Zoosymposia 6: 180–192 (2011)
www.mapress.com/zoosymposia/

ISSN 1178-9905 (print edition)
ZOOSYMPOSIA
ISSN 1178-9913 (online edition)

An overview of *Brevipalpus* mites (Acari: Tenuipalpidae) and the plant viruses they transmit*

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* *In:* Moraes, G.J. de & Proctor, H. (eds) Acarology XIII: Proceedings of the International Congress. Zoosymposia, 6, 1–304.

Abstract

The significance of the family Tenuipalpidae has risen from near obscurity to that of considerable economic importance over the last five decades. One or more species within the genera *Brevipalpus*, *Cenopalpus*, *Dolichotetranychus*, *Raoiella*, and *Tenuipalpus* are recognized as serious economic plant pests. However, only three species within the genus *Brevipalpus* are known to vector one or more cytoplasmic or nuclear type plant viruses, including citrus leprosis, coffee ringspot, green spot on passion fruit, and orchid fleck viruses. Related viruses have been identified in numerous ornamental plants that are vectored by *B. phoenicis* and *B. obovatus*. Affected plant species, their current distributions and known mite vectors are summarized in this paper. The life cycle and developmental times for the three *Brevipalpus* species are reviewed. Cryptic species within *B. phoenicis* have been identified on *Hibiscus* in Florida and *Citrus sinensis* in Honduras within recent years. This dictates the need for more intensive research to identify the extent of this species complex throughout the western hemisphere. More stringent guidelines are needed for the inspection and movement of live plant materials that are host plants for *Brevipalpus* mites from one country to another.

Key words: Citrus leprosis, green spot of passion fruit, coffee ringspot, orchid fleck virus, false spider mites, flat mites.

Introduction

The Tenuipalpidae are commonly referred to as false spider mites or flat mites. The significance of this acarine family has risen from near obscurity to that of considerable economic importance over the last five decades. One or more species within the genera *Brevipalpus*, *Cenopalpus*, *Dolichotetranychus*, *Raoiella* and *Tenuipalpus* are recognized as plant pests. However, five species within the genus *Brevipalpus* [*B. californicus* (Banks), *B. chilensis* Baker, *B. lewisi* McGregor, *B. obovatus* Donnadieu and *B. phoenicis* (Geijskes)] and *Raioella indica* Hirst are currently recognized as the most important economic pests within the family.

Raoiella indica was present in Mauritius, Reunion, Sudan, Egypt, the Middle East, India, Sri Lanka, Thailand and the Philippines prior to its introduction to the Caribbean, Venezuela, Florida and more recently Brazil (Jeppson *et al*., 1975; Flechtmann & Etienne, 2004; Vásquez *et al*., 2008; Espinosa & Hodges, 2009, Navia *et al*., 2011). The mite was first identified in Palm Beach, Florida in 2007. It is a serious pest on coconut and various ornamental palms as well as banana. Its impact has been devastating to the economies of many countries within the Caribbean region (Rodrigues *et al*., 2010).

Brevipalpus chilensis is currently restricted to Chile where it is a pest on several crops, including grapes and citrus (Jeppson *et al*., 1975). The mite poses a significant threat to agriculture in many countries as a high risk exotic pest introduction due to its wide host range and destructive potential. The ability of this mite to vector plant viruses is unknown.

Accepted by G. J. de Moraes: 30 Jul. 2011; Published: 20 Dec. 2011

Brevipalpus lewisi occurs from Texas to California in the United States, the Eastern and Western Palearctic Regions and Australia (Mesa *et al*., 2009). The mite is a pest of pistachio, citrus, pomegranates, walnuts, grapes and various ornamentals (Elmer & Jeppson, 1957; Jeppson *et al*., 1975; Buchanan *et al*., 1980; Rice & Weinberger, 1981). The remaining three species of *Brevipalpus* (*B. californicus*, *B. obovatus*, and *B. phoenicis*) are considered important crop pests in different tropical and subtropical areas of the world (Lewis, 1949; Schwartz, 1977; Ochoa *et al*., 1994). They have extensive host ranges consisting primarily of perennials (Childers *et al*., 2003b). Each of these species is a known vector of one or more cytoplasmic or nuclear type viruses that attack major horticultural crops, orchids and various ornamental plants.

Brevipalpus mite biology

Many *Brevipalpus* species including *B. californicus, B. obovatus,* and *B. phoenicis* are parthenogenetic with thelytokous reproduction due to the presence of feminizing bacterial symbionts of the genus *Cardinium* (Groot & Breeuwer, 2006). Males occur in low frequencies (Helle *et al*., 1980; Weeks *et al*., 2001; Groot & Breeuwer, 2006). Females are haploid (n= 2 chromosomes). Other species such as *B. chilensis, B. russulus* (Boisduval) and *R. indica* have both males and females, with females being diploid, having 2n= 4 chromosomes, and males being haploid, with n= 2 chromosomes (Pijnacker *et al*., 1980; E.W. Kitajima, Univ. São Paulo, Brazil, 2010 *pers. comm.*).

False spider mites have four active stages in their life cycle (i.e., larva, protonymph, deutonymph, and adult). Between each active stage is a quiescent developmental (chrysalis) stage that is sessile but physiologically active. The chrysalis stages and eggs appear to be glued to the plant surface. *Brevipalpus* mites do not produce webbing. However, the motile stages are often difficult to remove, even using alcohol washes. Developmental rates are strongly influenced by temperature and host plant. Several researchers conducted life cycle and developmental rate studies of *B. californicus, B. obovatus* and *B. phoenicis* (Manglitz & Cory, 1953; Morishita, 1954; Haramoto, 1969; Chandra & ChannaBasavanna, 1974; Lal, 1978; Buchanan *et al*., 1980; Goyal *et al*., 1985; Trinidade & Chiavegato, 1994). The longevity of individual *Brevipalpus* mites was shown to be two to three times greater than corresponding longevities of various tetranychid mites. Developmental times for *B. phoenicis* reared on tea leaves at 26°C were: 9.53 ± 1.71 days for eggs, 19.13 ± 1.73 days for completion of immature stages and 41.68 ± 5.92 days for the total life cycle (Kennedy *et al*., 1996). Their study reported a gross reproductive rate of 56.7 eggs/female, a generation time of 27.6 days, and a population doubling every 5.5 days. This and previous studies were conducted on excised leaves or fruits of different plants and held under artificial conditions either in screen houses or laboratories. The use of excised plant leaves or fruit was successful as food substrates for *Brevipalpus* mites in these studies. However, concerns exist about the true accuracy of individual *Brevipalpus* mite longevity and number of eggs produced per female. This may be especially relevant at high temperature-low humidity conditions that occur during the dry season in Brazil and in normally arid areas worldwide.

Brevipalpus californicus, B. lewisi, B. obovatus and *B. phoenicis* are approximately half the size of spider mites and about twice as large as many eriophyoid mites. The size of the mite affects its ability to survive and live on intact, naturally functioning plant surfaces. Attempting to rear small mite species on excised plant tissues creates many problems. Identification of the optimal developmental and oviposition rates of small plant feeding arthropods is exacerbated by several physiological factors previously not addressed. Citrus trees and other vascular plants move water from the roots up through the plant and out through the stomata which are regulated by guard cells (Hopkins & Huner, 2004). During dry periods and with optimal water to the plant, this process results in the formation of a boundary layer or micro-atmosphere that is formed above intact fruit and leaf surfaces (Allen & Syvertsen, 1979). They calculated an optimal unstirred boundary layer of 500 to 1,000μm on the surface of citrus fruit. An optimal atmosphere for survival of very small plant feeding mites such as vagrant eriophyids and possibly small tenuipalpids is thus provided.

During a trip to Mexico in the 1990s, several non-irrigated citrus orchards were inspected for arthropod activity by the first author. No arthropods were found and the trees were obviously stressed from both a lack of water and high temperature conditions. The air temperature was 46°C, very dry, and a clear sunny summer day. An irrigated citrus orchard was then inspected just south of the Tropic of Cancer. All stages of citrus rust mite, *Phyllocoptruta oleivora* (Ashmead), were readily found in very high numbers. According to Hobza & Jeppson (1974), complete mortality of the citrus rust mite occurred by the second generation at temperatures at or exceeding 30°C in their laboratory studies that focused on regulating humidity and temperature conditions. They reported that optimal development of the citrus rust mite was 26°C. Citrus rust mites aggregate in very large numbers on partially shaded fruit surfaces. Characteristic russetting of fruit occurs when these populations feed on the fruit epidermis for a period of time. Strong temperature gradients occur on these sun-exposed fruit with lethal temperature conditions occurring close to the areas of rust mite concentrations during the summer and fall months. When plants are adequately watered, then optimal movement of water vapor occurs up through the plant and out through the stomata. When the plant is water stressed, then the stomata close.

Large populations of *Brevipalpus* mites occur on citrus in California and Texas during the hot, dry summers on well-irrigated trees. *Brevipalpus phoenicis* is most abundant during the dry season in Brazil and during dry periods in Florida. Such conditions likely provide optimal formation of the boundary layer on fruit and leaf surfaces of various host plants and benefit the *Brevipalpus* populations.

Brevipalpus mites are generally found in more shaded areas on their hosts in more humid environments, thus avoiding higher temperature conditions on sun-exposed plant surfaces and favoring higher micro-humidity conditions such as the interior canopies of citrus or coffee plants. These are important points to consider when assessing developmental rates, longevity, or reproductive potentials of *Brevipalpus* species (or other Tenuipalpidae of comparable size). Also, it is likely that both adult longevity and number of eggs produced per female are actually much higher than previous estimates based on rearing studies that used excised leaf tissue substrates. The impact of various pesticides on increasing egg production of *Brevipalpus* populations is another factor. Increased numbers of *B. phoenicis* were reported by Oomen (1982) following application of copper formulations. Also, significantly greater densities of *P. oleivora* extending over longer periods of time were shown following copper fungicide applications in Florida citrus (Childers, 2002). Hormesis (a stimulatory effect on an arthropod species within a specific range of concentrations) also must be considered when calculating egg production per female in horticultural crops treated with pesticides (Morse, 1998; Childers, 2002).

Examples of feeding injury by *Brevipalpus* mites

Feeding injury by *Brevipalpus* mites on various plants including citrus was reviewed by Childers *et al*. (2003a). Tenuipalpid mites inject toxic saliva into fruit, leaf, stem and bud tissues of citrus and other host plants. Their mouthparts are long relative to their body size. Feeding damage by *Brevipalpus* mites to citrus fruit in Texas is most prevalent on inside fruits, especially for grapefruit. Damage to the fruit usually occurs in the lower tree canopy, below two meters. Fruit lesions initially appear as very slight yellowish circular areas in depressions on the fruit surfaces of grapefruit or oranges (Dean & Maxwell, 1967; French & Rakha, 1994). The lesions gradually develop a central brown necrotic area or spot and ultimately become darker with a corky texture. The brown spots are irregular in shape and vary from 3 to 12 mm in diameter. Close examination of the areas where lesions first appear often include infestations of *Brevipalpus* mite stages actively feeding and laying eggs (Childers *et al*., 2003a). *Brevipalpus californicus, B. obovatus* and *B. phoenicis* have all been identified on Texas citrus varieties.

Brevipalpus lewisi causes similar feeding injury on pistachios in California as reported for citrus fruits in Texas (Rice & Weinberger, 1981; Childers *et al*., 2003a). The mite feeds on the nut cluster petioles, stems, and nuts. Dark, irregular and roughened scab-like blotches form on the surface where the mites aggregate and feed along the edges of damaged tissue. *Brevipalpus lewisi* is most abundant in late July and early August on pistachio in California despite daily temperatures that often exceed 40°C with very low humidity. *Brevipalpus lewisi* is not adversely affected by high temperatures (Rice & Weinberger, 1981).

Brevipalpus phoenicis is considered to be a serious pest of tea in Indonesia and less of a problem in India and Sri Lanka (Oomen, 1982). The mite lives on mature or maintenance leaves of tea bushes. *B. phoenicis* feeds on the lower leaf surface from the petiole and leaf base, along the midrib and edges of the leaf. Severe infestations lead to nearly complete defoliation of the maintenance leaves followed by reduced yields.

An outbreak of *B. phoenicis* and *B. obovatus* was observed on 'Robinson' tangerine leaves of non-bearing young trees in Florida (Childers *et al*., 2003a). The mites fed on the lower leaf surface, primarily along the midvein. However, some leaves were heavily damaged on the outer margins and at the base adjacent to the petiole. This damage closely resembled leaf damage on tea by *B. phoenicis* (Oomen, 1982). Premature defoliation of the citrus leaves likely would have occurred if the grower had not applied an acaricide.

Viral diseases vectored by *Brevipalpus* mites

Species of Eriophyidae, Tetranychidae and Tenuipalpidae have been shown to vector one or more plant viruses (Robertson & Carroll, 1988; Skaf & Carroll, 1995; Oldfield & Proeseler, 1996; Smidansky, 1996; Rodrigues *et al*., 2000, 2003; Kitajima *et al*., 2010).

Citrus leprosis is caused by two viruses and both produce similar symptoms. One is a cytoplasmic type and the other a nuclear type. The cytoplasmic type is referred to as Citrus leprosis virus C (CiLV-C) and is vectored by *B. phoenicis* (Rodrigues *et al*., 2003). According to Locali-Fabris *et al*. (2006), this virus should be classified as the type member of a new virus genus, *Cilevirus*. The disease produces localized chlorotic lesions on the fruit, leaves and twigs that do not result in systemic infections. Differences in chlorotic patterns occur in different citrus varieties in Brazil. Death of a twig or branch results when they become girdled by individual lesions. Premature fruit drop, defoliation and death of the twigs can occur with devastating results (Fig. 1). If the mite vector is not controlled, CiLV-C can kill a tree within three years. This *Brevipalpus*-borne virus is one of the most serious emerging exotic diseases threatening sweet orange production within the United States, the Caribbean and potentially other citrus producing countries in Africa, Asia, Australasia and Europe. Citrus species, especially oranges (*Citrus sinensis*), can be infected by citrus leprosis viruses. Mandarins and hybrids such as 'Murcott' are considerably less susceptible.

The nuclear type of citrus leprosis will likely be assigned as a new species within the virus genus *Dichorhabdovirus* (Bastianel *et al*., 2010). This genus is within the Rhabdoviridae. It is suspected by Kitajima and others (unpublished) that the nuclear type of citrus leprosis (CiLV-N) was present in Florida prior to the 1960s. Also, the nuclear type of citrus leprosis has been found in isolated areas of Brazil and more recently identified from the outbreak in Panama. The nuclear type of virus is also non-systemic in the plant and produces similar types of damage as CiLV-C.

FIGURE 1. Damaged and dying citrus trees resulting from the combined effects of citrus leprosis on fruits, leaves and twigs.

Citrus leprosis does not occur in the United States, although it was reported in Florida prior to 1962 and incorrectly reported in Texas (Dean & Maxwell, 1967; French & Rakha, 1994; Childers *et al*., 2003c). Citrus leprosis is one of the most economically important viral diseases in Brazil and has spread throughout the citrus growing areas of that country from the 1930s (Bastianel *et al*., 2010).

Citrus leprosis was first reported in Florida from what is now known as the Odette Phillippi State Park in Safety Harbor, Florida by Fawcett (1907). Phillippi eventually became a principal supplier of citrus trees for the area that extended north to Tarpon Springs. The disease spread across the citrus growing areas of Florida on sweet orange varieties and nearly destroyed the industry between 1906 and 1925 (Knorr & Price, 1958; Knorr, 1968). Citrus leprosis disappeared from much of the citrus producing counties in Florida sometime between 1925 and 1962.

Citrus leprosis occurs in Argentina, Brazil, Paraguay, Bolivia and Colombia in South America (Table 1). The disease has spread into Panama prior to 2000 (Dominguez *et al*., 2001), Guatemala in 1995 (Palmieri *et al*., 2007), Costa Rica in 2001, Honduras in 2003, and by 2005 it was present throughout Central America, with the exception of Belize. In 2004, the State of Chiapas in Mexico was confirmed to have citrus leprosis followed by Tabasco in 2005 and Oaxaca in 2008

TABLE 1. The occurrence and spread of citrus leprosis through the Americas.

Year	Country
1880–1962[1]	Florida, United States
1920	Argentina
1933	Brazil
1974	Venezuela
1995	Guatemala (reported in 2007)
1995	Panama (reported in 2000)
2000	Colombia
2001	Costa Rica
2004	Chiapas, Mexico
2005	Present throughout Central America except Belize
2005	Tabasco, Mexico
2005	Bolivia, Paraguay
2008	Oaxaca, Mexico
2009	Campeche, Mexico

[1] Disease last reported in Florida.

(SAGARPA, 2009). The Mexican budget for dealing with citrus leprosis in four states included the addition of Veracruz that year. In 2009, five states including Campeche received a budget exceeding 2 million US dollars (SAGARPA, 2006).

The threat of further spread into the United States via illegal movement of infected plants or movement of infested live ornamental plant materials from Central America is real (Childers & Rodrigues, 2005). Increasing international trade and travel combined with illegal activities exacerbate the unwanted movement of exotic pests, including citrus leprosis.

Ten species of *Brevipalpus,* five species of *Tenuipalpus, Pentamerismus tauricus* Livshitz & Mitrofanov and *Ultratenuipalpus gonianensis* Sadana & Sidhu have been identified on citrus worldwide (Childers *et al*., 2001). Four known false spider mite species occur on citrus within the United States, including *B. californicus, B. lewisi, B. obovatus,* and *B. phoenicis* (Childers *et al*., 2003a). The known vector of citrus leprosis in Brazil is *B. phoenicis* (Rodrigues *et al*., 2003). Both *B. californicus* in Florida and *B. obovatus* in Argentina were reported as vectors of citrus leprosis (Frezzi, 1940; Vergani, 1945; Knorr, 1968). However, subsequent examination of the voucher specimens collected from these earlier reports contained both *B. californicus* and *B. phoenicis* species in the Florida samples and *B. obovatus* and *B. phoenicis* in the Argentina samples (Ronald Ochoa, USDA, SEL, 2002. *pers. comm*.). Therefore, the vector status remains unclear based on the earlier reports. *Brevipalpus californicus* and *B. phoenicis* are the reported vectors of citrus leprosis in Guatemala (Palmieri *et al*., 2007). However, no direct transmission tests have been published to prove that *B. californicus* is a vector. Furthermore, there are no available voucher specimens for either *B. phoenicis* or *B. californicus* from citrus samples collected in that country. Therefore, the only confirmed vector of citrus leprosis in the Western Hemisphere to date is *B. phoenicis*.

Brevipalpus phoenicis is the only known vector of passion fruit green spot virus in Brazil (Kitajima *et al*., 2003). It is a cytoplasmic viral disease. In severe outbreaks, entire orchards of a few hectares have been destroyed. Considerable leaf and fruit drop occurred in association with high populations of *B. phoenicis*. Mature yellow fruits showed characteristic green spotting along with patches of green spotting on the leaves. The most serious damage results from necrotic lesions that girdle the stems and kill the plants. The disease is known to occur only in Brazil at this time.

Brevipalpus phoenicis is the known vector of coffee ringspot virus in Brazil. This nuclear type of viral disease occurs in Brazil and Costa Rica (Chagas *et al*., 2003). Conspicuous, localized ringspot lesions occur on both leaves and berries. The disease is capable of causing significant leaf and fruit drop with accompanying reduced coffee berry yields. A similar disease occurs in the Philippines according to Chagas *et al*. (2003).

Brevipalpus californicus is the known vector of orchid fleck virus (OFV) (Kondo *et al*., 2003). OFV is a nuclear type of virus and occurs in Australia, Brazil, Denmark, Germany, Japan, Korea and the United States (Kondo *et al*., 2006). Its actual distribution is likely much greater. OFV particles accumulate in the nucleus of infected orchid plants and this virus has been classified in a new genus, *Dichorhabdovirus*, in the Rhabdoviridae (Kondo *et al*., 2006; Bastianel *et al*., 2010). OFV produces chlorotic or necrotic spots and rings on the leaf fronds of many genera of Orchidaceae (Kondo *et al*., 2006).

Both *B. obovatus* and *B. phoenicis* have been identified as vectors of *Cestrum* ringspot virus on *Cestrum nocturum* L. in Brazil (Kitajima *et al*., 2010). This is a nuclear type virus with chlorotic ring spots occurring on the leaves. In addition, *Solanum violaefolium* ringspot virus was shown to be transmitted by both *B. obovatus* and *B. phoenicis*. This cytoplasmic type of virus produced conspicuous ring spots on the leaves and was also found in Brazil (Kitajima *et al*., 2010).

Kitajima *et al*. (2010) reported 37 ornamental plant species, including orchids as one species, to be hosts of *Brevipalpus* transmitted viruses. This list includes plant species in 18 families of dicotyledons. In many instances, the viruses are not important if one focuses strictly on the economic value of the currently known ornamental host plants. However, the potential danger is that they, and other non-symptomatic host plants, may serve as reservoirs to sustain the citrus leprosis virus and substantially decrease our ability to control or eradicate this serious citrus disease from an area once the virus(es) become established.

The extent of cryptic species within *B. phoenicis, B. obovatus,* and *B. californicus* and their geographical distributions as well as determination of the extent of mite vector species within the genus *Brevipalpus* are needed. In addition, understanding the dispersal mechanisms of these vectors to more efficiently minimize their destructive impact on our agricultural and ornamental industries is essential.

Cryptic species within *Brevipalpus phoenicis*, *B. obovatus* and *B. californicus* and their roles in vectoring cytoplasmic or nuclear viruses

Based on research to date there is clear evidence that cryptic species exist within *B. californicus, B. obovatus,* and *B. phoenicis*. In one study, mitochondrial DNA from different populations of *B. phoenicis* was collected from citrus and other plants in Florida and Brazil and compared against DNA samples of *B. obovatus,* another tenuipalpid *Cenopalpus pulcher* (Conestrini & Fanzago), and the tetranychid *Eutetranychus banksi* (McGregor) (Rodrigues *et al*., 2004). The last two species were included as outgroups. All of the *B. phoenicis* populations were identified to this species based on morphological characters. However, one population found on *Hibiscus* did not match the DNA fingerprint for *B. phoenicis* even though the morphological characters identified it as *B. phoenicis*.

In a similar study conducted by Rodrigues *et al*. (2004), *Brevipalpus* populations were collected from citrus leprosis infected trees in Honduras (Fig. 2). Again, a different population (haplotype) was identified that was not *B. phoenicis*. More importantly, perhaps, was the fact that two different *Brevipalpus* populations came from citrus. Mite populations from different host plants show high degrees of polymorphism in DNA fragments amplified by PCR. More recently, Groot & Breeuwer (2006) found different haplotypes of *B. californicus* and *B. obovatus* that were morphologically identified as being one of those two species but differed based on DNA samples of the populations. Those same populations showed differential capabilities to colonize different host plants, indicating a closed relationship between the mite and plant that tended towards specialization as reported by Groot *et al*. (2005).

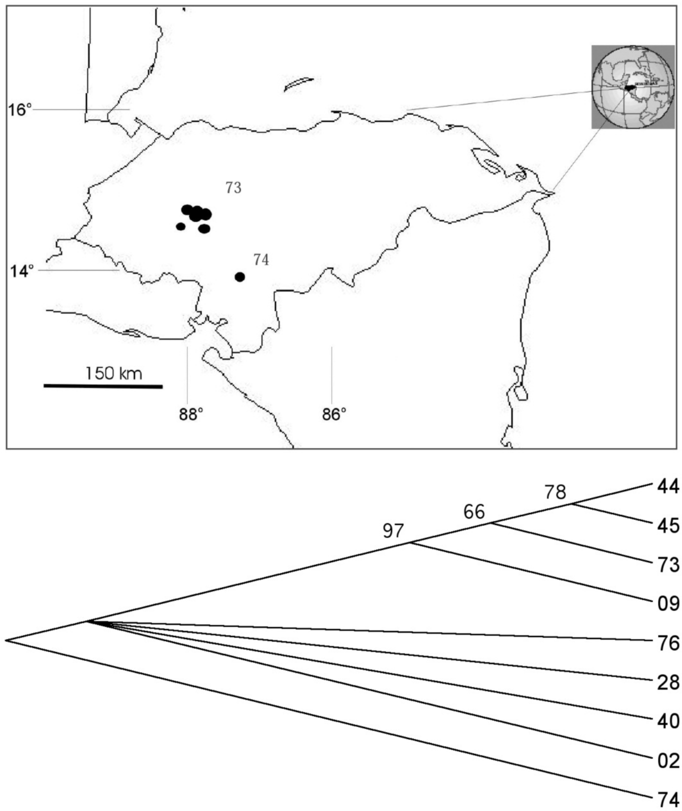

FIGURE 2. Phylogenetic relationships among *Brevipalpus* haplotypes (#73 and #74) found on citrus in Honduras and other *Brevipalpus* haplotypes reported in Rodrigues *et al*. (2004). The Honduran #73 haplotype clustered with *Brevipalpus* sp. (morphotype *B. phoenicis*) reported on *Hibiscus* in Florida and genetically placed between the groups *phoenicis* and *obovatus*. Haplotype #74 clustered with *B. phoenicis* populations. Numbers refer to bootstrap values (1,000 replicates) as shown on some nodes. The Neighbor Joining (NJ) method was used based on distances calculated using Kimura's two-parameter Gamma model. Mitochondrial fragment 374 bp.

Identification of the *Brevipalpus* species on citrus and other plant hosts in proximity, especially those plants that show signs of *Brevipalpus*-transmitted viruses are needed. Parallel classical taxonomic identifications need to be compared along with the continued refinement of molecular methods to identify the genetic fingerprints of the *Brevipalpus* populations sampled. Hopefully, by identifying these relationships, we will improve our ability to reduce inoculum of the virus(es) in citrus orchards, thus breaking the mite-pathosystem cycle and promoting more effective management of *Brevipalpus* mites.

Identifying when, why and how *Brevipalpus* mites disperse

Movement of mites including *Brevipalpus* species by ambulatory means alone from patchy host plant distributions is inefficient given the small size of these animals. Various methods of dispersal by many acarine families are known. Usually dispersal of a mite species is achieved either aerially or by phoretic movement on arthropods, birds or mammals. Aerial dispersal of mites is known for mite species within the Eriophyoidea, Phytoseiidae, Tetranychidae, Tydeidae, and Penthaleidae. Methods of aerial dispersal that utilize wind vary considerably among acarine species. For example, mummified females of *Halotydeus destructor* (Tucker) retain eggs within their bodies. Some individuals become windborne and thus are moved from one location to another (Ridsdill-Smith, 1997). Another example is "roping" by some spider mite species. Here, one or more mites climb down on individual silk threads and crawl away or are lifted off by wind currents. Individual *Tetranychus urticae* Koch concentrate on the upper portions of the plant and raise their front legs in a posturing stance on the plant surface in the presence of both wind and light (Kennedy & Smitley, 1985). Many species of eriophyoid mites also disperse aerially. *Aceria tosichella* Keifer (wheat curl mite) disperses via wind currents from winter wheat in the spring and early summer to volunteer wheat or seeded spring wheat, corn, or other grass hosts and returns from these hosts to winter wheat in the fall (G. L. Hein, Univ. Nebraska, 2010 *pers. comm.*).

Wheat curl mite is the vector of several viral diseases: wheat streak mosaic, wheat spot mosaic virus, High Plains virus, Brome streak mosaic virus and *Triticum* mosaic virus (Stephan *et al.*, 2008; Seifers *et al.*, 2009).

Aculops pelekassi (pink citrus rust mite = PCRM) is an economic pest on citrus in Florida, Japan, and the Mediterranean (Childers & Achor, 1999). PCRM aggregates in masses on the sun-exposed surfaces of young citrus fruits following depletion of their food sources and then become caught up in wind currents and disperse aerially.

Brevipalpus mites are quite small, dorso-ventrally flattened and slow moving. Their body shape is not too different from larger phytoseiid mites. Neither group of mites spins silk yet the much larger phytoseiids are capable of lifting off of plant surfaces and moving aerially (Croft & Jung, 2001). Croft & Jung (2001) stated "Aerial take-off of mites from a leaf occurs when the drag of wind overcomes the force of attachment". *Neoseiulus fallacis* (Garman) raises its body with legs 3 and 4 and faces away from the wind to disperse aerially. This behavior was correlated with starvation and occurred most frequently in gravid females (Johnson & Croft, 1979).

Given that citrus leprosis is known to be transmitted by *B. phoenicis* and possibly other species within that genus and that the disease is non-systemic, movement of the disease must then be achieved either through introduction of infected plant materials into each citrus tree from one area to another and/or by movement of the mite vector. Oomen (1982) noted that immature and adult *B. phoenicis* moved toward the leaf petiole in response to senescing tea leaves in an artificially maintained environment. The stems of the detached leaves were held in water where the mites subsequently drowned as they attempted to move off the plants. Haramoto (1969) clearly demonstrated aerial dispersal of this mite from heavily infested papaya in Hawaii. Mites were only recovered from sticky traps held downwind from the infested plant. Haramoto further reported that ambulatory movement of *B. phoenicis* from plant to plant was unlikely as all stages of this species could not go without food for more than three days. It is more likely that exposure to the elements, especially from desiccation, would kill the mites much sooner. Alves *et al.* (2005) set sticky traps at three heights in two citrus orchard locations in Brazil and held them for 15 days. Capture rates of *B. phoenicis* from the two commercial blocks were reported to be low. This may have reflected the very low *Brevipalpus* mite populations that were present within those pesticide sprayed sites. More importantly, essentially all of the dispersing mites would be female, validating the results of Haramoto (1969).

There are several possible situations that could trigger aerial dispersal of *Brevipalpus* mites. First, physiological changes in the mite population due to a declining food supply or overcrowding. Mite dispersal resulting from wind speed alone over a plant surface would not make sense when the mite has a suitable food supply (Croft & Jung, 2001). Second, changes in the fitness of the host plant due to senescence, disease, or plant death. Third, environmental changes resulting from localized or area-wide severe weather conditions may result in movement of viral-infected *Brevipalpus* motile stages from one tree, block, or area to another. Fourth, citrus orchard management practices may allow for the rapid spread of infected mites through harvesting practices. Movement of infected mites from harvested fruits that have been left in field-collecting bins for a period of time could occur. Conditions on or around those sun and heat exposed fruits would likely be unsuitable to sustain the *Brevipalpus* mites and thus trigger dispersal. Movement of open fruit bins from the field to the packinghouse by truck or tractor would afford additional stimulus for the mites to disperse aerially. This would be especially important when mite populations are at or near peak densities on harvested fruits. Spraying pesticides with high pressure handgun equipment could aerially disperse mites as well as pruning and movement of infested plant parts through an orchard. Harvesting crews working in and out of different trees could get the mites on their clothing and then physically move them from one tree to another. Field scouts moving in and out of mite infested citrus trees or other horticultural crops could also facilitate their dispersal. Kennedy & Smitley (1985) reported this problem where careless field scouts had infested cotton fields with spider mites following visits to heavily infested maize.

Kennedy *et al*. (1996) listed five important criteria for *B. phoenicis* that allow this mite to be such an important pest: (1) It has high fertility and survival rates; (2) It has a high reproductive rate early in the female's life cycle; (3) There is no diapause stage; (4) Reproduction is by thelytokous parthenogenesis; and (5) *B. phoenicis* has a wide host plant range with most hosts being perennials.

A sixth important criterion for *B. phoenicis, B. obovatus* and *B. californicus* is their ability to vector one or more cytoplasmic or nuclear types of viruses. A seventh important criterion for *B. californicus, B. lewisi, B. obovatus* and *B. phoenicis* is their tendency to aggregate, feed, and oviposit around damaged areas on fruit, leaves and branches. The damaged areas may have been from their earlier feeding or from other sources such as wind scarring, thorn punctures, or damaged tissues from other arthropods or diseases, including the cytoplasmic and nuclear viruses. This phenomenon is most evident on citrus fruit and increases the likelihood of more rapid spread of citrus leprosis.

Growers in Brazil and other countries affected by citrus leprosis are applying acaricides at frequent intervals and pruning symptomatic twigs or limbs from trees in an effort to control the disease. Greatly increased production costs have resulted. Also, acaricide resistance has emerged within populations of *B. phoenicis* in recent years (Omoto, 1999).

Citrus leprosis and the complex of potential and known *Brevipalpus* mite vectors pose serious threats to those countries or regions currently free of this disease. This review is intended to identify several areas of needed research on this complex of *Brevipalpus* mites.

Acknowledgements

Grateful appreciation is extended to Barbara Thompson and Katherine Snyder for the typing and formatting of this manuscript.

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