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Research

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Development and Field Validation of a Beta-cyfluthrin-Based 'Attract-and-Kill' Device for Suppression of Asian Citrus Psyllid (Hemiptera: Liviidae) on Residential Citrus

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Abstract

An 'attract-and-kill' (AK) device was evaluated for suppression of adult Asian citrus psyllid, *Diaphorina citri* Kuwayama (Hemiptera: Liviidae), on residential citrus. The AK device, made from weather-resistant plasticized PVC, lured *D. citri* adults by simulating the color of citrus flush and killed them with beta-cyfluthrin. This study evaluated: 1) lethality of AK devices weathered up to 8 wk on residential citrus; 2) survival of psyllids caged with potted plants and AK devices; 3) psyllid suppression achieved by AK devices on individual dooryard trees. AK devices weathered for up to 8 wk remained lethal to psyllids. Greenhouse trials evaluated survival of adult psyllids caged for 4 d with orange jasmine plants that were: 1) treated with an (beta-cyfluthrin-infused) AK device; 2) treated with a blank (no insecticide) AK device; or 3) 'untreated' with no AK device. After 4 d, psyllid survival was on average 95% lower among adults exposed to plants with AK devices than adults exposed to untreated plants or plants with blank AK devices. Less than half of the adults exposed to plants with AK devices were alive after 1 d and nearly all were dead after 4 d. Deployment of 20 AK devices per tree provided significant psyllid suppression on infested lemon trees from winter to summer and reduced mean reproduction (cumulative eggs) by 91% and mean attack intensity (cumulative psyllid-days) of adults by 59% and nymphs by 53%. AK devices could be an effective control option for *D. citri* in urban areas.

Key words: Asian citrus psyllid, attract-and-kill, huanglongbing, invasive species, integrated pest management

Attract-and-kill (AK) strategies have great potential for the management of invasive insect species (EL-Sayed et al. 2009). Behavior-based control tactics, such as AK devices, are desirable because they can target specific pest insects, reduce insecticide inputs, and minimize risks to beneficial arthropods (Rahman and Broughton 2016, Rice et al. 2017). AK devices could provide environment-friendly and sustainable control of the Asian citrus psyllid, *Diaphorina citri* Kuwayama (Hemiptera: Liviidae), in settings where conventional chemical control is problematic such as residential areas.

Diaphorina citri is a world-wide pest of citrus that invaded Florida in the 1990s and has spread to other U.S. citrus growing regions (see Hall et al. 2012 for summary of geographical distribution and invasion history). Nymphs and adults of *D. citri* vector *Candidatus* Liberibacter asiaticus Jagoueix, Bové, and Garnier 1994 (Rhizobiales: Phyllobacteriaceae), a phloem-limited bacterium which is the putative causative agent of citrus greening disease or huanglongbing (HLB) (Bové 2006, Gottwald 2010). HLB causes foliage dieback, inferior fruit quality, yield reduction, and eventually tree death (da Graça 1991). Control of *D. citri* is essential for reducing HLB incidence and spread.

Area-wide pest management (AW-PM) programs rely heavily on insecticides for control of *D. citri* in commercial citrus groves. However, effective and sustainable psyllid control is also needed for urban areas. Citrus and rutaceous host plants for *D. citri* and *Ca.* L. asiaticus (CLas) are widely used as ornamental flora in the United States (Damsteegt et al. 2010, Sétamou et al. 2016a). Spread and establishment of *D. citri* and CLas across the residential landscapes of South Texas and Southern California pose a serious threat to nearby citrus groves (Sétamou et al. 2012, Richards et al. 2014, Bayles et al. 2017).

In Southern California, treatment of psyllid-infested dooryard citrus trees with conventional insecticidal sprays was unsustainable due to high treatment costs, property access issues, and public opposition (Hoddle and Pandey 2014). Introduced parasitoids and native predators currently provide insufficient control of *D. citri* in urban areas of Southern California or South Texas because parasitism and predation rates are highly variable and the impact on psyllid populations is low during seasons when nymphs are scarce (Kistner et al. 2016a, 2016b; Flores and Ciomperlik 2017). AK devices that target *D. citri* will complement psyllid control by natural enemies in residential citrus.

AK devices usually lure pest insects to a discrete point source for elimination by an insecticidal formulation. The lure component can be visual-, olfactory-, or feeding attractants that induce targeted pest insects to contact or ingest the formulation. AK devices have been developed for various invasive pest insects of fruit trees and berry crops (Mangan and Moreno 2007, Stelinski and Czokajlo 2010, Wright et al. 2012, Navarro-Llopis et al. 2013, Huang et al. 2014, Rahman and Broughton 2016, Morrison et al. 2016a, Rice et al. 2017). Advantages of these devices over canopy sprays of insecticides include: 1) use of pest-specific attractants to reduce nontarget effects and amount of insecticide needed to treat an area; 2) use of physical components or chemical stabilizers to prolong the efficacy of insecticidal formulations; and 3) less intrusive and problematic deployment in urban settings.

Studies on the use of AK systems for control of *D. citri* in urban areas are limited. Chow et al. (2018) reported significant suppression of *D. citri* on residential citrus trees in South Texas by a dispenser (autodisseminator) that visually attracts adult psyllids to infect and kill them with the PFR-97 (Certis, United States) microbial insecticide, a blastospore formulation of the Apoka 97 strain of *Isaria fumosorosea* Wize (Hypocreales: Cordycipitaceae). Deployment of a single PFR-97 dispenser per tree was effective for suppressing high to moderate levels of psyllid infestations on dooryard trees. However, due to decline in the pathogenicity of *I. fumosorosea* (*Ifr*) spores over time, the dispensers required replacement every 2 wk. An AK device that uses a durable insecticidal formulation to kill adult psyllids is needed to prolong *D. citri* suppression in residential landscapes.

In this study, we conducted greenhouse trials and field trials that evaluated the efficacy of a beta-cyfluthrin-based AK device for *D. citri* suppression on dooryard citrus trees in the Lower Rio Grande Valley of South Texas. The aims of this study were to evaluate: 1) lethality of AK devices over time on residential citrus; 2) survival of *D. citri* adults exposed to AK devices under controlled conditions, 3) effectiveness of AK devices for psyllid suppression on dooryard trees.

Materials and Methods

AK Device

The AK device, conceived and developed by M. Sétamou (M. Sétamou, unpublished data) and manufactured by Alpha Scents Inc. (West Linn, OR), was an isosceles triangle (14.5 cm base with 10.5 cm sides) made of weather-resistant, plasticized polyvinyl chloride (PVC) treated with a pyrethroid insecticide, beta-cyfluthrin, and UV stabilizers (Fig. 1). Because this device constitutes a proprietary technology, the authors are unable to disclose detailed compositions while regulatory approval is pending. The device had six flaps and was colored the same lime-green hue as the 'ACP Trap' (Alpha Scents Inc.), a color that is visually attractive to *D. citri* because it mimics the color of citrus flush (Hall et al. 2010) (Fig. 1). Adult psyllids came into contact with the insecticide when they landed on and walked along the flaps. To deploy individual or multiple AK devices on dooryard trees, a jute twine was knotted through a hole near the top of each device and the twine was tied around a branch at both ends (Fig. 1).

Study Sites

Magic Valley Park, a recreational vehicle and mobile home park, in Weslaco, TX, was selected as a study site because it had residential lots planted with mature trees (>20 yr of age) of navel orange (*Citrus* × *sinensis* Osbeck) and Meyer lemon (*Citrus* × *limon* Burm.). Trial trees were standardized for size (3.0–4.0 m in height) and remained untreated with fertilizers or pesticides during the study. To minimize

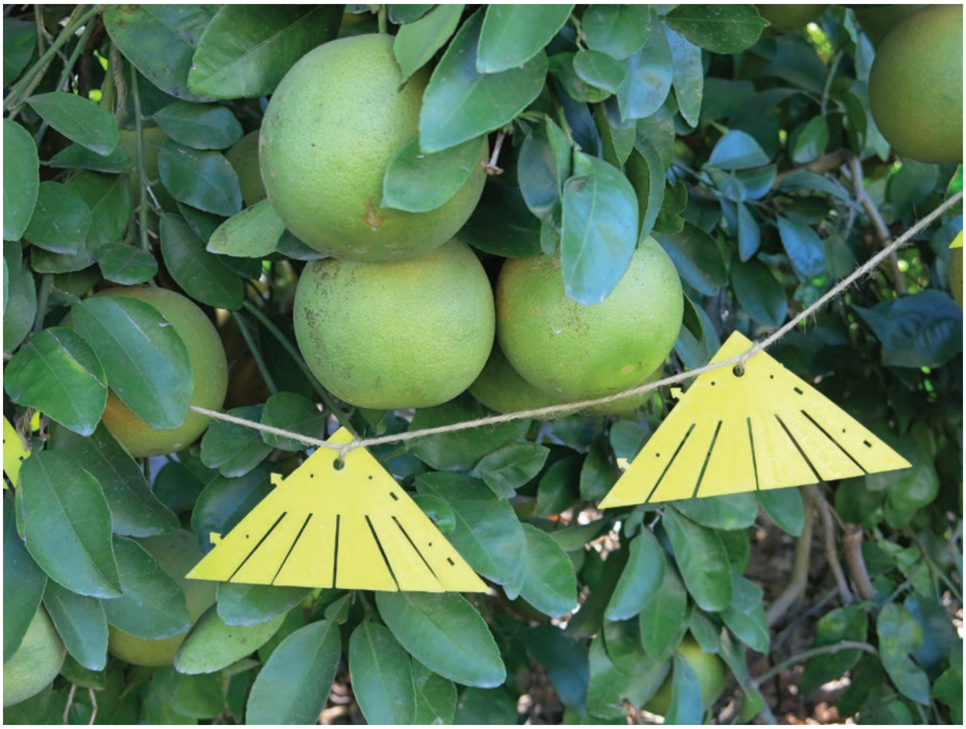

Fig. 1. String of beta-cyfluthrin-treated AK devices in a tree canopy.

contamination between treatments, all trial trees were separated by a distance of at least 30 m, by one or more non-treated buffer trees, and also one or more residential structures. Daily temperature and relative humidity at the perimeter of tree canopies were monitored by HOBO data loggers (U23 Pro v2 Series, Onset Computer Corporation, Bourne, MA). The data recorded by the HOBOs were used to prepare summaries for temperature and humidity within tree canopies at all study sites for the duration of the field trials (Supp. Tables 1 and 2 [online only]).

Cage Trial Plants

Orange jasmine, *Murraya exotica* (L.) Millsp cv. 'Lakeview' was used for rearing *D. citri*. Three- to four-year-old plants were grown in plastic pots (8.5 liters) with a commercial potting mixture (Sunshine Mix 4 Aggregate Plus, Sungro Horticulture, Agawam, MA). These plants were pruned to promote production of young flush shoots and insecticidal soap was used as needed to control pest insects or mites. Plants used for cage trials had canopies that were around 60 cm in height and 30 cm in diameter.

Insect Colonies

Adult psyllids for laboratory bioassays or greenhouse cage trials were collected from insectary colonies at the Texas A&M University-Kingsville Citrus Center. The *D. citri* colonies were established from field-collected individuals in 2006, maintained on potted orange jasmine that were trimmed, fertilized and watered as needed in temperature and light controlled rooms set at 25°C and a 14:10 (L: D) h photoperiod. These psyllid colonies were tested for CLas and confirmed to be disease-free before the adults were used for bioassays or cage trials.

Effects of Weathering Time on Lethality of AK Devices

A field trial was conducted to evaluate the effect of weathering on the lethality of AK devices over time. A navel orange tree at Magic Valley Park was selected for an 8-wk trial completed during the spring (24 February 2016 to 21 April 2016). To maximize the effect of wind exposure, the AK devices were deployed on the east side of the tree canopy, which was exposed to prevailing winds. Three strings of AK devices were hung 1.0–1.5 m high along the canopy perimeter. Each string consisted of five AK devices spaced 15 cm apart along the jute twine (108 cm in length).

One string of AK devices was recovered at 2, 4, or 8 wk after deployment. A 3.0 cm by 1.5 cm strip was cut from a recovered AK device and placed in a 1.5 ml centrifuge tube. Adult psyllids were individually released into the tube for 5-, 15-, or 60-s exposures to the strip. Following each exposure interval, the psyllids were transferred to clear plastic Petri-dishes and survival times were recorded. All Petri-dishes with psyllids were held under fluorescent lighting in temperature-regulated rooms set at 23°C.

One bioassay set of 25 adult psyllids was completed for each of the nine different combinations of weathering time and psyllid exposure time. At the start of the trial, baseline lethality of the beta-cyfluthrin-treated PVC was determined by exposing 25 adult psyllids for 5, 15, or 60 s to strips from fresh, not weathered, AK devices.

Survival of *D. citri* Adults Caged With Orange Jasmine and AK Devices

From 15 September 2016 to 16 December 2016, cage trials were conducted in a temperature-regulated greenhouse at the Texas A&M University-Kingsville Citrus Center to assess the efficacy of AK devices against adult psyllids under controlled conditions. Twenty adult psyllids were released into individual cages (75 cm in width by 75 cm in depth by 115 cm in height, BugDorm-2400F Insect Rearing Tent, MegaView Science Co., Taichung, Taiwan) (Fig. 2a) each containing a potted orange jasmine plant. There were three treatments for individual plants: 1) treated with an (beta-cyfluthrin-infused) AK device; 2) treated with a blank (no insecticide) AK device; or 3) 'untreated' with no AK device (Fig. 2b). White butcher paper was laid over the soil, around the trunk of each plant, and at the base of the cage to facilitate recovery of dead adult psyllids (Fig. 2b). Every 24 h over four consecutive days, the dead adults in each cage were removed and sexed. Precautions were taken to minimize escape of live adults from cages during cadaver removal. On the fourth day, all live adults were removed from each cage, killed by freezing and then sexed. Each of the three treatments was replicated 11 times. All insects and plants were subjected to natural light and seasonal diurnal cycles. Daily temperature and relative humidity within the cages were monitored by HOBO data loggers and within known ranges for ACP activity and survival (mean ± SE = 23.6 ± 0.3°C and 81.0 ± 0.7% RH).

Suppression of *D. citri* on Lemon Trees With AK Devices

AK Device Deployment

A field trial was conducted at the Magic Valley Park to evaluate suppression of *D. citri* via AK devices. Flushing lemon trees were selected for a 28-wk trial conducted from 12 January 2017 to 26 July 2017. This period was selected because three discrete flush cycles corresponding to peaks in *D. citri* populations are generally observed in residential citrus (Arredondo 2009). The canopy of each trial tree was divided into north, south, east, and west quadrants. AK devices were deployed in assigned trees at the start of the trial and replaced every 8 wk. For each canopy quadrant, a single string of five AK devices was hung approximately 1.5 m high at the canopy perimeter (total AK devices per tree = 20) (Fig. 3). Each string consisted of five AK devices spaced 15 cm apart along the jute twine (108 cm in length). Four strings of AK devices was sufficient to completely encircle the canopies of the trial trees. AK devices were not deployed on control trees. The two treatments were each replicated on four different lemon trees (total trees = 8).

Psyllid Population Monitoring

The four canopy quadrants of each lemon tree were monitored for *D. citri* adults and nymphs on the first day of the trial and then every other following week. Stem-tap samples for adult psyllids and visual samples for nymphs were taken in each quadrant. For each stem-tap sample, a white sheet (21.5 cm in width by 27.5 cm in length) was held horizontally under a selected branch that was tapped three times and the number of adult psyllids that fell onto the sheet was counted. For each visual sample, all *D. citri* nymphs and eggs on a selected flush shoot were counted. Efforts were made to select young flush shoots but often only mature shoots were present. Two stem-tap samples and two flush shoots were randomly taken from the north or south quadrants but three samples of each type were taken from the larger east or west quadrants (total stem-tap samples per tree = 10; total visual samples per tree = 10). Psyllid monitoring and trials were terminated after the trees were hedged and skirted by landscaping crews at the end of July 2017.

Statistical Analysis

All data analyses, except where noted, were performed using SigmaPlot 12.5 Exact Graphs and Data Analysis software package

Fig. 2. (a) Cages used for greenhouse trials with *D. citri* adults and (b) AK device on a potted orange jasmine plant.

(Systat Software 2013). The Gehan-Breslow test was used to compare survival curves for adult psyllids exposed to PVC strips cut from AK devices and the Holm-Sidak test was used for pair-wise comparisons of treatment groups. Linear regression was used to estimate the rate at which survival times of adult psyllids increased with prolonged weathering of the AK devices. The number of live *D. citri* adults left in a cage on the first, second, or third day was calculated by subtracting the cumulative number of dead adults (up to that day) from the total number of dead or live adults recovered from that cage by the end of the trial (fourth day). 'Psyllid survival' was the proportion

Fig. 3. Deployment of AK devices on a residential lemon tree.

of adults that were still alive on a given trial day. 'Sex ratio' was the proportion of males among all the adult psyllids recovered from a cage over the 4 d of a trial. The Kruskal–Wallis test was used to compare total numbers of adults recovered per cage, psyllid survival, and sex ratio among treatments and the Student–Newman–Keuls test was used for pair-wise comparisons of treatments.

To better assess the effectiveness of AK devices for reducing *D. citri* populations over time on lemon trees, numbers of adults or nymphs recorded per tree over sampling periods were expressed as cumulative psyllid-days. This technique combines the number of observed psyllids and their persistence (time) on a tree into a single measure or index of pest attack intensity (see Ruppel 1983, Sétamou et al. 2016b for procedure). The IBM SPSS 25.0 Statistics for Windows software package (IBM Corporation 2017) was used to perform χ^2 tests on numbers of adult psyllids at the start of the trial and effects of AK treatments on cumulative numbers of psyllid eggs (reproduction) or cumulative psyllid-days (attack intensity) of adults or nymphs.

Results

Effects of Weathering Time on Lethality of AK Devices

All *D. citri* adults were killed after exposure to both weathered and non-weathered AK devices indicating high lethality of the beta-cyfluthrin-treated plasticized PVC. However, weathering of AK devices prolonged time to mortality of adult psyllids (Fig. 4). Mean survival times of adults exposed for 5, 25, or 60 s to strips from weathered AK devices increased respectively by 9.0, 21.8, and 20.8 s for each week of deployment over the 8-wk trial (Fig. 4). Survival times of adult psyllids generally decreased with longer exposure to strips from non-weathered or 2- and 4-wk weathered AK devices (Table 1). In comparison, survival times of adult psyllids did not significantly decrease with longer exposure to 8-wk weathered AK devices (Table 1).

Survival of *D. citri* Adults Caged With Orange Jasmine and AK Devices

AK devices were able to attract and rapidly kill *D. citri* adults caged with orange jasmine plants (Fig. 5). Psyllid survival was significantly affected by the plant and device combination that the insects were exposed to (Kruskal–Wallis test: $H = 23.024$, df = 2; $P < 0.001$). By day 4, psyllid survival on plants with AK devices (mean ± SE = 0.048 ± 0.033, $n = 11$) was on average 95% lower than on untreated plants (mean ± SE = 0.903 ± 0.033, $n = 11$) or plants with blank (no insecticide) AK devices (mean ± SE = 0.961 ± 0.012, $n = 11$). Less than half of the adult psyllids exposed to plants with AK devices were alive after 1 d and nearly all of the psyllids were dead after 4 d (Fig. 5). In comparison, nearly all of the adult psyllids exposed to untreated plants or plants with blank AK devices remained alive during the 4 d of the trials. Psyllid survival was not statistically different among adults exposed for 4 d to untreated plants or plants with blank AK devices (Fig. 5). By the end of the study, total numbers of adults recovered per cage was not significantly different among the three treatments (pooled mean ± SE = 16.6 ± 0.3 adults per cage, $n = 33$; $H = 0.752$, df = 2; $P = 0.686$, Kruskal–Wallis test). Sex ratio was slightly male-biased and similar among the three treatments (pooled mean ± SE = 0.52 ± 0.02, $n = 33$; $H = 0.572$, df = 2; $P = 0.751$, Kruskal–Wallis test).

Suppression of *D. citri* on Lemon Trees With AK Devices

Treatment with AK devices reduced populations of *D. citri* adults on residential lemon trees on most sampling dates from winter to mid-summer. At the start of the trial, all lemon trees were infested with low numbers of adult psyllids (mean ± SE = 4.25 ± 1.75 adults per

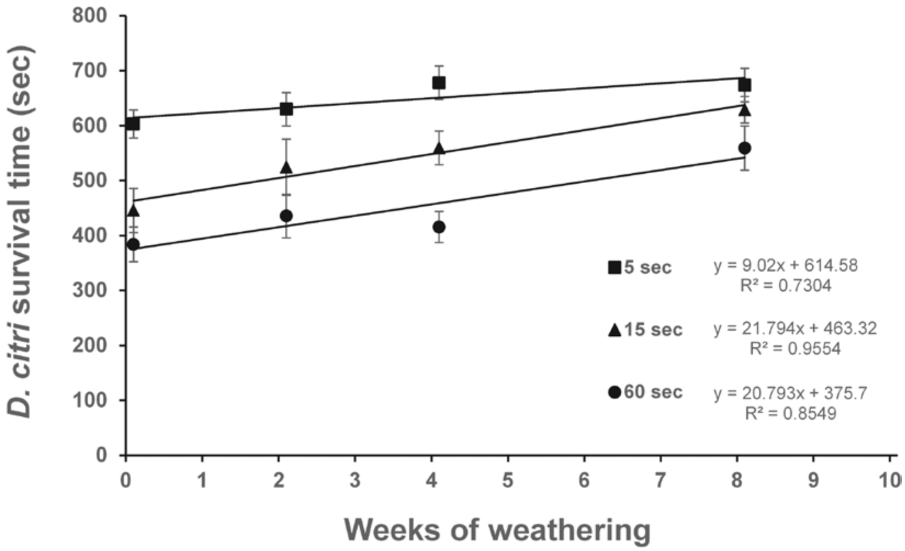

Fig. 4. Mean (±SE) survival times of *D. citri* adults ($n = 25$) exposed for 5, 15, or 60 s to strips recovered 0, 2, 4, or 8 wk post-weathering from beta-cyfluthrin-treated AK devices deployed on a residential orange tree in spring (24 February 2016 to 21 April 2016).

Table 1. Mean survival times of *D. citri* adults exposed for 5, 15, or 60 s to strips recovered 0, 2, 4, or 8 wk post-weathering from beta-cyfluthrin-treated AK devices deployed on a residential orange tree in spring (24 February to 21 April 2016)

	Genhan-Breslow test results					Survival time (s)		
Weathering	Statistic	*P* value	df	Exposure (s)	Adults (*N*)	Mean	SE	95% CI
0 wk	11.95	0.003	2	5	25	603.4A	25.5	553.4–653.4
				15	25	445.7B	40.2	367.0–524.5
				60	25	383.8B	31.8	321.0–446.2
2 wk	18.97	<0.001	2	5	25	629.9A	30.6	569.9–689.9
				15	25	524.4AB	50.9	424.6–634.1
				60	25	438.4B	39.9	359.3–515.6
4 wk	30.99	<0.001	2	5	25	677.9A	30.4	618.0–737.6
				15	25	559.5A	30.5	499.7–619.2
				60	25	415.5B	28.5	359.5–471.4
8 wk	5.40	0.067	2	5	25	673.8A	30.5	614.1–733.5
				15	25	628.8A	24.1	581.6–676.0
				60	25	559.2A	40.3	480.2–638.3

The Genhan-Breslow test was used to compare survival curves of adults exposed for different times to the same types of AK strips. Different letters indicate survival times of adults exposed for different times to the same types of strips are significantly different at $P < 0.05$ (Holm-Sidak test).

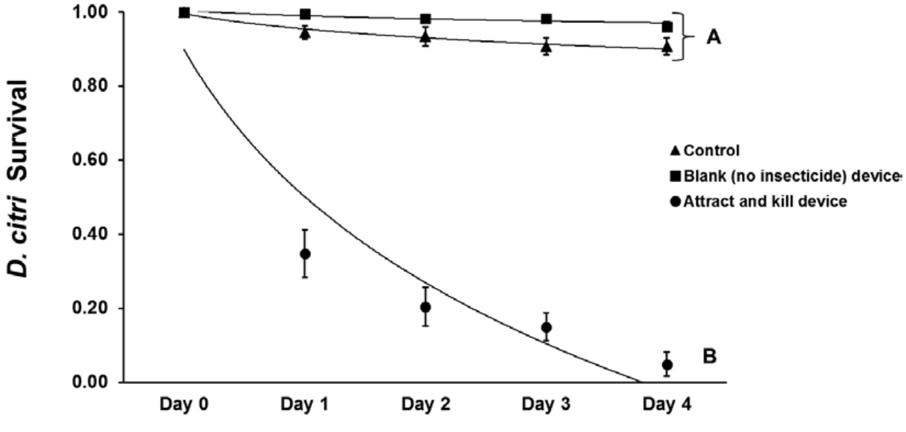

Fig. 5. Survival (±SE) of *D. citri* adults caged with orange jasmine plants and beta-cyfluthrin-treated AK devices. Plant treatments were: 1) AK device; 2) blank (no insecticide) AK device; or 3) no device 'control'. Survival curves were significantly different (Kruskal–Wallis test: $H = 23.024$, df = 2, $P < 0.001$) and treatments with different letters are significantly different at $P < 0.05$ (Student–Newman–Keuls test).

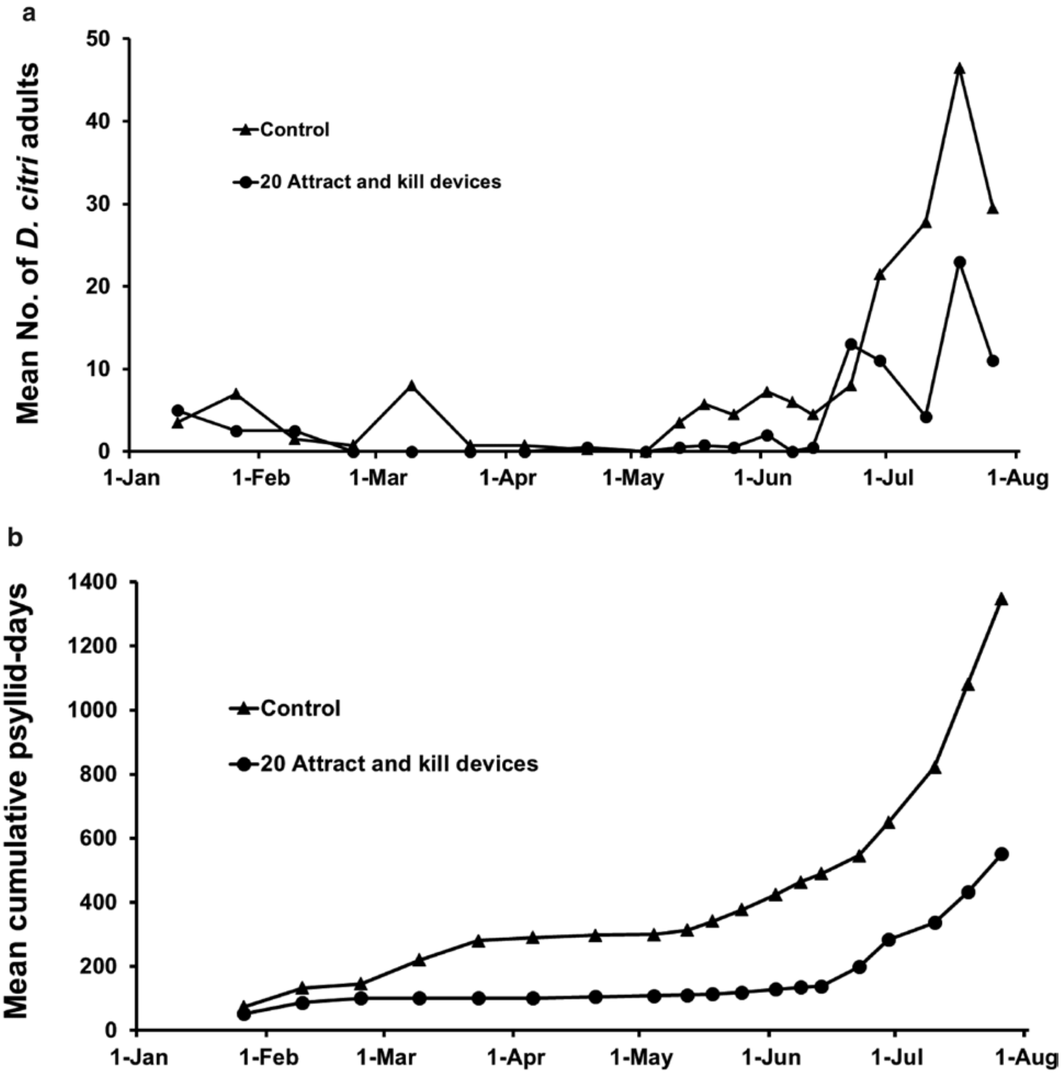

Fig. 6. (a) Mean numbers of *D. citri* adults per tree from stem-tap counts and (b) corresponding mean cumulative psyllid-days (attack intensity) per tree for adults on residential lemon trees treated for *D. citri* from 12 January 2017 to 26 July 2017. Tree treatments were: 1) untreated 'control'; 2) 20 AK devices per tree. By July 26, cumulative psyllid-days for untreated trees were significantly greater than for trees with AK devices (χ^2 test: x^2 = 1336.816; df = 1; one-tailed $P < 0.001$).

tree, $n = 8$) that were not significantly different among control trees and trees assigned AK devices (χ^2 test: x^2 = 1.059; df = 1; $P = 0.303$). Numbers of adults on all trees peaked during flush cycles from June to July but were greater on control trees than those on trees protected by AK devices (Fig. 6a). After 28 wk, the attack intensity of adults psyllids was significantly higher on control trees (mean ± SE = 1347.75 ± 321.13 cumulative psyllid-days per tree, $n = 4$) than on protected trees (mean ± SE = 551.13 ± 91.46 cumulative psyllid-days per tree, $n = 4$; Fig. 6b). Overall, deployment of AK devices reduced the mean attack intensity of adult psyllids by 59% on lemon trees that were lightly infested from winter to spring and heavily infested during summer.

During winter to mid-summer, production of *D. citri* eggs and nymphs on lemon trees was substantially reduced by AK devices. Psyllid reproduction was highest on all trees during flush cycles from May to July of 2017, but numbers of eggs or nymphs were consistently lower on trees protected by AK devices than on control trees. By the end of the trial, cumulative psyllid eggs per tree was significantly lower (χ^2 test: x^2 = 332.237; df = 1; $P < 0.001$) on trees with AK devices (mean ± SE = 9.50 ± 4.09 eggs per tree, $n = 4$) than control trees (mean ± SE = 108.50 ± 66.23 eggs per tree, $n = 4$). Attack intensity by ACP nymphs was also significantly lower on trees with AK devices (mean ± SE = 746.38 ± 53.94 cumulative psyllid-days per tree, $n = 4$) than control trees (mean ± SE = 1581.25 ± 361.72 cumulative psyllid-days per tree, $n = 4$; Fig. 7). From winter to mid-summer deployment of AK devices on lemon trees reduced the mean cumulative numbers of psyllids eggs by 91% and mean attack intensity of nymphs by 53%.

Discussion

This study is the first to report significant suppression of *D. citri* by an AK device using a pyrethroid insecticide, beta-cyfluthrin, as the killing agent. These results are based on cage trials with potted plants and field trials on dooryard trees that supported varying degrees of *D. citri* infestation during seasonal tree flushing cycles. Under controlled conditions, the AK device attracted adult psyllids from the foliage of a preferred host plant, orange jasmine, and rapidly killed the insects. Canopy deployment of 20 AK devices per tree was effective for suppressing psyllid infestations on residential lemon trees from late winter to early summer. Efficacy of AK treatments was most apparent from May to July when psyllid reproduction and densities

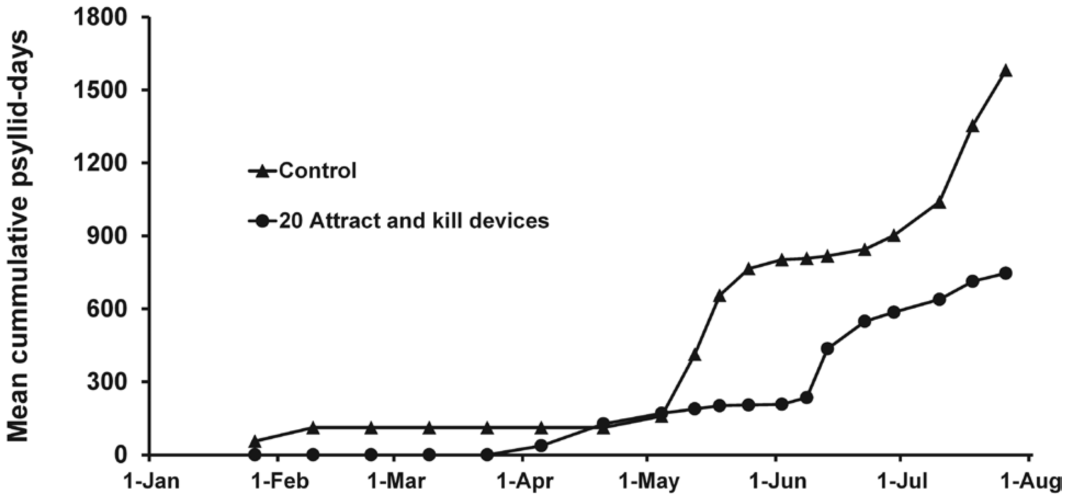

Fig. 7. Mean cumulative psyllid-days (attack intensity) per tree for nymphs on residential lemon trees treated for *D. citri* from 12 January 2017 to 26 July 2017. Tree treatments were: 1) untreated 'control'; 2) 20 AK devices per tree. By July 26, cumulative psyllid-days for untreated trees were significantly greater than for trees with AK devices (χ^2 test: $x^2 = 1197.815$; df = 1; one-tailed $P < 0.001$).

peaked during extensive flush cycles on the lemon trees. Our findings suggest that AW-PM programs for *D. citri* could use the AK device to significantly reduce psyllid populations on residential citrus.

Issues of property access for licensed applicators and public opposition to frequent chemical sprays thwarted management programs for psyllid-infested dooryard citrus trees in Southern California (Hoddle and Pandey 2014). Adoption of the current AK device could be simpler and less controversial than foliar sprays since it can be deployed and replaced on residential trees by anyone during seasonal flush cycles. Residents who volunteered their trees for our trials expressed high approval of this AK device for *D. citri* control. In a preliminary study evaluating the potential attractiveness of AK devices to honey bees, less than 2% of bees visiting flowering citrus trees came into contact with the AK devices and this contact lasted less than 1 s, on average, suggesting a very low exposure risk (M. Sétamou, unpublished data). The AK device has high potential as a user-friendly and bee-friendly control system for *D. citri* in not only residential landscapes but also other situations such as abandoned citrus groves or protected natural areas where conventional insecticide control is problematic.

Additional studies are needed to develop cost-effective deployment strategies for the AK device in residential neighborhoods. This device is visually attractive to *D. citri* adults, and its deployment on a dooryard tree could attract adult psyllids from nearby trees. However, the device's effective range of attraction for *D. citri* adults is presently unknown. In addition, it is not known if deploying more than 20 AK devices per tree will enhance psyllid control for nearby trees. Control of insect pests, reduction in crop damage, and conservation of natural enemy communities can be enhanced by concentrating AK tactics on either border trees or the most susceptible tree varieties of fruit orchards (Hossain et al. 2013; Morrison et al. 2016b, 2019). Treating every citrus tree in a residential block or neighborhood is costly; therefore, it is essential to test strategies such as deploying AK devices primarily and at higher densities on lemon and other citrus cultivars that are preferred by *D. citri* and thus more at risk of psyllid infestation and CLas infection.

Prolonged exposure to direct sunlight, heavy rain, or high temperature can reduce the efficacy of microbial or synthetic chemical insecticides used as killing agents by AK devices (Leahey 1979, Jaronski 2010). Adult psyllids were always killed after short (5 s), moderate (15 s), or long (60 s) exposure to strips from AK devices field-weathered for up to 8 wk on a dooryard orange tree. However, mean survival times of adults exposed to strips from field-weathered AK devices increased for short, moderate, and long exposures by respectively 1.5, 5.0, and 5.4% per week over the 8-wk trial. The increase in psyllid survival times indicates that lethality of the beta-cyfluthrin formulation on the AK devices will gradually decline over time in citrus tree canopies. Under South Texas conditions, a replacement time of 8 wk for the AK devices in dooryard trees was recommended for effective *D. citri* suppression and minimizing the risk of psyllid populations becoming resistant to beta-cyfluthrin. However, in cooler and less humid environments such as California, longer replacement intervals are expected because of less degradation by high temperature, sunlight, and rainfall as compared to South Texas. In comparison to devices treated with blastospores of entomopathogenic fungi (*Ifr* dispensers), which require replacement every 2 wk (Chow et al. 2018), beta-cyfluthrin-treated AK devices should kill adult psyllids for up to four times longer on residential citrus. Future research is needed to determine whether additional UV stabilizers and design features can further prolong the lethality of beta-cyfluthrin formulation on AK devices.

It is generally accepted that parasitoid and predator guilds presently provide insufficient control of *D. citri* in urban areas of Southern California or South Texas because impact on psyllid populations is low when nymphs are scarce (Kistner et al. 2016a, 2016b; Flores and Ciomperlik 2017). AK devices that kill adult psyllids with either microbial or chemical insecticide formulations will complement biological control of *D. citri* on dooryard citrus. Heavy infestations of *D. citri* on residential citrus can be suppressed by *Ifr* dispensers that attract adults and infect them to initiate, under conducive conditions, epizootics that will decimate psyllid populations on dooryard trees (Chow et al. 2018). The current AK device can rapidly kill individual adults and could be more effective than dispensers if psyllid densities are low or abiotic conditions are unfavorable for *Ifr* epizootics. To optimize control of *D. citri* in residential landscapes, we propose: 1) *Ifr* dispensers and AK devices be prioritized for citrus cultivars most at risk of infestation by *D. citri* and infection by HLB; 2) *Ifr* dispensers and AK devices be reserved for the late fall, early winter, and early spring when *D. citri* populations consist primarily of adults; 3) augmentative releases of parasitoids and predators are made during late spring to early fall when populations of psyllid nymphs peak with the major flush cycles of citrus trees. Coordinated use of the AK device, *Ifr* dispensers, and parasitoid or predatory guilds in AW-PM programs for *D. citri* could effectively suppress psyllid populations on residential citrus and reduce the risk of HLB spread to commercial groves. However, future field evaluations are needed to validate this management strategy.

Supplementary Data

Supplementary data are available at *Journal of Economic Entomology* online.

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