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Canker, a Threat to Citrus in the Gulf-Coast States

Concern about citrus canker, caused by *Xanthomonas campestris* pv. *citri* (Hasse) Dye, has resurged in recent years. Two events have been primarily responsible: Citrus fruit are now imported into the United States from Japan where citrus canker is endemic, and an epidemic of canker is in progress in South America. Both events have increased the probability for introduction of canker into the United States and have rekindled the memory of the heavy cost of eradicating the disease from southeastern states early in this century.

The quarantine restrictions against importation of citrus fruit from Japan were removed in 1968. Unshiu oranges (*Citrus reticulata* Blanco 'Unshiu') are allowed into Alaska, Hawaii, Idaho, Montana, Oregon, and Washington (1). Because citrus canker occurs in Japan, certain safeguards to prevent importation of the citrus canker organism on the fruit were included in the amendment that removed the restrictions. These safeguards were: 1) oranges must be grown and packed in an area of Japan determined to be free from canker by plant pathologists of both Japan and the United States, 2) fruit must be inspected by plant pathologists of Japan and the United States in the grove before and during harvest and in the packing sheds, 3) fruit must be surface-sterilized by a bactericidal dip before packing, and 4) fruit must be tested by a recognized bacteriophage method and found to be free from citrus canker (this safeguard was dropped in 1978). The fruit from Japan are marked to show the country of origin, and the shipping boxes are stamped with a statement specifying the states into which Unshiu oranges may be imported. After more than 14 years of importing citrus from Japan, no outbreak of canker has occurred in the United States. Nevertheless, a vigil for possible reestablishment of citrus canker was stimulated with the importation of the oranges.

The epidemic of citrus canker in Argentina, Brazil, Paraguay, and Uruguay was reviewed by Rossetti (15). The epidemic began in 1957 in Brazil, and attempts to eradicate the disease were not successful. The causal organism spread slowly until the 1975–1976 season. Weather conditions apparently were very conducive for development of canker that season in Argentina, and canker was suddenly widespread in three citrus-producing provinces. National and provincial eradication programs were initiated in Argentina (Fig. 1) but were abandoned in 1978. Some growers are still attempting to eradicate canker in foci, but essentially, citrus canker has been permanently established in Argentina.

Canker has been established permanently also in some provinces of Brazil (Paraná and Mato Grosso), where commercial production of citrus is not important. In São Paulo province, however, where commercial production of citrus is second only to that in Florida, periodic outbreaks of canker have been contained by eradication programs. The last large outbreak was in 1979, and diseased trees were found on 150 properties in two counties. The diseased trees were destroyed in an eradication campaign (M. Cohen, *unpublished*).

Canker is widely distributed in Paraguay, where no eradication program exists. Canker-diseased trees are being eradicated in Uruguay. Only relatively small amounts of commercial citrus are produced in those countries.

What Is Citrus Canker?

Canker is a bacterial disease of citrus causing necrotic spots on fruit, leaves, and stems. Infections by the causal bacterium usually occur in immature tissues in nature, and under favorable conditions, lesions may be noticed with a hand lens by 7 days after infection. The primordial lesions may be confused with oil glands in the leaf but can be distinguished by their aggregated

Fig. 1. Destruction of a citrus tree with canker in Argentina.

Fig. 2. Symptoms of canker on leaves of navel orange. The yellow halo around a necrotic area is very distinctive of a canker lesion. Lesions enlarge up to 10 mm in diameter or until leaf abscission occurs.

Fig. 3. Premature fruit abscission of Hamlin orange. Fruit change color before abscission, so green fruit have few or no lesions.

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Table 1. Relative pathogenicity of three strains of the citrus canker organism, *Xanthomonas campestris* pv. *citri*, on five species of *Citrus*

Citrus sp.	Common name	Strains of *X. campestris* pv. *citri*		
		A	B	C
C. sinensis	Sweet orange	+++[a]	+	–
C. paradisi	Grapefruit	++++	+	–
C. limon	Lemon	+++	+++	–
C. reticulata	Mandarin	+	+	–
C. aurantifolia	Mexican lime	++++	++++	++++

[a] – = No disease development, ++++ = very pathogenic reaction.

distribution. The lesions then become raised above the surface of the host tissue and can be detected by drawing the fingers over the surface of infected fruit, leaves, or stems. About 14 days after infection, lesions can be seen with the naked eye. Lesions continue to enlarge and may be as large as 10 mm in diameter on susceptible cultivars. A diagnostic yellow halo usually forms around a lesion when it reaches 1–2 mm in diameter (Fig. 2). The halo may fade or disappear as lesions become 5–10 mm in diameter. Sometimes hundreds of lesions will form on a single fruit, leaf, or stem.

Infection of citrus foliage by the canker organism does not occur uniformly throughout the year but is associated with growth of the tree. Bearing citrus trees usually grow in flushes during warm weather. A major growth flush occurs in the spring after winter dormancy, but temperature and rainfall are usually not optimum for severe infection. Canker is commonly most severe on the second flush of growth 6–8 weeks later, in early summer. Third and fourth flushes also may occur in the same year and may be severely diseased.

Uninjured leaves are infected during a relatively short period under natural conditions. Infections rarely occur until leaves are about 85% of full expansion, and most form during the following 2-week period. Mature leaves, which are dark green, are resistant to infection through stomatal invasion but not to infection through injuries. The period of susceptibility of twigs has not been accurately determined but from observations is probably similar to that of leaves.

Fruit are susceptible to canker for a much longer period than leaves, which often results in canker being more severe on fruit. Grapefruit can be infected throughout the summer months, but the most economically important infections develop during the first 90 days of growth (18). Lesions formed from those infections become large and result in fruit drop. Several infection cycles can occur on fruit, and lesions of many sizes often appear on the same fruit. Lesions may deform the fruit if infection occurs early in fruit growth. Fruit lesions do not penetrate the albedo, so juice quality is not affected. Fruit-rotting fungi, such as *Penicillium* spp., may enter through fruit lesions, however.

The optimum climatic conditions for canker development have been researched. The optimum temperature for disease development is about 30 C, and the minimum and maximum temperatures for disease development are 5 and 35 C, respectively (14). Free moisture is required for spread of the bacterium, but wind also seems to be very important. If the average wind speed during rains exceeds 8 m/sec, the disease may be very severe (10). This may be related to the pressures necessary for bacteria to enter through stomata (11).

The environmental requirements for disease development do not seem to be restricted and probably exist in all citrus-growing regions. Peltier and Frederick (14) studied climates in citrus-producing regions around the world and related them to severity of canker. The disease was severe in regions where curves based on monthly means of temperature and rainfall ascend and descend together during the year. The disease has not been important in regions where high temperatures are accompanied by low rainfall. The climate of the Gulf-Coast states is similar to the former, and that of the southwestern United States is similar to the latter.

The citrus canker organism may have a wide host range within the family Rutaceae. Plants of many species within the family develop lesions when artificially inoculated. However, Peltier and Frederick (13) concluded that, with the exception of *Poncirus trifoliata* (L.) Raf., none of the relatives of the genus *Citrus* is sufficiently susceptible to warrant attention. Wide differences in susceptibility of species, hybrids, and cultivars have been recorded within the genus *Citrus* (13).

At least three strains of the organism have been distinguished by different pathogenicity to members of the genus *Citrus*. The most aggressive is native to Asia and is commonly designated A-strain. This strain is most pathogenic on grapefruit (*C. paradisi* Macf.), some limes (*C. aurantifolia* Swingle and *C. limettiodes* Tanaka), and sweet orange (*C. sinensis* Osbeck). B-strain occurs in Argentina, Paraguay, and Uruguay and is most aggressive on lemon (*C. limon* (L.) Burm.). The third strain was isolated from Mexican lime (*C. aurantifolia*) in Brazil and is pathogenic on that species. This strain was named *X. citri* f. sp. *aurantifolia* Nemakata but is commonly designated C-strain. The relative susceptibility of some citrus species to the three strains is shown in Table 1.

A-strain is the only one posing a threat to citrus production at present. Host range and aggressiveness have limited the seriousness of the other strains. Introduction of all strains into citrus-growing regions of the United States

should be prevented, however, because the relationship of the strains to each other is not clear at present.

History of Citrus Canker

Fawcett (7) thought canker originated in southeastern Asia. He found the disease on museum specimens of citrus collected from that area in the mid-1800s and speculated that canker was disseminated from the islands of the Pacific Ocean to Japan and from Japan to such countries as the United States and South Africa. Berger et al (2) thought canker was first introduced into the United States in 1910 with nursery trees shipped from Japan. Canker was probably present in Japan as well as in other Asian countries prior to 1910 but was not recognized. After introduction into the United States, the disease was recognized as unique because of its severity in wet, warm weather. Also, the copper sprays used to control other citrus diseases did not control canker. In 1915, Hasse (9) described a bacterium as the causal agent.

Trees with canker from Japan were planted in nurseries in Florida and Texas. Young trees with canker from these nurseries were shipped to growers and homeowners in Alabama, Florida, Georgia, Louisiana, Mississippi, South Carolina, and Texas. In Florida alone, 338,512 trees were received from infested nurseries, resulting in 62 centers of the disease throughout the state (2). A campaign to destroy diseased trees and restrict movement of citrus fruit from the centers of disease was first organized by growers in Dade County, Florida, in 1914. The campaign became statewide with passage of a crop pest bill by the Florida State Legislature in 1915. The U.S. Department of Agriculture (USDA) joined the campaign the same year, and the campaign was extended to the other states that had received infested trees.

Records were kept where trees were destroyed, and the properties were inspected routinely for new outbreaks of the disease. If canker reappeared, again diseased trees were destroyed. As fewer and fewer trees were found and destroyed, the realization occurred that canker could be eradicated from the United States if the campaign of inspection, quarantine, and destruction was continued.

Canker was thought to be eradicated from Florida by 1920, but a grove with diseased trees was found near Ft. Lauderdale in 1927. Canker was declared eradicated from Florida in 1933. The last canker lesion in the United States was reported in 1943 in Texas on a hedge of *P. trifoliata* trees. No canker was found in an extensive inspection in Texas in 1947 (12) or in Louisiana after 1949 (16). Canker was considered to be eradicated from the United States (5), which remains free from the disease to this date.

Canker was also eradicated from South Africa (4), Australia (7), and New Zealand (6) by the techniques established in the United States. Infestations in those countries, however, were not as extensive as in the United States.

Losses to Citrus Canker

Canker is one of the most feared diseases of citrus, but information on losses to citrus canker is scarce. Losses to canker were not determined when the disease was in the United States. Data on losses could be obtained from regions where canker is endemic, but such data cannot be validly extrapolated to another region because of fluctuations in yields of trees without disease. Also, in regions where citrus canker is endemic, types of citrus that are highly resistant to canker are cultivated predominantly. Data on losses under those conditions would not apply to the susceptible cultivars planted in the United States.

Losses to citrus canker are undoubtedly related to severity of the disease. In Argentina, where the climate and cultivars planted are much like those of Florida, 83–97% of the fruit of grapefruit trees were diseased in unsprayed plots during 1979–1980 (18). In the same plots, up to 88% of the leaves of summer growth flushes had at least one lesion. Of the two types of damage, disease of the fruit is probably the most economically important. As the result of canker, 15% of the fruit from unsprayed grapefruit plots fell prematurely to the ground. With some cultivars, such as Hamlin orange, up to 50% of the diseased fruit fell prematurely (Fig. 3). The diseased fruit that remained on the tree were suitable for juice extraction, but fruit with large lesions were not acceptable for fresh market. Production of citrus with susceptible cultivars becomes unprofitable after introduction of canker. Over 99% of the citrus trees planted in the United States must be classed as susceptible.

Control Measures

When canker occurred in the United States, the emphasis was on eradication, and other measures for control of canker were not adequately researched. In Japan, 85% of citrus production is of the moderately resistant Unshiu (Satsuma) orange, and other control measures are not needed with that cultivar. Nevertheless, research on control of citrus canker began in Japan after World War II with the goals of shipping fruit to the United States and of growing susceptible types, ie, navel oranges, as substitutes for the Unshiu orange. A surplus of Unshiu fruit occurs on the Japanese market (10).

Control measures developed in Japan include windbreaks of trees or netting, pruning of diseased summer and autumn shoots, forecasting, and chemical sprays. Six or seven sprays of copper are necessary to protect new growth from infection. Control of canker on resistant or moderately resistant trees is considered easy to achieve in Japan, but control on susceptible or highly susceptible trees has not been adequate to this date for commercial production (10).

Canker disappeared in plantings of Unshiu oranges when susceptible citrus trees were not planted in the vicinity and other control measures were applied. Susceptible trees provided inoculum to maintain canker on the Unshiu oranges, and control measures were not sufficient to prevent susceptible trees from being a source of inoculum.

Outlook

Inadvertent introduction of citrus canker into the United States is a real possibility. Canker was intercepted 2,603 times at ports of entry from 1973 to 1978 (8), and that rate of interception continued through 1980. The principal sources of canker interceptions are ship's stores and passenger baggage. Canker has never been detected on budwood or other plant material that came through quarantine procedures. Living cells of *X. campestris* pv. *citri* were found in dried leaves (for food-flavoring use) of *C. hystrix* DC. in a commercial store (E. L. Civerolo, *unpublished*).

With the knowledge of the canker interceptions, the potential danger of

canker on fruit from Japan, and the epidemic in South America, scientists from the USDA's Animal and Plant Health Inspection Service (APHIS) and Agricultural Research Service (ARS) and from research and regulatory agencies of Florida and Texas met in Washington, D.C., in 1976 for a technical workshop. Objectives were: 1) to determine the need for research to identify, control, and eradicate canker in this country if it was introduced, 2) to identify locations for citrus canker research and scientists interested in performing the research, 3) to establish priorities for research needs, and 4) to create a working group that would become knowledgeable about citrus canker.

Remarkable progress toward these goals has been achieved since that workshop. The Citrus Canker Coordinating Committee was formed and elected S. M. Garnsey as chairman. C. P. Seymour assumed the chairmanship of the committee in 1979. Although the committee has no official status, meetings have been held annually. These meetings have served to bring members up to date on canker research and as sounding boards for future work.

Research on modern techniques of identifying the citrus canker organism began under the direction of E. L. Civerolo at the quarantine facilities of the USDA-ARS's Plant Disease Research Laboratory at Frederick, Maryland. He has traveled to Japan, Taiwan, India, and countries in South America to review the citrus canker problem and collect cultures of the causal organism. He has developed serologic techniques for rapid identification of the bacterium (3). Specimens suspected of being citrus canker can be sent to the Plant Disease Research Laboratory for identification.

At the initiative of E. P. DuCharme, an agreement was reached with the government of Argentina for scientists from the United States to work with scientists of Argentina on citrus canker. A cooperative project was established at the Instituto Nacional de Tecnología Agropecuaria (INTA), Bella Vista, Corrientes, Argentina, to investigate the control, epidemiology, and hosts of citrus canker. R. E. Stall, J. W. Miller, and D. Zagory have worked with G. M. Marco and B. I. Canteros de Echenique in the field. This project is particularly valuable to the United States because research is in progress with citrus types and strains of the organism in an environment similar to that in Florida.

The population dynamics of *X. campestris* pv. *citri* in lesions and in rainwater have been studied in Argentina (17). The distance the canker organism was disseminated from diseased trees was determined during several rainy periods. How long the bacterium survived on and in several nonhost plants was investigated.

The relative susceptibility of many cultivars of citrus to the canker bacterium was noted under field conditions in Argentina. The amount of disease on trees of a cultivar may differ from location to location and from season to season. The presence and amount of susceptible tissues during a rainy period are not always the same for each cultivar. Thus, rankings of cultivars in regard to amount of disease may differ with each cycle of disease. As a result, the relative resistance of cultivars of citrus in the field should be assessed only after many years of observation. New cultivars under evaluation for canker resistance should be ranked with that in mind.

Much of the work in Japan on control of citrus canker with sprays has been confirmed in Argentina. Copper compounds provided significant control when applied at the proper time, ie, to immature growth. Sprays applied when inoculum was low provided better control than those applied when inoculum was high. Thus, sprays on the year's first flush of growth were important for preventing inoculum buildup even though conditions for disease were not optimum. Control of the disease on fruit was very poor because of the long period of susceptibility. Canker on susceptible types of citrus has been reduced in Argentina, but the degree of control is not adequate and the cost of control measures is too high for competition on the world market.

A campaign to eradicate canker should be initiated in the United States if the disease is reintroduced. Eradication can be successful if the disease is recognized early and if the citrus industry resolves to prevent the disease from becoming established. This requires education of citrus workers.

Circulars and slide illustrations of symptoms of the disease and the latest results of research with canker have been disseminated in Florida. Plant inspectors of the Florida Division of Plant Industry who routinely visit citrus nurseries in Florida are trained to recognize canker. A plan for eradication has been prepared based on research in Argentina, information obtained from eradication campaigns in Brazil and Argentina, and experiences with the successful eradication of canker in the United States early in this century. This plan has been submitted to segments of the Florida citrus industry for suggestions. The laws, rules, and regulations of the Florida Department of Agriculture and Consumer Services needed for eradication of canker have been reviewed by legal counsel and appear to be in order. The process of updating citrus canker knowledge among citrus producers also may have the benefit of making them aware of where the disease exists and the danger of bringing illegal budwood or trees into the United States. The latter may be the most efficient method of importing canker.

Conclusion

Canker distribution is increasing in the world, and with the ease of worldwide travel, one might believe that the phrase "*when* canker is introduced" is more appropriate than "*if* canker is introduced" into the United States. In the absence of canker, trees that produce high-quality citrus have been planted in the United States, and these trees are susceptible to the disease. The climate in the Gulf-Coast states is ideal for canker development. Losses to canker are primarily through defoliation, premature fruit abscission, and blemished fruit. Production costs per box of fruit increase because of low yields and high costs of control measures. The control measures on susceptible cultivars are not adequate at present to "live with" this bacterial disease and compete on the world market for citrus.

Eradication of diseased trees soon after introduction is the best control. The efforts of the Citrus Canker Coordinating Committee have increased the probability of successful eradication by stimulating plant pathologists to obtain experience with canker. The disease can be identified rapidly, modern methods of eradication have been outlined, and the laws, rules, and regulations allowing eradication have been reviewed in Florida. If canker is found in the United States, quick action is essential, and provisions for such quick action are now available.

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