

Biology, Ecology, and Management of Hemipteran Pests in Almond Orchards in the United States

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Abstract

Almond, *Prunus dulcis* (Miller) D. A. Webb, is an important tree nut crop cultivated primarily in the Mediterranean climatic regions. However, the United States, specifically the state of California, is the largest producer and exporter of almond nuts in the world. At least 60 species of insect pests attack almonds worldwide. Hemipterans can be important pests in almond orchards. Some hemipteran insect pests in almonds include lace bugs, plant bugs, stink bugs, and leaffooted bugs. These pests use needle-like mouthparts to pierce and feed upon fruits or other parts of the plant, causing direct or indirect crop damage. Nonetheless, the biology, life history, and management practices for many hemipteran pests of almonds are not available in the literature or come from research of these insects on other crops and host plants. In this article, we discuss the current understanding of biology, ecology, and management of hemipteran pests of almonds and outline future research to advance the integrated pest management of these pests in almond orchard systems.

Key words: almond, stink bug, leaffooted bug, Hemiptera, Coreidae

Almond, *Prunus dulcis* (Miller) D.A. Webb, is the most produced tree nut crop globally, with total production exceeding 1.3 million metric tons (INC 2020). This crop is adapted to various parts of the world; however, the major commercial production of almonds is limited to regions with Mediterranean climates. The Mediterranean climate is characterized by a mild winter and dry-and-hot summer. Production regions include the Mediterranean countries (e.g., Italy, Spain, Morocco, Turkey, Portugal), the Central Valley of California, Middle East countries (e.g., Iran, Turkey), and a few countries in the Southern Hemisphere (e.g., Chile, Argentina, South Africa, Australia) (Gradziel et al. 2017). The United States is the largest producer of almonds, contributing 75% of the global production (INC 2020), with current total orchard cultivation of over 620, 000 ha (=1.5 million acres) in orchards in California (NASS 2020), and much of this production occurs in the Central Valley of California.

Numerous pests attack almond fruits and trees globally (Hill 1987), including a number of Hemiptera (Table 1). These insects feed on fruits, leaves, or other parts of the plant, causing direct or indirect crop damage. For feeding, hemipteran insects insert their stylets into host plant tissues and some of them may inject toxic saliva that spreads into the surrounding tissue. Their feeding process on plant tissues can be categorized in one of the four feeding mechanisms – stylet-sheath, lacerate-and-flush, macerate-and-flush, or osmotic pump (Hori 2000). The manifestation of the damage symptoms in host plants due to phytophagous heteropteran feeding is a

complex process that involves both mechanical injury (injury to the cell) as well as hormonal and physiological imbalances, and in some species, salivary enzymes can play a significant role in the process (Hori 2000). Details of the feeding mechanisms related to these particular hemipteran pests in almonds have not been studied. However, the damage symptoms resulting from the feeding by the major hemipterans can cause fruit abortion, fruit abscission, or kernel necrosis; and we will describe these symptoms under each pest category in the article. Among reported almond insect pests, only a few are considered significant pests in various growing regions (Hill 1987). While the information on pest biology and management practices of many common almond pests, such as navel orangeworm, *Amyelois transitella* (Walker) (Lepidoptera: Pyralidae) is more developed (Wilson et al. 2020b), there is a lack of similar pertinent information on many other pests including hemipteran, which are another group of insects which are almond pests in the United States.

Several species of hemipteran insects ‘true bugs’ that include both predators and pests can be found in almond orchards (Zalom et al. 2017b, Sisterson et al. 2020). Some of the hemipteran pests can cause significant economic damage to almonds. The economic damage occurs due to the gummy or necrotic kernels at harvest or due to the reduced yield due to the abscission of the immature fruits. This article describes the biology, ecology, and current management practices of hemipterans associated with almond orchards in California. These insect pests are placed into five groups, (1) fruit-feeding leaffooted

Table 1. List of hemipteran pests reported in almond orchards in the Euro-Mediterranean region and the United States

Pest species	Family	Nature of Damage	Countries where reported as pest	References
<i>Leptoglossus</i> spp. (Leaffooted bugs)	Coreidae	Adults feed on fruits, cause fruit abortion, kernel necrosis	USA	Zalom et al. (2017a)
<i>Calocoris</i> spp. (Gmelin)	Miridae	Adults can feed on young fruits; minor issue	USA	Lodos (1980)
<i>Lygus hesperus</i> Knight, (Western tarnished plant bug)	Miridae	Adults can feed on young fruits; minor issue	USA	Goodell and Ribeiro (2006)
<i>Phytocoris</i> spp.	Miridae	Adults can feed on young fruits; minor issue	USA	Beede et al. (2020)
<i>Chinavia hilaris</i> Say (Green stink bug)	Pentatomidae	Nymphs and adults feed on fruit and kernel causing fruit abortion and drop	USA	Zalom et al. (2017a)
<i>Chlorochroa uhleri</i> (Stål)	Pentatomidae	Nymphs and adults feed on fruit and kernel causing fruit abortion and drop	USA	Zalom et al. (2017a)
<i>Halyomorpha halys</i> (Stål) (Brown marmorated stink bug)	Pentatomidae	Nymphs and adults feed on fruit and kernel causing fruit abortion and drop	USA	Rijal and Gyawaly (2018), Rijal and Zalom (2020)
<i>Thyanta pallidovirens</i> (Stål)	Pentatomidae	Nymphs and adults feed on fruit and kernel causing fruit abortion and drop	USA	Zalom et al. (2017a)
<i>Boisea rubrolineata</i> (Barber) (Western boxelder bug)	Rhopalidae	Nymphs and adults feed on fruit, cause fruit abortion and kernel damage	USA	Michailides et al. (1988)
<i>Monosteira lobulifera</i> Reuter	Tingidae	Adults and nymphs feed on leaves	Turkey, Iran, Lebanon, Syria, Libya	Talhok (1977), Hill (1987), Bolu (2007)
<i>M. unicosta</i> (Mulsant & Rey)	Tingidae	Adults and nymphs feed on leaves	Spain, Italy, Turkey, Iran, and Lebanon	Talhok (1977), Bolu (2007), Russo et al. (1994), Sánchez-Ramos et al. (2014)

bugs, (2) fruit-feeding North American stink bugs, (3) fruit-feeding invasive brown marmorated stink bug, (4) fruit-feeding occasional plant bugs, (5) leaf-feeding occasional plant bugs and other future potential pests. Additionally, this article provides a comprehensive list of hemipterans affecting almonds; scientific and common names of pest species were obtained from the Entomological Society of America's Common Names of Insects online database (ESA 2020), but for those not available in the database, only the scientific names have been used. Finally, the limits and considerations for improved integrated pest management (IPM) practices of these hemipteran pests in almonds are discussed.

Fruit-Feeding Leaffooted Bugs

Leptoglossus spp. (Hemiptera: Coreidae)

Pest Description

The genus *Leptoglossus* Guérin-Méneville (Hemiptera: Coreidae) is commonly known as leaffooted bugs (LFBs), and is widely distributed in the Western Hemisphere from southern Canada into South America and the Caribbean (Allen 1969, Brailovsky and Barrera 2004), with at least 61 species currently documented in the Americas. *Leptoglossus* spp. feed on seeds, nuts, and fruits, and several *Leptoglossus* species are considered agricultural or forest pests (Allen 1969, Brailovsky 2014). Adults are relatively large insects (10–20 mm or more in length) and typically brown, often with a narrow white 'zig-zag' band across the back and a leaf-like structure on the tibiae of the hind legs. In almonds, they

are the largest of the Hemiptera. Some species of *Leptoglossus* are considered occasional pests and, at times, feeding results in severe economic loss.

Adults may overwinter in the orchard or on other host plants surrounding orchards. In spring, LFB movement is noticed in orchards during April-May as bug feeding on developing almonds results in gummosis (sap) and almond drop. Bug feeding later in the season (May-June) can result in kernel damage, which is noticed at harvest evaluation (Joyce et al. 2019). Three species of LFBs have been observed in almonds in the Central Valley of California: *Leptoglossus zonatus* (Dallas), *Leptoglossus clypealis* Heidemann, and *Leptoglossus occidentalis* Heidemann (Zalom et al. 2012). Although *L. occidentalis* is reported in almonds, it has been infrequently observed in recent years and will not be further discussed here.

Leptoglossus zonatus adults are distinctive, with two orange spots behind the head on the prothorax (Fig. 1a). There are five nymphal instars. The first instar is orange, which differs from that of *L. clypealis*, which is green in color. Eggs of the two species (*L. clypealis* and *L. zonatus*) look similar. Like *L. clypealis*, *L. zonatus* oviposits its eggs in a row, consisting of 20–50 or more eggs. The developmental time of *L. zonatus* from egg to adult ranges from 54 to 83 d, depending on the host crop (Matrangolo and Waquil 1994, Grimm 1999, Grimm and Somarriba 1999, Tepole-García 2012, Daane et al. 2019). There are three generations of *L. zonatus* per year in the Central Valley of California (Daane et al. 2019). *Leptoglossus zonatus* is the most common LFB species in almond orchards in California. This LFB species is significantly larger

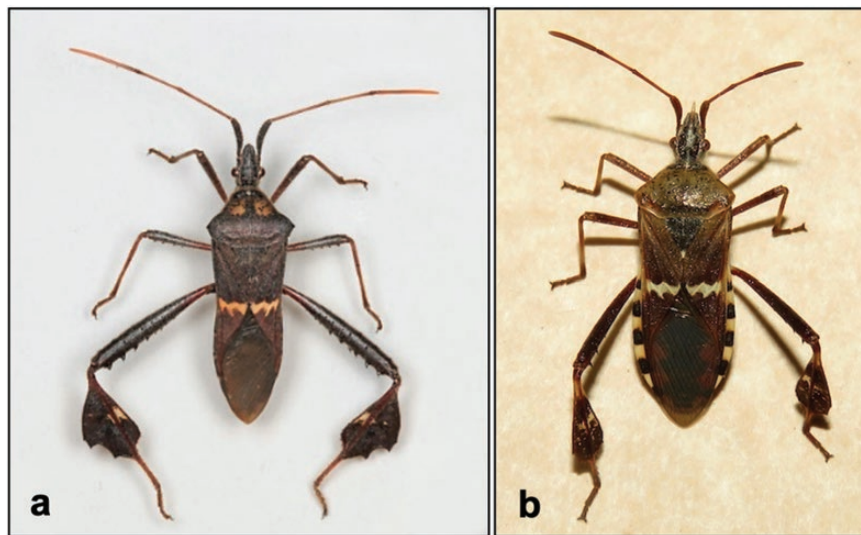


Fig. 1. *Leptoglossus zonatus* and *Leptoglossus clypealis* adults (Avg. size: ~19–25 mm long). (a) *L. zonatus* adult with two distinct spots on pronotum; (b) *L. clypealis* adult with a spine-like projection on head. Sources: (a) <https://bugguide.net/node/view/469766>; (b) <https://bugguide.net/node/view/1696697/bgimage>.

than *L. clypealis* and occurs widely throughout much of the Western Hemisphere (Allen 1969, McPherson et al. 1990, Buss et al. 2005, Gonzaga-Segura et al. 2013).

Leptoglossus clypealis adults are distinguished from all other LFBs by a spike-like projection extending from the front of the head (Fig. 1b). There are five nymphal instars. *L. clypealis* occasionally occurs in almonds in California (Joyce et al. 2017). The distribution of *L. clypealis* is more limited than that of *L. zonatus*, and spans from Northern Mexico into the southwest United States and the Midwest (Heidemann 1910, Allen 1969, Esquivel et al. 2020), with additional records into the east coast (Wheeler 2018).

Leptoglossus zonatus is polyphagous and recorded on at least 48 plant species in 24 families, and host plants include: almond; pistachio, *Pistacia vera* L.; pomegranate, *Punica granatum* L.; corn, *Zea mays* L.; soybean, *Glycine max*, (L.) Merrill. and others (Xiao and Fadamiro 2010, Pires et al. 2011, Joyce et al. 2017). While *L. clypealis* infests almonds and pistachios in California, it has also been reported with 44 plant associations within 20 plant families (preferring Cupressaceae) throughout its range consisting of native and exotic plant species, as well as row crops (i.e., sorghum, *Sorghum bicolor* (L.) Moench) (Esquivel et al. 2020). Generally, it consumes fruits and seeds but also attacks the stem and the leaves of trees (Mitchell 2000).

Biology and Ecology

Leptoglossus zonatus adults aggregate to survive through the winter (Zalom 2017a). Overwintering *L. zonatus* suffer low mortality if exposed several hours to 0°C (Tollerup 2019). Mortality increased if *L. zonatus* were exposed to colder temperatures for more extended periods, but these sustained cold temperatures are unlikely in the Central Valley. In the spring, aggregations of adults disperse into nearby orchards.

In almonds in California, two genetically divergent *L. zonatus* strains (~2% divergent) are found, one which matches a genotype that occurs in Brazil (Joyce et al. 2017). This may be a widespread strain occurring throughout the Western Hemisphere. The two *L. zonatus* strains may have distinct biological characteristics, host plant preferences, unique pheromone blends, and varied susceptibility to biological controls such as parasitoids, which could have

implications in managing *L. zonatus* in almonds and other host plants (Joyce et al. 2017).

Leptoglossus clypealis are also reported to overwinter in adult aggregations, in trees and shrubs, under the bark of the trees, and in leaf litter (McPherson et al. 1990, Daane et al. 2008). As temperatures warm in the spring, the adults disperse from aggregations and can be observed in almond orchards. Similar to *L. zonatus*, females oviposit a row of eggs. The developmental time from nymph to adult is 31–34 d, and *L. clypealis* has 1–2 generations per year (Mitchell 2000). Mating behavior studied in the lab found that males produce a pheromone that attracts females, and there is a pre-mating period which averages 16 d (Wang and Millar 2000).

Populations of *L. clypealis* from almonds and pistachios in California were compared with molecular markers, and no genetically divergent host-plant strains or cryptic species were found (Joyce et al. 2017). The study suggested this species moves from almonds into pistachios during the growing season of the two crops and does not appear to overwinter in pomegranates (as is common for *L. zonatus*) (Joyce et al. 2017). In addition, *L. clypealis* from almond and pistachio orchards in the Central Valley of California had a high haplotype diversity (17 haplotypes), suggesting the insect is in its native range (Joyce et al. 2017).

Direct damage to almonds is caused when *Leptoglossus* spp. feed by probing their stylets into fruits and seeds, and secondary damage can occur through the transmission of pathogens at the feeding site (Raga et al. 1995, Xiao and Fadamiro 2010, Pires et al. 2011). Feeding by *L. zonatus* adults can result in crop damage and decreased yields in other crops such as *P. vera*; maize, *Zea mays* L.; and citrus (Bolkan et al. 1984, Rice et al. 1985, Marchiori 2002, Henne et al. 2003, Xiao and Fadamiro 2010), as well as in almonds (Joyce et al. 2019). A field-cage study on almonds found more damage from feeding by *L. zonatus* than by *L. clypealis* (Joyce et al. 2019). Early-season feeding resulted in almond drop and late-season feeding caused strikes on kernels, kernel necrosis, and shriveled kernel damage (Joyce et al. 2019). *Leptoglossus clypealis* can also reduce yield in other crops such as pistachio (Bolkan et al. 1984, Rice et al. 1985, Michailides et al. 1987, Michailides 1989), and can transmit the fungal pathogens *Botryosphaeria dothidea* (Moug.) Ces. & De Not (Rice et al. 1985) and *Eremothecium coryli* (Peglion) Kurtzman (Michailides and Morgan 1991, 2019).

Monitoring and Management

Traps or lures are not currently commercially available, although host plant volatiles and pheromones have been demonstrated to attract *L. zonatus* adults (Joyce 2016, Beck et al. 2018, Franco-Archundia et al. 2018). Traps have been investigated, and panel traps with or without bait caught more *L. zonatus* than pyramid or bucket traps (Wilson et al. 2020a). Alarm pheromones and evidence of sex pheromones are documented for *L. clypealis* (Aldrich et al. 1979, Wang and Millar 2000).

The presence of LFB is often noted by observation of sap (gummosis) exuding from developing almonds or when trees have a significant almond drop. Unfortunately, the damage from *Leptoglossus* feeding sometimes occurs before the insect is observed in the orchard. Scouting for presence of LFB eggs and nymphs will provide confirmation of LFB. Nymphs can be sampled using a beating tray, but no economic thresholds have been established (Zalom et al. 2012). Large numbers of LFBs have also been observed during the almond harvest as almonds accumulate on the orchard floor and during pistachio harvest on the collection bins (ALJ, pers. observation). Cultural control could include monitoring overwintering sites to remove aggregations and prevent bug movement into orchards (Ingels and Haviland 2014).

In almonds, the eggs of *L. zonatus* can be parasitized by *Gyron pennsylvanicus* (Zalom et al. 2012). Egg parasitism of *L. clypealis* by *Gyron* spp. has also been observed in pistachios in California (ALJ, pers. observation). Biological control of *L. zonatus* has been more thoroughly investigated in crops other than almonds; parasitism is known to occur by hymenopterans, *Trissolcus* spp. (Marchiori 2002), *Anastus* spp. and *Gyron* spp., and by the tachinids, *Trichopoda pennipes* Fabr. (Souza and Amaral Filho 1999) and *Trichopoda* spp. (Duarte-Sanchez et al. 2008).

LFBs are sporadic pests in almonds but can cause significant yield loss through almond drop or kernel damage. If gummosis, almond drop, and a considerable insect population are identified, chemical control may be warranted. Recommended chemical controls will vary in different regions and may change depending on pesticide regulations (Zalom et al. 2012). Currently, pyrethroids are one of the preferred insecticide classes for LFBs (Zalom 2017a).

Fruit-Feeding North American Stink Bugs

Many stink bugs of North American origin infest almond fruits throughout the fruit development period in California (Zalom

et al. 2017b). However, the stink bug species composition, their biology, and life in almond orchards are limited. Though some other noninvasive stink bug species may be present in the almond orchards, the species described below are the common noninvasive stink bug pests of almonds in the United States.

Chlorochroa uhleri (Stål) (Hemiptera: Pentatomidae)

Pest Description

Chlorochroa uhleri adults are 12–16 mm long (Zalom et al. 2017a, Capinera 2020). They have a greenish body, and the apical membranous part of their hemelytra is transparent and pale (Fig. 2) (Capinera 2020). Several species in this genus are difficult to distinguish from each other (Barman et al. 2017). *Chlorochroa uhleri* can be distinguished from related species, *C. sayi* (Stål), by looking at the membranous part of hemelytra. *Chlorochroa sayi* has a purple fleck on the apical membrane of hemelytra, but the purple fleck is absent in *C. uhleri* (McPherson and McPherson 2000, Capinera 2020). In California, the two species look very similar and are difficult to distinguish (Fig. 2b and c). However, genetic markers such as mitochondrial DNA barcodes can separate these species (Barman et al. 2017).

Chlorochroa uhleri is native to North America and is common in the Western US and Canada (McPherson and McPherson 2000). In the US, it has been reported from California, Arizona, New Mexico, Colorado, Idaho, Montana, and Washington in the west and some mid-western states such as Nebraska, North Dakota, and South Dakota (McPherson and McPherson 2000). It has also been reported to occur in Mexico (Ehler 2000).

Biology and Ecology

Chlorochroa uhleri biology and life history are not well described in the literature. However, it is believed to have similar biology and life history as *C. sayi*, a related stink bug species (Capinera 2020). *Chlorochroa sayi* lays eggs in masses with an average of 26 eggs (13–43 eggs per mass), and eggs hatch in 5–7 d. *Chlorochroa sayi* has five nymphal instars. It takes about six weeks for nymphs to become adults. *Chlorochroa uhleri* overwinters as adults and becomes active in spring in California and has two generations each season (Hasey et al. 2010). They feed on field crops and other weed hosts and immigrate to almond orchards during spring (Zalom et al. 2017a).

In addition to almonds, *C. uhleri* infests many weeds and cultivated plants (McPherson and McPherson 2000). Major cultivated plant hosts reported for this species include: alfalfa, *Medicago sativa* L. and wheat, *Triticum aestivum* L. (Williams 2003); sorghum



Fig. 2. North American stink bug species, a) *Chinavia hilaris* (Avg. size: ~17 mm long); b) *Chlorochroa uhleri* (Avg. size: ~14 mm long); c) *Chlorochroa sayi* (Avg. size: ~14 mm long); d) *Thyanta pallidovirens* (Avg. size: ~11 mm long). Sources: (a–c) Barman et al. 2017; (d) Jack Kelly Clark, University of California Statewide IPM Program.

(Jubb and Watson 1971); cotton, *Gossypium arboreum* L. (Toscano and Stern 1976); pistachio (Daane et al. 2005, Barman et al. 2017); tomato, *Solanum lycopersicum* L. (Ehler 2000); radish, *Raphanus sativus* L.; and mustard, *Brassica* spp (Ehler 2000).

Thyanta pallidovirens (Stål) (Hemiptera: Pentatomidae)

Pest Description

There are several species of *Thyanta* in the US, and they are difficult to distinguish from each other (Ruckes 1957). However, *T. pallidovirens* is believed to be a common species in nut orchards in California (Wang and Millar 1997). *Thyanta pallidovirens* adults are 9–13 mm long. They can be green or brown (Zalom et al. 2017a). The green form of adults, which are common in spring and summer, have a red stripe across the pronotum or ‘shoulder’ and usually have a pink marking on the tip of their scutellum (Zalom et al. 2017a) (Fig. 2d). The brown form is common in the fall (Zalom et al. 2017a). In general, *T. pallidovirens* can be distinguished from a similar species, *T. custator accerra* McAtee, by the presence of more rounded shoulders (the humeral angle) and a reddish transhumeral band (Rider and Chapin 1992).

Thyanta pallidovirens is native to North America and occurs in the Western USA and Southwestern Canada (i.e., Southern British Columbia) (Rider and Chapin 1992, Wang and Millar 1997). It commonly occurs in the Central Valley of California in pistachios (Barman et al. 2017).

Biology and Ecology

Thyanta pallidovirens produced an average of 23 eggs per egg mass when reared on peas and lentils (Schotzko and O’Keefe, 1990). Oetting and Yonke (1971) described the laboratory biology of *T. custator*, a species of red-shouldered stink bug in the species complex which includes *T. pallidovirens*. *Thyanta custator* eggs hatch in 5–7 d. There are five nymphal instars. Nymphs take about six weeks to emerge as adults. Nymphs have a dark reddish-brown to black body with black and white stripes on the abdomen. *Thyanta pallidovirens* overwinter as adults, resume activity in April or May, and there are two generations per year (Wang and Millar 1997).

In addition to almonds, *T. pallidovirens* feed on many non-crop and crop hosts, including peas (*Pisum sativum* L.) and lentils (*Lens culinaris* L.) (Schotzko and O’Keefe 1990); corn, sorghum, wheat, soybean, alfalfa, bean (*Phaseolus vulgaris* L.), peach [*Prunus persica* (L.) Batsch], apple (*Malus domestica* Borkh.), and pear (*Pyrus* spp.) (Panizzi et al. 2000); pistachio (Wang and Millar 1997, Daane et al. 2005, Barman et al. 2017) and tomato (Ehler 2000).

Chinavia hilaris (Say) (Hemiptera: Pentatomidae)

Pest Description

Chinavia hilaris (= *Acrosternum hilare*), green stink bug, adults are large green stink bugs (about 12–20 mm in length), with yellow margins around the thorax and abdomen and black dash-like markings on the lateral edges of the abdomen (Barman et al. 2017) (Fig. 2a). Several antennal segments have black bands, which helps distinguish adults from those of the southern green stink bug, *Nezara viridula* (L.) (Kamminga et al. 2012). *Chinavia hilaris* nymphs have five instars, young instars are black and white with red bands. In contrast, older instars are typically green and black with some red coloration, and there can be color morphs (Gomez and Mizell 2019). Eggs are usually laid on the underside of leaves, are barrel-shaped and pale in color, and deposited in a cluster of approximately 15 eggs (Da Silva and Daane 2014).

Chinavia hilaris is native to North America and is widespread from the west coast to the east coast of the United States, and is also found from the Pacific Northwest into Quebec in Canada (McPherson and McPherson 2000, Kamminga et al. 2012).

Biology and Ecology

Unlike other stink bugs, *C. hilaris* overwinters in orchards under debris such as leaf litter or on weeds in the orchard. Large numbers can overwinter and become active in spring. There are one to two generations per year, depending on the climate (Simmons and Yeargan 1988). Lab studies found that at 27.5°C females oviposited an average of three egg masses, the average egg mass size was 15.5 eggs, and the average fecundity per female was 53.5 eggs (Da Silva and Daane 2014). Egg hatch at 27°C required 7.7 d (Simmons and Yeargan 1988). The average time for a generation from egg to adult was 40.5 d (Simmons and Yeargan 1988). Female adult longevity averaged 53.5 d (Da Silva and Daane 2014).

Chinavia hilaris is polyphagous and occurs on numerous host plants, including almonds and pistachios (Da Silva and Daane 2014, Barman et al. 2017). Other host plants include cotton, tomato, and soybean, and fruit trees such as peaches, apple, and cherry (*Prunus avium* L.) (Simmons and Yeargan 1988, Kamminga et al. 2012).

Although stink bug nymphs can feed on young almonds, adult feeding is the most impactful in crop damage and crop loss. All stink bugs damage almonds by feeding with their needle-like piercing and sucking mouthparts. The mouthparts pierce developing fruit, causing direct damage such as blemishes, deformities, necrotic lesions, and premature fruit loss (Rice et al. 1985, McPherson and McPherson 2000). Also, after attack by stink bugs, nuts exude clear gumming from the puncture site, which indicates feeding has occurred; this symptom is similar to when the sap is produced after feeding by the brown marmorated stink bug (*Halyomorpha halys* (Stål)) or LFBs (Rijal and Gyawaly 2018, Joyce et al. 2019). The fruit-feeding North American stink bugs occur later in the growing season and rarely result in nut abortion (Zalom et al. 2017a).

Euschistus conspersus Uhler (Hemiptera: Pentatomidae)

Pest Description

Euschistus conspersus adults are about 12 mm long, shield-shaped, pale brown insects with reddish antennae (Beers et al. 1993) (Fig. 3). The back of the body has small black spots, and the legs have brown spots (Herbert et al. 2014). *Euschistus conspersus* bugs are believed to be native in California. They are common on the Pacific Coast (Borden et al. 1952). Some of the states where they are reported include California, Oregon, Washington, Nevada, Idaho, and British Columbia, Canada (McPherson and McPherson 2000).

Biology and Ecology

The life history of *E. conspersus* was studied and described by Hunter and Leigh (1965). Adult females lay barrel-shaped eggs in masses with an average of 19 eggs, but as many as 28 eggs per cluster and eggs are oviposited under leaves (Borden et al. 1952). Eggs are initially white and turn pink as they age. Eggs hatch in about six days into nymphs. Nymphs have five instars that last for 25–54 d, depending on the food source. Nymphs have black and white bodies and red markings on the abdomen, but their bodies turn yellowish-brown and have black markings as they develop (Beers et al. 1993).

Adults overwinter on the ground under weeds, or other vegetation, or leaf litter in and around orchards (Ehler 2000). Adults resume activity in early April. There is one generation per year in

Washington, but this species can have two generations per year in California (Alcock 1971, Borden et al. 1952).

Besides almond, *E. conspersus* feed on many cultivated and non-cultivated plant species (Borden et al. 1952). Cultivated plant hosts include many fruits and field crops such as apple and pear (Beers et al. 1993); blackberries, *Rubus* spp. (Alcock 1971); tomato (Ehler 2000); and cotton (Toscano and Stern 1976).

Monitoring and Management

The current practice of sampling these stink bugs in almonds is by conducting visual sampling. The visual monitoring for fruits with gummosis, barrel-shaped egg masses, and live bugs from May through July is recommended (Zalom et al. 2017a). These bugs, especially as nymphs, feed in groups, and damage by these bugs can be observed in nut clusters.

A pheromone has been characterized for *C. hiliaris* (McBrien et al. 2001). It should be noted that there are two genetically divergent strains of *C. hiliaris* known on the west coast and east coast of the United States (Barman et al. 2017). Genetic variation within *C. hiliaris* collections is significant (4.7%) and suggests the presence of a cryptic species (Barman et al. 2017). Pheromones have been identified and used for management in other crops (Kamminga et al. 2012). Despite the identification of the pheromone and availability of the commercial lures for these stink bugs, these are not commonly used in almonds (Zalom et al. 2017a,b). Because the first generation of these stink bugs develops in non-cultivated host plants, cultural management practices such as keeping the orchard and its vicinity as weed-free as possible may help reduce their population (Capinera 2020).

Various groups of natural enemies are observed to attack stink bugs in California. These natural enemies include hymenopteran egg parasitoids in Scelionidae, Encyrtidae, and Eupelmidae families

(Ehler 2000). Egg parasitoids of *C. hiliaris* include wasps of the genera *Trissolcus*, *Anastatus*, and *Telenomus* (Kamminga et al. 2012) and the tachinid fly *Trichopoda pennipes* (Gomez and Mizell 2019). The eggs of *C. ubleri* are parasitized by a scelionid wasp, *Telenomus utahensis* Ashmead. The parasitism by this parasitoid in Arizona was as high as 51 % on wheat and alfalfa field (Jubb and Watson 1971). Eggs of the stink bug, *T. custator* (in the *T. pallidovirens* species complex) were parasitized by *Telenomus podisi* Ashmead (Hymenoptera: Platygasteridae). Several tachinid flies are reported as the natural enemies of *T. custator* as well (Oetting and Yonke 1971). *Euschistus conspersus* eggs are reported to be parasitized by four species of scelionid parasitoids in California (Borden et al. 1952). In favorable conditions, these parasitoids can result in high egg parasitism (85%) in some systems (Borden et al. 1952). Among predators, a reduviid bug (Hemiptera) was observed attacking an adult *E. conspersus* (Borden et al. 1952). Despite these findings in various orchards in cropping systems, the role of natural enemies in effectively controlling stink bugs, specifically in almonds, is not extensively studied.

Since stink bugs are sporadic pests in almond orchards, treatment thresholds have not been developed (Zalom et al. 2017a). The general recommendation of spray for an almond orchard with a history of damage is one in-season spray of broad-spectrum insecticide every three years (Zalom et al. 2017a).

Fruit-Feeding Invasive Stink Bug

Halyomorpha halys (Stål) (Hemiptera: Pentatomidae)

Pest Description

Although *H. halys*, brown marmorated stink bug, recently gained pest status in almonds as an invasive pest (Rijal and Gyawaly 2018), it has already caused damage to almond orchards in the upper San Joaquin Valley (Rijal and Zalom 2020). Adults have marbled coloration on the upper body surface with some variation of shades from brown to black (Fig. 4). The edges of the abdomen have a black and white striped pattern. *Halyomorpha halys* adult body size varies from 12 to 17 mm long and 7–10 mm wide (Hoebeker and Carter 2003). Adults and nymphs (except the 1st instar) have two white



Fig. 3. Adult *Euschistus conspersus* (Avg. size: ~12 mm long). Source: <https://bugguide.net/node/view/1345260/bgimage>.



Fig. 4. Adult brown marmorated stink bug, *Halyomorpha halys* (Avg. size: ~15 mm long). Source: Jhalendra Rijal.

bands on their antennae and legs as one of their identifying characteristics. There are several pentatomid species (*E. conspersus* and *Brochymena* spp.) present in almonds that may resemble *H. halys*.

Halyomorpha halys is native to East Asia, particularly China, Taiwan, Japan, and South Korea (Xu et al. 2014), and has become an invasive pest outside of this range, where it occurs in the rest of the world. *Halyomorpha halys* was first detected in the eastern United States in the late 1990s (Hoebeke and Carter 2003) and has spread to over 47 U.S. states and 4 Canadian provinces (Stop BMSB 2021). *Halyomorpha halys* has also been established in various almond producing countries such as Spain, Italy, Greece, France, Turkey, many former USSR countries, and Chile (Leskey and Nielsen 2018, CABI 2020). Although detection and interceptions in ports are common, no established population of *H. halys* has been reported in Australia as of 2019 (Horwood et al. 2019). The infestation of *H. halys* in commercial almond orchards is reported in the United States only since 2017. This pest is established in residential areas of more than 16 counties in California, the major almond-producing state in the US (Lara et al. 2019). *Halyomorpha halys* was first reported in 2017 in commercial almond orchards in the Central Valley of California, where over 75% of global almond production occurs (Rijal and Gyawaly 2018, INC 2020). As of 2020, the infestations of *H. halys* in commercial almond orchards is limited to a few counties; however, this pest has been spreading and causing economic damage in multiple orchards in the area (Rijal et al. 2019a).

Halyomorpha halys attack multiple host plants (Bergmann et al. 2016, Stop BMSB 2021) which includes over 170 crops, ornamental, and landscape tree species. The major host crops include apple, peach, nectarine [*Prunus persica* var. *nucipersica* (Suckow) C. K. Schneid], pear, cherry, grape (*Vitis vinifera* L.), pepper (*Capsicum annuum* L.), tomato, sweet corn, bean, soybean, and more. *Halyomorpha halys* adults overwinter in human-made structures such as houses, barns, shops, and even in dry and dead trees during the late fall and early winter (Inkley 2012, Lee et al. 2014). Therefore, *H. halys* is also considered as a significant nuisance pest in residential areas as well.

Biology and Ecology

In spring, within two weeks after emergence, overwintering adults mate and are ready to deposit eggs on host plants. Females lay a cluster of an average of 28 eggs on the underside of the leaves of the host plant (Leskey and Nielsen 2018). A single female can lay an average of 9.3 egg masses (Nielsen et al. 2008). Eggs are initially light green and gradually become whitish near hatching. A single female can produce over 480 eggs in her lifetime (Kawada and Kitamura 1983). It takes approximately 538 degree-days (DD) (base = 14°C) for eggs to develop into adults, and after the eclosion, female adults take an additional 148 DD before depositing eggs (Nielsen et al. 2008). There are five nymphal instars. First instars have dark, reddish eyes and a yellow-reddish body with a black stripe. They do not feed and are typically clustered around the egg mass after hatching. Second to 5th instars are dark black to brown and actively walk searching for food; only the adult stage can fly. In California, *H. halys* has two overlapping generations per year (Ingels and Daane 2018).

Feeding may begin at the fruit set, which coincides with the migration of surviving overwintered adults to the orchard. *Halyomorpha halys* feeding on almonds can continue throughout the season, as suggested by the presence of adults and nymphs in almond orchards throughout the growing season (Rijal et al. 2019a). However, early-season feeding (from fruit set to before shell hardening) tends to be more destructive. Feeding by adults results in nut abortion and drop (Rijal and Zalom 2020). Feeding after shell hardening results in

gumming and dark spots on the kernel (i.e., endosperm). In almonds, internal feeding signs on the hull (i.e., epicarp and pericarp) consist of pinholes, water-soaked lesions, and necrotic spots. An exclusion cage feeding study has shown that *H. halys* can cause injury to almond kernels until harvest (Rijal et al. 2019b). Damage caused by *H. halys* and other larger hemipterans (i.e., North American native stink bugs and LFBs) are roughly similar; however, some differences can help distinguish the damage symptoms caused by these true bugs (Table 2). Similar to tree fruits (Leskey et al. 2012a, Joseph et al. 2014, Blaauw et al. 2016), the presence of adults and the crop damage in almonds have been noticeably higher along orchard edges next to the open field or in alternate hosts such as the tree of heaven, *Ailanthus altissima* (Mill.) Swingle (Rijal et al. 2019b).

Monitoring and Management

Ground-deployed pyramid traps and sticky panel traps, baited with *H. halys* aggregation pheromone and the pheromone synergist, methyl decatrienoate, are used to monitor *H. halys* adults and nymphs in multiple cropping systems across the United States (Leskey and Nielsen 2018, Acebes-Doria et al. 2018, Acebes-Doria et al. 2020). In almonds, the current recommendation is to use the sticky panel trap for *H. halys* detection and seasonal monitoring (Rijal et al. 2019b, Rijal and Zalom 2020). The sticky panel (22.8 cm × 30.4 cm; double-sided sticky) can be affixed to the top of a 5-ft long wooden stake, 1-ft of which is pounded into the ground. The commercial *H. halys* dual lure (Trécé, Inc., Adair, OK, USA) is suspended on top near the sticky panel. A minimum of three traps is recommended in a border-tree row facing parallel to the open field and other potential overwintering shelters.

It is crucial to scout for this pest and its damage in the almond orchard regularly. Visual samplings of *H. halys* (eggs, nymphs, and adults), beat-tray sampling, and infested fruits, preferably in trees in the edges, are essential for early detection of the *H. halys* invasion in an almond orchard. *Halyomorpha halys* population overwintering near farmland seems to be the primary source of orchard infestation. Therefore, any activity targeted to minimize the overwintering sites such as human-made structures and woodpiles can help reduce *H. halys* abundance in the orchard during the following season. Rijal and Zalom (2020) recommended removing wild hosts such as

Table 2. Summary of large Heteropteran bug feeding damage symptoms in almond orchards in California, USA

Description	Native Stink Bugs	Leaffooted Bug (LFB)	Brown Marmorated Stink Bug (BMSB)
Gummosis (clear gumming)	Multiple gumming spots per nut: thread-like gumming	1–2 feeding spots per nut: thread-like gumming	Multiple gumming spots per nut: 'glob-like' gumming
Nut drop	Not common	Common (Mar.-May)	Common (Mar.-early May)
Kernel damage	Wrinkled or dark spots. Late-season feeding may not damage kernel	Aborted, gummy or sunken dark spots	Aborted, gummy or sunken dark spots

Source: Modified from Rijal and Zalom (2020).

the tree of heaven, *Ailanthus* spp., as they tend to support *H. halys* populations and become a source for orchard infestation throughout the season (J.P.R., unpublished data).

Several generalist arthropod predators and parasitoids are reported to provide biological control services by attacking *H. halys* and their egg masses in various agroecosystems (Morrison et al. 2016, Abram et al. 2017, Jones et al. 2017). These natural enemies include assassin bugs, ground beetles, lady beetles, jumping spiders, praying mantis, earwigs, ground beetles, big-eyed bugs, damsel bugs, and some species of crickets and katydids that are also present in the California landscape (Dreistadt 2014, Lara et al. 2016). Although these predators are reported to attack other hemipteran bugs and *H. halys* in various parts of the U.S., their impact in reducing the population tends to be minimal. A generalist egg parasitoid, *Anastatus pearsalli* Ashmead was recovered from sentinel egg masses of *H. halys* deployed in urban areas of California (Lara et al. 2016), but the rate of parasitism is negligible. A specialist *H. halys* egg parasitoid, *Trissolcus japonicus* (Ashmead), or the samurai wasp, has high parasitism (up to 70%) in its native range (Yang et al. 2009). In the United States, *T. japonicus* has been found in several states from east to west where *H. halys* has been established (McIntosh et al. 2019). The samurai wasp was recently detected in an urban setting in southern California (Lara et al. 2019). The potential commercial release of this egg parasitoid in almond orchards in the future may help reduce the impact of *H. halys* in California.

Several insecticide groups that include pyrethroid, organophosphate, neonicotinoid, and a few others are effective against *H. halys* in various fruit tree fruit species (Leskey et al. 2012b, Bergh et al. 2016). However, *H. halys* is a new pest, and pest control options to control *H. halys* in almonds are still being developed. Multiple insecticide applications may be required due to overlapping generations and the extended period of the movement of overwintering adults into the orchard from spring through summer. As a part of the IPM program, Rijal and Zalom (2020) suggested some conventional (pyrethroids, neonicotinoids) and organic alternatives (i.e., pyrethrin, azadirachtin, and spinosyn-based insecticides) to manage *H. halys* in almonds. However, most of these insecticides are broad-spectrum and are a poor fit in an IPM program, especially when applied early in the growing season, because of their negative impacts on natural enemies and other beneficial fauna in the orchard.

Fruit-Feeding Occasional Plant Bugs

At least five species of plant bugs may be present and attack almond fruits, although they rarely cause any economic damage. These include four mirid species (Hemiptera: Miridae): western tarnished plant bug, *Lygus hesperus* Knight; *Calocoris norvegicus* (Gmelin); *Phytocoris californicus* Knight; *P. relativus* Knight; and the western boxelder bug, *Boisea rubrolineata* (Barber) (Hemiptera: Rhopalidae) (Fig. 5a-d). These insects are much smaller in overall size than the above described native stink bug species, and their shorter mouthparts suggest their feeding results in less severe damage to the fruits (Daane et al. 2005). However, detailed roles of various parts of the Heteropteran mouthparts to the nature and degrees of host damage have not been fully understood even for many economically important hemipterans (Esquivel 2019).

Pest Description

In North America, *Lygus hesperus* is commonly found in southwestern Canada, the southern and western United States, and the northern part of Mexico (Schwartz and Footitt 1998). Adults are brown to green with a yellow triangular area on the back (Beede et al. 2020) (Fig. 5a). Adult males are 4.25–4.99 mm long, and females are 4.33–5.24 mm (Schwartz and Footitt 1998). Known as the western tarnished bug, *L. hesperus* is highly polyphagous, has over 100 plant host species, and is multivoltine (Wheeler 2000). *Lygus hesperus* is a common pest of crops such as alfalfa, beans, strawberry (*Fragaria ananassa* Duch.), and weeds such as Russian thistle (*Salsola kali* L.), London rocket (*Sisymbrium irio* L.), and lupine (*Lupinus albus* L.). If weed hosts are present and conditions favorable, they may move into the almond orchard in the spring and be a population source for other crops such as cotton (Goodell and Ribeiro 2006). Sufficient rainfall and a cooler spring promote weed growth and buildup of the population. They only tend to attack almonds when other hosts are unsuitable for feeding (Beede et al. 2020).

Calocoris norvegicus is native to Europe but was introduced into both coasts of North America as early as the 1880s (Wheeler 2000). Adults are mostly green on top and have two small black dots on the pronotum (Scudder and Footitt 2006). The membranous portion of the forewing is dusky brown, giving a 'dark-tailed' appearance (Scudder and Footitt 2006). Adult size ranges from 6 to 8 mm (Scudder and Footitt 2006, Beede et al. 2020). *Calocoris norvegicus*

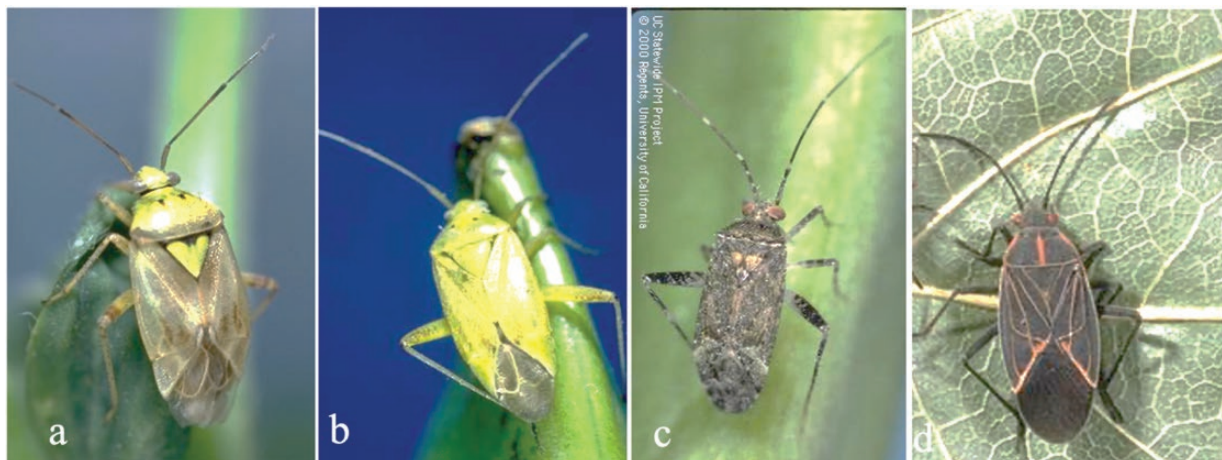


Fig. 5. Fruit-feeding occasional plant bugs, a) *Lygus* bug (Avg. size: ~2.5 mm long); b) *Calocoris* sp. (Avg. size: 6.5 mm long); c) *Phytocoris* sp. (Avg. size: 6.5 mm long); d) *Boisea rubrolineata* (Avg. size: 12.7 mm long). Source: Jack Kelly Clark, University of California Statewide IPM Program.

is a univoltine in Europe (Wheeler 2000) and the almond and pistachio growing Central Valley region of California in the United States (Michailides et al. 1987, Purcell and Welter 1990). A *C. norvegicus* population was found from March through May in vegetation surrounding pistachio orchards (Purcell and Welter 1990). *Calocoris norvegicus* may cause petal distortion and flower drop when they feed on almonds before fruit set (Lodos 1980). This pest has a wide host range. Some important hosts in California are white clover (*Trifolium repens* L.), lupine, curly dock (*Rumex crispus* L.), alfalfa, morning glory (*Ipomoea purpurea* (L.) Roth), wheat, wild mustard (*Sinapis arvensis* L.), wild vetch (*Vicia sativa* L.), and wild radish (*R. raphanistrum* L.) (Purcell and Welter 1990).

Adult *Phytocoris californicus* are 5–8 mm long and are dark gray to light brown, mottled with yellow, white, or dark brown spots (Fig. 5c) (McLeod 2020, Beede et al. 2020). They have long antennae and legs and tend to move fast upon disturbance. They feed on weed hosts and occasionally become a pest in almonds. Although their impact is negligible, *Phytocoris* can also prey on immature scale insects and navel orangeworm eggs, especially in the spring in March–April (Beede et al. 2020).

Boisea rubrolineata adults are larger (12 mm long, 8.5 mm wide) than the mirid bugs described above. Adults have a gray to black body and have three red lines on the thorax (one in the middle and one on the two margins each) (Fig. 5d). *Boisea rubrolineata* is the primary pest of the boxelder tree, *Acer negundo* L. Still, it can also feed on almonds, especially during the early nut development period, and may cause some damage. In one instance, *B. rubrolineata* was reported to infest almond fruits, damage kernels, and cause nut abortion resulting in up to 20% almond damage in an orchard in northern California (Michailides et al. 1989).

Monitoring and Management

Plant bugs of the family Miridae and Rhopalidae can be present in and around almond orchards, mostly in weed hosts. They occasionally migrate to the orchards and feed on young almond fruits. Feeding by these smaller bugs results in nut abortion, and in some

cases, kernel damage. However, the impact of feeding is minimal. Orchards close to the river and those with other hosts may have western boxelder bugs become a problem (Michailides et al. 1988).

As these bugs rely on weeds and other vegetation to build the population before moving into the orchard, the best way to manage these bugs is by properly managing the grass and other vegetation in and around the orchard (Goodell and Ribeiro 2006). Also, paying attention to these bugs early in the season may help spot the problem if the orchard has a history of damage by these minor pests. Small hemipteran bugs can be sampled using beating tray sampling and conducting visual inspections of the bugs and nut damage. Economic thresholds for these small plant bugs feeding on almonds are not established as they rarely cause economic damage or need any control or intervention. Unless numbers are very high, and the orchard has a history of damage, especially the early part of the season, insecticides are not recommended to control these minor pests.

Leaf-Feeding Plant Bugs and Other Future Potential Pests

Nysius raphanus Howard (Hemiptera: Lygaeidae)

Pest Description

Nysium raphanus, false chinch bug, adults are small (3.2 mm - 4.2 mm long), grayish bugs with numerous short hairs on the body, and black eyes (Fig. 6a). They have 4-segmented antennae (Howard 1872, Haviland and Bentley 2010). The forewings are partly leathery and partly membranous, and they form a clear X-shape on the back of the body when wings are at rest. Other similar-looking bugs are big-eyed bugs, *Geocoris* spp. However, big-eyed bugs are predators in the family Geocoridae, and are not present in abundance in almond orchards. Big-eyed bugs are oval, somewhat flattened, and have wide bulging eyes (Haviland and Bentley 2010).

Nysium raphanus is believed to be native to the Great Plains regions, as it was first described from Kansas in the early 1870s (Howard 1872). Since that time, *N. raphanus* has been incorrectly



Fig. 6. leaf-feeding occasional plant bug, a) *Nysius raphanus* (Avg. size: ~3.0 mm long), and future potential hemipteran pest, *Monosteira unicastate* (Avg. size: ~2.5 mm long). Sources: Jack Kelly Clark, University of California Statewide IPM Program; Ukrainian Biodiversity Information Network (http://ukrbin.com/show_image.php?imageid=64878).

referred to as *N. niger* Baker, *N. tenellus* Barber, *N. ericae* (Schilling), *N. strigosus* Uhler, and *N. minutus* Uhler (Sweet 2000). Historically, this species has been associated with plants of cruciferous and composite families and reported from several states such as Kansas, Texas, Florida, Missouri, and Arizona (Sweet 2000). In California, *N. raphanus* was reported as a cotton pest, but referred to as *N. minutus* (Smith 1942).

Biology and Ecology

Nysium raphanus overwinter as adults and nymphs, probably at their late developmental stage, under dried vegetation, weeds, and other debris in the almond growing region of California, and it is considered an occasional pest. In the spring, emerging nymphs and adults begin to feed on the leaves of early weed hosts (preferably mustard family), and increase their population. Females lay eggs in the soil, in flowers of weeds, or on leaves, depending on the hosts' availability. Eggs hatch in a few days, and nymphs may develop through five instars before becoming adults. There are multiple generations per year. Adults can fly long distances, and once their weed hosts dry up, they can aggregate on irrigated crops, including almonds, and feed on the leaves and twigs (Haviland and Bentley 2010). For most years, *N. raphanus* is not a major concern in almonds as they primarily feed on weeds and other host plants that may be present on the orchard floor and edges. Both adults and nymphs insert their stylets and feed on host plants. Barnes (1970) suggested that nymphs inject salivary toxins in the feeding process based on the observations in grapes. When *N. raphanus* are highly abundant, they can cause injury to young almond orchards. In rare events, the feeding damage by thousands of these bugs may result in the plant wilting, then tree decline. The risk to the young almonds is higher in July-August when other vegetations and weed hosts dry up (Haviland and Bentley 2010). *Nysium raphanus* may be a problem in California almond orchards in years with a wet, cool spring due to heavy weed flush and growth. Almond is a secondary host of *N. raphanus*. Primary hosts include plants of the mustard family—radish, canola (*Brassica napus* L.), London rocket, and mustard greens.

Monitoring and Management

Since *N. raphanus* is a sporadic and occasional pest in almonds, an economic threshold has not been established for this bug. For young trees, invasion in mass numbers of *N. raphanus* can kill the trees (Haviland and Bentley 2010). Therefore, it is vital to protect young trees. Specific recommendations to control this insect in mature orchards are not available as the insects may not be economically damaging the crop despite their feeding.

Monosteira unicostata (Mulsant & Rey) (Hemiptera: Tingidae)

Pest Description

Monosteira unicostata is one of the major pests in almond growing Euro-Mediterranean region, but this pest has not been established in the two major almond-producing countries - the United States and Australia. Since this pest has been reported in British Columbia, Canada (Scudder 2013), and recently in Argentina (Carpintero et al. 2017), and in Chile (Campodonico et al. 2021), this pest could be a potential threat to almonds in the future globally. *Monosteira unicostata* is also commonly referred to as the false tiger bug or almond lace bug. As the name suggests, the bug has a lacy appearance formed from the reticulated forewings and unique pronotal outgrowth (Talhouk 1977, Neal and Schaefer 2000). Adults are 2.0 - 2.8 mm long, 0.65 - 0.70 mm wide, and pale brown bugs with a

black ventral side (Fig. 6b). The head is reddish-brown with prominent eyes and has four-segmented antennae (Talhouk 1977). The hemelytra are heavily reticulated and have small brownish spots along their margins (Neal and Schaefer 2000). For nymphs, 1st to 2nd instars are dark-brown, while later instars (3rd - 5th instars) are lighter in color and have wing pads.

Monosteira unicostata occurs in the Euro-Mediterranean region, North Africa, and some parts of Asia (Drake and Ruhoff, 1965, Péricart 1983, Tolga and Yoldas 2019). There are at least two species of *Monosteira* (*M. lobulifera* and *M. unicostata*) that can cause damage in almond orchards in countries such as Iran, Syria, Lebanon, and Turkey (Talhouk 1977, Bolu 2007, Baspinar et al. 2018). *Monosteira unicostata* is the more widespread species (Talhouk 1977, Liotta and Maniglia 1994, Russo et al. 1994, Sánchez-Ramos et al. 2017a, Baspinar et al. 2018).

Biology and Ecology

Monosteira unicostata overwinters as an adult under fallen litter on the ground, on weeds, and almond tree barks (Talhouk 1977, Liotta and Maniglia 1994). In spring, overwintered adults resume activity and begin to feed on young leaves. Females deposit eggs inside leaf tissues of almonds, and cover the surface by female anal excretions (Talhouk 1977, Liotta and Maniglia 1994, Baspinar et al. 2018). After hatching from the eggs, nymphs feed on the underside of the leaves. Nymphs have five stages (instars), and they feed on the underside of the leaves (Sánchez-Ramos et al. 2014, Neal and Schaefer 2000). Depending on the geographic regions, there are 2–4 generations per year, and the later generations are more damaging due to high insect abundance (Sánchez-Ramos et al. 2014, Baspinar et al. 2018). Adults and nymphs can infest the orchard simultaneously as generations tend to overlap (Péricart 1983). Individual generation time takes from 3 to 7 wk depending on geographic region (Talhouk 1977, Sánchez-Ramos et al. 2014).

Monosteira unicostata has piercing and sucking mouthparts with which adults and nymphs feed on almond leaves. They suck the chlorophyll content of leaves, especially the abaxial surface (underside), resulting in 'stippling' (scattered whitish spots) on the leaf. Severely infested leaves turn brown, brittle, and ultimately fall from the tree. A large number of nymphs and adults may feed and deposit a copious amount of bug excrement on the leaf. Direct feeding damage and frass deposition can ultimately reduce almond yield by interfering with the plant's photosynthesis and transpiration (Liotta and Maniglia 1994, Sánchez-Ramos et al. 2017b). A dry environment is favorable for *M. unicostata* reproduction and survival; therefore this pest is less severe in coastal and humid regions of its native range (Talhouk 1977). Peak adult activity and leaf damage by *M. unicostata* occur between mid-summer through early fall in Turkey (Tolga and Yoldas 2019). In Italy, the first generation which population is less abundant, begins when the almond fruit gains the full size, but the second and overlapping third generations individuals in July-August cause excessive damage, including significant leaf drops (Neal and Schaefer 2000). Besides almond, *M. unicostata* can attack plants that include both fruit (e.g., cherry, peach, plum, (*Prunus domestica* L.), pear) and forest trees (e.g., poplar, [*Populus tremula* L.] and willow, [*Salix alba* L.]) (Sánchez-Ramos et al. 2014).

Although *M. unicostata* can damage all varieties of almonds in Europe, some are less susceptible than others. Russo et al. (1994) reported that 'Tuono' cultivar is highly susceptible compared to other cultivars such as Nonpareil, Texas, Vinci a tutti, and Ferragnes, while 'Pizzuta d'Avola' is considered a tolerant variety.

Monitoring

Specific traps and lures are not available for monitoring *M. unicolorata* in almonds. Methods for determining pest presence include scouting for the different life stages of the pest on the leaves, conducting beat tray sampling, and visual inspection of the damage on the leaves (Tolga and Yoldas 2019). Beat tray sampling is common practice for many hemipteran bugs. This method consists of gently hitting the tree branches and twigs using a stick to dislodge insects to a piece of the cloth (i.e., 40 cm × 40 cm) stretched across a frame.

Conclusion and Future Directions

A number of hemipteran species can be pests of almonds. However, information on Hemiptera associated with almonds comes largely from research of these insects on other crops and host plants. Economic thresholds do not exist for any of the species discussed. Current management relies on visual observations of large numbers of almonds with gummosis (sap) and/or almond drop early in the season. Beating tray samples of hemiptera and sticky traps may help determine the presence or absence of hemiptera species, but quantifying damage present in orchards with insect abundance would provide information to develop an economic threshold and would advance IPM. The native stink bugs, leaf-footed bugs, and invasive brown marmorated stink bug have longer piercing stylet mouthparts than the smaller hemipterans such as *Calocoris* may inflict more damage on almonds since developing fruit is susceptible to these larger bugs for a more extended period during the growing season. The differences in stylet size, and consequently the stylet penetration potential, could be considered when determining which hemiptera are key pests affecting almonds. Also, the seasonal abundance of these hemipteran pests, other host crops near almond orchards, insect migration and dispersal ability can make some species more important than others.

IPM of hemipterans in almonds will likely vary in conventional and organic production systems due to factors such as whether broad-spectrum pesticides are used, which may reduce natural enemies of Hemiptera. Moreover, conventional and organic farms may vary in the composition of hemiptera due to the presence or absence of on-farm vegetation such as cover crops and border plantings which harbor natural enemies and promote biological control. Hemipteran abundance may also be influenced by the management of other pests such as navel orangeworm (NOW), a primary pest of almonds in the United States. NOW management can be through winter sanitation of the orchard to remove last season's infested almonds, conventional insecticides, mating disruption, or early harvest of the nuts.

Climatic conditions vary in different regions of almond production. In California, the west side of the Central Valley is drier than the east side. The southern portion of the Central Valley is much drier than the mid-to-north Central Valley. This may influence which Hemiptera are more abundant in each area and during the year.

Future research focusing on investigating the seasonal abundance and geographic distribution of key hemipteran pests in almond orchards is needed to develop IPM practices of these insects. Several external factors, such as ground vegetation, almond variety, the proximity of orchards to alternative hosts or riparian areas, etc., can influence the abundance of hemipterans in almond orchards. Moreover, these pest compositions can vary based on the production practices (i.e., conventional and organic) and other pest (e.g., navel orangeworm) management practices. Ultimately, the IPM of

hemipterans in almonds could be advanced by determining key hemipteran pests of almond and their economic thresholds, identifications of natural enemies of key hemipteran, and development of pest management tactics specific to those pests.

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