

Polyphagotarsonemus latus (Acari: Tarsonemidae) Research Status on Citrus

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Abstract. This paper discusses major current research trends on the broad mite, *Polyphagotarsonemus latus* (Banks) in citrus. *P. latus* infestations tend to be concentrated on young leaves of citrus and often causing damage to specific plant parts, e.g., stems, flowers, fruitlets or tips of shoots. This mite is found on shaded parts of the fruit as opposed to the styler, peduncle and sunlit regions of citrus fruits. Injury by *P. latus* often retards growth of damaged structures and is shown to reduce the total leaf area and leaf water content of damaged lime and sour orange. Despite the economic importance of *P. latus*, few authors have determined the relationship between *P. latus* density and injury to citrus. Estimates of economic injury can be obtained using equations that describe the relationship between lime fruit surface area damaged and broad mite days, and between percentage of fruits damaged per tree and broad mite days. Although chemical control is not advised, the rapid injury to fruits, leaves and flowers necessitates treatment at an early stage in population development to prevent excessive damage. Few studies have been conducted to investigate the suitability of broad mites as targets for biological control in citrus. The potential of phytoseiid mites as predators of the broad mite has been reported, but specific studies are lacking to determine the effectiveness of mite predators for controlling broad mite populations. Effectiveness of field applications of fungi against mites is reduced by poor germination of spores and poor penetration of the fungus into the mite at humidities below 100%.

Broad mite, *Polyphagotarsonemus latus* (Banks), is an important pest of tropical and temperate crops (Jeppson et al., 1975). Judging from several reports (e.g., Hugon, 1983; Hugon and Chapin, 1986; Mineo and Ragusa, 1976), this potential for damage has become more evident during the last three decades. Gerson (1992) provided a comprehensive list of 57 plant families that were hosts for *P. latus*. In the neotropics, the list includes important crops such as cotton, citrus, tomato, potato, chili-pepper, beans, papaya, and mango (Hill 1975).

The manner whereby *P. latus* attacks several plants has been described and illustrated by different authors (Aubert et al., 1981; Costilla, 1980; Dhoria and Bindra, 1977; Fletchman and Rosa, 1980; Laffi, 1982; Nucifora, 1963; Smith et al., 1997) suggesting that because of the polyphagy of *P. latus*, broad leaf plants located in citrus orchards should be considered as potential infestation sources. Attacks tend to be concentrated on the young leaves, but sometimes cause damage to specific plant parts, e.g., stems, flowers, fruitlets, or tips of shoots. Symptoms of broad mite attack are variable and may depend, on the characteristics of the plant species, including their anatomical structure, chemical composition and the weather conditions during or shortly after attack. Chatterji et al. (1978) reported that high temperature and low humidity favor *P. latus* development. Later, Brown and Jones (1983) and Jones and Brown (1983) published some of the most detailed descriptions of *P. latus* development and damage to citrus. They concluded that humid weather (75% to 90% RH) is needed for *P. latus* development and that hot, humid weather during exposure to broad mite feeding seems to intensify the symptoms of damage. Ramos and Alvarez (1987) reported that at 63% RH, 22°C, *P. latus* completed development on 'Persian' lime in only 4 d. In Australia, damage occurs during spring and early summer, but second crop fruit are often attacked later in the season. In New South Wales, damage is most frequent on valuable summer-crop fruit that set in summer and early autumn. In Italy, *P. latus* is considered as an occasional pest of lemon (Tsolakis et al., 1998). The principal symptoms of attacks on different plants consist of de-pigmentation, deformation, thickening, suberization and browning of the leaves, suberization of growing tips, and shortened internodes in the shoots and suberization of the fruits (Cross and Bassett, 1982; Laffi, 1982; Lo and Chao, 1972; Nemesthoty et al.,

1981, 1982). Symptoms, which have been linked to the mechanics of the pest's feeding and toxins, were often confused with disease symptoms, herbicide damage or micronutrient deficiencies (Ammin, 1979; Aubert et al., 1981; Higa and Namba, 1970).

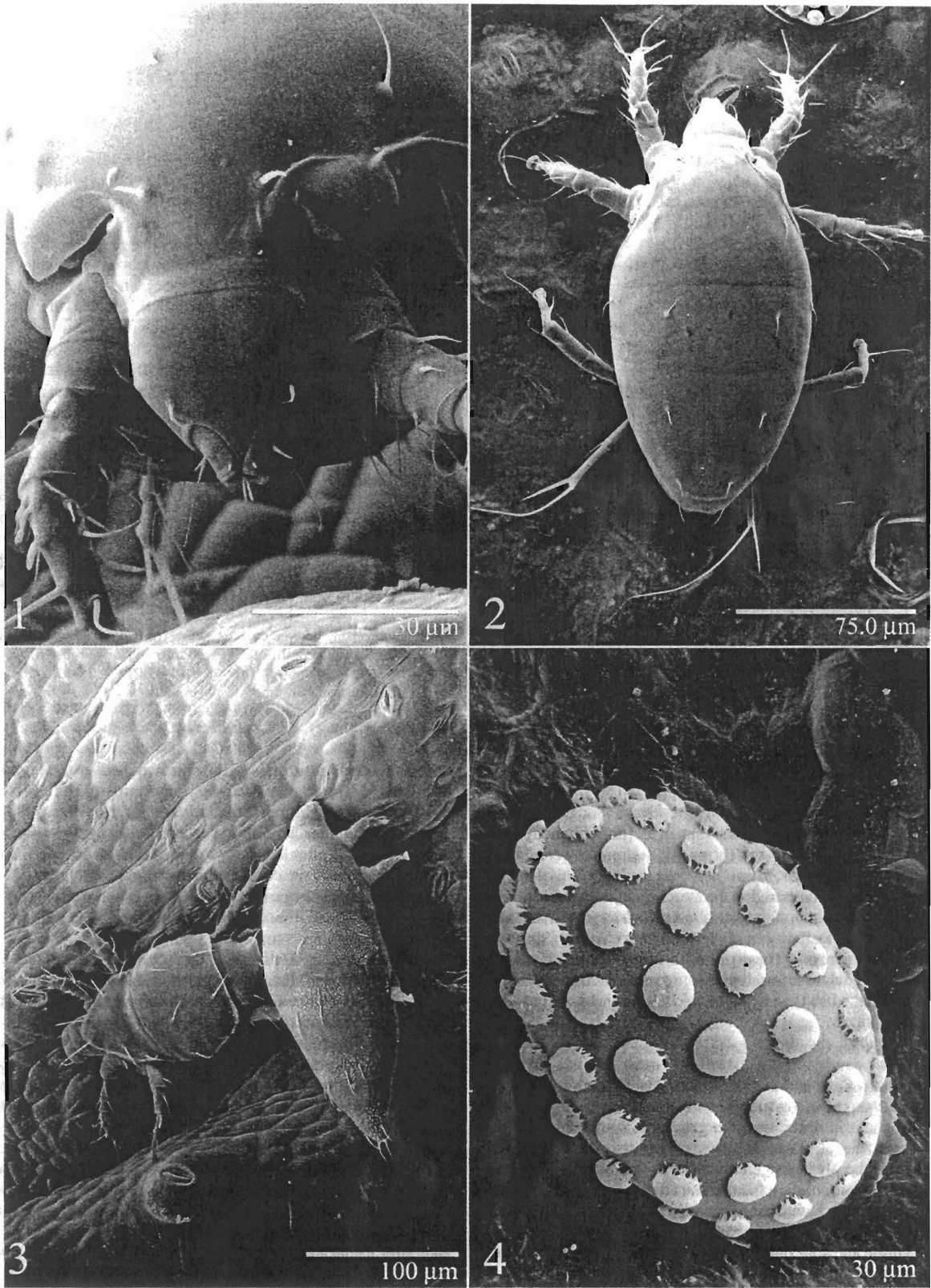
Injury as used in this paper, follows the description of Pedigo et al. (1986). These authors define injury as the effect of pest activities on host physiology, which results in measurable loss of host utility, most often including yield quantity, quality or aesthetics.

Taxonomy

The female, male, immatures, and egg are bright-white to translucent light-yellow. Females are from 200 to 256 µm in length and 135 µm in width (Fig 1). The females have the dorsal shield unornamented and not extending over the gnathosoma (Fig 2); dorsal setae are short and slightly barbed; bothridial setae are present; ventral region has a prosternal apodeme united to segujugal apodeme; aggenital and pseudanal setae are present; leg I with strong conspicuous tarsal claw (Lindquist 1986) (Fig. 1). Males are smaller than females, 150 to 190 µm in length and 95 to 105 µm in width. The leg IV is used to carry inactive larvae, and has a tarsal button-like claw (Lindquist 1986) (Fig. 3). The larval stage is highly mobile, with three pairs of legs and ornamented dorsum. Eggs are characterized by the presence of wax-like domes arranged in a symmetrical form on the surface (Fig 4). Ramos et al. (1988) reported that laboratory-reared mites showed a reduction in length and width when compared with those collected from limes. The females, males, and larvae are suspected to carry and spread spores of *Cladosporium* sp. (Ochoa et al., 1994).

Dispersal

Females are the most important dispersal stage by being phoretic on whiteflies and aphids (Natarajan, 1988; Smith, 1935). The females disperse from tender leaves where they transfer their colonies to other plants. By using leg I, they cling on legs of aphids or whiteflies. One insect leg may carry seven female broad mites. This behavior was reported in Australia, India, Costa Rica, Colombia, Venezuela and the



Figs. 1–4. *Polyphagotarsonemus latus* (Banks). Fig 1. Front view of female. Fig. 2. Dorsal view of female. Fig 3. Male carrying an inactive larva. Fig. 4. Egg with wax-like domes.

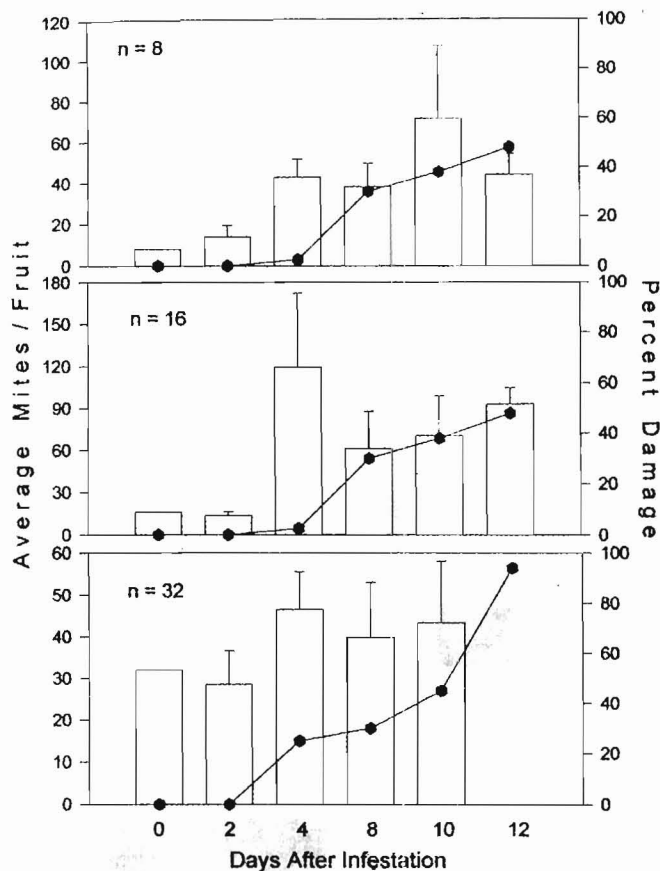


Fig. 5. Damage to lime fruits following broad mite infestations under laboratory conditions.

United States (Fletcher et al., 1990; Natarajan, 1988; Ochoa et al., 1994; Smith, 1935; Walter, 1999). Palevsky et al. [unpublished] determined that *P. latus* attaches to the thrips, *Frankliniella occidentalis* (Pergande) and to allate aphids, *Myzus persicae* (Sulzer). This dispersal behavior was negligible compared to the attachment to *Bemisia tabaci*. *P. latus* also attached to the whiteflies *Dialeurodes citri* (Ashmead), *Aleyrodes singularis* Danzing and *Trialeurodes lauri* (Signoret) (Palevsky et al., In Press). These mites are also disseminated by humans, particularly when infested plants are moved from one area to another (Ochoa et al., 1994).

Influence on Growth, Flowering, and Cropping

Injury to plant tissues and disturbance of plant physiological processes, result in changes in growth intensity, flowering and yield. The most common change is inhibition of the growth of the organs of injured plants; moreover, the effect of *P. latus* injury also depends on the growth process of the plant, its genetic constitution, stage of development and various environmental factors that affect growth. Injury of the apical bud is associated with initial proliferation of axillary buds, followed by a reduction in leaf water content on lime, *Citrus aurantiifolia* (Christm.) Swingle and sour orange, *Citrus aurantium* L. (Ochoa et al., 1994; Peña and Bullock, 1994). Plant height suppression is not always a characteristic for plants damaged with broad mites. No influence on plant height was observed in bean, lime or sour orange, but it was demonstrated for potato (*Solanum tuberosum* L.) and peppers (*Capsicum annum* L.) (De Coss-Romero et al., 1993; Peña and Bullock, 1994). The influence of broad mite injury on cropping in fruit trees and vegetables may occur in the early stage of fruit development; Mineo and Ragusa (1976) and Brown and Jones (1983) described silvering of lemon fruit. Injury to lime fruit is characterized by early discoloration and opaqueness that later results in silvering of the surface (Peña 1990). The interaction between plant response and injury caused by broad

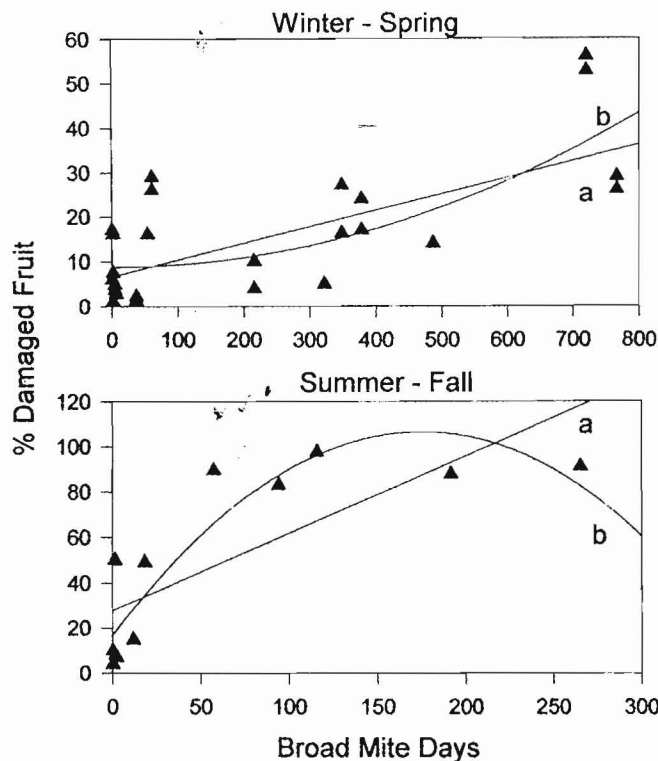


Fig. 6. Relationship between percentage of fruit damaged per tree and broad mite days under field conditions. Top: Winter-spring harvest. a) $y = 7.45 + 0.03x$ ($r^2 = 0.43$; $P \leq 0.0001$). b) $y = 9.44 - 0.001x + 0.00005x^2$ ($r^2 = 0.48$; $P \leq 0.0002$). Bottom: Summer-fall harvest (a) $y = 27.80 + 9.39x$ ($r^2 = 0.59$; $P \leq 0.003$). b) $y = 17.01 + 1.03x - 0.03x^2$ ($r^2 = 0.82$; $P \leq 0.0004$).

mites is related to the time of injury with respect to plant growth, the part of the plant injured, the intensity of the injury and the environmental effects on the plant's ability to withstand injury. Peña (1990) conducted experiments under laboratory, greenhouse and field conditions to demonstrate broad mite injury to lime fruits. Under laboratory conditions, limes placed on a water saturated foam pad with *P. latus* confined to the styler area, began to show damage 4–6 d after infestation and severe damage to the fruit epidermis occurred within 12 d after infestation (Fig. 5). Broad mite damage to citrus fruits is considered similar in appearance to damage by the citrus rust mite, *Phyllocoptruta oleivora* (Ashmead) (Smith et al., 1997). However, broad mite damage to all citrus varieties appears as a thin, silver-grey skin that can be readily scratched off (Smith et al. 1997). When the number of mites was regressed on the percentage of damage to the fruit, the first order model [$y = a + bx$ (where y is the percentage of fruit surface damaged and x is the number of broad mite days/cm²)] was used to describe the relationship between damage to the fruit and broad mite numbers. Peña (1990) questioned the validity of these results because the damage caused by broad mites may be intensified by the condition of detached fruits. When fruits are detached from the plant, the injured fruit surface discolors faster and then becomes darkened. Characteristic silvering was not observed under these conditions. In the greenhouse study, when fruit injury was studied biweekly, a silvering was observed 10–14 d after initial *P. latus* infestation. This suggested that susceptibility of fruit to broad mite feeding is greatest 10–14 d after infestation. Field experiments indicated that a significant relationship existed between absolute counts of broad mite per fruit and the relative sampling method (mites per cm²) with percent fruit surface damaged and broad mite days [$y = 16.50 + 0.14x$; $r^2 = 0.49$] where $y = \%$ fruit surface damaged and $x =$ broad mite days. Peña (1990) demonstrated that broad mite significantly affected the weight of fresh limes, but moderately injured fruits (10% to 30%) did not show measurable weight loss. Data indicated that as fruit surface damage by broad mites increased, weight and volume of juice per fruit decreased. These studies demonstrated that *P. latus* injury to harvestable produce is not straightforward. Variations in

density and damage in the field could be associated with natural enemies, intraspecific competition with other mite species, or environmental conditions. Plant compensatory mechanisms need to be identified to properly quantify relationships of losses to this type of injury.

Economic Injury Levels

Economic injury levels are probably the most often discussed issue in economic entomology and arthropod-pest management today (Pedigo et al., 1986). Economic injury level has been defined as the lowest population density that will cause economic damage (Stern et al., 1959). The major advantage of this concept is its simplicity and practicality. Despite the economic importance of *P. latus*, few authors have determined the relationship between *P. latus* density and injury to affected crops. The difficulties in obtaining economic injury level estimates for *P. latus*, are illustrated in the following example. In a study from 1985 to 1986 Peña (1990) observed *P. latus* populations in a lime orchard that were artificially adjusted by applying sulfur and permethrin to different tree plots. Significant differences were observed after application of sulfur sprays, which increased the number of undamaged fruits 20% to 86% compared to that of treatments in which permethrin was applied or the control. For the purpose of calculation, the injury per mite is assumed to have a linear relationship with mite density. However, in some instances the responses displayed by lime fruit are likely to differ. The relationship between percentage fruit damaged per tree and *P. latus* days was obtained for the winter-spring harvest and for the summer-fall harvest. A significant curvilinear relationship ($r^2 = 0.82$; $P = 0.0004$) of the form $y = 17.01 + 1.02x - 0.003x^2$ was found when *P. latus* days were plotted versus percentage damaged fruit per tree, during the summer-fall harvest (Fig. 6). Curvilinear and linear regressions provided similar fits between the two variables from the winter-spring harvest. These different responses between seasons can result from *P. latus* and lime plant interaction during high temperature-high humidity vs. low temperature-low humidity regimes. The complexity of intensity of injury and plant yield have been analyzed by Pedigo et al. (1986) who recognized that a damage curve describes best the theoretical relationship between yield and injury. Not all plants manifest an injury response that includes every portion of the damage curve, but all potential responses can be described for some part of the damage curve.

To fit the EIL model described by Stone and Pedigo (1972), Hopkins et al. (1982) and Hall and Teetes (1982), Peña (1990) used linear regression to describe the fruit-response/injury interaction. A linear regression was used by Stone and Pedigo (1972), Hopkins et al. (1982), Hall and Teetes (1982) when they suggested the EIL model, $EIL = c/p/b$ where c is the total cost of controlling the pest per ha, p is the price or market value of the crop per ha, and b is the regression coefficient from the regression equation used. Gain Threshold was the result of dividing the total cost of management procedures by the market value of the crop per ha (Stone and Pedigo 1972). For example, if the cost of controlling broad mite in limes during the spring is \$34 per ha, and the market value of limes is \$2,678 per ha, the percentage gain threshold would be equal to $0.0126 \times 100 = 1.26$. The EIL for an infestation of broad mite can be calculated from the regression coefficient ($b = 0.14$) from the linear equation ($y = 16.50 + 0.14$ broad mite days). Therefore, the EIL equals $1.26/0.14 = 9.0$ broad mite days.

Results also vary depending on the time of year this crop is produced (Table 1). Economic injury level can also be estimated by determining the average population which may cause yield losses per tree (Peña 1990). Fig 6 shows the relationship of broad mite days per cm^2 and percentage of fruit damaged at harvest. Results of the effect of broad mites differ between two harvests. If 1.26 and 1.98 are the gain thresholds for the spring and summer, respectively, fewer broad mite days will be necessary during the summer to reduce yield than during the spring. The EIL can also be calculated from the regression coefficients b from the linear regression equations: $y = 7.45 + 0.03x$ (spring harvest) and $y = 29.03 + 0.35x$ (summer harvest) where y = percentage fruit damaged per tree, b_0 = intercept, b = regression coefficient and x = broad mite days per cm^2 . Therefore EIL per tree will fluctuate between 42 and 4.5 broad mite days for the spring and summer harvest, respectively.

Table 1. Estimates of economic injury levels (EIL) of broad mites to limes.

Season ^r	Price		EIL1 ^s	EIL2 ^w
	market/ha, \$	Gain ^r threshold		
Winter	1607	2.11	15.0	—
Spring	2678	1.26	9.0	42.0
Summer	1714	1.98	14.0	5.7
Fall	2142	1.58	11.0	—

^rWinter, January-March; Spring, April-June; Summer, July-September; Fall, October-December.

^sGain threshold = Cost of spray/ha \times 100, Cost of spray = \$34/ha, Price market/ha.

^wEIL1, based on the percent surface fruit damaged.

^wEIL2, based on the percent of fruit damaged per tree.

In Australia, action levels are carried when more than 5% of citrus fruit infested with live broad mites are found in coastal areas (Smith et al., 1997). However, Smith et al. (1997) suggested that if sufficient numbers of predatory phytoseiid mites are present (i.e., 40% or more leaves with predators visible), broad mite infestations will not develop. Considerable differences in economic injury levels exist for different geographical areas. Based on references from the neotropics, experiments are needed where the specific conditions under which trials are performed should be well defined.

The basic interactions between broad mites and their host plants are affected by several biotic and abiotic factors. Their interactions may influence the population dynamics and the relationship between yield loss and number of mite units either in mite density or mite days. Effects of humidity, temperature and predators on *P. latus* population dynamics have been described (Brown and Jones, 1983; Costilla, 1980; Peña et al., 1989); however, more detailed studies of these phenomena under field conditions are extremely scarce and would require a major multidisciplinary effort. The absence of quantitative information on the exact effect of crop conditions on damage relations of broad mites is probably due to the lack of physiological data about those citrus species which suffer most from broad mite damage.

Chemical Control

P. latus rapid injury of citrus fruits, leaves and flowers necessitates treatment at an early stage in population development to prevent excessive injury. Several acaricides, including chlorinated hydrocarbons (DDT), cyclocompounds (propargite), diphenyl compounds, (dicofol), organic phosphates, (carbophenothion) and avermectins, have been tested against broad mites on lime and orange (Buerger et al., 1986; Bullock, 1978; Peña, 1989). A recent report by Oliveira and Oliveira (2000), evaluated the efficacy of spirodiclofen and Azocyclotin against *P. latus* in citrus in Brazil. Results demonstrated that both products were highly efficient for control of *P. latus* on citrus. These acaricides provided 100% reduction of the mite population for 20 d posttreatment. The average annual number of sprays required to limit broad mite infestations on lime ranged from two to 10, depending on the damage levels, the crop in question, and the geographical area. At present, when the resistance of arthropods to chemical compounds has been proven, few records report resistance of broad mites to pesticides (Ingram 1967, Sombatsiri 1978) or resurgence of broad mites due to excessive use of insecticides (Rodrigues 1967).

Plant Resistance

Breeding plants resistant to broad mites is in its infancy. Lemons are less prone to broad mite damage after fruit are half grown (Smith et al., 1997), while mandarins are susceptible until they begin to color and limes are susceptible until they are two-thirds mature (Smith et al., 1997). Because of the short life cycle of broad mites, the age of the plant may confer some pseudoresistance. Because *P. latus* mouth parts are unsuitable for effective penetration of lignified tissues, cultivars that pass through the most susceptible stage quickly can be used to reduce

P. latus injury. Ochoa et al. (1994) reported that buds of *C. aurantium* are very susceptible to attack by *P. latus*. In Carrizo citrange, young leaves show marked cracking whereas in Swingle citrumelo only defoliation was observed. In Costa Rica, attacks by this mite were occasionally observed on *C. limon* cv. Messina, resulting in fine cracking of the epidermis. Ramos (1986a, 1986b) reported that *P. latus* development is the same on lime, oranges, or grapefruits. In Australia, Smith et al. (1997) indicate that lemons and limes were consistently attacked. Young grapefruit, oranges and mandarins were also susceptible, particularly 'Hickson' mandarins.

Biological Control

Few studies investigated the suitability of broad mites as targets for biological control. The potential of phytoseiid mites as predators of the broad mite has been reported for different areas and crops (Badii and McMurtry, 1984; Moutia, 1958). For a review of predacious mites on broad mites, see Gerson (1992). In Florida, six species of predacious mites (4 Phytoseiidae, 1 Bdellidae and 1 Ascidae) were observed on lime fruits (Peña et al. 1989). *Typhlodromalus peregrinus* (Muma) (Peña 1992) accounted for 72.4% of the predacious mites and outnumbered *Typhlodromips dentilis* (DeLeon), *Amblyseius aerealis* (Muma), *Galendromus helveolus* (Chant), *Bdella distincta* Baker and Balock and *Asca muma* Hurlbutt. In Australia, the predator *Euseius victorensis* (Womersley, 1954) was considered an effective predator in subcoastal areas, but less effective in coastal orchards. *Euseius elinae* (Schicha, 1977) fed on broad mite, particularly in glasshouses in south east Queensland. In coastal New South Wales, *E. elinae* and *Amblyseius herbicolus* (Chant) were common predators of broad mite, rust mites and citrus red mite on citrus (Smith et al., 1997). In Australia, a coccinellid beetle, *Scymnus* sp., was observed feeding on broad mites by Smith et al. (1997). The effectiveness of mite predators for controlling broad mite populations was demonstrated by Peña et al. (1989). In an exclusion experiment, population densities of *P. latus* increased in plots treated with pyrethroids immediately after the first insecticide application. During the dry season, the percentage of damaged fruits per tree was 3.20 and 3.65 times higher in predator-free plots than in plots with predators. During the humid season, however, no significant differences occurred between the percentage of fruits injured per tree in the predator-free plots and plots with predators. Several factors could be responsible for this. Most of these mites are facultative predators, therefore, the presence of other preferred prey species or food substrates might influence the predator mite response. Also, because the broad mite has a short generation time (Jones and Brown 1983), and fruit injury is observed in 4 to 6 d (Peña 1990), the ratio of predator to broad mite populations may need to be higher than that observed.

Short-term studies on limes in Florida have indicated predator control of broad mites under greenhouse and field conditions. As a result of the significance of two different predators of *P. latus*, Peña and Osborne (1996a) concluded that the more voracious *Neoseiulus californicus* (McGregor) was able to hold *P. latus* in check better than *N. barkeri* (Hughes) under greenhouse conditions. The author also presented indications that *N. californicus* might provide effective control of *P. latus* in the field, but would be more susceptible to pesticides used in the lime agroecosystem.

Microbial Control

Pathogens have potential as control agents of phytophagous mites, or contribute to the natural regulation of mite populations. Fungus infecting Tetranychidae and Eriophyidae have been documented by researchers (Cabrera et al., 1987) who indicated that the major constraint is the germination of spores and that penetration of the fungus into the mite is very poor at humidities below 100%.

Since development of *P. latus* is positively related to relative humidities between 75% and 90%, and development of entomopathogenic fungi require between 90% to 100% RH, fungi might offer another possible way to reduce broad mite populations. Peña et al. (1996b) compared the toxicity of *Beauveria bassiana* Balsamo (Vuillemin), *Paelelomyces fumoso-roseous* (Wize) Brown and Smith, and *Hirsutella thompsoni* Smith and confirmed that all isolates tested

were able to infect *P. latus* under laboratory conditions. Under greenhouse conditions, despite significant mortality of *P. latus*, a fungal epizootic was variable among performed tests. Failures of this nature are not uncommon when attempts are made to use fungi as mycoacaricides. In this instance, the failure is most likely related to fluctuation of relative humidity and temperature differences between environments where fungi are tested. The relative humidities were high (approaching 100%) in the petri dish bioassay, but variable (50% to 90%) in the whole-plant experiments.

Conclusions

Polyphagotarsonemus latus (Banks) is an important pest of citrus in regions with a humid climate or in orchards where predaceous mites have been reduced to non-effective levels. Investigations on mite-citrus interactions are urgently needed. Little is known about the mechanisms by which broad mite feeding provokes proliferation of buds, silvering, and bronzing of affected fruit. Very few studies deal with the morphogenesis, ultrastructure and etiology of broad mite injured tissue. The first evidence of mite attack is mechanical injury caused by piercing, water losses occur but no data are available to determine reductions in photosynthesis, transpiration, plant sugars and amino acids. Injected toxins may alter cellular process in the meristematic tissue. The composition of this toxin needs to be identified. Injured plants show reduction in growth, flowering and cropping. Future studies should determine plant hormone levels and mineral content that might influence this process.

The results of economic injury levels cited here can be extended, particularly for tropical conditions; damage relations are difficult to formulate when the mite in question is attacking different plant organs at the same time. Perhaps formulating realistic economic injury levels under these circumstances is not possible.

Chemical control remains at present the only economical option for many growers in the neotropics. The economic injury level, particularly for export crops in developing countries, is extremely low, as aesthetic elements are involved which are not connected with production levels. The rapid development from low populations to injury levels when young structures and humid weather predominate, demands a frequent sampling program for the affected crops.

Successful biological control of broad mites can be achieved. Commercial trials showed that early establishment of the predator is essential, but also that the use of predators tolerant to fungicides and insecticides is a "must" if biological control is to be implemented when other pest problems are prevalent. Use of pathogens, merits further study. A reduction in broad mite numbers may occur following the application of fungi. The effectiveness or efficacy of these fungi depends on the climatic conditions, broad mite population densities and presence or absence of predacious mites. Moreover, the use of fungicides for the control of plant pathogenic fungi should be selected carefully to avoid detrimental effects on entomopathogenic fungi.

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