Diseases and their control

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Several times in the past 75 years, California's citrus industry faced catastrophic losses from fruit and tree diseases. In every case, timely research greatly reduced the damage.

Gummosis and psorosis, old maladies

Heavy losses of trees from gummosis (foot rot) in 1900-15 alarmed citrus growers and stimulated their interest in research, thus providing impetus to the new Citrus Experiment Station (CES). Gummosis-affected trees turn yellow, decline, and die if the trunk or primary roots are girdled. The gummosis outbreaks led, in 1913, to the appointment of a plant pathologist, H.S. Fawcett, to the CES staff. Dr. Fawcett determined that phytophthora fungi were killing citrus bark near the soil level and were causing both the gummosis disease and brown rot of fruits, which were especially destructive in lemon orchards. Dr. Fawcett and Dr. L.J. Klotz developed practical phytophthora control measures with applications of Bordeaux mixture and surgical excision of lesions.

Dr. Klotz and colleagues subsequently worked extensively on the life cycles of these water molds, and refined brown rot control measures using copper-bearing sprays. Sour orange rootstocks were found gummosis-resistant and were soon extensively used in California. Recently, plant pathologists have obtained good control of root, trunk, and fruit infections of *Phytophthora* spp. by treatments with the systemic fungicides, metalaxyl (Ridomil) and fosetyl-Al (Aliette).

Gummosis is not the only potentially catastrophic disease the California citrus industry has faced in this century. Psorosis (California scaly bark), an incurable graft-transmissible disease destructive to oranges, grapefruit, and tangerine trees, though rare among the seedling trees of California's citrus industry more than a century ago, became widespread and destructive in grafted trees before 1900. Apparently due to virus infection, psorosis caused bark scaling and death of inner wood, followed by gradual decline of affected trees. It remained the most important graft-transmissible citrus disease in California until the 1940s, when it was overshadowed by tristeza. Scraping the bark of lesioned areas delayed or reduced tree damage by psorosis. Transmissibility of the disease was demonstrated and preventive measures were developed by CES scientists in the 1930s. Clean planting stock was found essential to prevention.

Tristeza, exocortis, and stubborn

A mysterious malady called "quick decline" began killing orange trees in southern California in 1939. Within 25 years it caused the loss of three million trees, mostly sweet orange on gummosis-resistant sour orange rootstock. Some trees wilted quickly, others declined slowly and lost foliage. CES began a crash research program in the early 1940s. J.M. Wallace and H.S. Fawcett showed that tristeza virus caused the disease, and R.C. Dickson and colleagues found that it was transmitted in California by the melon aphid. Further research determined that Troyer and Carrizo citranges were tolerant to tristeza, so these rootstocks were used extensively for replants and new orchards. Tristeza was, for a time at least, brought under substantial control. Recent spread of new strains of tristeza virus that cause severe damage to sweet orange and grapefruit trees on all rootstocks has stimulated additional studies at the Citrus Research Center to contain the new threat.

Citrange and trifoliate orange rootstocks are, unfortunately, susceptible to exocortis, shown by pathologists in the experiment station to be caused by a viroid, which is much smaller than any virus. Exocortis viroid causes stunting and bark scaling of these two rootstocks. It is spread by tools and through grafting, but can be largely prevented by the use of clean stock, sanitation, and resistant rootstocks, such as sweet orange, grapefruit, and rough lemon.

When CES was less than 10 years old, a strange stunting and fruit deforming disease, then called sheepnose, appeared on navel oranges in the Redlands area. Growers found it was perpetuated by propagation and called it stubborn, because affected trees would not respond to treatment. CES scientists and growers worked together to show its transmissibility. Nearly 50 years after its discovery, several CES, U.S. Department of Agriculture (USDA), and overseas scientists discovered that citrus stubborn disease is caused by a subbacterial organism new to science, the mycoplasma *Spiroplasma citri*, and that the stubborn organism also infects many ornamentals, vegetables, and weeds after transmission by beet leafhoppers and two species of *Scaphytopius* (leafhoppers). Control is by prevention and by removal of stubborn trees.

The clean stock program

The need for disease-free propagative budwood was evident long ago, but efforts to find such material were thwarted for many years by numerous symptomless carrier trees and the lack of techniques for eliminating disease organisms from otherwise desirable trees.

The first effective move toward a clean stock program for citrus was taken by the CES and the California Department of Agriculture in the 1930s, soon after psorosis was found graft-transmissible. A registration program was established to identify parent trees from which nurseries could obtain budwood free of the psorosis pathogen. This program prospered until tristeza virus overran most registered trees in the 1940s. With losses from virus and other bud-perpetuated diseases mounting in the 1950s, the citrus industry sought help from CES in establishing a "Variety Improvement Program" to provide disease-free, true-to-name budwood for increase by nurseries. The psorosis registration program was reactivated quickly, but it took about 10 years for the experiment station to produce trees that indexed free of all known diseases.

Despite some problems with stubborn disease, expanded citrus registration and certification, now called the "Citrus Clonal Protection Program," has, thanks to strong support by the industry and excellent cooperation by the California Department of Food and Agriculture, Cooperative Extension, and USDA, provided a good supply of clean budwood for increase by nurseries during the past 13 years. This goal was achieved only by developing methods, or adapting those developed elsewhere, for detection by indexing and elimination of all pathogens present in desirable clones. The ongoing program at the Citrus Research Center is a joint effort of the departments of Botany and Plant Sciences and of Plant Pathology to discover ways of eliminating and avoiding *Phytophthora* and other fungi, psorosis, tristeza, stubborn disease, vein enation-woody gall, exocortis, cachexia, ringspot, concave gum, infectious variegation, crinkly leaf, tatter leaf-citrange stunt, and others. Thermo-therapy and shoot-tip grafting have been effective in eliminating pathogens.

Thus far, the clean trees have been successfully maintained and the more important ones are established in the Lindcove Foundation Block east of Visalia. The California program has reduced citrus tree disease losses and has been used as a model for similar projects in other countries. A comprehensive clean stock program is essential to the continued production of healthy citrus trees.

Postharvest decay, a costly mess

Decay of citrus fruits after harvest has caused substantial losses to growers and consumers for more than a century. The California citrus industry estimated loss due to decay during 1979 at $84 million. The major postharvest diseases of citrus fruits are blue and green molds (*Penicillium*), sour rot (*Geotrichum*), brown rot (*Phytophthora*), and alternaria stem-end rot. Brown rot and alternaria rot begin from infections of fruit on the tree; blue and green molds and sour rot start from spores deposited in injuries.

L.J. Klotz found that copper fungicides were ineffective against brown rot if the fungus had penetrated the peel, but submerging fruit with incipient infections in hot water (115°-118° F) for two to four minutes killed the fungus. Various modifications of this treatment have been used in California packinghouses for many years to control brown rot, despite the potential for heat damage to turgid citrus fruits. Recently, experiment station researchers found that metalaxyl (Ridomil) eradicates phytophthora infections as well as hot water without the injury potential.

Alternaria stem-end rot is a major factor limiting the storage period of lemons. Bartholomew showed in 1926 that *Alternaria* infected the stem buttons of the fruit early in their development on the tree and, at harvest, the fungus was deeply imbedded in the tissue, where it survived postharvest fungicidal treatment. Many buttons were infested, but the fungus attacked the fruit only after the buttons became senescent. W.S. Stewart demonstrated in the early 1950s that postharvest treatment of fruit with 2,4-D delayed senescence and postponed the attack. Today, all lemons produced in California are treated with 2,4-D in the packinghouse to control alternaria stem-end rot during storage.

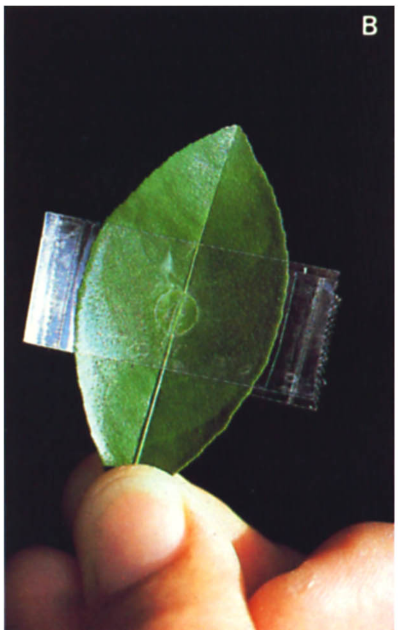
Work continues at the Citrus Research Center to reduce losses caused by blue and green molds, the most serious market diseases of citrus fruits produced in California. These investigations have two purposes—to prevent infection of injuries on the fruit by *Penicillium* and to inhibit sporulation on diseased fruit, thereby preventing spoilage of sound fruit. Research was started in the 1950s to find a substitute for biphenyl, a postharvest fungicide then severely criticized in European markets. *Sec*-butylamine (2-aminobutane), discovered in this program and released to the industry in the early 1960s, has been widely used to prevent infection of lemons during storage and of oranges during ethylene degreening. During the past 15 years, several new fungicides have been investigated, each more effective than its predecessor in preventing infection and inhibiting sporulation of *Penicillium.*

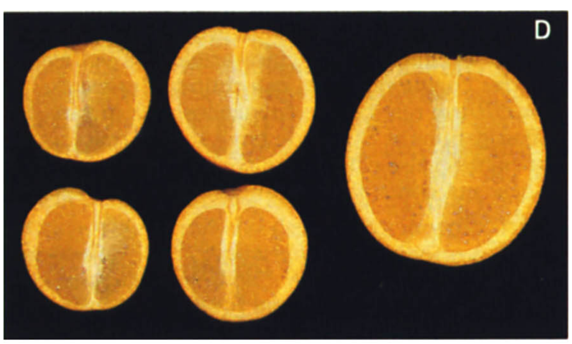
The intensive use of *sec*-butylamine, thiabendazole, and benomyl has selected strains of *Penicillium* resistant to these fungicides, resulting in their failure to control decay. Packinghouse management strategies for controlling the resistance problem are being actively investigated. Two new fungicides, imazalil and etaconazole, not yet available for commercial use, can control strains of *Penicillium* resistant to fungicides now in use. Investigations at Riverside have shown that etaconazole also effectively controls sour rot, a disease not controlled by any existing commercial treatment.

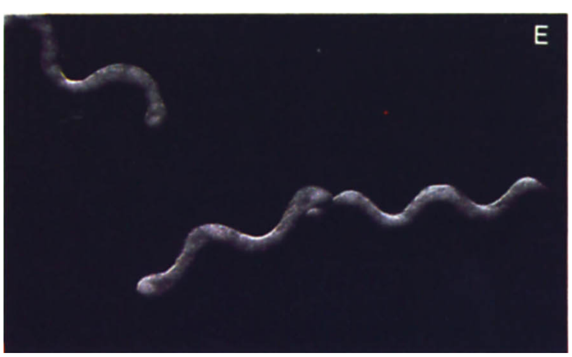
Some fungi are good for citrus

Mycorrhizae are beneficial fungi that grow in symbiotic association with roots and aid in the uptake of many nutrients, particularly phosphorus. These fungi are sometimes described as "biotic fertilizers," because they can be partially substituted for high fertilization. Unfortunately, concentrations of methyl bromide used for fumigating citrus nurseries to kill soil pathogens are also lethal to mycorrhizal fungi.

U.C., Riverside, researchers collected, screened, and selected the most efficient strain of *Glomus fasciculatus,* a mycorrhizal fungus associated with citrus. The relative dependencies of various citrus







A. Phytophthora gummosis, the worst fungus disease of California citrus trees.

B. Indexing for tristeza virus. Disc from leaf of candidate tree is placed in Mexican lime, which will develop symptoms if candidate is infected.

C. The first certified citrus nursery tree produced in California and its developers in 1970: D.A. Newcomb, S.M. Mather, W. Reuther, E.C. Calavan, H.W. Duncan.

D. Small, misshapen fruits caused by stubborn disease, compared with normal orange.

E. *Spiroplasma citri,* cause of citrus stubborn disease.

rootstocks on mycorrhizae in fumigated low-nutrient soil were determined. Information from responses in 26 soils was computer analyzed, producing formulae for predicting citrus growth. A commercial production system for mycorrhizal inoculum was developed recently and has been adopted by one California nursery.

Citrus nematode

Since the citrus nematode, *Tylenchulus semipenetrans* Cobb (slow decline), was first discovered in Los Angeles County by J.R. Hodges in 1912, the CES has been the international center for research on its biology and control. Nathaniel A. Cobb, who had just joined the Bureau of Plant Industry in Washington, D.C., immediately described this species and organized an international survey, which established that this pest was worldwide in distribution. He used this example of a plant parasitic nematode to draw attention to the scientific and economic importance of soil-inhabiting nematodes to agriculture and soon established the first Nematology Laboratory.

Results of a thorough study by Edward E. Thomas of the CES, completed in 1923, demonstrated that the parasite was widespread on citrus rootlets in California and that it greatly retarded root development and growth of young citrus trees. Thomas also called attention to the danger of distributing this nematode on nursery trees. Some 30 years later, after the development of soil fumigation, the California Department of Food and Agriculture established a nursery certification program, which continues to ensure the production of clean planting stock.

Although Thomas showed the importance of citrus nematode, no means were available for controlling it on bearing trees and little attention was focused on this citrus production problem until Richard C. Baines joined the experiment station in 1947. At about that time, the chemicals 1,3-dichloropene (1,3-D) and ethylene dibromide (EDB) were discovered to be effective soil fumigants for the control of nematodes in pineapple. Baines seized the opportunity to study these and other chemicals for control of the citrus nematode. During the 1950s and the 1960s the station conducted two major interdisciplinary programs to find solutions to the "citrus replant" and the "citrus grove rejuvenation" problems. The research by Baines and his colleagues in Nematology, Plant Pathology, Plant Sciences and Soil Sciences clearly demonstrated that these problems could be solved by control of the citrus nematode by soil fumigation and use of tolerant rootstocks.

The citrus nematode is a semi-endoparasitic worm, feeding internally in citrus roots while a major portion of the body remains external to the root surface. Severely infected rootlets may contain as many as 5,000 females per gram. Each female produces 100 to 200 eggs, which hatch into larvae that reinfect the spring root flush. Feeding by the nematodes reduces the number of new root tips, decreases uptake of nutrients and water, and increases the root's susceptibility to soil fungi. During the late 1940s and early 1950s, Baines showed that young nematode-free citrus trees replanted in heavily infested citrus orchard soil were stunted as much as 60 percent when compared with trees planted in fumigated soil. Fumigation of citrus soil before replanting is now standard practice throughout the California citrus areas.

In the search for nematode resistance in citrus species and close relatives, CES scientists identified the trifoliate orange as highly resistant to the citrus nematode and to *Phytophthora*. They tested and released the Troyer citrange, now a widely used rootstock in California and other citrus growing regions.

In about 1950 Baines also pioneered in the development and use of the soil fumigant, 1,2-dibromo-3-chloropropane (DBCP) on producing citrus. DBCP was the first nematicide that could be used around living plants, and it improved growth and production of citrus by 10 to 32 percent. Unfortunately, use of DBCP was cancelled in 1977, a loss that caused major concern to the citrus industry and a renewed research effort at the University for new chemical and biological alternatives.