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Citrus Tristeza Virus and Its Aphid Vector *Toxoptera citricida*

Threats to Citrus Production in the Caribbean and Central and North America

Citrus is a major crop in terms of nutrition and the generation of employment and commerce. More than 400,000 ha of citrus are distributed throughout Mexico. In the United States, there are almost 500,000 ha of citrus, mostly in Florida, Texas, Arizona, and California. The citrus industries of the Caribbean Islands, Central America, Mexico, and the United States represent more than 1.1 million hectares (60).

Tristeza disease of citrus, caused by citrus tristeza virus (CTV), a closterovirus, occurs in most citrus-producing areas of the world and is the most economically important viral disease of citrus (4,6,31,32). The most important vector of CTV is the brown citrus aphid, *Toxoptera citricida* (Kirkaldy) (BrCA). Due to the recent outbreaks of the BrCA and the spread of severe strains of CTV, tristeza now threatens an estimated 185 million citrus trees grafted on sour orange (*Citrus aurantium* L.) rootstock in the Caribbean Basin countries (60).

In view of the possible future impact of tristeza, we are providing information on the history of the disease, the characteristics of the virus and its diversity, the distribution of the virus and its vectors, and possible control options. Portions of this information have been presented in various recent regional workshop reports, but the information is not widely or easily available.

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Journal Series INIFAP/CIRNE-A001; University of Florida Journal Series R-04361.

Citrus Tristeza Virus

Tristeza, which means "sadness" in Portuguese and Spanish, has long been recognized as a decline disease of citrus scions propagated on sour orange rootstock (6,31,32). CTV apparently originated in the Orient and was distributed worldwide by the movement of citrus budwood and plants in the quest for new citrus varieties (6,33,52,53). Severe epidemics of tristeza occurred in Argentina and Brazil during the 1930s, when over 30 million citrus trees were killed (6,9), and in Spain during the 1960s and Venezuela during the 1980s, when 10.0 and 6.6 million trees were killed, respectively (8,36). Less severe epidemics have occurred in California and Israel, and continue in Florida (6,32).

Although propagation of citrus on sour orange rootstock increased the vulnerability of citrus to tristeza, this rootstock has many advantages: It is well-adapted to most soils, tolerant to *Phytophthora* and most graft-transmissible pathogens, and compatible with most scions. A switch to tristeza-tolerant rootstocks would open the door to numerous other problems.

Strain variability and disease syndromes. CTV occurs as a diverse complex of strains that vary greatly in aphid transmissibility and severity in citrus

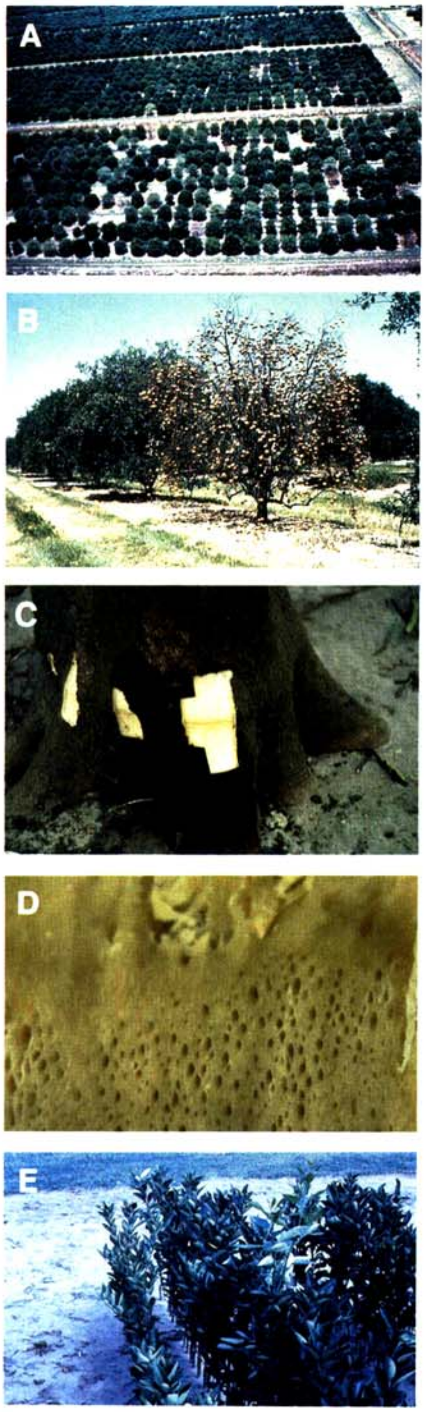

Fig. 1. Disease syndromes caused by citrus tristeza virus (CTV) in field plants grafted on sour orange rootstock. (A) Aerial view of a decline-inducing epidemic of CTV. (B) Symptoms of decline and wilting, followed by defoliation and death. (C) Yellowish brown coloration at the bud union frequently present in declining plants grafted on sour orange. (D) Honeycombing or pinholing of the inner surface of the bark, formed by corresponding pegs on the wood of the sour orange rootstock. This symptom is highly diagnostic for tristeza, and it is common when trees gradually decline. (E) Row on the right shows severe stunting of young plants grafted on sour orange rootstock and nursery propagated with budwood from plants infected with severe induced-decline CTV strains. In this case, plants do not die but never reach the bearing stage.

hosts (4,6,16,17,32). The virus is transmitted by grafting, but it is not seedborne (4,6,58). It is mechanically transmissible with difficulty by slash inoculation of partially purified preparations into the stems of sensitive indicators (18). Its host range is restricted to *Citrus* and *Citrus* relatives in the family Rutaceae, with the exception that it is able to infect *Passiflora gracilis* (18,39). Creation of an international collection of isolates and use of a standardized host range (17) of four *Citrus* species and a scion–rootstock combination has enabled comparison of CTV isolates from around the world and a description of the major strains of CTV (16).

Mexican lime (*Citrus aurantifolia* (Christm.) Swingle) is probably the most sensitive indicator plant for CTV, but the severity of symptoms (veinclearing, leaf cupping, dwarfing, and stem pitting [SP]) does not necessarily reflect the severity of the strain on other *Citrus* hosts.

Sweet orange (*Citrus sinensis* (L.) Osbeck) grafted onto sour orange seedlings is the indicator host of decline-inducing (DI) strains. In field trees, the decline may be rapid (Fig. 1A and B) or gradual, as the phloem necrosis develops at the bud union. In trees undergoing rapid decline, a brown to yellowish discoloration (Fig. 1C) at the bud union is often seen after removing the bark at the bud union. Inverse pitting projections of the xylem into the internal bark of the sour orange rootstock of declining trees, a process commonly referred to as pinholing or honeycombing, is common just below the union (Fig. 1D). When CTV-DI infected budwood is propagated onto sour orange seedlings, severe stunting results (Fig. 1E). The affected trees do not die, but they are stunted, grow poorly, and seldom bear marketable fruit.

Sour orange seedlings determine the presence of seedling yellows (SY) strains. These strains cause chlorosis and stunting in sour orange (Fig. 2A), acid lemon (*Citrus limon* (L.) Burm.), and grapefruit (*Citrus paradisi* Macf.) indicator plants. The SY reaction is normally a greenhouse or nursery disorder, but it is frequently used as presumptive evidence of the presence of the more serious DI or SP strains.

Strains of CTV causing SP on grapefruit, sweet orange, or both hosts are detected by indexing on Duncan grapefruit and Madam Vinous sweet orange seedlings (Fig. 2B). In the field, longitudinal pits or channels are formed in the wood of stems and/or branches of the scions, regardless of the rootstock. In extreme cases, the trunk may have a ropelike appearance (Fig. 2C), and the branches may become brittle and break in the wind or under a fruit load. Loss of plant vigor, severe yield reduction, and small fruit size (Fig. 2D and E) all result from infection with CTV-SP strains. Grapefruit and lime commonly are most severely affected, but severe SP can occur in some sweet oranges. SP strains may also cause veinclearing (Fig. 2F) and a severe vein-corking on leaves of limes or sweet oranges (Fig. 2G).

By comparing the reactions of these host plants, 11 probable reaction patterns have been predicted, and to date 10 of them have been collected (Table 1) (16,17). The viral determinants for SP and DI are apparently independent, based on reaction patterns observed.

Serological diversity occurs among different CTV isolates. A monoclonal antibody (MCA-13) that reacts with most CTV-DI strains was selected (46). This antibody does not discriminate between SP and DI strains but does not react with most mild strains. The antigenic determinant for reactivity of CTV severe strains to MCA-13 was shown to be phenylalanine at position 124 of the CTV coat protein; whereas tyrosine was present at this position in the coat protein of nonreactive CTV strains (44). Thus, MCA-13 is useful as a rapid indicator to determine whether an unknown strain of CTV is mild or severe, but the ultimate determination of mildness or severity and whether severe strains are DI or SP must be obtained by biological indexing. More rapid methods for CTV strain differentiation may be achieved with a greater molecular understanding of CTV (44,45).

Virus properties. CTV virions are approximately $2{,}000 \times 11$ nm; they contain a single-stranded positive-sense RNA of about 20 kb (3,4,6) encapsidated by a viral coat protein (CP) having a M_r of about 25,000 (4,55). The entire viral genome has been sequenced (25), including the ORF coding for the CP (44,45,55). The genome structure and organization at the 3′ end of CTV is similar to that of beet yellows virus, the type member of the closterovirus group (4,6).

Aphid transmission. CTV is vectored by several aphid species in a semipersistent manner with the aphid retaining the ability to transmit CTV for up to 24–48 hours after acquisition (6, 47,60). Aphid species vary in their ability to transmit the virus. The most efficient aphid vector for CTV is *T. citricida* (6,32,47,51,60). *Aphis gossypii* Glover is the next most efficient vector, and in some locations *A. gossypii* has efficiently vectored certain severe strains of CTV (5,6,50,59). Other aphid species reported as CTV vectors but with lower degrees of efficiency, based on experimental work, include *A. spiraecola* Patch (formerly *A. citricola* van der Goot) (59), *Toxoptera aurantii* Boyer de Fonscolombe (40), *A. craccivora* Koch, and *Dactynotus jacae* L. (4,51).

The relative efficiency in transmitting CTV of *T. citricida,* the most efficient vector, and *A. gossypii,* the most common vector wherever *T. citricida* is not present, was demonstrated in side-by-side comparative studies under uniform conditions by Yokomi et al (60) at the USDA Foreign Disease-Weed Science Research Unit, Ft. Detrick, Frederick, Maryland. The results from transmitting five selected exotic CTV strains indicate an average single-aphid transmission rate of 16% for *T. citricida* compared to 1.4% for *A. gossypii* (60).

Changes in the transmissibility of CTV by aphids and the occurrence of tristeza epidemics. The severe CTV epidemics in Argentina and Brazil in the 1930s and 1940s established the role and efficiency of *T. citricida* as a vector of CTV (10). Early transmission tests conducted in the 1950s in California (11) and Florida (40) with *A. gossypii, A. spiraecola,* and *T. aurantii,* indicated these aphid species were poor vectors of CTV. Because these aphids were indigenous species, it was thought that in the absence of *T. citricida,* CTV would not become a problem (33,52,53). However, in the 1960s and 1970s, CTV-DI epidemics occurred in Spain, Israel, California, and Florida in the absence of *T. citricida* (2,32,50,52). Subsequent transmission tests conducted in Israel (2,5), California (50), and Florida (59) indicated *A. gossypii* was the primary vector for a number of CTV-DI strains. In California, it was an efficient vector of a CTV-SP strain (50). Interestingly, there was a 30- to 50-year lag period between the first plant introductions from the Asiatic countries and the natural spread of severe CTV strains by *A. gossypii.* This has happened in Israel, Spain, California, and Florida (2,51,52). Figure 3 summarizes the different forms in which CTV epidemics have occurred in different parts of the world.

The brown citrus aphid (BrCA). The BrCA (Fig. 4) probably originated in China and is now distributed throughout many regions of the world, excluding Mexico, the U.S. mainland, and the Mediterranean region (33,52,53,60). For many years, the BrCA was thought to be the only vector responsible for CTV dissemination in the field (33,52). Direct importations of trees from South Africa and Australia into Argentina and Brazil were made in the late 1920s as those citrus industries were expanding. Plantings were primarily on sour orange rootstock. These importations undoubtedly led to the introduction of both CTV and the BrCA into South America (33,52,53). The combined presence of CTV and the BrCA resulted in the destructive tristeza epidemic to citrus on sour orange rootstock in Argentina and Brazil during the 1930s and 1940s. Over time, the BrCA, followed by severe strains of CTV, became established in other South American countries, including Uruguay, Peru, Chile, Colombia, and Venezuela. Plantings on sour orange rootstock in these countries were subsequently destroyed (33,52). In Spain, California, and Florida, and more recently, in Israel, CTV was also introduced, but without the BrCA. These importations were apparently made into the 1940s, also from Asiatic countries (33,52,53).

Movement of the BrCA northward in the Caribbean Basin. In the past 20 years, a natural northward movement of the BrCA through the Caribbean Basin has been observed (Fig. 5). In 1976, the BrCA was first identified in Venezuela at multiple locations near the southern Lake Maracaibo region, and in south-

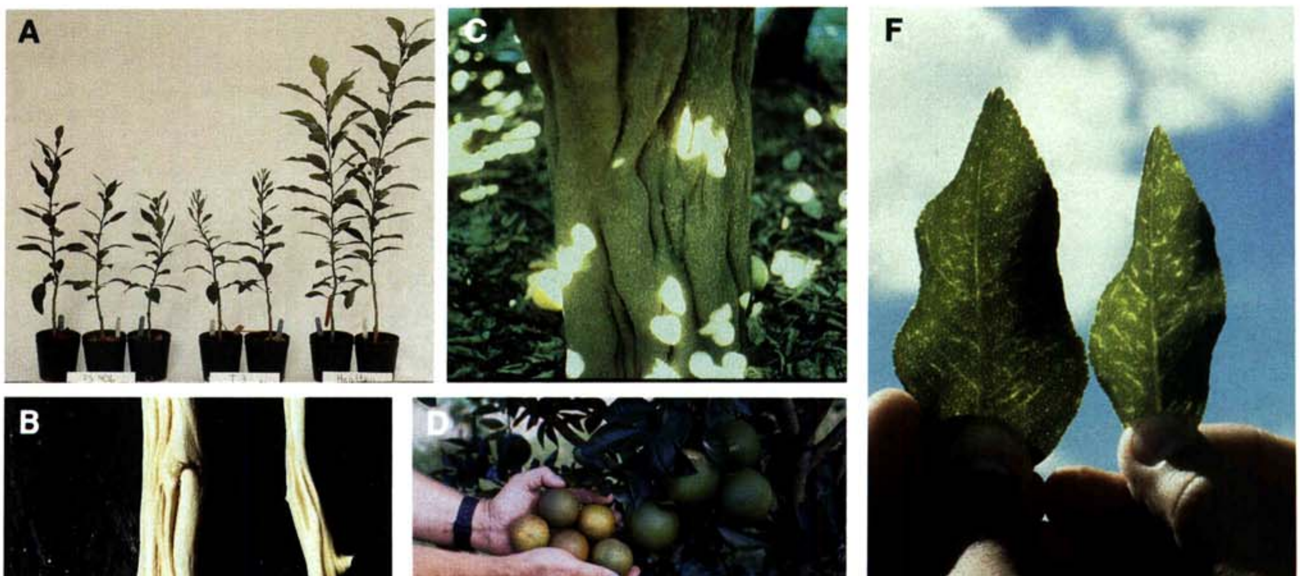

Fig. 2. Reactions caused by different strains of citrus tristeza virus (CTV) in several citrus hosts. (A) Seedling yellows reaction on sour orange seedlings. The two plants on the right are healthy. A similar reaction may occur on grapefruit seedlings. (B) Stem-pitting in the peeled stem of grapefruit. (C) Ropelike depressions in the stem of a Marsh grapefruit plant infected with a severe stem-pitting strain in South Africa. (D) and (E) Severe reduction of fruit size and quality of Valencia sweet orange and Marsh grapefruit, respectively, by severe stem-pitting CTV strains in Venezuela. Severe symptoms caused by stem-pitting strains of citrus tristeza virus (CTV) in Tahiti lime: (F) vein-clearing on younger leaves and (G) severe vein-corking on mature leaves.

west Venezuela near the Brazilian border (19,20). By 1979, the BrCA was widespread throughout the mountainous country of Venezuela (20,33,52).

In 1989, Lastra et al found the BrCA in a localized area of northeastern Costa Rica (30). A subsequent survey conducted in Costa Rica in 1990 showed the BrCA was established and widespread throughout the country (27). In 1991, a survey for CTV and BrCA indicated the BrCA was also present in Panama and as far north as the Nicaragua–Costa Rica border (28). Since 1991, the BrCA has been moving northward along the Pacific coast of Nicaragua (G. Narvaes-Ruíz, *personal communication*).

In the Caribbean area, the BrCA was reported in Trinidad in 1985 (60). In the spring of 1992, the BrCA was reported in Guadeloupe, Martinque, and St. Lucia (1,29,33). It was not found at these location in earlier surveys. In May 1992, the BrCA was reported in Puerto Rico and the Dominican Republic (29,33,60). In March 1993, Cuban scientists reported its presence in the four eastern provinces of Cuba (31); and in July 1993, it was reported in Jamaica (R. F. Lee, *unpublished*). In all areas newly invaded by the BrCA, populations rapidly reached high levels. Various reports have indicated anecdotal observations of BrCA in the West Indies from 1949. Because citrus was not commonly planted and the BrCA's narrow host range, it likely did not become permanently established there until recently (60).

The BrCA is able to spread CTV strains, especially severe strains, which are not easily transmitted by other aphid species. Its ability to spread "sleeping" severe strains of CTV prompts concern about the further spread of BrCA. A case history of the impact of the BrCA on the Venezuelan citrus industry is presented here to illustrate the impact this vector can have on a citrus industry.

Venezuela: a case history. After the severe epidemic of CTV in Brazil and Argentina in the 1930s, the BrCA spread slowly northward across the Amazonian jungle and was identified at several sites in southern Venezuela in 1976 (19,20). By 1979, it was widespread (20,29,33,52). The first CTV decline occurred in the north central region of Venezuela in 1980 (7,13). In the 1980s, Venezuela had 35,000 ha of citrus with about 6.5 million highly productive citrus trees, nearly all on sour orange rootstock (35,37). By 1987, 6 million trees were dead (14). Cir-

Table 1. Host plant reactions to strains of citrus tristeza virus (CTV)

Strain category[a]	Mexican lime	Sweet/sour orange	Sour orange	Grapefruit stempit	Sweet orange stempit
0	–	–	–	–	–
I	+	–	–	–	–
II	+	+	–	–	–
III	+	+	+	–	–
IV	+	+	+	+	–
V	+	+	+	–	+
VI	+	–	+	+	–
VII	+	–	–	+	+
VIII	+	–	–	+	–
IX	+	–	–	–	+
X	+	+	+	+	+

[a]Based on biological indexing of CTV isolates at the Exotic Citrus Pathogen Collection in the USDA, Beltsville, Maryland.

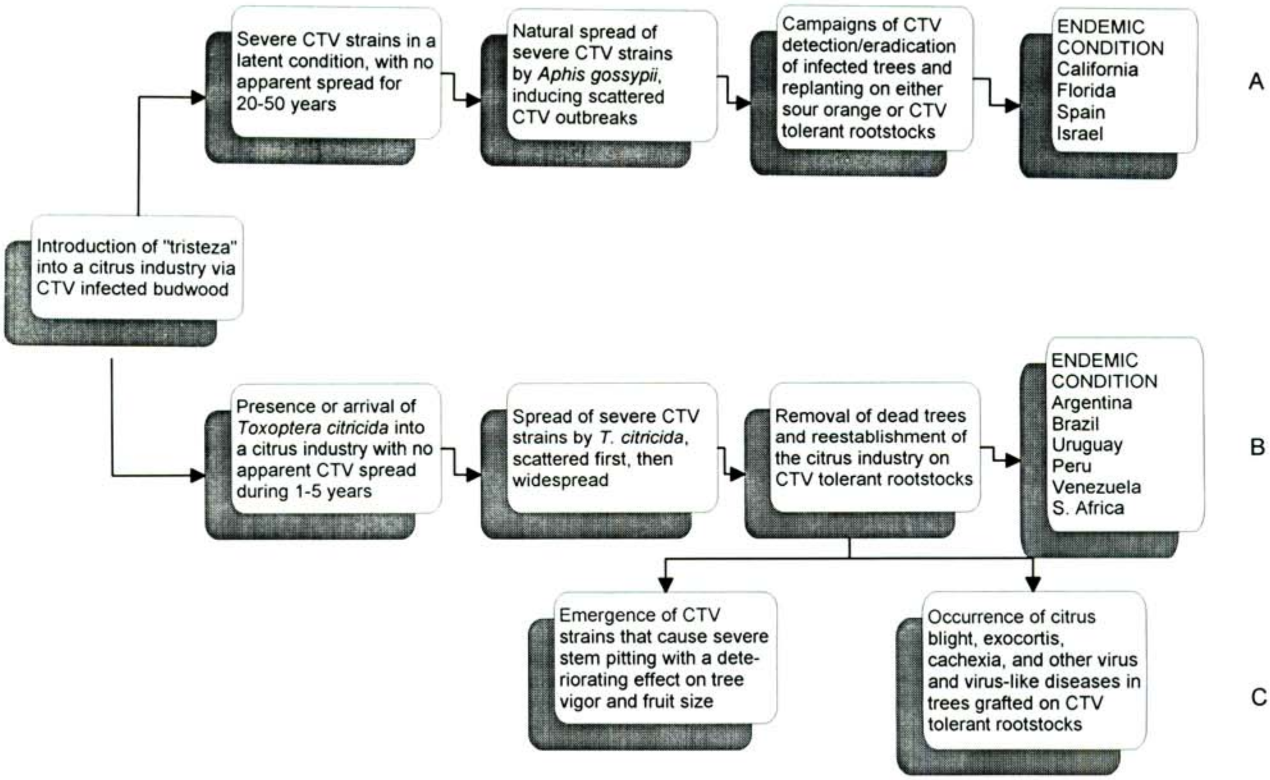

Fig. 3. Introduction of citrus tristeza virus (CTV) and epidemics in several parts of the world. (A) CTV epidemics in California, Florida, Spain, and Israel with the melon aphid *Aphis gossypii* Glover as primary vector. (B) CTV epidemics in Argentina, Brazil, Uruguay, etc., where CTV spread after arrival and colonization of the brown citrus aphid *Toxoptera citricida* (Kirkaldy). In both cases, CTV was present in a latent condition in CTV-infected propagative material brought from aboard. The simultaneous presence of CTV strains and *T. citricida* notably shortens the time of occurrence of the CTV epidemics. (C) After 10-20 years of CTV epidemics and establishment of *T. citricida*, the citrus industries contend with the occurrence of severe CTV stem-pitting strains, citrus blight, and other virus and viruslike diseases. (Modification of similar figure previously published by Rocha-Peña et al, 1992)

cumstantial evidence suggests that DI strains of CTV were present in scattered localized areas for almost 20 years in north central Venezuela in plantings established with budwood brought from abroad, but no decline was observed (33,52). Based on Mexican lime indexing in 1960, early CTV strains were apparently mild (26). However, sleeping strains of CTV were probably also introduced with illegal budwood due to the lack of a certification program. These strains were not a problem initially because they were not efficiently spread by the indigenous aphids. They became a severe problem after they were "awakened" and efficiently spread by the BrCA (33,41,52).

Venezuelan citriculturists, although unprepared for a devastating epidemic of CTV, responded promptly. Existing groves were interplanted and dead groves were replanted on CTV-DI tolerant rootstocks (14), such as Volkamer lemon, Cleopatra mandarin, and citranges. About 5 years after the appearance of the first CTV epidemic, severe strains appeared, which caused stem pitting in scions of sweet orange and grapefruit on tolerant rootstocks (42). These CTV-SP strains were either brought into Venezuela by the BrCA or had been "sleeping" in germ plasm or illegal budwood introductions. Tahiti lime, which was being cultivated because of its apparent CTV tolerance, also developed severe stem pitting. Trees on most CTV-resistant or -tolerant rootstocks are sensitive to citrus blight, an infectious disease of unknown etiology (56). Blight appeared in and currently has become a limiting factor in many groves grafted on Volkamer lemon rootstock in Venezuela (43,57). Other rootstocks, such as citranges, citrumelos, and *Poncirus trifoliata* hybrids, have been affected by viroids that are widespread in Venezuela (R. La Rosa, J. Albanese, and F. Ochoa-Corona, *unpublished*).

Fifteen years after the appearance of CTV decline, the Venezuelan citrus industry has yet to return to its original productiveness. A similar fate may face other countries in this region.

Management Strategies

The finding of the BrCA in Costa Rica in 1989 (30) stimulated the formation of a working group to confront the situation as a regional problem for the citrus industries of the Caribbean Basin and Central and North America. There have been two international workshops (27,29), as well as an extensive survey for CTV and the BrCA in Central America (28), as a result of the working group's efforts. The first workshop in Costa Rica in 1991 identified the need for more accurate information on the current distribution of CTV and BrCA. As a result, surveys were conducted and are continuing in most countries. The current distribution and incidence of CTV and BrCA has been described in general terms (21,28,29,60). At the International Workshop on Citrus Tristeza Virus and *Toxoptera citricida* in Central America held in September 1992 at Maracay, Venezuela (29), 150 participants from 22 countries identified several strategies for the management of CTV and the BrCA. The promotion of budwood certification–clean stock programs for citrus was universally recognized as the most important strategy to prevent and reduce future crop losses, especially where incidence is still low. In many countries, information is lacking about the occurrence of other citrus pathogens and the performance of different rootstocks under their local soil and climatic conditions. The need to promote extension activities to create a better awareness of CTV, the BrCA, and what alternatives are available for their management and control was also universally recognized. Many countries lack diagnostic laboratories to perform serological assays, other diagnostic procedures, or biological indexing to determine the presence of CTV or other pathogens. Training in diagnostic procedures has been provided to participants from a number of countries, but more effort is needed.

Following is a brief review of the management strategies available for CTV and the BrCA.

Certification schemes. Certification schemes coupled with clean stock programs can ensure that all budwood available in a country is certified free of CTV as well as other graft-transmissible pathogens. California, Cuba, South Africa, and Spain have operational programs that can serve as models. Certification–clean stock programs coupled with protection of budwood source trees from insects and the use of nursery increase blocks helps prevent the widespread distribution of severe CTV strains

Fig. 4. The brown citrus aphid, *Toxoptera citricida* (Kirkaldy).

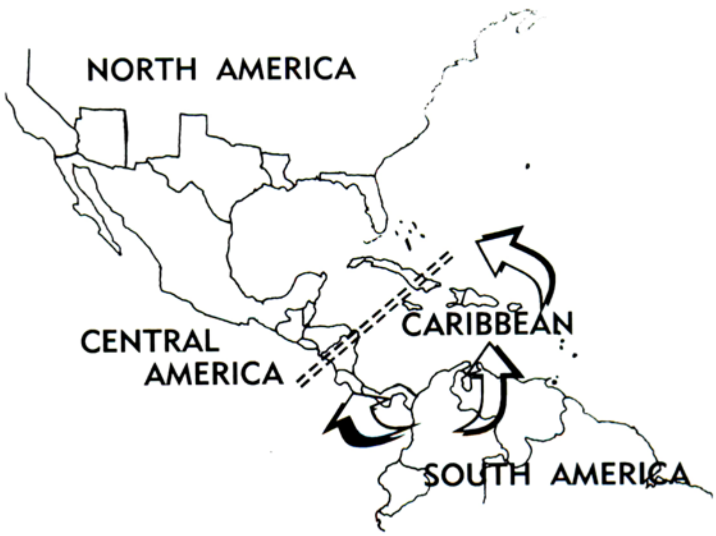

Fig. 5. Map of Caribbean Basin showing the current distribution of the brown citrus aphid, *Toxoptera citricida* (Kirkaldy).

through the citrus industry via nursery propagations. Additionally, certification programs may serve as vehicles for implementing mild strain cross protection (MSCP) throughout a citrus industry if conditions warrant such action. To be effective, certification programs should be mandatory, covering all citrus propagations. The needs of the respective citrus industry must be met by the regulations of the certification programs, and provisions must be made to allow for the safe introduction of germ plasm. The problem is that 12 countries in addition to the United States, Mexico, and Cuba produce citrus, and not many can afford a complete certification program. A regional approach is more efficient but is hampered by quarantine and political constraints.

Virus immunity and tolerance. Genetic immunity to CTV (i.e., the inability of the virus to replicate in the plant) is rare in the genera of the Aurantiodeae. Virtually all citrus species can harbor at least some isolates of CTV. Many species are tolerant and express no obvious symptoms. Rootstocks may be tolerant (Cleopatra mandarin, Volkamer, Rough lemon, Rangpur lime, and some citranges and citrumelos) or immune (P. trifoliata and some citranges and citrumelos) (12,15,32,49). In either case, trees grafted on these stocks are called CTV resistant or tolerant because they do not decline when infected with CTV-DI strains (31,32,49). CTV-resistant or -tolerant rootstocks have successfully reduced the effect of CTV in areas where neither CTV-SP strains nor the BrCA are prevalent. However, CTV-SP strains commonly affect severely either the scion or the rootstock and cause a significant debilitating effect on the tree and a resultant loss of productivity. In areas where both CTV-SP strains and BrCA become endemic, it is often necessary to implement MSCP to reduce stem pitting in the scion, which is discussed in the next section.

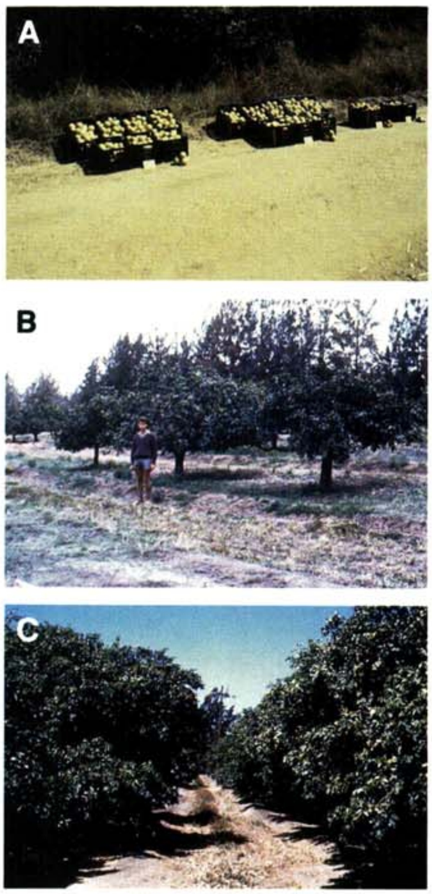

Fig. 6. Use of cross-protection as an alternative to reduce the effect of severe stem-pitting strains of citrus tristeza virus (CTV) (A) Yield of Marsh grapefruit trees unprotected (left), and protected (right and center) with mild CTV strains in South Africa. The yield is for the same number of trees (two) in every treatment. (B) Effect of CTV stem-pitting strains on an unprotected Marsh grapefruit grove after planting. (C) Effect of cross-protection by a locally selected CTV mild strain (Nartia) on Marsh grapefruit grove after planting. Marsh grapefruit trees are on Rough lemon rootstock (Photographs courtesy of Lawrence J. Marais).

To use most CTV resistant–tolerant rootstocks, a clean stock–budwood certification program is needed to prevent the occurrence of other virus–viroid diseases that may affect trees on rootstocks other than sour orange (6,30).

Scion varieties with immunity to CTV would be highly desirable. Plants in genera of the Aurantiodeae with known resistance include *Hesperethusa, Luvunga, Merope, Oxantherea, Poncirus, Severina,* and *Swinglea* (31). However, with the exception of *Poncirus,* incompatibility problems have made the incorporation of this CTV resistance into commercially acceptable cultivars difficult. A hybrid between sweet orange and *P. trifoliata* (US 119) was developed, where the CTV resistance present in *Poncirus* was transferred to develop a sexually compatible breeding parent (24,31); and further hybrids have been made (24). The coupling of conventional breeding with new techniques also offers promise. Hybrids of *Citrus sinensis* with other citrus species and non-sexually-compatible citrus relatives by protoplast fusion (somatic hybrids) have been accomplished (22,23). These somatic hybrid plants contain a set of chromosomes from each parent and express an intermediate morphology compared to either parent.

Genetic engineering methods offer great potential in the development of CTV-resistant plants. Transformed citrus plants have recently been developed which contain several foreign genes, including the coat protein gene of CTV (34,38,54). The recently developed sequence information on the CTV genome (25,45,55) now makes possible the production of transformed citrus containing different CTV genes, which may confer virus resistance. Strategies being developed for other plant viruses, including antisense DNA, defective interfering sequences, ribozymes, and "plantibodies," may also be effective against CTV (31,32). Even if CTV-resistant plants can be developed more rapidly by genetic engineering than by breeding, horticultural and field evaluations of the citrus fruit qualities still will require additional years after virus resistance is confirmed.

MSCP. MSCP is the phenomenon that occurs when a plant previously infected with a mild strain of a virus, in this case CTV, does not display the symptoms of a second, more severe CTV strain introduced later into the same plant. This management strategy for CTV is used on a commercial basis in South Africa (Fig. 6), Australia, Brazil, India, and Japan to allow continued production of citrus despite the presence of severe CTV-SP strains (6,31). More research effort has been devoted to the selection of mild strains for protection against CTV-SP strains than for protection against CTV-DI strains, partly because DI-tolerant rootstocks are available. MSCP is usually strain selective, and isolates protective in one location may not work in others.

MSCP should not be viewed as a solution for long-term protection against severe CTV strains. Rather, it is a intermediate control strategy that can be used to prolong the economic life of citrus plantings in areas where CTV is causing tree death and/or the production of small, unmarketable fruit. MSCP is most effective when implemented throughout the entire industry. The major advantage of MSCP is that it can be employed immediately in areas where protecting mild CTV strains have already been empirically selected. It can be used as a part of an integrated pest management approach to effectively prolong economic productivity. It should help buy time to introduce better and possibly more complete protection from CTV into commercially desirable citrus scions and rootstocks by genetic engineering, tissue culture, and plant breeding. At this point, we lack sufficient knowledge to display MSCP as a preventative measure in areas where severe strains are rare and the challenge threat is not clear and the challenge isolates known. The present status of cross protection has been reviewed recently (31).

Suppression–eradication. The elimination of CTV-infected trees in areas having low virus incidence has been a useful strategy to extend productivity on sour orange rootstock. This approach has been successful in central California since 1957. About 700,000 ELISAs are performed in California yearly, where samples are collected according to a statistical method. If CTV is detected, a more detailed follow-up survey is conducted in the area, and infected trees are removed regardless of the rootstock (31; J. Burr, *personal communication*).

Israel has been involved with a large CTV eradication–suppression project since 1970 (6). ELISAs in 1979–1980 over the whole citrus-producing area revealed a CTV infection rate of 0.13%. By 1982, the rate had increased to 0.57%, with 3.25 million ELISAs performed. In 1986, an additional 1.5 million trees were tested, and widespread occurrence of CTV in the coastal plain was confirmed. It was deemed impossible to remove all infected trees quickly enough to halt further spread in the coastal plain area, and further eradication was confined to peripheral areas. Overall, testing 6 million trees and eradicating were not effective in totally suppressing the disease, but the effort undoubtedly extended citrus production on sour orange rootstock for 5–10 years. Eradication efforts in Israel were hampered by: 1) a slow start on the program; 2) failure to impose regulations and achieve complete grower participation (regulatory authority was not adequately achieved); 3) failure in certain groves to detect by ELISA an isolate that caused quick decline; and 4) hedging and topping trees, which favored the buildup of aphids on new growth (6).

Summary and Outlook

The CTV–BrCA complex represents a real threat to citrus production in the countries of the Caribbean Basin and Central and North America. The promptness in recognizing the situation by scientists, government officials, and citrus growers of this geographical area will pay dividends by delaying the occurrence of CTV epidemics.

Immediate strategies should include preventing any further introduction of any severe CTV isolate into the region, and preventing any further dissemination of the virus via infected budwood. Continued education is essential to make prevention work as well and as long as possible. Eradication and suppression should be considered where the number of infected trees is small and they are restricted to well-defined locations. Large-scale suppression should be guided by analysis of cost–benefit ratios and accurate survey information. Long-range movement of plant materials infested with the BrCA should be carefully avoided. Field evaluation of alternate rootstocks is essential in all areas where sour orange is threatened by CTV.

Intermediate strategies include deployment of MSCP as other options fail, especially in the context of an integrated pest management scheme (61).

Long-range strategies include development of immune scion varieties through genetic engineering and breeding.

Several areas that need additional research have been identified by scientists and citrus growers at the various international workshops held in Costa Rica in 1991 and in Venezuela in 1992 (27,29). These areas are summarized as follows: 1) development of rapid methods to differentiate among mild, DI, and SP strains of CTV; 2) development of virus resistance in commercially desirable cultivars by either biotechnology methods, including somatic hybridization, production of transgenic plants, and genetic engineering approaches, or conventional breeding to transfer the CTV immunity present in some citrus relatives into acceptable cultivars; 3) gathering of data on distribution and spread of CTV, as affected by strains of CTV, vector type, and dynamics, hosts, and location effects; 4) developing a better understanding of virus–aphid relationships to determine how CTV is affected by aphid species, virus strain, and hosts; 5) developing biological control methods for the BrCA as part of an integrated pest management system to reduce spread of CTV; and 6) developing improved methods of MSCP.

Acknowledgments

We thank for support the International Workshops on CTV/BrCA from USDA/OICD and FAO, which have enabled a regional coordination of research efforts on CTV/BrCA. M. A. Rocha-Peña thanks project INIFAP 080 for support for research on CTV in Mexico. R. F. Lee and C. L. Niblett thank the USDA/University of Florida Specific Cooperative Research Agreement and the Binational Agricultural Research and Development with Israel (BARD) for support. We thank L. J. Marais for allowing the use of his slides on cross protection experiments of Marsh grapefruit from South Africa; K. S. Derrick and J. V. da Graca for valuable suggestions on manuscript preparation; and Mercedes González-Maltos for preparation of the graphics.

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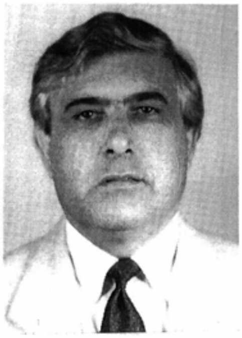
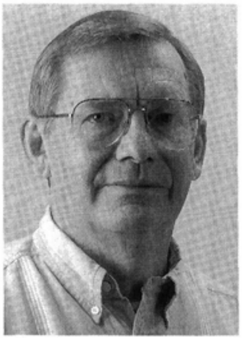


Ramón Lastra

C. L. Niblett

Francisco M. Ochoa-Corona



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Dr. Niblett received his B.S. degree in botany and plant pathology from the University of New Hampshire in 1965. He received his Ph.D. in plant pathology from the University of California, Riverside, in 1969. As an assistant and associate professor of plant pathology at Kansas State University from 1969 to 1980, he and colleagues developed Newton, a high-yielding and soilborne-wheat-mosaic-resistant wheat cultivar, and described maize chlorotic mottle virus and its synergistic interaction with potyviruses to cause corn lethal necrosis. From 1980 to 1986, he served as professor and chairman of the Plant Pathology Department at the University of Florida, where he is currently a professor. His research and extension programs are on detection, identification, and control of viruses and viroids of tropical and subtropical fruits, with the emphasis on diseases of citrus.

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