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Invasions of Leaf Feeding Arthropods: Why Are So Many New Pests Attacking California-Grown Avocados?

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Historically, pesticide use in California avocado orchards has been minimal. Important pests like greenhouse thrips, *Heliothrips haemorrhoidalis* (Bouché) (Thysanoptera: Thripidae), avocado brown mite, *Oligonychus punicae* (Hirst) (Acari: Tetranychidae), six-spotted mite, *Eotetranychus sexmaculatm* (Riley) (Acari: Tetranychidae), and omnivorous looper, *Sabulodes aegrotata* (Guenée) (Lepidoptera: Tortricidae), *Amorbia cuneana* (Walsingham) (Lepidoptera: Tortricidae) have been kept below economically injurious levels by natural enemies (Fleschner, 1954; Fleschner *et al.*, 1955; McMurtry 1992). Until relatively recently, California avocado production was world-renowned because it relied almost exclusively on biological control for suppression of noxious pests.

The Foliage Feeding Invaders Set One

The importance of natural enemies for avocado pest control has been slowly eroding in California. This declining trend began in 1982, when red-banded whitefly, *Tetraleurodes perseae* Nakahara (Hemiptera: Aleyrodidae) (Fig. 1a), established in San Diego County (Hoddle & Soliman, 2001; Nakahara, 1995; Rose & Wooley, 1984a, b).

Following red-banded whitefly, persea mite, *Oligonychus perseae* Turtle, Baker & Abbatiello (Acari: Tetranychidae) (Fig. 1b), was discovered attacking avocados in San Diego in 1990 (Bender, 1993). In 1996, avocado thrips, *Scirtothrips perseae* Nakahara (Thysanoptera: Thripidae) (Fig. 1c), was discovered almost simultaneously in orchards 160 km apart in Ventura and Irvine Counties (Hoddle & Morse, 1998). Over a period of approximately 14 years (1982-1996), three new avocado feeding insects established in California, an establishment rate of a new pest around every seven years.

A historical analysis of this situation is interesting. All three pests (Fig. 1a-c) were species new to science when first discovered in the U.S.A. Red-banded whitefly was not described until 1995 (13 years after it established in California) and is native to Central America. Specimens have been collected from the Caribbean, Central America, Florida, and México (Nakahara, 1995). Red-banded whitefly invaded Israel in 2001. Persea mite was first described in 1975 from specimens collected from smuggled avocados that were intercepted from México at an El Paso, Texas quarantine facility. This mite is native to México and has invaded Costa Rica (established 1970 in San Antonio de Coronado, Province of San Jose, on *Persea americana* and was

misidentified as *O. peruvianus* [Salas 1978]), Israel (established 2001), and Spain (established 2002/03). Avocado thrips was described in 1997 (Nakahara, 1997), but two females were first intercepted in California in 1971 at the Port of San Diego on smuggled avocados (Hoddle *et al*., 2002) suggesting that this pest may have entered California several times prior to 1996 when it finally established.

Figure 1. Invasive pests attacking avocados in California. **a)** red-banded whitefly established in 1982, **b)** persea mite established in 1990, and **c)** avocado thrips established in 1996 (all photos UC Regents).

a) **b)** **c)**

Do These Pests Move on Budwood, Fruit, or Leaves used for Cooking?

Bud Wood or Fruit?

All three of these pests (red-banded whitefly, persea mite, and avocado thrips) feed and reproduce almost exclusively on avocado leaves, and to a lesser extent several closely related plants within the family Lauraceae (e.g., persea mite attacks camphor (*Cinnomum camphora),* but red-banded whitefly and avocado thrips are known only from avocados in California). These pests cannot survive or reproduce on mature avocado fruit, which is the usual smuggled commodity targeted by border control authorities. Consequently, the only likely conduit for red-banded whitefly, persea mite, and avocado thrips from their home ranges in México or Central America to California is illegally transported avocado branches with leaves (this could include entire plants) or small branches without leaves (i.e., budwood) to be used for grafting, or detached leaves for cooking. Budwood with remnant petioles provide favorable hiding places for eggs, larvae, and adult persea mites and avocado thrips. In fact, avocado thrips can lay eggs into petioles and immature and adult mites and thrips shelter in petiole axils or other hiding places on small branches. Small branches used for grafting could also harbor whitefly crawlers, the mobile first instars that look for suitable feeding spots before settling to feed.

It is particularly instructive that Israel received the persea mite and red-banded whitefly simultaneously in 2001. For such a unique subset of avocado feeding arthropods to establish strongly suggests that branches bearing older leaves (most preferred host

stage for these two pests) or even budwood contaminated with mites or whitefly crawlers were probably smuggled from California to Israel and propagated in avocado orchards. If plant material with leaves had been illegally moved from a locale other than California, such as México, it is more likely that a different subset of pests would have invaded Israel. This "probable conduit hypothesis" from California to Israel can be easily verified for persea mite and red-banded whitefly with molecular tools that utilize standard population genetics analysis methods such as mitochondrial DNA and micro satellite markers to compare the genetic profile of source (California) and invader populations (Israel). Similarly for Spain, persea mite must have arrived on imported (either legal or illegal) avocado branches with leaves or possibly leafless bud wood with remnant petioles with either mite eggs or motiles hiding in petiole axils.

Leaves used for Cooking?

Another potential source of leaf-feeding avocado pests to California is avocado leaves (*hojas de aguacate*) that are imported from México and used for cooking. Leaves can be used fresh (for tamales) or dried (for soups and stews) and are used to flavor cuisines traditional to southern México by adding an anise flavor. Several constraints may act in minimizing pest invasion on avocado leaves used for culinary purposes. Harvested leaves will begin to deteriorate quickly after picking and packaging. Leaf feeding insects and mites will not perform well for long on leaves that are desiccating. Survivors that reach a kitchen on leaves will most likely be weakened from transit stress, however, if they are not impaired, they still need to escape the kitchen by either flying or walking out a door or window or being transported on clothing and escapees will need to find either a backyard avocado plant or orchard to establish in. This may be difficult to achieve from a trash can, or after cooking (either being boiled, baked, or toasted). It is conceivable that smuggled leaves and branches with living contaminants could be dumped in a trash heap under an avocado plant but this seems unlikely for four reasons: (1) cooks would be unlikely to immediately discard imported fresh avocado leaves before their useful life was over (leaves can be used dried so there is no harm in keeping fresh leaves that have dried completely); (2) cooks using leaves would be unlikely to pay for expensive imports if fresh free leaves are available on avocados in the backyard (the possible food source for kitchen escapees); (3) Hass leaves are recommended for cooking (GourmetSleuth 2005), a variety that is common in California which minimizes the need to smuggle leaves of this variety. However, it is possible that Mexican avocado varieties with an anise flavor stronger than Hass that are not grown in California are brought in either legally or illegally and used for cooking. Finally, (4) the adult stages of the avocado pests that have established in California are all relatively poor fliers and cannot disperse over wide areas. It would be unlikely for these pests to escape from a kitchen in an urban area and to cover vast distances over hostile terrain in search of isolated avocados in an area with a favorable climate and with plants in a suitable state of growth that would support incipient populations. Further, it would be virtually impossible for immature thrips, mites, whiteflies, and most other pests to walk off leaves discarded under avocado trees in a backyard, climb the trunk, traverse branches, and find suitable leaves to feed on. These motile stages would either die of starvation, desiccation, or be eaten by generalist predators during

their search for food. Studies on thrips pests of tobacco, grapes, currants, and other leaf and fruit products that are packaged either partially or fully dry are usually not successful invaders as they do not survive on shipped product as it is unsuitable for long-term survival (Morse and Hoddle, 2006).

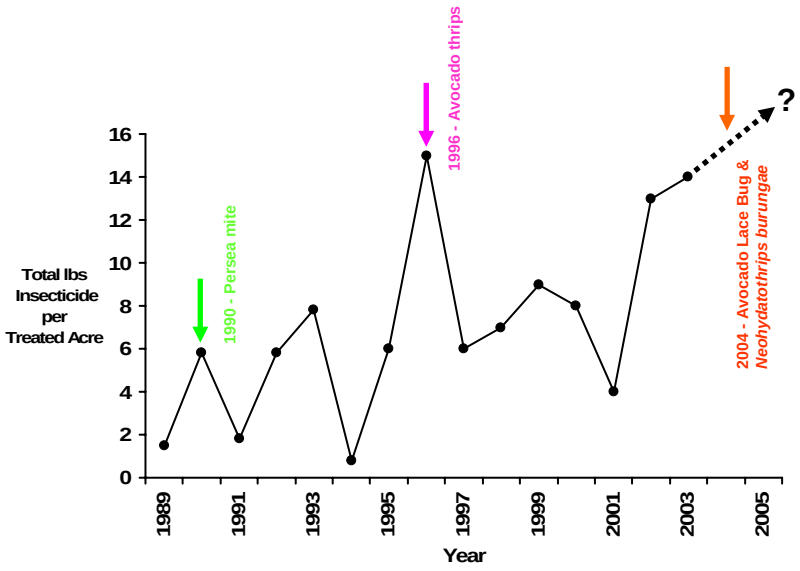
One comment from the GourmetSleuth website is of major concern with respect to avocado leaves used for cooking: *"It is common to see small "galls" on the underside of the avocado leaves. They are totally edible and actually add an enhanced flavor. (Chef Reed Hearon, Cafe Marimba, Restaurant LuLu, Rose Pistola et. al.)"* The galls being referred are almost certainly those caused by *Trioza* spp. (Hemiptera: Psyllidae) that are common (mainly on the upper leaf surface not the underside as mentioned by Gourmet-Sleuth) on some varieties of avocados in México and Guatemala (some Hass orchards around Antigua, Guatemala can be negatively impacted by high density populations of *Trioza* spp.). Given the fact that this comment is made on the website one must assume that galls on imported avocado leaves are encountered in high numbers and commonly enough to have piqued consumer concern, hence the need to address their presence on imported leaves. Since *Trioza* spp. have not established in California to date, this may indicate that leaves imported from México for cooking with potential pestiferous contaminants face major establishment obstacles in urban areas as outlined above which are not easily overcome. It is unlikely that *Trioza* spp. would be imported on budwood as the adults are quite large, winged, and readily fly when disturbed. Eggs are laid by females into leaves and the immature *Trioza* nymphs promote gall growth within which they spend their entire immature life cycle. Flightless immature stages are poor walkers and would be unable to move from galls on discarded avocado leaves to infest nearby avocado trees.

Why Could Avocado Budwood be the Potential the Pest Carrier?

Given the highly competitive global market for avocados, many growers instinctively look for a production or marketing edge. This may drive the Machiavellian attitude of some of the more cavalier producers to risk smuggling novel varieties from one country to another for "testing" under home conditions. Branches with or without foliage (i.e., bud wood) rather than seeds are moved because scions will propagate true to the donor plant; small branches with or without leaves are easy to conceal in luggage or sent through postal or courier services; and time from importation to fruiting is much reduced using grafted material as opposed to the growing and screening of plants produced from seeds. As a conduit for moving pests, branches and budwood have the following advantages for increasing pest survival during transit: (1) branches or bud wood must be kept alive during transportation if they are to be viable at the destination and this provides a continuous food source for arthropod contaminants; (2) during transportation branches or budwood must be kept under conditions that promote branch survival and thus survival of any contaminants; (3) after arrival at the destination, grafting and propagation of branches or budwood with contaminants in avocado orchards will almost certainly guarantee that pests will be introduced into a climate on host material to which they are ideally suited. Additionally, orchards often have trees in various stages of development which are closely spaced so invaders weakened from transit stress do not need to migrate far or through hostile

environmental conditions to find shelter, food, and sites suitable for reproduction; (4) human management of the new grafts or scions in the orchard will most likely be diligent to ensure survival and will greatly reduce the adverse impact of any stochastic events (e.g., storm damage, or excessive heat) that could accidentally kill the imported grafts and associated contaminants, and (5) the invaders will often arrive without their specialist natural enemies, so incipient populations are more likely to increase and spread until climate checks spread and available food and breeding sites are exhausted.

Figure 2. Total pounds of insecticide applied per treated growing acre of avocado combined for San Diego and Ventura Counties. Acreage and insecticide application data were obtained from the CA DPR website (http://www.cdpr.ca.gov/index.htm). Arrows indicate years in which exotic avocado pests established in CA after the CA DPR initiated mandatory pesticide record keeping in 1989. At the time of writing pesticide records for California were available only through 2003. Pesticide usage may continue in an upward trend for 2004 and 2005 as two new insects feeding on California avocados were discovered in 2004.



The Impact of Establishments

I perceive two extremely annoying things about the behavior and attitude of individuals that illegally move avocado foliage, budwood, or plants between countries: (1) perpetrators are flagrantly disregarding bio-security legislation that has been designed and implemented specifically to protect agricultural industries from which many individuals derive their livelihood from unwanted and destructive pests and diseases. (2) The often catastrophic economic situation that arises from a pest invasion brought about by deliberately smuggled plant material would not be so severe if the pests

remained confined to the perpetrator's orchard and they alone suffered the consequences. This is never the case, however, and often the entire industry suffers crop loses, additional and unnecessary expenditures for pest management, lower premiums for damaged fruit, reduce yields, decreased competitiveness, environmental contamination problems from pesticide use and disposal, and extreme angst over future profitability.

Establishment of new exotic pest species almost always results in increased pesticide use to control the invaders. Analysis of the California Department of Pesticide Regulations (CA DPR) database for insecticides applied to avocados in San Diego and Ventura Counties shows a clearly discernible trend: total pesticide application combined for both counties on a treated per acre basis has been steadily increasing since CA DPR initiated mandatory record keeping in 1989 (Fig. 2). Unwanted incursive species affecting avocado production are probably the most important cause of increase pesticide use. Other factors such as high market values for fruit in some years may also encourage growers to spray more as an "insurance policy" against crop loses caused by insects and mites. The avocado thrips in California alone has been estimated to cost California growers around $4-5 million (US) per year now that the industry has adjusted to the initial insult and developed reliable control strategies (Hoddle *et al*., 2003). The amount of time and research dollars (grower, state, and federal monies are usually combined to fund projects over a 3-5 year period) put into investigating and developing cost-effective and sustainable management programs is not inconsequential and these financial expenses could be averted if these pests were not introduced and allowed to proliferate and spread.

The Foliage Feeding Invaders Set Two.

In 2004, two more leaf feeding exotic insects were added to the resident pest phalanx attacking California avocados. In September 2004, the avocado lace bug (ALB), *Pseudacysta perseae* (Heideman) (Hemiptera:Tingidae) (Fig. 3a), and in November 2004 *Neohydatothrips burungae* (Hood) (Thysanoptera: Thripidae) (Fig. 3b) were discovered feeding and reproducing on backyard avocados in San Diego County.

ALB is known from Florida, the Caribbean and México. ALB adults and nymphs feed in colonies on the undersides of leaves. Feeding damage results in necrotic brown spots forming that can lead to defoliation and reduced fruit yields. Infested avocado trees in San Diego County have a severely scorched appearance. In addition to avocado, ALB is known to feed on ornamental camphor and red bay *(Persea borbonia)* (all Lauraceae). Thus, ALB poses a significant pest threat to ornamental plantings in urban areas. There are virtually no published data on avocado lace bug biology, ecology, natural enemies, or chemical control. There is a single paper from Florida that has been of some use but its application to California conditions is tenuous (Peña *et al*., 1998). ALB is a serious pest of 'Hass' avocados in The Dominican Republic and Puerto Rico. In 2001, Hoddle and Phillips (UCCE Ventura County) witnessed first-hand massive outbreaks of ALB in commercial Hass orchards in the Dominican Republic while searching for avocado thrips natural enemies. Similar outbreaks, should they occur in California, will be devastating and will cost the avocado industry millions of dollars in

pesticide applications and reduced crop yields. Additional chemical use for avocado lace bug control will increase the likelihood of secondary pest flare ups (especially problematic are induced outbreaks of several mite and lepidopteran species), and insecticide applications for ALB will likely promote pesticide resistance development by persea mite and avocado thrips.

Figure 3. Two new pests were discovered on avocados in California in 2004. **a)** avocado lace bug (photo, G. Witney), and **b)** *Neohydatothrips burungae* (photo, M. Hoddle).

a) **b)**

At time of writing, ALB had infested an area exceeding 250 square miles and only backyard grown avocados were infested in San Diego County. Surveys by the California Department of Food and Agriculture and the San Diego Agricultural Commissioner's Office are monitoring the spread of the ALB in San Diego County. Eradication of this pest has been ruled out by CDFA for the following three reasons: (1) the infested area is too large to treat effectively, and most of the area that would require spraying is residential. (2) There are no effective monitoring tools (e.g., pheromone traps) that can be used to detect low density populations to determine the efficacy of eradication treatments. Small residual ALB populations in avocado trees 30-40 feet tall are difficult to detect by eye from the ground. (3) There are few data on pesticides and their efficacy against ALB so choice of products to use in area-wide treatments would be largely speculative.

A single adult female of *Neohydatothrips burungae* was discovered in Chula Vista, San Diego County during a survey for ALB in November 2004. This thrips can be distinguished from avocado thrips with a hand lens by the heavy maculation (brown shading) on the thoracic region and heavy maculated lines (i.e., brown stripes) running

across the dorsal surface of the abdomen (compare Figs. 1c and 3b). The genera, *Neohydatothrips* and *Scirtothrips* are very similar in gross morphological appearance and habit. *Neohydatothrips burungae* is known from México and it has been collected by Hoddle from avocados in Atlixco, Coatepec Harinas, Michoacán, Oaxaca, Orizaba, Tepic, and Tonatico (all in México), Guatemala, Honduras, Nicaragua; and published records indicate it is in Panama too. There are no records from Costa Rica either in the scientific literature or from extensive collections from avocados by Hoddle. Disjunct distributions of plant and animal populations as they move south from northern areas in Central America towards Costa Rica are common for many native species. However, it is uncertain why *N. burungae* is in Panama (which is south of Costa Rica) but not Costa Rica. One possibility is that *N. burungae* is really a color variant of the widespread and variable *N. signifier* and *N. burungae* should be synonomized with *N. signifier* (Mound and Marullo 1996). However, this suggestion has been challenged and *N. burungae* is not considered a synonym of *N. signifer* by some thrips taxonomists (L. A. Mound pers. comm. 2005). The type series of *N. burungae* was described from 14 females and 2 males collected from an unknown host plant on Barro Colorado Island, Panama (Mound and Marullo, 1996).

What we do know about *N. burungae* is based largely on field experience in México and Guatemala where Hoddle has collected this thrips from avocados and other host plants (electronic searches on the internet and library references have not recovered any publications on this thrips). At high altitudes (>1500 meters) *S. perseae* (the avocado thrips) dominates on avocados. At lower levels where it is hotter and humid *N. burungae* dominates totally, likely excluding *S. perseae.* Both species can be found co-occurring on avocados in areas of intermediate altitude (Hoddle *et al*., 2002). In areas of México such as Tepic (Nayarit), *N. burungae* is very common to what appears to be the total exclusion of avocado thrips on avocado. *Neohydatothrips burungae* has been collected from mango flush in Tepic, strongly suggesting that this insect is polyphagous and may feed and reproduce on more than one host plant and on hosts that are not closely related.

Currently it is unknown how widespread *N. burungae* is in California, or how common this thrips is in areas in which it has established. These two facts can only be elucidated through thorough and comprehensive surveys by specialists with expertise in thrips collection and identification. Consequently, it is uncertain how *N. burungae* will behave in California. This thrips may become problematic in hotter avocado growing areas (i.e., inland) where *S. persea* is not able to function well because of high temperatures. Conversely, humidity levels may be too low in California for it to reach its full pest potential. Until field surveys are undertaken the impact *N. burungae* will have on California avocado production is speculative.

The periodicity of avocado pest arrival in California is interesting: red-banded whitefly 1982, persea mite 1990, avocado thrips 1996, ALB and *N. burungae* 2004. These pests have been arriving at roughly eight year intervals, perhaps suggesting a regular pattern of visitation to particular avocado growing locations by an agent illegally importing plant material. The possible simultaneous arrival of ALB and *N. burungae* suggests that a warm humid avocado growing region was last visited from which plant material was taken and smuggled back into California. Analysis of pest DNA and associated

endosymbiotic bacteria can help reveal donor regions and frequency of arrival of invasive exotic avocado pests. Molecular-based work can help answer these perplexing questions.

CSI of Entomology Identifying Donor Regions

The University of California Exotic Pests and Diseases Research Program funded a two-year study at UC Riverside using molecular techniques to determine the area of origin for avocado thrips in México and Central America. The California Avocado Commission provided funds to cover costs associated with collecting thrips from avocados in México, Guatemala, Honduras, Nicaragua, Costa Rica, and Panama. To identify likely sources and routes of entry of invasive pests, we examined the population genetics of avocado thrips using mitochondrial DNA (mtDNA) and micro satellite markers. The mtDNA sequences revealed three geographically distinct and divergent lineages for avocado thrips, of which the mtDNA haplotypes of Californian individuals were most closely related to populations in the center of the pest's native range (avocado thrips has a range that stretches from Uruapan (Michoacán in México) south to Central Guatemala (Hoddle *et al*., 2002). Analysis of allele frequencies at four micro-satellite loci strongly indicated Coatepec-Harinas, México, as the most likely source of the Californian population. The identification of Coatepec-Harinas as the source of the California population fits well with our knowledge of the native populations of avocado thrips. Coatepec Harinas is the site of a large avocado germplasm bank and breeding station, the Fundación Salvador Sánchez Colín-CICTAMEX S.C., which is regularly visited by foreign researchers and growers and this donor region may be a likely source of previous and future avocado pest introductions. In contrast, the other populations of avocado thrips we identified and sampled that had similar genetic profiles to the California population of avocado thrips lay in areas (e.g., backyard plants in Atlixco and Tonatico) close to Coatepec-Harinas that are much less likely to draw attention from international travelers with interest in avocado breeding and novel cultivars.

Conclusions

Invasive arthropod pests have begun to threaten the economic viability of avocado production in California. There are two easily recognizable conduits facilitating invasion: 1) smuggling of foliage, branches with leaves, whole plants, and budwood that brings in secretive leaf feeding pests (as discussed here), and 2) the legal and illegal importation of fruit. Federally sanctioned fruit imports from México and elsewhere (e.g., Dominican Republic, and Chile) may ultimately result in the establishment of several potentially devastating fruit pests that hitch hike into California either in or on fruit smuggled into the Los Angeles basin from U.S. states that can legally import Mexican fruit. The most serious of these fruit pests are fruit flies (*Anastrepha* spp. [Diptera: Tephritidae]), seed weevils (*Heilipus* spp. [Coleoptera: Curculionidae]), and seed moths (*Stenoma* spp. [Lepidotpera: Elachistidae]). It would appear that the seed importation (and by definition fruit) ban enacted by the U.S. Congress in 1914 has been extremely successful in preventing fruit damaging pests from establishing in California, as none of these major pests have established here. As fruit importation from México and elsewhere increases,

it is inevitable that fruit pests will find their way into California and establish incipient populations that may ultimately become widespread and problematic. Molecular techniques are enabling researchers to track down the source populations of California's pest populations in foreign countries and delineating their geographic range. It may only be a matter of time before such techniques are used as evidence to help prosecute individuals that illegally move plant material between countries. Ultimately, as more fruit is imported and travel and immigration from México and Central America increases, avocado growers in California will most likely need to efficiently manage not only the resident destructive leaf feeders but future phytophages and frugivores as well if the industry is to remain viable.

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