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The brown citrus aphid, *Toxoptera citricida*

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I – Identity

1. Preferred scientific name

Toxoptera citricida (Kirkaldy)

2. Taxonomic position

Kingdom:	Animalia
Phylum:	Arthropoda
Class:	Insecta
Order:	Homoptera (Hemiptera)
Suborder:	Sternorrhyncha (Homoptera)
Superfamily:	Aphidoidea
Family:	Aphididae
Subfamily:	Aphidinae
Tribe:	Aphidini

3. Synonyms

Aphis aeglis Shinji
Aphis citricidus (Kirkaldy)
Aphis citricola van der Goot
Aphis nigricans van der Goot
Aphis tavaresi Del Guercio
Myzus citricidus Kirkaldy
Paratoxoptera argentiniensis EE Blanchard
Toxoptera aphoides van der Goot
Toxoptera citricidus (Kirkaldy)

4. Common names

Brown citrus aphid (English)
Oriental citrus aphid (English)
Tropical citrus aphid (English)
Black citrus aphid (English)
Abura mushi (Japaese)
Dà jú yá (Chinese)

5. Notes on taxonomy and nomenclature

The aphid was first described as *Myzus citricidus* and was noted to be similar to *Myzus cerasi*, common on citrus throughout Hawaii, and a likely an introduction from China (Kirkaldy 1907). The species name, *citricidus*, was derived as a Latin adjective of the noun meaning “citrus killer” and had a masculine ending to agree with *Myzus*. Since *Toxoptera* Koch is the correct genus for the aphid and is feminine, it is necessary that its nomenclature be feminine (e.g., *Toxoptera citricida*), as apposed to the feminine/masculine combination (e.g., *Toxoptera citricidus*) (Stoetzel 1994b).

II – Hosts

1. Affected plant stages

T. citricida colonizes young leaves, stems, blossoms, and growing points of host plants. Established colonies may be able to complete their life history on hardening shoots but these will not support new colonies.

2. List of hosts

Major hosts (citrus scion varieties): sweet orange [*Citrus sinensis* (L.) Osbeck.], grapefruit [*C. paradisi* Macfad.], mandarin [*C. reticulata* Blanco], lime [*C. aurantifolia* (Christm.) Swing.)], lemon [*C. limon* (L.) Burm. f.], pummelo [*C. maxima* (Burm.) Merr.], satsuma [*C. unshiu* (Mack.) Marc.], tangelo [*C.* x *tangelo* J. Ingram and H.E. Moore], tangor [*C.* x *nobilis* Lour.].

3. Notes on host range

Primary hosts of *T. citricida* are citrus and citrus relatives (Rutaceae) (Order Geraniales, Suborder Geraniineae, mostly in the Subfamily Aurantiodeae, Tribe Citreae). Typically, Aurantioideae are trees or shrubs with evergreen leaves. Flowers are usually white and often fragrant. Many genera bear subglobose fruit with a green, yellow, or orange peel with numerous oil glands that result in a nice aroma when handled. Most commercial citrus varieties and rootstocks are good hosts of *T. citricida.* In addition, relatives such as calamondin [X *Citrofortunella microcarpa* (Bunge) Wijnands] and orange jessamine [*Murraya paniculata* (L.) Jack.] can support *T. citricida*. There are reports that *T. citricida* has been collected on many non-citrus plants (Essig 1949), however, there is no verification that these are reproductive hosts capable of sustaining a population of the aphid. These reports may have resulted from misidentification of aphids. In addition, the aphid may be able to survive on some nonrutaceous hosts temporarily as they migrate away from a crowded food source (Yokomi *et al*. 1994).

III – Geographic distribution

T. citricida is believed to be native to Asia where citrus originated. Since the first half of the twentieth century, the aphid has been known to be widely distributed on citrus in Asia, India, New Zealand, Australia, Pacific Islands (including Hawaii), Africa south of the Sahara, Madagascar, Indian Ocean Islands, and South America. This distribution is attributed to movement of infested leaves or propagations. Areas where citrus was established by seed or aphid-free propagations have remained uninfested (e.g., North and Central America, Caribbean Basin) until recently (Yokomi *et al*. 1994). The Mediterranean region except for NorthWest Spain and northern Portugal remains free of the aphid. Because ancestral citrus (old line) is known to contain many virus and virus-like agents, many countries prevent entry of citrus propagations from abroad. This, undoubtedly, has restricted the aphid’s hitchhiking potential. On the other hand, there is now more intercontinental movement of people and commerce than ever before and the threat of introduction by this route remains at its highest level (Tab. 1).

Although the aphid’s origin is tropical/subtropical, presence of a sexual stage and overwintering as eggs in Japan (Komazaki 1982) suggests that *T. citricida* can adapt to different climates. Due to the aphids’s restricted host range to citrus and its relatives, the most favorable citrus environs for *T. citricida* occur when weather is warm and humid which result in frequent stimulation of new growth cycles. Similarly, desert/semi-arid and cooler regions provides conditions favorable for *T. citricida* only seasonally. Populations typically increase rapidly following colony initiation and results crowding, in a decline in host suitability, and production of winged (alate) aphids. Winged morph production could also be triggered by the physiology of the host. A key requirement for spread of *T. citricida*, however, is that the alata must alight on citrus with new shoot growth to successfully establish a new colony.

Table 1. Geographic distribution of *Toxoptera citricida.*

COUNTRY	STATUS	REFERENCES
ASIA		
-Cambodia	W	Blackman and Eastop 1984
-China	W	Essig 1949
-Hong Kong	W	Blackman and Eastop 1984
-India	W	Prunthi and Mani 1945
-Indonesia	W	Blackman and Eastop 1984
-Japan	W	Essig 1949
-Malaysia	W	Essig 1949
-Nepal	W	Knorr and Shah 1971
-Philippines	W	Blackman and Eastop 1984
-Singapore	W	Blackman and Eastop 1984
-Taiwan	W	Essig 1949
-Viet Nam	W	Essig 1949
-Thailand (SE Asia)	W	Blackman and Eastop 1984
AFRICA		
-Kenya	P	Essig 1949
-Ivory Coast	P	Thouvenel and Fauquet 1977
-Ethiopia	P	Abate 1988
-Burundi	P	Seco *et al*. 1992
-Mauritius	W	Essig 1949
-Reunion	W	Etienne and Vilardebo 1978
-South Africa	W	Essig 1949
-Swaziland	W	Essig 1949
-Belgium Congo	P	Essig 1949
-British East Africa	P	Essig 1949
-Cameroon	P	Essig 1949
-French West Africa	P	Essig 1949
-Mozambique	P	Essig 1949
-Nairobi	P	Essig 1949
-Rhodesia	P	Essig 1949
-Uganda	P	Essig 1949
-Angola	P	Van Harten and Ilharco 1975
NORTH AND CENTRAL AMERICA		
-Cayman Islands	P	Halbert 1996b.
-Costa Rica	W	Lastra *et al* 1991
-Cuba	W	Yokomi *et al*. 1994
-Dominica	W	Aubert *et al*. 1992
-Dominican Republic	W	Aubert *et al*. 1992
-Guadeloupe	W	Aubert et al. 1992

COUNTRY	STATUS	REFERENCES
-Haiti	W	Yokomi et al. 1994
-Jamaica	W	Yokomi *et al*. 1994
-Martinique	W	Aubert *et al*. 1992
-Mexico	W	Michaud and Alvarez 2000
-Nicaragua	W	Yokomi *et al*. 1994
-Panama	W	Yokomi *et al*. 1994
-Puerto Rico	W	Yokomi *et al*. 1994
-St. Kitts and Nevis	W	Yokomi *et al*. 1994
-St. Lucia	W	Yokomi *et al*. 1994
-Trinidad and Tobago	W	Essig 1949
United States		
-*Florida*	P	Halbert 1996a
SOUTH AMERICA		
-Argentina	W	Essig 1949
-Bolivia	P	Smith and Cermeli 1979
-Brazil	W	Essig 1949
-Chile	W	Essig 1949
-Colombia	W	Smith and Cermeli 1979
-Ecuador (So. America)	W	Stoetzel 1994a
-Paraguay	P	Smith and Cermeli 1979
-Peru	W	Essig 1949
-Surinam	P	Smith and Cermeli 1979
-Uruguay (So. America)	W	Stoetzel 1994a
-Venezuela	W	Smith and Cermeli 1979
EUROPE		
-Madeira and NW Portugal	W	Aguiar *et al*. 1994, D’Onghia, 2005
-NW Spain		D’Onghia, 2005
OCEANA		
-Australia	W	Essig 1949
-Cook Islands (Pacific Islands)	W	Blackman and Eastop 1984
-New Zealand	P	Essig 1949
-Tonga	P	Carver *et al*. 1993
-Fiji	P	Essig 1949
-Samoa	P	Essig 1949

W: Widespread; P: Present.

IV – Biology and ecology

T. citricida is anholocyclic and thelytokous throughout most of its range, preferring warm climates. It can, however, tolerate colder areas such as southern Japan by developing a holocyclic stage and overwintering as eggs (Komazaki 1993). Development time is temperature dependent. At 20°C, *T. citricida* has a nymphal development time is 6-8 d with an average pre-reproductive period of 8.1 d, longevity is 28.4 d. Fecundity is 58.5 offspring/female with an intrinsic rate of natural increase (r_c) of 0.36, net reproductive rate of 56.2, mean generation time of 11.2 d. Its thermal threshold is 8.4°C and required 125 degree days for development (Komazaki 1982). Takanashi (1989) reported slightly longer generation time under similar conditions and differentiated between alata and aptera development time. Winged morphs develop when populations become crowded and/or food source declines in quality and disperse in search of new hosts to begin new colonies. A spring and a fall flight peak of *T. citricida* occur in South Africa (Schwartz 1965), Australia (Carver 1978), and Brazil (Nickel *et al*. 1984). In Japan, *T. citricida* populations peak 3 times per year but can be found on citrus in all seasons, except when overwintering (Komazaki 1993). Because the host range of the aphid is restricted to citrus and its relatives (all relatively non-cold hardy), it is unlikely that the aphid can exist outside citrus growing areas or climates.

T. citricida's major impact is due to its efficient transmission of *Citrus tristeza virus* (CTV) (Costa and Grant 1951, Yokomi *et al*. 1994), a phloem-limited closterovirus (Bar-Joseph and Lee 1989). Two types of CTV strains are economically important: 1) those that cause decline of citrus budded onto sour orange (*Citrus aurantium* L.) rootstock; and 2) those that cause stem pitting of grapefruit and sweet orange regardless of rootstock. Both are readily transmissible by *T. citricida*.

CTV is semipersistently transmitted by citrus aphids (Raccah *et al*. 1976). Aphids acquire virus from an infected trees with feeding times as short as 5-10 min. but transmission efficiency increase with feeding times up to 24 h. There is no latent period and the virus does not multiply or circulate in the aphid. The time required to inoculate a plant is the same as for acquisition. The aphid is capable of spreading the virus for 24-48 hours without reacquisition (Meneghini 1948). *T. citricida* also transmits citrus vein enation (woody gall) virus, a probable luteovirus (da Graça and Maharaj 1991). Migrating populations of *T. citricida* are also associated with the spread of certain nonpersistently-transmitted viruses such as chili veinal mottle virus (Blackman and Eastop 1984) and soybean mosaic virus in China (Halbert *et al*. 1986).

Symptoms. New, tender shoots are vulnerable to *T. citricida* colonization and support rapid population buildup. Aphids are external feeders and extract plant sap from the host by penetrating their stylets into phloem. Excess plant sap is excreted as honeydew which supports sooty mold growth. Heavy infestation by *T. citricida* is noted when growing points of citrus are covered by the dark-colored aphid and the flush bends under the physical weight of the colony. Aphid-tending ants are often present with *T. citricida* and collect honeydew. When disturbed, *T. citricida* populations sway rapidly in unison, making stridulatory movements with their hind legs presumably to fend off their enemies Flowers are not a preferred host tissue. Mature leaves, stems, and fruit can not sustain *T. citricida* population.

V – Natural enemies

Most of the reported natural enemies of *T. citricida* are predators. If predators are present in or adjacent to the citrus grove when *T. citricida* colonies are forming, they can be effective even when aphid levels are low. Recently in Puerto Rico, predators, especially coccinellids, were observed decimating small *T. citricida* colonies and eliminating or reducing and/or delaying winged aphid production (JP Michaud, personal communication).

The principal primary parasitoids of *T. citricida* are solitary endophagous Hymenoptera in the families Aphidiidae and Aphelinidae. The aphidiids are wasplike in appearance and, at pupation, produce a mummy with a typical crusty golden, swollen appearance. They range in adult size from one to several mm. Aphelinids are usually less than 1 mm in adult size, possess reduced wing venation and an abdomen which appears broadly attached to thorax. They turn an aphid into a black mummy. Female adult aphelinids also feed on aphid haemolymph, a behavior that is essential for completion of oogenesis. In Taiwan, *T. citricida* is parasitized by *Lipolexis gracilis* and *Lipolexis scutellaris* (Tao and Chiu 1971), whereas in Australia, it is parasitized by *Aphelinus gossypii* (Carver 1978). In Japan, *Lysiphlebia japonica* is the principal parasitoid of *T. citricida* (Kato 1970, Takanashi 1990).

Entomopathogenic fungi attack *T. citricida* and can decimate a population with dramatic speed. A critical requirement for efficacy of such fungi is high humidity. *Verticillium lecanii* has been reported to attack *T. citricida* in Venezuela (Rondón *et al*. 1980) and other fungi has been observed associated with the aphid in South Africa (Samways 1984) (Tab. 2).

Table 2. List of the natural enemies of *Toxoptera citricida*

NAME	TYPE	STAGES	COUNTRIES
Aphelinidae			
Aphelinus gossypii Timberlake	Parasitoid	All	So. China, Australia
Aphelinus spiraecolae Evans and Schauff	Parasitoid	All	So. China
Aphidiidae			
Aphidius colemani Viereck (*A. platensis* Brethes)	Parasitoid	All	Argentina, Australia
Aphidius matricariae Haliday	Parasitoid	All	Peru
Lipolexis gracilis Forster	Parasitoid	All	So. China, Taiwan
Lipolexis scutellaris Mackauer	Parasitoid	All	Taiwan, India
Lysiphlebia japonica (Ashmead)	Parasitoid	All	Japan
Lysiphlebus testaceipes (Cresson)	Parasitoid	All	Peru, Puerto Rico, Venezuela, USA, Cuba, Europe
Trioxys indicus Subba Rao and Sharma (*Binodoxys indicus*)	Parasitoid	All	India
Coccinellidae			
Chiomenes sexmaculata (Fabricius)	Predator	All	So. China
Ceothera sp.	Predator	All	Brazil
Coccinella octopunctata (Fabricius)	Predator	All	Taiwan, Japan
Coccinella repanda Thumberg	Predator	All	Australia, Taiwan, Japan
Coccinella septempunctata Mulsant	Predator	All	Taiwan
Cycloneda sanguinea (Linnaeus)	Predator	All	Brazil, Venezuela
Diomus sp.	Predator	All	Brazil
Exoplectra sp.	Predator	All	Brazil
Harmonia conformis (Boisdural)	Predator	All	Australia
Leis axyridis (Pallas)	Predator	All	So. China
Leis conformis (Boisd.)	Predator	All	So. Australia
Leis dimidiata Fabricius	Predator	All	So. China, Taiwan
Lemnia biplagiata Schwartz	Predator	All	Taiwan
Lemnia saucia (Mulsant)	Predator	All	So. China, Japan
Lemnia swinhoei Crotch	Predator	All	Taiwan
Menochilus sexmaculatus (Fabricius)	Predator	All	Taiwan
Pentilia sp.	Predator	All	Brazil
Propylea japonica (Thumberg)	Predator	All	Taiwan
Pseudaspidimerus japonensis Nakune and Araki	Predator	All	Taiwan
Scymnus frontalis quadripustulatus Herbst	Predator	All	Taiwan
Scymnus hoffmanni Weise	Predator	All	So. China, Taiwan
Syrphidae			
Epistrophe balteata (De Geer)	Predator	All	So. China
Ischiodon scutellaris Fabricius	Predator	All	So. China
Melangyna viridiceps (Macquart)	Predator	All	Australia
Ocyptamus gastrostactus (Wiedemann)	Predator	All	Venezuela
Simosyrphus grandicornis (Macquart)	Predator	All	Australia
Syrphus serrarius Wiedemann	Predator	All	S. China, Japan
Chrysopidae			
Chrysopa boninensis Okamoto	Predator	All	Taiwan, So. China
Chrysopa formosana Matsumura	Predator	All	Taiwan, Japan
Chrysopa septempunctata Wesmael	Predator	All	So. China, Japan
Chrysopa signata Schneider	Predator	All	Australia
Chamaemyiidae	Predator	All	So. China

VI – Pest significance (economic impact)

T. citricida is the most important of the six reported aphid species that transmit CTV because of its high vector efficiency, prolific reproduction, and dispersal timed with citrus flush cycles to maximize chances of acquiring and transmitting the virus. High populations of aphids during bloom periods can cause direct damage to citrus (Hall and Ford 1933). The major damage associated with *T. citricida*, however, is the transmission and spread of severe strains of CTV. Such strains cause rapid decline and death of citrus trees planted on sour orange (*C. aurantium*) rootstock regardless of tree age. The most virulent strains of CTV cause stem pitting in twigs, branches, and trunks of citrus trees regardless of rootstock. Stem pitting CTV weakens a tree and reduces fruit size, quality, and quantity. This occurs over a period of 6 to 25 years depending on the virulence and challenge level of CTV. Grapefruit cultivars are most sensitive to stem pitting but sweet orange varieties (e.g., Pera) are also susceptible; mandarins are most tolerant.

T. citricida was the vector responsible for the rapid spread of CTV decline that caused death of many tens of millions of citrus trees on sour orange in Brazil and Argentina in the 1930's and 1940's (Knorr and DuCharme 1951 and in the 1970's in Colombia, Venezuela, and Peru over a 10-year period (Geraud 1976, Lee *et al*. 1992). Currently in South Africa, *T. citricida* is spreading CTV strains that are so virulent that economic longevity of grapefruit has been shortened to 6-8 years even though it contains a cross-protecting CTV isolate (Marais *et al*. 1996). *T. citricida* was found to be 6 to 25 times more efficient in transmission of various CTV isolates than was *Aphis gossypii* (melon or cotton aphid) (Yokomi *et al*. 1994). Currently, there are an estimated 200 million citrus trees on sour orange rootstock worldwide and are all at immediate risk to CTV decline (Garnsey *et al*. 1996).

VII – Identification

1. Morphology

Of the 16 to 20 aphid species reported to feed on citrus, 5 species are most commonly encountered: *T. citricida*; *Aphis spiraecola* Patch; *Aphis gossypii* Glover; *Toxoptera aurantii* (Boyer de Fonscolombe); and *Aphis craccivora* Koch (latter not common). Adult *T. citricida* are shiny black and nymphs are grey or reddish brown, but color alone is not distinctive because other aphids on citrus have dark coloration.

Winged adult female (alata): 1.1-2.6 mm in length; antennae six segmented with I, II, and III heavy black and other segments banded at joints, secondary rhinaria 7-20 on III and 0-4 on IV, setae on ant. III subequal to or exceeding diameter of segment; siphunculi black, elongate; cauda black, elongate with 25-40 setae; stridulatory apparatus on abdomen present; forewing with pterostigma light brown and media usually twice-branched.

Wingless adult female (aptera): 1.5-2.8 mm in length; oval; antennae six segmented with no secondary rhinaria; segments not banded, but segments I and II black, segments III and IV pale and slightly swollen, and segments V and VI dark at least at joints, setae on antennal III at least as long as the diameter of the segment; siphunculi black, elongate, and only slightly longer than cauda; cauda black and elongate with about 30 setae; "knees" of all three pairs of legs very dark; stridulatory apparatus present.

2. Similarities to other pests

T. citricida can be confused with *T. aurantii*, the black citrus aphid, because of its presence on citrus, dark brown-black coloration, size, and presence of stridulatory apparatus on the abdomen. However, alata of these aphids can be readily differentiated using a hand lens. *T. citricida* has antennae III entirely black, forewing pterostigma light brown and media vein twice branched; *T. aurantii* has antennae III, IV, V, and VI banded at joints, forewing pterostigma conspicuously dark blackish-brown and media vein once-branched. Wingless adults and nymphs are more difficult to distinguish. The easiest character on apterae is the antennae. *T. aurantii* antennae have several banded joints; whereas *T. citricida* antennae have one prominent band near the middle. Setal length and patterns can be used to differentiate the aphids but require higher magnification. The cauda of *T. citricida* is bushy with 25-40 setae; whereas that of *T. aurantii* is less bushy with 8-19 setae. Another black aphid that occur on citrus is *Aphis craccivora* Koch, cowpea aphid. It can be distinguished by its strikingly white legs (knees of hind leg may be dark) and 7 caudal setae. Full descriptions and citrus aphid keys are reported im more details by Stroyan (1961), Stoezel (1994a) and Halbert and Brown (1996).

3. Detection and inspection methods

Field infestations of *T. citricida* can best be detected by periodic visual inspection of new shoot growth of citrus. Winged forms can be monitored by yellow traps or suction traps.

VIII – Control

1. Cultural Control

Efforts to manage virus inoculum are the most important control strategy (Garnsey *et al* 1996) because spread of severe strains of CTV is the major problem associated with *T. citricida*. The first factor to consider is the prevalence of CTV and its strains in your area. If virulent stem pitting strains and *T. citricida* are endemic, citrus scion varieties tolerant to CTV should be planted. These include mandarins, pummelos, tangelos, and tangor. Only CTV-tolerant or resistant rootstock should be used. Avoid planting grapefruit or Pera sweet orange unless they have been preinfected with a cross-protecting CTV strain. If CTV strains are less virulent than the previous scenario, sweet oranges and grapefruit, preferably preinoculated with a mild CTV isolate, can be grown with consideration for the market targeted (e.g., fresh fruit, domestic, export, juice, etc.). When CTV problems are anticipated, closer plant spacing should be considered to maximize land use during the grove’s early years. Trees that decline or become stunted can either be replaced or simply removed and neighboring trees allowed to fill in.

Close plant spacing is becoming a common practice in the United States in new groves. Tree size is managed by mechanical hedgers that trim the sides and tops of trees. This practice produces conditions excellent for CTV spread and allows tree canopies to touch in the direction of the row. Pruning induces new shoot growth in which CTV multiplication is optimal as long as temperature and moisture are favorable. Citrus aphid migration, including that of *T. citricida*, peak in spring and fall (Carver 1978, Schwartz 1965). Hence, the uniform growth that results from pruning maximizes opportunities for CTV acquisition and inoculation.

If CTV incidence is undetectable or mild and *T. citricida* is not established in your region, citrus trees grafted on sour orange rootstock may still be acceptable (Garnsey *et al*. 1996). This decision depends on the risk of losses due to CTV versuses the advantages gained by the use of sour orange (e.g., salinity, cold hardiness, phytophthora, high soil pH, poor drainage). Several areas have managed CTV by eradication of infected trees (e.g., Israel, California). This program is cost effective if virus incidence is low and spread is slow (Garnsey *et al*. 1996).

Regardless of the present CTV/aphid vector situation, a citrus budwood certification program is essential for a good citrus industry. CTV and all other citrus virus and viruslike agents are readily graft transmissible. Diagnostic methods are available for testing and detection of citrus pathogens in budwood sources. Recent developments in serology and molecular biology allow some rapid evaluation of pathogen virulence. Thermotherapy and shoot tip grafting are now standard methods to eliminate pathogens from budwood. If a cross-protective CTV isolates are available, they can be incorporated into the budwood certification program.

2. Biological control

Although natural enemies are important in regulating aphid populations, they alone may not be satisfactory for controlling plant virus diseases. Aphid populations on citrus are often too variable to provide sufficient natural enemies for effective vector control. One concept is to direct biological control activities to reduce migrant vector populations before they spread through susceptible crops (Mackuaer 1976). Given that alternate prey are available, natural enemies could reduce *T. citricida* populations to mitigate secondary spread of CTV (tree to tree within a field), especially if conservation and augmentation efforts are used. In Japan, *L. japonica* is the most important parasitoid of *T. citricida* (Takanashi 1990). In South America, various natural enemies have been observed attacking *T. citricida* but none have been used for augmentation in a biological control program.

Lysiphlebus testaceipes (Cresson) was found attacking *T. citricida* in Puerto Rico (Yokomi and Tang 1996) but parasitism rate was low as was previously observed in Australia (Carver 1984). Murakami *et al*. (1984) did not find effective parasitoids of *T. citricida* in the Cerrados region of Brazil and suggested that *L. japonica* be imported and released against *T. citricida*. *T. citricida* was introduced in south Florida in the later half of 1995 and spread throughtout the state on citrus in a few years. Assuming that biological agents colonize new areas slower that their hosts, multiple augmentative releases of mass-reared parasitoids at various sites should be conducted (Wellings 1994). A classical biological control effort have been undertaken using this strategy in Florida with the release of *L. japonica* and *Aphelinus spiraecolae* (Tang *et al*. 1996). Both these and other parasitoids have not become established. However, *L. testaceipes* now effectively parasitizes *T. citricida* (Persad and Hoy 2003) This suggests that this parasitoid has adapted to the aphid. *L. testaceipes* is a robust species and should be a good prospect for introduction to new areas where the aphid becomes established.

Since most predators are generalist feeders, presence of alternate prey provides stability to their contribution as a biological control agent. The spirea aphid, *Aphis spiraecola* Patch is a cosmopolitan species with a wide host range and is quick to colonize new citrus shoots (Cole 1925, Miller 1929). This aphid also develops large populations rapidly on citrus which attracts predators. If *T. citricida* arrive when these predators are present, they readily attack *T. citricida*. However, if predators discover *T. citricida* population shortly after colonization, their probability of establishment is low without alternate prey as another food source (JP Michaud, personal communication).

3. Host plant resistance

No information is available on the experimental range of *T. citricida* on rutaceous or nonrutaceous plants.

4. Chemical control

Insecticidal control of *T. citricida* to slow spread of CTV is an unproven strategy. Although insecticides may not act quickly enough to prevent primary infection by viruliferous aphids, reduction of aphid populations would decrease secondary spread. Its effectiveness depends on longevity of suppression and extent of the treated area in relation to inoculum reservoir and migratory activity of the aphid (Knapp *et al*. 1996). It should be cautioned that use of foliar insecticides can interfere with biological control agents and, ultimately, their use to protect citrus, a perennial crop, is temporary. In the continental United States, most CTV spread occurs during spring and fall when temperatures are mild. This is concomitant with when CTV titer (virus replication) in infected citrus trees are highest and when shoot growth and migration of *T. citricida* peak. Therefore, this time frame should be targeted if chemical control is attempted.

CTV is transmitted only by vectors that colonize citrus because it is phloem-limited. Thus, its epidemiology resembles persistently transmitted viruses more in this regard than nonpersistently transmitted viruses. Since vector control has been shown to limit spread of some luteoviruses (Gourmet *et al*. 1994) it could be expected to have some impact on CTV spread. Please note, however, that no data exists to recommend chemical control for CTV control.

5. Integrated pest management

It is not clear what level of vector control is necessary to reduce spread of CTV. The typical integrated pest management (IPM) approaches do not apply for CTV control. Economic thresholds are contingent both on *T. citricida* population and CTV inoculum pressure. Host plant resistance to the aphid is not available. A unique management strategy must be practiced for CTV in the presence of *T. citricida*. A strong regulatory component covering both propagation and inoculum control (detection and removal of wild and possibly urban reservoirs of CTV) (Garnsey *et al* 1996, Halbert and Brown 1996). Management (conservation and/or augmentation) of biological control agents is feasible. Insecticidal control of vector populations may have use in specific situations such as in a citrus nursery or to protect budwood sources. Some value may result by use of selective insecticides working in tandem with natural enemies. In the final analysis, vector management should be one component of a disease management strategy which also other available elements including: mild strain cross-protection; tolerant rootstocks; above mentioned regulatory measures, isolation or protection of nursery stock; and citrus scions with tolerance or resistance to CTV (Garnsey *et al*. 1996).

References

Abate T., 1988. The identity and bionomics of insect vectors of tristeza and greening diseases of citrus in Ethiopia. *Trop. Pest Management* 34: 19-23.

Aguiar A.M.F., Fernandes A., Ilharco F.A., 1994. On the sudden appearance and spread of the black citrus aphid *Toxoptera citricidus* (Kirkaldy), (Homoptera: Aphidoidea) on the island of Madeira. Bocagiana Museu Municipal do Funchal (História Natural) 168: 1-7.

Aubert B., Etienne J., Cottin R., Leclant F., Cao Van P., Vuillaume C., Jaramillo C., Barbeau G., 1992. Citrus tristeza disease a new threat for the Caribbean Basin. Report of a survey to Colombia, Dominican Republic, Guadeloupe, Martinique, and Trinidad. *Fruits* 47: 393-404.

Bar-Joseph M., Lee R.F., 1989. Citrus tristeza virus. In: CMI/AAB Descriptions of Plant Viruses. No. 353. *Assoc. Appl. Biol.,* Wellesbourne, Warwick, U.K.

Blackman R.L., Eastop V.F., 1984. Aphids on the world's crops. An identification guide. Wiley and Sons, Chichester.

Carver M., 1978. The black citrus aphid, *Toxoptera citricidus* (Kirkaldy) and *T. aurantii* (Boyer de Fonscolombe) (Homoptera: Aphididae). *J. Aust. Ent. Soc.* 17: 263-270.

Carver M., 1984. The potential host ranges in Australia of some imported aphid parasites (Hym.: Ichneumonoidea: Aphidiidae). *Entomophaga* 29: 351-359.

Carver M., Hart P.J., Wellings P.W., 1993. Aphids (Hemiptera: Aphididae) and associated biota from the Kingdom of Tonga, with respect to biological control. *Pan-Pac. Entomol*. 69: 250-260.

Cole F. R., 1925. The natural enemies of the citrus aphid, *Aphis spiraecola* (Patch). *J. Econ. Entomol.* 18: 219-223.

Costa A.S., Grant T.J., 1951. Studies on transmission of the tristeza virus by the vector, *Aphis citricidus*. *Phytopathology* 41: 105-113.

Da Garça J.V., Maharaj S.B., 1991. Citrus vein enation virus, a probable luteovirus, In: RH Brlansky, RF Lee, LW Timmer (eds.). *Proc. 11th Conf. of Int. Org. Citrus virologists*, IOCV Riverside: 391-394.

D'Onghia A.M., 2005. *Citrus tristeza virus* and *Toxoptera citricida*: Development of management and control strategies in the Mediterranean region. Centre International de Hautes Études Agronomiques

Mediterranéennes. Report on the 10th Annual Meeting of the Mediterranean Network on Certification of Citrus (MNCC). Faro, Portugal. April 8-13, 2005. 10 p.

Essig E.O., 1949. Aphids in relation to quick decline tristeza of citrus. Pan-Pac. *Entomol.* 25: 13-23.

Etienne J., Vilardebo A., 1978. Notes sur les principaux ravageurs des agrumes de l'île de La Réunion. Fruits 33: 873-876.

Garnsey S.M., Gottwald T.R., Yokomi R.K., 1996. Control strategies for citrus tristeza virus, In: A. Hadidi, R. K. Khetarpal, and H. Koganezawa (eds.). Plant Viral Disease Control: Principles and Practices *APS Press.* St. Paul, MN: 639-658.

Geraud F., 1976. El Alfido negro de los citricos, *Toxoptera citricida* Kirkaldy en Venezuela (Resumen) 1. Encveatro Venezolano de Entomologia. Univ. Central de Venezuela, Facultad de Agronomia. Inst. Zool. Agric. Maracay.

Gourmet C., Hewings A.D., Kolb F.L., Smyth C.A., 1994. Effect of imidacloprid on nonflight movement of *Rhopalosiphum padi* and the subsequent spread of *Barley yellow dwarf virus. Plant Dis.* 78: 1098-1101

Halbert S.E., 1996a. Entomology Section: Citrus. Tri-ology 35(1). Div. Plant Ind.PI96T-05. January-February 1996.

Halbert S.E., 1996b. Entomology Section: Citrus. Tri-ology 34(6). Div. Plant Ind Mar-Apr. 1996.

Halbert S.E., Brown L.G., 1996. *Toxoptera citricida* (Kirkaldy), brown citrus aphid - identification, biology and management strategies. Fla. Dept. Agric. and Cons. Serv, Div. Plant Industry, Entomol. Cir. No. 374. 6 pp.

Halbert S.E., Zhang G.X., Pu Z.Q., 1986. Comparison of sampling methods for alate aphids and observations on epidemiology of soybean mosaic virus in Nanjing, *China. Ann. Appl. Biol.* 109: 473-483.

Hall W.J., Ford W.K., 1933. Notes on some citrus insects of southern Rhodesia. British South Africa Co., Mazce Citrus Expt. Station Publ. 2a.

Kato T., 1970. Efficiency of *Lysiphlebus japonicus* Ashmead (Hymenoptera, Aphidiidae) in control of the citrus aphid, *Toxoptera citricidus* Kirkaldy, infesting citrus young shoots in summer. *Odökon-Chûgoku* 12: 1-6.

Kirkaldy G.W., 1907. On some peregrine Aphidae in Oahu (Hemiptera). Proc. *Hawaiian Entomol. Soc*. 1: 99-102.

Knapp J.L., Browning H.W., Lee R.F., Stansly P.A., 1996. The brown citrus aphid. Citrus tristeza virus relationship and management guidelines for Florida citrus. *Citrus Indus.* 77: 12-14,16.

Knorr L.C., DuCharme E.P., 1951. This is tristeza- Ravager of Argentina's citrus industry. *Citrus Mag.* 13: 17-19.

Knorr L.C., Shah S.M., 1971. World citrus problems V. Nepal. *FAO Plant Prot. Bull.* 19: 73-79.

Komazaki S., 1982. Effects of constant temperatures on population growth of three aphid species, *Toxoptera citricidus* (Kirkaldy), *Aphis citricola* van der Goot and *Aphis gossypii* Glover (Homoptera: Aphididae) on citrus. *Appl. Entomol. And Zool.* 17: 75-81.

Komazaki S., 1993. Biology and virus transmission of citrus aphids. Food and Fertilizer Technology Center *Tech. Bull.* No. 136. 9 pp.

Lastra R., Meneses R., Still P.E., Niblett C.L., 1991. The citrus tristeza situation in Central America, In: R. H. Brlansky, R. F. Lee, and L. W. Timmer (eds.). *Proc. 11th Conf. Int. Org. Citrus virologists,* IOCV Riverside: 146-149.

Lee R.F., Roistacher C.N., Niblett C.L., Lastra R., Rocha-Peña M., Garnsey S.M., Yokomi R.K., Gumpf D.J., Dodds J.A., 1992. Presence of *Toxoptera citricidus* in Central America: a threat to citrus in Florida and the United States. *Citrus Ind.* 73: 13-24, 62, 63.

Marais L.J., Marais M.L., Ra M., 1996. Effect of citrus tristeza stem pitting on fruit size and yield of Marsh grapefruit in southern Africa, In: P. Moreno, JV da Graça, RK Yokomi (eds.). *Proc. 13th Conf. Int. Org. Citrus virologists,* IOCV Riverside: 163-167.

Mackauer M., 1976. *Myzus persicae* Sulz., an aphid of world importance, In: VL Delucchi (ed.). Studies in Biological Control. International Biological Programme 9. Cambridge Univ. Press: 51-119.

Meneghini M., 1948. Experiencias de transmissao doc doenea "tristeza" dos citrus pelo pulgo da laranjera. Biologico 14: 115-118.

Michaud J.P., Alvarez R., 2000. First collection of brown citrus aphid from Quintana Roo, *Mexico. Fla. Entomol.* 83: 357-358.

Miller R.L., 1929. A contribution to the biology and control of the green citrus aphid, *Aphis spiraecola Patch. Fla. Agric. Exp. Stn. Bull.* 203: 431-476.

Murakami Y., Abe N., Cosenza G.W., 1984. Parasitoids of scale insects and aphids on citrus in the Cerados Region of Brazil (Hymenoptera: Chalcidoidea). *Appl. Entomol. Zool.* 19: 237-244.

Nickel O., Klingauf F., Fischer H.U., 1984. Transmission of citrus tristeza virus (CTV) from "Declinamiento"-diseased sweet orange trees on trifoliate orange rootstocks and its epidemiology in relation to the flight activity of the vector, *Toxoptera citricida* Kirk. (Homoptera: Aphididae) in Misiones, Argentina, In: *Proc. 9th Conf. Int. Org. Citrus virologists*, IOCV Riverside: 28-32.

Persad A.B., Hoy M.A., 2003. Intra- and inter-specific interactions between *Lysiphlebus testaceipes* and *Lipolexis scutellaris* on *Toxoptera citricidus*. *J. Econ. Entomol.* 96: 564-569.

Prunthi H.S., Mani M.S., 1945. Our knowledge of the insect and mite pests of citrus in India and their control. Imp. Coun. Agric. Res. Sci., Mong. No. 16. 42 pp.

Raccah B., Loebenstein G., Bar-Joseph M., 1976. Transmission of citrus tristeza virus by the melon aphid. *Phytopathology* 66: 1102-1104.

Rondón G.A., Arnal E., Godoy F., 1980. Comportamiento del *Verticillium lecanii* (Zimm.) Viegas, Patogeno del afido *Toxoptera citricidus* (Kirk.). *Agronomia Tropical* 30: 201-212.

Samways M.J., 1984. Assessment of the fungus *Cladosporium* sp. near *oxysporum* (Berk. and Curt.) as a biocontrol agent for certain Homoptera. Entomol. Section. Outspan Citrus Centre, South African Coop. Citrus Exchange, Annual Report, July 1982-July 1984. Nelspruit.

Schwartz R.E., 1965. Aphid-borne virus diseases of citrus and their vectors in South Africa. B. Flight activity of citrus aphids. *S. Afr. Agric. Sci*. 8: 931-940.

Seco M.V., Remaudiere G., Nieto J.M., 1992. Graphic representations of the flight curves of alate aphids (Hom.: Aphidoidea) caught in traps: a new proposal. Ann. Soc. Entomol. France 28: 241-249.

Smith C.F., Cermeli M.M., 1979. An annotated list of Aphididae (Homoptera) of the Caribbean Islands and South Central America. North Carolina Agric. Res. Serv. Tech. Bull. no. 259.

Stoetzel M.B., 1994a. Aphids (Homoptera: Aphididae) of potential importance on citrus in the United States with illustrated keys to species. *Proc. Entomol. Soc. Wash.* 96: 74-90.

Stoetzel M.B., 1994b. The correct spelling of the scientific name for the brown citrus aphid. Proc. Entomol. Soc. Wash. 96: 179

Stroyan H.L.G., 1961. Identification of aphids living on citrus. FAO Plant Prot. Bull. 9: 44-65.

Takanashi M., 1989. The reproductive ability of apterous and alate viviparous morphs of the citrus brown aphid, *Toxoptera citricida* (Kirkaldy) (Homoptera: Aphididae). *Jpn. J. Appl. Entomol. Zool.* 33: 266-269.

Takanashi M., 1990. Development and reproductive ability of *Lysiphlebus japonicus* Ashmead (Hymenoptera: Aphidiidae) parasitizing the citrus brown aphid, *Toxoptera citricidus* (Kirkaldy) (Homoptera: Aphididae). *Jpn. J. Appl. Entomol. Zool.* 34: 237-243.

Tang Y.Q., Yokomi R.K., Brown L.G., 1996. Parasitoids of brown citrus aphid -recent observations, In: P. Moreno, JV da Graça, RK Yokomi (eds.). *Proc. 13th Conf. Int. Organ. Citrus Virol.*, IOCV Riverside: 130-137.

Tao C.C., Chiu S.C., 1971. Biological control of citrus, vegetables and tobacco aphids. *The Taiwan Agricultural Research Institute,* Special Publication No. 10: 1-110.

Thouvenel, J. C., Fauquet C., 1977. A mosaic of yam (*Dioscorea cayenensis*) caused by a filamentous virus in the Ivory Coast. *Comptes Rendus Hebdomadaires des Seances de l'Academie de Sciences* 284: 1947-1949.

Van Harten A., Ilharco F. A., 1975. A further contribution to the aphid fauna of Angola, including the description of a new genus and species. *Agronomia Lusit.* 37: 13-35.

Wellings P. W., 1994. How variable are rates of colonisation?, *Eur. J. Entomol.* 91: 121-125.

Yokomi R.K., Tang Y.Q., 1996. A survey of parasitoids of brown citrus aphid (Homoptera: Aphididae) in Puerto Rico. *Biological Control* 6: 222-225.

Yokomi R.K., Lastra R., Stoetzel M.B., Damsteegt V.D., Lee R.F., Garnsey S.M., Gottwald T.R., Rocha-Peña M.A., Niblett C.L., 1994. Establishment of the brown citrus aphid (Homoptera: Aphididae) in Central America and the Caribbean Basin and transmission of citrus tristeza virus. *J. Econ. Entomol.* 87: 1078-1085.