing with the effort being focused on footrot and nematode tolerance in Florida. More recently, germplasm of the citrus relatives has been introduced into the intergeneric breeding program as sources of superior drought, cold, salt, nematode and footrot tolerance (2).

The Future

The present commercial rootstocks are relatively satisfactory. Their status and continued use is based on many years of field experience and grower recognition that the advantages of a particular rootstock frequently more than balance its risks. It is difficult, barring some disease epidemic or other disaster, to introduce a new rootstock. Neverthless, all rootstocks have certain limitations which can be improved upon, and new problems constantly appear such as blight in Florida. Citrus rootstocks researchers will continue to search for new rootstock solutions to old problems with a new emphasis on tree size control, drought tolerance (as public use of water competes with agriculture) and salinity tolerance. Tree size control is an integral part of planting density and management research. Changes in the concepts of citriculture will undoubtedly also influence rootstock research and development.

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