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Journal
International Organization of Citrus Virologists Conference Proceedings (1957-2010), 1(1)

ISSN
2313-5123

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Publication Date
1957

DOI
10.5070/C543m6c8mv

Peer reviewed

ROOTSTOCKS IN RELATION TO CONTROL OF TRISTEZA[1]

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INTRODUCTION

The relation of citrus rootstocks to the occurrence of tristeza was recognized long before the cause of the disorder was identified. In South Africa, the Cape Department of Agriculture, after recognizing and investigating the merits of sour orange rootstock in other countries, advocated, in 1891, that citrus varieties in South Africa be budded on sour orange stock (*13*). The failure of orange trees on sour orange rootstock resulted in an investigation, in 1904, by a Commission of Enquiry of the Cape Department of Agriculture (*1*), which also pointed out that most of the healthy trees in that country were budded on Rough lemon stock.

In Java in 1937, Toxopeus (*21*), using reciprocal grafts of sweet orange, sour orange, and Japanese citron, showed that the use of tolerant intermediate stock neither prevented nor delayed a decline similar to that in South Africa. As long as the top was sweet orange and the stock or interstock was sour orange, the combination failed. Toxopeus also showed that parallel insertion of sweet orange and Japanese citron tops simultaneously into sour orange roots also resulted in death of the plants. Inarching sweet orange trees with sour orange or Japanese citron seedlings resulted only in the failure of the tree with the sour orange inarches. These results are in accord with later observations reported by Bitters and Parker (*4*).

According to Bitancourt (*2, 3*), the disease appeared in Argentina in 1931, where orange, grapefruit, and mandarin scions on sour orange root declined, but sour orange seedlings or lemons budded on sour orange roots remained healthy. The disease was reported in Brazil (*2*) in 1937. Moreira (*18*) reported from Brazil that sweet orange tops on Thornton tangelo stock were affected by the disease, but that Sampson tangelo was completely tolerant when used with sweet orange tops. Marloth, however, in studies made in Nelspruit, Transvaal (*14*), reported the behavior of Sampson tangelo root budded to sweet orange to be similar to that of sour orange. These results later proved to be in accord with observations by Bitters and Parker (*4*).

As the presence of the virus was identified in other citrus-producing areas, the importance of top-root combinations was also noted. In California, the association of quick decline with sour rootstocks has been reported (*11*). In Australia, McAlpin (*15*) reported that trees on sour orange were the first to show bud-union decline. Reports from the Gold Coast Colony (*12, 20*) indicated that West Indian lime trees budded on Rough lemon did well, but that lime seedlings died. This is the first instance in which seedlings or unbudded trees were reported to be susceptible to the disease. The use of West Indian lime seedlings as indicator plants has since proved a very valuable diagnostic tool (*16, 22*).

The virus nature of the disease was established in 1946 by Fawcett and Wallace (*7*)

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and Meneghini (*17*). The role of insect vectors was clearly indicated, with transmission of the disease by *Toxoptera citricidus* (Kirk.) (*12, 16, 17*), Aphis *gossypii Glover* (*6*), and *Aphis spiraecola* Patch (*19*).

Investigations have not been in complete agreement as to the susceptibility or tolerance of certain rootstock-scion combinations in various countries (*4, 5, 8, 9, 10*). In general, however, the correlation is amazingly uniform. The few differences that do exist are somewhat understandable when one considers some of the variables in those testing programs.

1. Some of the transmission studies have made use of an insect vector; others have used diseased buds as the source of the inoculum. While *Toxoptera citricidus* has been used in South Africa and South America, *Aphis gossypii* and *A. spiraecola* have been used in California and Florida, because *T. citricidus* does not exist in those areas. It is recognized that *A. gossypii* and *A. spiraecola* are not as efficient in their transmission as *T. citricidus*, or may be more selective in their scion preference.

Certain scion sources may not be as susceptible to vector inoculation as to tissue inoculation. In California, grapefruit on sour orange root has readily expressed symptoms of the disease when tissue-inoculated. However, not one grapefruit tree on sour orange root has been found in commercial orchards which has expressed symptoms of the disease in the fifteen years the disease has been prevalent in the quarantine zone. Similarly, while Valencia orange trees on grapefruit root have expressed symptoms of the disease when tissue-inoculated, not one case is known in commercial orchards where the same combination has expressed symptoms when exposed to natural infection by the vector.

2. Inoculation with diseased buds as in California, for example, implies inoculation with whatever virus complex exists in the inoculation sources. In the original rootstock experiments in California (in addition to tristeza), psorosis, exocortis, and perhaps other viruses were also involved. The fact that an inoculated tree is stunted, or chlorotic, or pitted may not necessarily be indicative of susceptibility to tristeza but may be instead a response to other accompanying viruses. Tissue inoculation would probably be more reliable if made from vector-infected seedlings.

3. Some of the scion sources used as tops for experimental trees may have been symptomless carriers of viruses other than tristeza. In much of the work done with budded combinations, the scion sources used were old-line selections and may have carried unrecognized viruses. In California, the original scion source used, while not nucellar, was free of tristeza, psorosis, exocortis, and perhaps of cachexia. Scion sources used since the 1948 plantings have been of nucellar origin.

4. Observations need to be made over an adequate length of time for best symptom expression in order to lessen the probability of contaminating viruses in the scion variety. In some of the rootstock work, conclusions were drawn less than a year after inoculation. In the rootstock trials in California, symptom expression has been extremely slow. The more susceptible combinations developed symptoms in twelve to eighteen months; some of the more tolerant combinations did not show symptoms until four or five years after inoculation. Inoculated combinations did not develop pitting symptoms until nearly four years after the inoculation, and the severity of pitting has increased considerably since that time. All of the inoculated trees have shown some effect of the inoculation and it is questionable whether even the so-called tolerant combinations may not show depressed growth and reduced yields in commercial orchards as a result of the presence of the virus.

5. Proper identification of the rootstock species or variety is essential. Too often a specimen in a variety collection is misidentified, mislabeled, or confused with another variety. It is also possible inadvertently to mix up seed lots, seedlings, or labels in the planting routine, and also to make errors in the planting plan. Several mistaken identi-

ties have appeared in the California rootstock plantings, as, for example, the variety "Dolandan," which was originally listed as a sour orange and turned out upon investigation to be a variety of sweet orange from the Philippines.

6. Assurance is needed that top symptoms observed are not due to girdling, rodent damage, cold injury, growth regulators, weed killers, nutritional disorders, gametic rootstocks, or other complicating factors.

ROOTSTOCK EXPERIMENTS IN CALIFORNIA

In relation to the progress of testing rootstock-scion combinations for tristeza susceptibility in California, a few plantings were made with various cooperators as early as 1945. These trees were exposed only to vector inoculation. In 1948 nearly 3,300 Valencia orange trees on 125 rootstocks were planted to further these studies. All of these trees were propagated from a known uniform Valencia orange parentage. Of the total, approximately 1,200 uninoculated trees were planted with various cooperators. They were exposed only to vector inoculation and thus served as further checks. Of the remaining trees, 2,112 were planted in a randomized block experiment at Baldwin Park, California. The trees were planted in four replications of 125 rootstock plots, each plot consisting of up to six trees. Approximately four months after planting, half of the trees in each rootstock plot were inoculated with buds from selected orchard trees presumed, because of the top symptoms they expressed, to be carrying tristeza virus. Each inoculated tree received three buds, one bud from each of three different tristeza-diseased trees. A total of six source trees were used as over-all sources of inoculum, and buds from each source tree were thus used in but two of the randomized blocks.

Subsequent plantings were made in later years so that approximately 200 stocks were included in the tests. The oldest plantings are now ten years old and a number of conclusions may be drawn.

DISCUSSION OF RESULTS

It was at first anticipated that the distinction between susceptibility and tolerance would be clear-cut and that the disease status of the various combinations would be as easy to determine as that of sweet orange tops on sour orange root. Such has not been the case, a complete range of effects being obtained. From observations of the experimental trees, the rootstocks might conveniently be divided into five groups. The first group consists of stocks which show a more marked reaction than sour orange when supporting sweet orange tops. This group includes such stocks as shaddock × sweet orange hybrids, Moroccan Rough lemon, and commercial lemons. Sweet orange trees on stocks of this group show rapid symptom expression, a great deal of collapse, and extreme dwarfing of inoculated survivors. The second group includes principally the sour oranges and shaddocks. Here again symptoms are severe and rapid, with considerable collapse and severe stunting. A third group is comprised of rootstocks that do not react as rapidly as those in the first and second groups; symptoms are much milder, with very little collapse. Dwarfing, small leaves, and lack of foliage are the most characteristic symptoms of this group, which includes the grapefruit stocks, most of the tangelos, Morton citrange, and a few others. These first three groups must all be considered susceptible to tristeza.

A fourth group consists of the sweet oranges, mandarins, mandarin hybrids other than tangelos, trifoliate orange, trifoliate hybrids, *Citrus ichangensis* hybrids, and others. This group must be considered tolerant, although infected sweet orange trees on these stocks show some effects of the inoculation, such as slight stunting, smaller leaves, and open growth habit. The fifth group, which has shown the least effect of the inoculations, includes the Rough lemons, Rangpur limes, West Indian lime, and others.

A more complete breakdown of the rootstocks according to common-names designation follows.

Sweet Oranges. All of the sweet oranges tested as stocks appeared to be tolerant to the disease. A rather severe reaction was obtained on one source of Bessie sweet orange.

Sour Oranges. Approximately all the 25 different selections of sour orange tested were extremely susceptible to the disease. The bittersweet groups appeared to react faster than the typical sours. The chinotto, a sour orange variant, was equally susceptible. There appears to be little hope of finding a true sour orange tolerant to the disease.

Lemons. The commercial lemons as rootstocks (Eureka, Lisbon, and Villafranca), certain Rough lemon types and hybrids, and sweet lemons such as the Dorshapo were very susceptible. The typical Rough lemon selections were very tolerant to the disease. The Palestine sweet lemon has shown some stunting and other reactions, but whether this is due to tristeza or other causes is still undetermined. Stem pitting was not a serious factor in this case.

Limes. The trees on the lime stocks are remarkably healthy. The trees on West Indian lime stock are also extremely healthy after ten years, even though seedlings of this variety show a marked reaction when infected by tristeza virus. All trees on the lime stocks showed excessive pinhole type of pitting; even the scion has been so affected.

Grapefruit. The grapefruits tested were extremely variable in their reaction, probably because of their genetic composition, as some were undoubtedly hybrids and classed with grapefruit only for convenience. A few combinations showed collapse, but varying degrees of stunting appeared to be more typical. There was very little pitting on the grapefruit stocks.

Shaddocks and Shaddock Hybrids. All the shaddocks tested as stocks were extremely susceptible to the disease. A number of shaddock hybrids were also included in the tests. The fact that one of the hybrid parents was tolerant to the disease did not in any case lessen the severity of the top symptoms.

Mandarin and Mandarin Hybrids. The mandarins tested appeared to be very tolerant to the disease. The Kinokuni showed more stunting than any of the others tested. The tangelos were extremely variable in their reaction. The Sampson and Owari were very susceptible. Other varieties showed a considerable range in susceptibility with the Williams appearing to be quite tolerant. The tangors as a whole appear to be very tolerant.

Trifoliate Oranges. This group has been difficult to work with, since exocortis was unintentionally introduced into three of the four replicates and a large number of the inoculated trees are showing shelling on the roots and are therefore in distress. This same inoculum placed in Rangpur lime trees in these replications caused no shelling of the stock whatsoever. In the fourth replication the inoculated trees on trifoliate are also somewhat stunted. There is considerable pitting in the trifoliate stocks although not extreme pitting. A tetraploid trifoliate was a complete failure, but is believed to be incompatible as determined from other evidence.

Trifoliate Hybrids. The trifoliate hybrids, the citranges, citremons, citrumelos, and others, showed little effect of the inoculation except some stunting and slight pitting. The Morton citrange, however, showed excessive pitting and must be considered susceptible. Poor results have been obtained with citradia, citraldin, and citrandarin.

***Citrus ichangensis* Hybrids.** Trees on Yuzu and ichang lemon (Shangyuan) have been somewhat variable in their reaction. Some stunting and defoliation are present and their tentative classification is somewhat uncertain but probably tolerant.

Miscellaneous Species. A number of miscellaneous species as stocks have shown good tolerance. Among these are *Citrus pennivesiculata* (*C. moi*, Gajanimma), *C.*

amblicarpa (Nasnaran), *C. pectinifera* (Shekwasha), *C. taiwanica*, *C. macrophylla* (Alemow), and others.

In conclusion, it may be stated that there are many rootstocks that are tolerant to the tristeza disease. The use of tolerant rootstocks offers a very practical approach to control of the disease, since spread of the virus cannot be prevented because of vector transmission. In California, at least, it would appear that our greatest hope for satisfactory stocks lies in the mandarin group and its hybrids, the trifoliate orange group and its hybrids, hybrids of *Citrus ichangensis*, and some of the miscellaneous species mentioned above. Through the cooperation of plant breeders, many new hybrids between these species are being created. Tristeza tolerance alone is not enough to warrant the commercial use of these stocks, but their tolerance to other diseases, to nematodes, and to the replant problem, and their effects on fruit production, fruit quality, and other factors must also be determined. From preliminary observations on some of these stocks over a ten-year period it appears that some of them are extremely promising and may provide more benefits to the citrus industry than the standard stocks which have been in use for the past fifty years.

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