*Journal of Economic Entomology*, XX(XX), 2019, 1–8
doi: 10.1093/jee/toz045
Research

Ecology and Behavior

# Screening Sticky Cards as a Simple Method for Improving Efficiency of *Diaphorina citri* (Hemiptera: Liviidae) Monitoring and Reducing Nontarget Organisms

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Subject Editor: Charles Burks

Received 30 November 2018; Editorial decision 7 February 2019

## Abstract

Management of *Diaphorina citri* Kuwayama (Hemiptera: Liviidae) (Rhizobiales: Phyllopbacteriaceae) populations is one of the major strategies for reducing the spread and incidence of huanglongbing (HLB). HLB is putatively caused by *Candidatus* Liberibacter spp. that are transmitted to citrus by psyllid vectors. *Diaphorina citri* population monitoring is done to detect its presence and inform on management decisions. Various methods are used for detecting and estimating *D. citri* densities but trapping with yellow or lime-green sticky cards has proven to be the most effective method. These sticky cards rely on the color preference of adult *D. citri*, but many flying organisms are attracted to the same color spectrum as psyllids. Hence, in field situations, sticky traps are hampered by large numbers of bycatches of nontarget organisms and debris. Here, we described a method using a mesh laid on the surface of traps as a sift to catch mainly psyllids, while reducing bycatches. By filtering *D. citri* through this mesh, they can be counted more rapidly and accurately. Although mesh-covered traps captured 5–15% less *D. citri* relative to uncovered ACP traps, both types of traps statistically agreed on *D. citri* detection and population densities. The effectiveness of mesh-covered traps did not vary with season. In addition, mesh-covered traps eliminated >90% of nontarget organisms and allowed for quicker enumeration of *D. citri*. We expect this method will become an important component of redesigning integrated pest management programs in citrus groves by reducing unintended impacts of beneficial arthropods during large scale *D. citri* monitoring.

**Key words:** Asian citrus psyllid, sticky cards, mesh screening, trapping, nontarget organisms

Central to any integrated pest management program is the population monitoring used to measure changes in pest abundance. Population monitoring of arthropod pests is used to determine their spatial distribution and inform on the need or effectiveness of management decisions (Conway 1984). In many agroecosystems, sticky cards are commonly used for estimating the densities of flying insects and determining control actions. Detection of host plants by phytophagous insects often involves visual recognition that may include responses to color, size, shape, or silhouettes (Prokopy and Owens 1983). Insects exhibit different color preferences; hence, various traps with a specific color spectrum are used for monitoring their populations (Brødsgaard 1989, Gillespie and Vernon 1990, Blackmer and Cañas 2005, Blackmer et al. 2006, Hall et al. 2010, Sétamou et al. 2014). The advantages of color traps include continuous activity that is independent of air movement, effective from a distance and any direction, as long as there is no obstacle between the insect and the trap (Miller and Strickler 1984). Glue or a sticky substance is applied on these traps for arrestment of any insect encountering them.

The Asian citrus psyllid, *Diaphorina citri* Kuwayama, vector of the bacterial pathogen *Candidatus* Liberibacter asiaticus (CLas) that causes citrus greening disease or huanglongbing (HLB), has become a major pest in the United States since its first detection in Florida in 1998 (Halbert and Manjunath 2004). The economic significance of *D. citri* stemmed from the fact that HLB is a destructive disease for which there is no known cure (Bové 2006). Hence, vector control remains one of the pillars for preventing HLB spread and reducing its incidence in commercial groves and residential areas. Detection and estimation of *D. citri* abundance or change in numbers provide the essential measures by which control decisions are generally made. A great deal of research effort has been directed at developing robust *D. citri* monitoring techniques. The presence and abundance of all *D. citri* life stages in citrus trees can be determined using visual inspections of flush shoots (Sétamou et al. 2008), while adult populations can also be monitored using stem tap sampling (Stansly et al. 2009), sticky traps (Aubert and Hua 1990, Hall et al. 2010, Sétamou et al. 2014, Monzo et al. 2015, Miranda et al. 2018), vacuum sampling (Thomas 2012), and sweep nets (Stansly et al. 2009). However, comparative studies of the different *D. citri* sampling methods revealed that yellow or lime-green sticky cards were more sensitive and effective than any other method at detecting the pest presence and monitoring its populations (Flores et al. 2009, Hall et al. 2010, Monzo et al. 2015), especially at low density (Miranda et al. 2018). Despite the amount of research carried out to find odorants attractive to *D. citri* adults (Aksenov et al. 2014, Coutinho-Abreu et al. 2014), there still is no effective semiochemicals for luring adequate numbers of *D. citri* adults in field population studies. Zanardi et al. (2018) reported that the use of acetic acid increased trap catches of both adult males and females, and this may be a *D. citri* pheromone. However, large-scale studies are yet to confirm the field efficacy of this pheromone. Thus, yellow or lime-green sticky cards that visually attract *D. citri* adults remain the gold standard in its population studies.

Despite large-scale use, colored sticky cards are plagued by their lack of specificity. They are attractive to any flying organism that uses visual cues for host finding. Assessing the presence and density of *D. citri* with yellow or lime-green sticky cards in citrus groves or residential trees has often proved challenging because sticky traps also collect debris and nontarget organisms including beneficial organisms, thus making psyllid counts a daunting task. These problems can lead to variability in psyllid detection on traps and make it more difficult for scouts and growers to get an accurate assessment of *D. citri* densities.

Improved trapping techniques are needed for effective detection and monitoring of *D. citri* populations, while substantially reducing the nontarget effects of sticky traps. In this study, we described a simple technique that uses tulle mesh laid on sticky cards as a filter to reduce nontarget organisms on traps, while facilitating counts of captured *D. citri* and prolonging the life span of these traps. The underlying principle is that the mesh coating creates a sifter on top of the trap surface, thus preventing organisms and debris larger than the mesh size from getting in contact with the sticky surface of the traps. As psyllids mostly land on the traps, their legs are stuck through the mesh and on the surface of the traps.

## Materials and Methods

### Efficacy Evaluation of Mesh-Covered Traps in *D. citri* Monitoring

This study was conducted in two commercial groves, an organic and conventional grove for over a 10-wk period. The organic grove was a 15-yr-old 'Valley' lemon (*Citrus limon* [L.] Osbeck) planted at a density of 7.3 m × 3 m, while the conventional grove was a 20-yr-old 'Rio Red' grapefruit (*Citrus* × *paradisi* Macfad.) with a planting density of 7.3 m × 4.6 m. Both groves had incipient psyllid infestations at the beginning of the study.

Lime-green sticky traps (10- × 30-cm) with dry adhesive known as ACP traps developed for monitoring *D. citri* populations (Alpha Scents Inc., West Linn, OR) were used in this study. Uncovered and covered traps with white (equilateral hexagon with 0.5 mm mesh size, model 'TL2402-SL'), yellow (1.5 mm by 1 mm parallelogram mesh type, model 'TL2400YL'), or glittered gold (hexagon type 'i4' with mesh size of 2 mm by 1 mm, model 'TUL_GLIT_GOLD') (Paper Mart, Orange, CA) (Fig. 1) were tested in three field studies conducted between 9 August and 23 November 2017. The different types of tulle nylon mesh were cut (10- × 28-cm) and used to

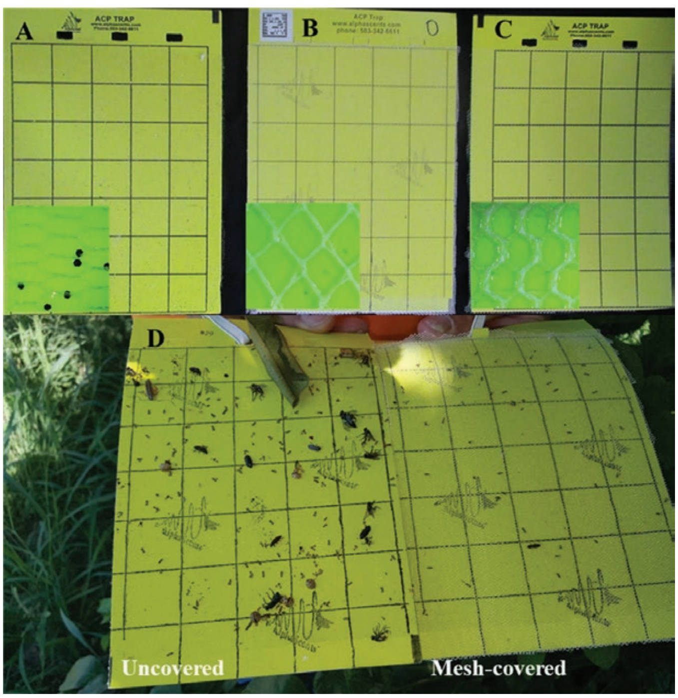


**Fig. 1.** Mesh-covered traps (A = glittered lime-green mesh, B = white mesh, C = yellow mesh) used in the trapping studies. Uncovered (bottom left) and mesh-covered (bottom right) traps retrieved from a citrus grove after a 2-wk exposure period showing *D. citri* and bycatches of other organisms and debris. D = Note the difference in trap cleanness resulting from the use of a mesh on trap.

cover the entire sticky surface on both sides of the traps (Fig. 1). In the first study conducted in the conventional grove (26.23649°N, 98.18707°W), the uncovered ACP traps (untreated control) were tested along with covered traps with each of the three mesh types. Ten replicates of each trap type were deployed along the four perimeters (two on the North and South sides, and three on the East and West sides) of the grove. A similar trapping design was used in the second study conducted in the organic grove (26.28858°N, 98.37764°W) with the exception that three traps were used per grove border for 12 replications per treatment. Because *D. citri* exhibit strong aggregation behavior (Sétamou et al. 2008), traps were deployed by groups of four (i.e., one trap for each type of mesh and a control) per replication. Traps in each replication were randomly assigned to four contiguous trees within the border row, or row-end trees of four contiguous rows. Row-end replicates were separated by three rows while four trees separated within-row replicates. For each study, traps were deployed for 2 wk in the grove, recovered, and brought to the laboratory for evaluation. Numbers of *D. citri* adults caught were counted under a microscope and recorded per trap.

In the third study conducted in the organic grove, the best performing mesh of the previous two studies was selected (glittered-meshed) and testing along with the uncovered trap as control. Sixteen (16) replications, four per grove border were used. Traps within each replication were deployed to two contiguous trees along border rows or row-end trees. Three to four trees separated replications per border. After 2 wk of deployment in the groves, traps were retrieved and evaluated for target and nontarget species under a microscope. Nontarget organisms were only tallied by type, and trap cleanness was scored on a scale of 1 to 5, with 1 indicating very clean trap (no nontarget organisms and debris) and 5 indicating very dirty trap full of both nontarget organisms and debris.

## Description of the Validation Study

### Short-term study

A large-scale field study was conducted to provide validity evidence to support the effectiveness of mesh-covered traps in large scale *D. citri* trapping programs. The study was conducted in 50 mature commercial grapefruit groves *C.* × *paradisi* Mcfad. cv. 'Rio Red' and 'Ruby Red' (32 groves) and sweet orange groves, *C. sinensis* [L.] Osbeck cv. 'Marrs', 'Pineapple', and 'Valencia' (18 groves) in South Texas for 3 wk during the spring flush cycle between 9 April and 25 May 2018. These commercial groves were under *D. citri* area-wide management and monitored by the Texas Citrus Pest and Disease Management Corporation to make spray recommendations to growers. Uncovered and mesh-covered traps were deployed by pairs on each the four corner trees of the grove. The two traps of each pair were deployed on the same tree canopy, separated by ca. 1 m and facing the same outer side of the grove. Traps were deployed for 3 wk in the grove, recovered, and brought to the laboratory for evaluation. Numbers of *D. citri* adults caught were tallied and the number of traps with psyllid detection recorded.

### Long-term study

In this study, *D. citri* monitoring was conducted from 9 April to 25 October 2018 in 16 (8 grapefruit and 8 sweet orange) randomly selected from the 50 studied groves in the short-term study with the goal of testing the effectiveness of mesh-covered trap throughout the most active citrus growing season in South Texas. Traps were replaced every 2 wk and the numbers of *D. citri* adults recorded as previously described.

## Statistical Analysis

In the first two method development studies, data over the period of the experiment were subjected to an analysis of variance to evaluate the effect of trap type, while grove border was used as block. Treatment means were separated using Tukey's test when significant *F*-values were obtained ($P < 0.05$).

Total numbers of traps per cleanness category were also tallied for the third study comparing the glittered mesh-covered trap and the uncovered control. A log-likelihood ratio test ($P < 0.05$) was used to determine whether the type of traps had any significant effect on their cleanness.

Comparison between the numbers of *D. citri* on mesh-covered traps and the numbers on control traps in the short-term validation study was first performed using a paired *t*-test. To see how well the two traps agreed in detecting occurrence and nonoccurrence of *D. citri* populations in groves, an agreement analysis (Watson and Petrie 2010) was conducted with the Proc Freq procedure of SAS (SAS Institute 2014). Traps within each treatment were first grouped in two categories: negative (traps with zero *D. citri*) and positive (traps with at least one *D. citri*) detections. Traps with positive *D. citri* detections were subsequently grouped into quartiles. Thus, the agreement test was based on traps with no *D. citri* detections and the four quartiles (Q1, Q2, Q3, and Q4) of traps that caught at least one *D. citri* during the short-term validation study. A simple linear regression analysis was also used to establish the relationship between *D. citri* densities on mesh-covered and uncovered traps.

*Diaphorina citri* data obtained during the long-term monitoring study were subjected to a repeated measures analysis of variance to evaluate the effects of trap type, time, and their interaction on total captures.

The numbers of *D. citri* in all studies and of nontarget organisms recorded per trap were log($x$ + 1)-transformed before analysis. All analyses were performed using SAS for Windows Version 9.4 (SAS Institute 2014).

# Results

## Trapping Efficiency of Mesh-Covered Traps

Numbers of *D. citri* recovered in the three studies were sufficient (Figs. 2 and 3) to determine the influence of mesh cover on catch in the different studies. Location differences were detected in *D. citri* catches (Fig. 2), which may be attributable to the grove production and management systems and citrus cultivar. However, the experiment was not designed to examine differences between citrus species or location, since trapping was not conducted over a whole season or over exactly the same periods in each grove.

In both groves, the mesh cover had a significant effect on catch of *D. citri* adults ($F_{3, 28} = 5.30$, $P = 0.005$ for the conventional groves and $F_{3, 36} = 3.23$, $P = 0.03$ for the organic grove); however, this effect varied with the type of mesh. While the white mesh and the tightly woven yellow mesh cover significantly reduced the number of *D. citri* caught in the conventional and organic groves, respectively, the glittered gold tulle mesh did not affect the effectiveness of traps in catching *D. citri*. Although a reduction of ca. 10% in *D. citri* numbers was observed in traps covered with the glittered tulle mesh relative to uncovered traps, mean numbers of *D. citri* caught did not statistically vary (Fig. 2). Hence, the glittered tulle mesh was selected for subsequent studies.

In the third study, trapping efficiency of the tulle mesh-covered trap was compared to that of the uncovered control. Mean numbers of *D. citri* adults recovered per trap did not vary with treatment ($F_{1,}$

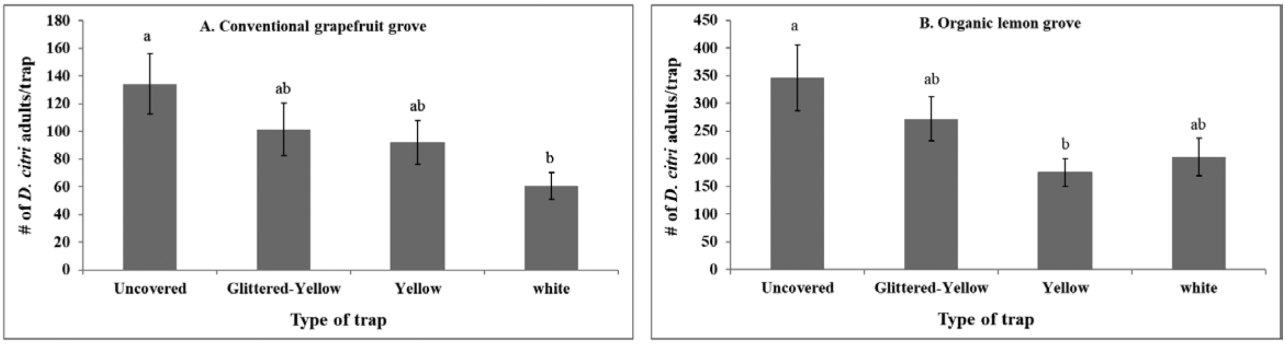


**Fig. 2.** Mean (+ SE) numbers of *D. citri* caught on uncovered and covered traps with various types of mesh in conventional grapefruit (A) and organic lemon (B) commercial groves. Columns bearing different letters were significantly different from one another (ANOVA followed by Tukey's test, $P < 0.05$).

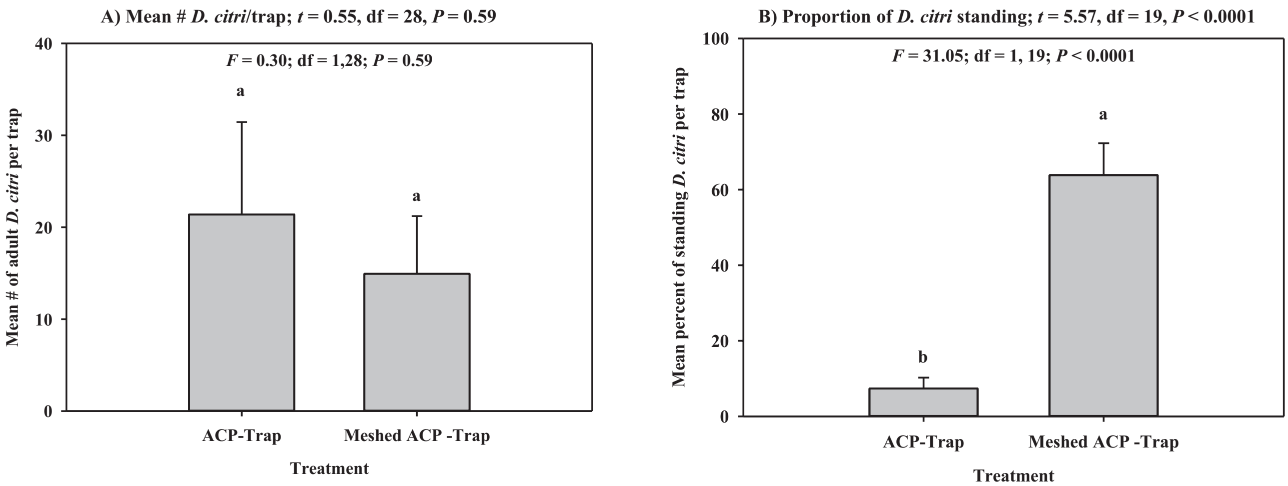


**Fig. 3.** Mean (+ SE) numbers of *D. citri* caught on uncovered and glittered mesh-covered traps (A) and proportion of *D. citri* adults caught standing on trap (B). Bars bearing different letters were significantly different from one another (ANOVA followed by Student *t*-test, $P < 0.05$).

$_{28}$ = 0.05, $P$ = 0.83; Fig. 3A). In addition, the proportions of traps with *D. citri* detections were comparable between the two treatments ($\chi^2$ = 1.43, df = 1, $P$ = 0.23). In contrast, the proportion of *D. citri* caught standing on their legs was 3.7-fold higher on mesh-covered traps relative to the uncovered ones (Fig. 3B).

Traps covered with glittered tulle mesh significantly reduced the number of nontarget species and debris (Table 1). A 95% reduction was recorded in the number of flies caught on traps with the mesh cover. While no other nontarget organism including lady beetles, roaches, spiders, bees, or grasshoppers, and debris were recorded on any of the mesh-covered trap during the study, the control traps collected significant numbers of these nontarget species, in addition to bird feathers and debris (Table 1). A log-likelihood ratio analysis indicated that covering trap with tulle mesh significantly affected their cleanness ($G$ = 29.3, df = 34, $P$ < 0.0001). While 100% of mesh-covered traps were in category 1 (completely clean), category 2 (slightly contaminated), and category 3 (moderately contaminated), no untreated control trap was classified as completely clean and most traps (67%) were in category 4 and 5 or highly and fully covered with debris after the 2-wk trapping period (Fig. 4).

## Validation Study

In the short-term validation study conducted in 50 groves, mean number of *D. citri* caught by the tulle mesh-covered traps (6.3 ± 0.94, mean ± SE) was comparable to the mean number (7.1 ± 0.94, mean ± SE) recorded on uncovered traps (paired $t$ = 0.5, df = 184, $P$ = 0.62). This indicated that the use of mesh cover did not significantly affect the efficiency of ACP traps. The agreement analysis between pairs of traps based on negative and positive *D. citri* detections indicated a strong agreement between the two types of traps (Fig. 5; $\chi^2$ = 3.13, df = 10, $P$ = 0.98). The weighted kappa coefficient had a value of 0.72 with confidence interval of (0.66–0.79) which does not include zero indicating good agreement between the two types of traps.

The numbers of *D. citri* recovered per uncovered control trap ($x$) were linearly and significantly related to that recorded on mesh-covered trap ($y$) ($y = 0.84x + 0.08$, $F$ = 444.77, df = 2, 183, adjusted $R^2$ = 0.71, $P$ < 0.0001; Fig. 6) with a relatively high explained variance ($R^2$ = 0.70).

In the long-term validation study, the performance of trap type was independent of the deployment period ($F_{13, 1551}$ = 0.38, $P$ = 0.98). In addition, no difference was observed between numbers of *D. citri* captured by the mesh-covered and uncovered traps ($F_{1, 30}$ = 1.39, $P$ = 0.25). However, *D. citri* captures on both types of traps significantly varied with sampling time ($F_{13, 1551}$ = 30.46, $P$ < 0.0001; Fig. 7).

## Discussion

*Diaphorina citri* control is one of the pillars of HLB management and reducing the disease spread across all citrus industries in the

**Table 1.** Comparison of nontarget organisms and debris caught on mesh-covered and uncovered traps (mean, SE) during *D. citri* adult population monitoring in commercial citrus in Texas

| Variable | Type of trap | | *F*-value | *P*-value[a] |
|---|---|---|---|---|
| | Meshed trap | Untreated control | | |
| Flies (house and compost) | 4.2 ± 1.9 | 79.3 ± 27.3 | 29.37 | <0.0001 |
| Glassy-winged sharpshooters | 0 | 3.1 ± 0.8 | 17.23 | <0.0001 |
| Roaches | 0 | 2.4 ± 1.0 | 15.81 | 0.0004 |
| Beetles | 0 | 0.9 ± 0.7 | 1.61 | 0.21 |
| Honeybee | 0 | 0.2 ± 0.1 | 1.91 | 0.18 |
| Mexican fruit fly | 0 | 0.1 ± 0.1 | 1.04 | 0.33 |
| Moths | 0 | 0.1 ± 0.1 | 1.03 | 0.33 |
| Grasshoppers | 0 | 0.1 ± 0.1 | 2.15 | 0.15 |
| Spiders | 0 | 0.1 ± 0.1 | 1.03 | 0.33 |
| Feathers | 0 | 0.1 ± 0.1 | 1.0 | 0.33 |
| Leaf debris | 0 | 0.7 ± 0.3 | 5.0 | 0.03 |

[a]df = 1, 28 for all analyses.

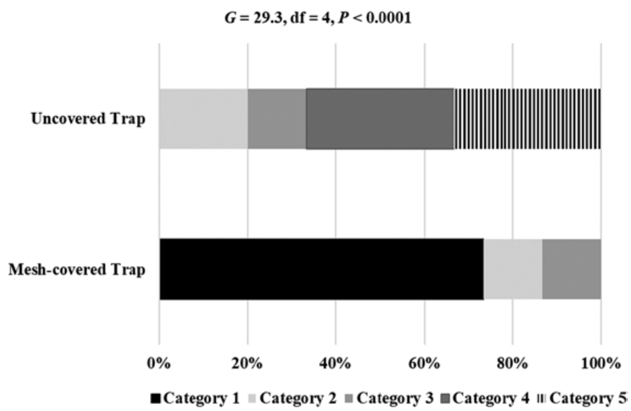


**Fig. 4.** Cleanness distribution of uncovered and mesh-covered traps after a 3-wk deployment period in a citrus grove. Category 1 = clean with no less than 10% of trap area covered with organisms and debris; category 2 = 10–25% of trap area covered; category 3 = 25–50% of trap area covered; category 4 = 50–75% of trap area covered, and category 5 = >75% of trap area covered.

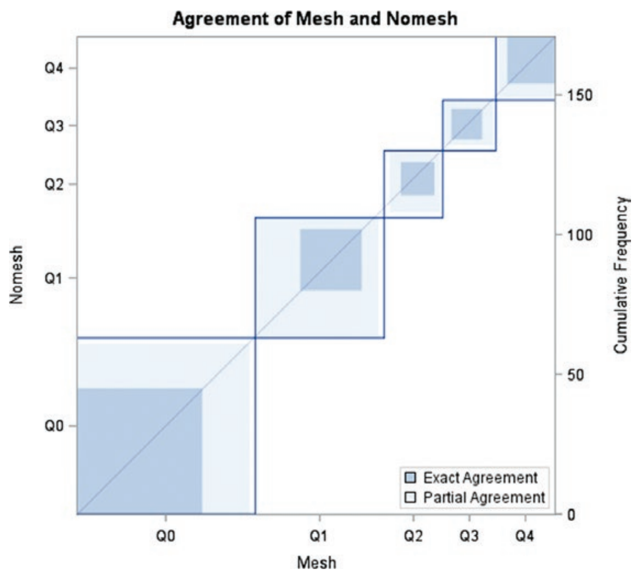


**Fig. 5.** Agreement plot between *D. citri* captured using mesh-covered and uncovered traps in large-scale ($n$ = 50) field study in South Texas (April to May 2018). Darker shade area indicated perfect agreement and lighter shade indicated partial agreement (Fig. 4; $\chi^2$ = 3.13, df = 10, $P$ = 0.98).

world where it is present. Monitoring of *D. citri* populations is critical for control decision-making and for evaluating efficacy in area-wide management programs. Various sampling methods including visual observation (Sétamou et al. 2008), tap sampling (Stansly et al. 2009), vacuum or suction sampling (Thomas 2012, Monzo et al. 2015), and the use of sticky traps (Flores et al. 2009, Hall et al. 2010, Sétamou et al. 2014, Monzo et al. 2015) have been proposed for estimating densities of *D. citri* adults, but sticky cards are shown to be the most effective method for assessing adult densities (Miranda et al. 2018).

*Diaphorina citri* is a diurnal insect that responds positively to light reflectance patterns of its host plant and specifically to the reflectance of young expanding flush shoots (Sétamou et al. 2014, Monzo et al. 2015). In light of the absence of any effective odorant for field population studies, yellow or lime-green sticky cards are currently the gold standard and most common method used for monitoring *D. citri* densities in citrus groves (Miranda et al. 2018). These sticky cards rely on the color preference of *D. citri* adults, but many other organisms including beneficial insects respond to the same color hues. Hence, the use of sticky cards for *D. citri* monitoring is plagued by a lack of specificity that can result in substantial off-target captures and collection of debris. These bycatches hamper proper evaluation of target insects on sticky traps and pose significant ecological risks when using them in area-wide monitoring programs.

To mitigate these nontarget effects of sticky cards used in *D. citri* monitoring, we developed a simple method of covering trap surface will mesh screen that will sieve out larger arthropods and debris and allow only *D. citri* adults and smaller insects to be trapped. The effectiveness of these mesh-covered traps in catching *D. citri* and reducing nontarget organisms and debris was tested in field studies along with uncovered traps. Notably, mesh-covered traps reduced the densities of *D. citri* caught on traps (Fig. 2), but this reduction varied with the type of mesh. While mesh covered traps caught fewer *D. citri* relative to the uncovered traps, differences were not significant for traps covered with the glittered tulle mesh ($P$ > 0.05). Large-scale validation studies also confirmed that the performance of traps covered with the glittered yellow mesh was independent of the season and was statistically similar to uncovered traps. Some of the differences observed in *D. citri* captures between mesh-covered and uncovered traps were only relevant under conditions of high abundance, but not during periods of lower densities (Figs. 6 and 7). This suggests that mesh traps could be important in areas where phytosanitary *D. citri* monitoring is being conducted to prevent establishment or spread. The observed reduction in *D. citri* captures with some mesh-covered traps may be due to changes in attractiveness of traps to incoming *D. citri* adults or in stickiness of the traps due to the mesh laid on the surface. Covering traps with a mesh will most likely change their reflectance of light and hue perception by many insects, including *D. citri*. As a visual specialist, *D. citri* strongly discriminates between colors (Sétamou et al. 2014), and the presence of the white or yellow mesh may have affected the trap reflectance and consequently perception by incoming adults.

Laying mesh on trap surface also created some grooves that reduced the effective sticky area, thus partly explaining the reduced numbers of *D. citri* captures. The grooves may have prevented *D. citri* landing sideways or on their bodies from making direct contact with the sticky surface. In fact, a high proportion (65%) of captured *D. citri* adults on mesh-covered traps were found standing in contrast to only 10% on the control trap (Fig. 3) when comparing only traps covered with the glittered mesh and uncovered traps. Such a high proportion of *D. citri* caught standing on mesh-covered traps indicated that most adults land on their legs on these traps. It may also be possible that the mesh laid on trap surface acts like bumpers or cushions, thereby letting the crash landing *D. citri* adults find their legs on the sticky part of the trap. However, despite the presence of grooves on traps and reduction of effective sticky area, the use of glittered tulle mesh did not significantly reduce *D. citri* captures. This observation suggested that the type (shape and size) and color of mesh might be critical factors determining *D. citri* trapping efficiency on mesh-covered traps. The glittered mesh used in the study resembled and blended well with the lime-green ACP trap, thus probably not significantly affecting the trap reflectance and perception by *D. citri*. Moreover, the white and yellow screens were more tightly woven than the glittered mesh, indicating that the reduction of effective sticky surface of traps was higher with the former mesh types.

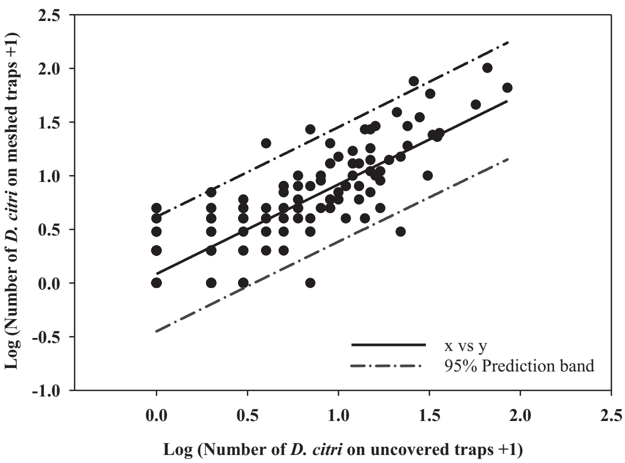


**Fig. 6.** Linear regression of numbers of *D. citri* captured on mesh-covered traps on numbers captured with uncovered traps in large-scale ($n$ = 50) validation study. All data were log($x$ + 1)-transformed before analysis ($y = 0.84x + 0.08$, $F = 444.77$, df = 2, 183, adjusted $R^2 = 0.71$, $P < 0.0001$).

The glittered mesh-covered traps significantly reduced the numbers of nontarget arthropods larger than *D. citri*. Specifically, our study found that honeybees, glassy-winged sharpshooters, and ladybird beetles were not caught on mesh-covered traps, unlike on uncovered traps (Table 1). Ladybird beetles (Kemp and Cottrell 2015, Atakan et al. 2016) and glassy-winged sharpshooters (Hix et al. 2003, Tipping et al. 2004, Patt and Sétamou 2007) are known to be highly attractive to yellow and lime green color. Although honeybees are reported to be more attracted to white and less to green, yellow, or red traps (Rodriguez-Saõna et al. 2012), few individuals were caught on uncovered lime-green traps. However, this study was conducted in summer when citrus trees are not in bloom, and honeybees are not very active in groves. Significantly high numbers of housefly (*Musca domestica* Linnaeus), compost fly (*Calliphora* sp.), and sterile Mexican fruit fly (*Anastrepha ludens* Loew) were found covering the control traps, while these flies were infrequently or not recovered from mesh-covered traps. These flies are ubiquitous in citrus groves in South Texas and are commonly recovered from sticky traps. The presence of bird feathers on uncovered traps is also indicative of birds encountering these traps. No bird feather was recovered on mesh-covered traps.

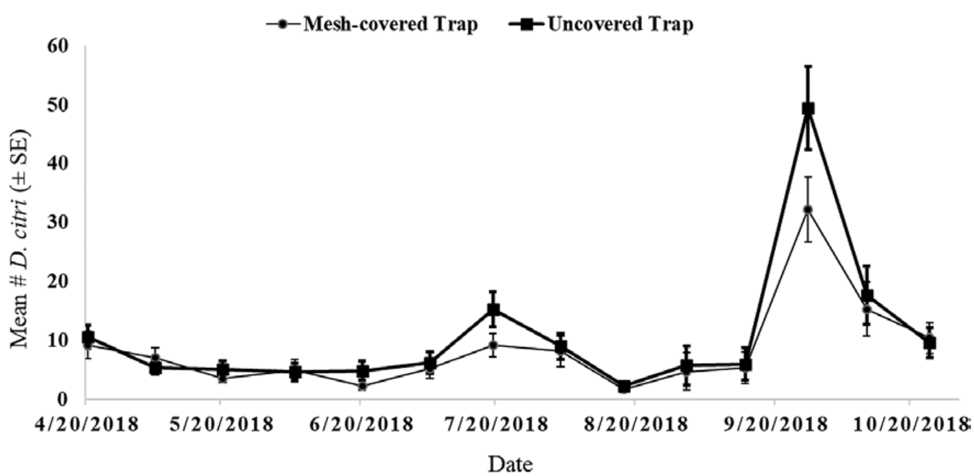


**Fig. 7.** Comparative densities of *D. citri* adults captured on mesh-covered and uncovered traps in long-term validation trial in commercial citrus groves ($n$ = 16) in Texas (April to October 2018).

In addition to the reduction in the number of bycatches of nontarget organisms, mesh-covered traps were relatively clean and free of debris after their exposure periods in groves in contrast to uncovered traps. As recorded for living organisms, the use of mesh on these traps prevented the collection of debris larger than *D. citri* adults.

The cleanness of mesh-covered traps coupled with the significant reduction of nontarget catches made the evaluation of these traps easy. As mesh-covered traps remained clean after the 2 to 3 wk exposure period, their field life could be increased during deployment. Moreover, with the higher proportion of *D. citri* adults recorded standing on traps, timely detection and enumeration of their population can be made, thus mitigating time-consuming evaluation of sticky cards (Monzo et al. 2015). Overall, the use of mesh-covered traps can provide accurate and cost-effective evaluations of *D. citri* densities on sticky cards.

In many citrus growing regions of the word, the invasion of *D. citri* has led to the implementation of area-wide management programs. To evaluate the effectiveness of these programs and help in control decision-making, sticky cards are used over a large area to monitor *D. citri* populations. As shown in this study, the large-scale use of yellow or lime sticky cards for *D. citri* monitoring could have negative impacts on populations of beneficial arthropods such as honeybees and ladybird beetles, which in turn could reduce pollination and biological control potential. As early as the mid-1990s, Mondor (1995) reported that the nontarget mass trapping of beneficial insects in pest monitoring programs with sticky traps might have negative effects, such as reducing their numbers, thus leading to an unintended increase of pest populations. Despite the growing understanding of the potential negative effects of widespread use of sticky cards, this study is the first to develop a simple method that mitigates these unintended risks while maintaining the effectiveness of the traps toward *D. citri*. The proposed method of covering traps with mesh rendered sticky cards environmentally friendlier through the conservation of beneficial arthropods and biodiversity.

## Data Availability Statement

Data from this study are available from the Dryad Digital Repository: doi:10.5061/dryad.6p394rh (Sétamou et al. 2019).

## Acknowledgments

We sincerely appreciate the assistance of Maura Rodriguez, Margarita Garcia, Gabriela Sanchez, Abelardo Rodriguez, Gisel Garza, Genoveva Carriles, and Richard Casares in laying the mesh cover on traps and assessing recovered traps from the groves. We acknowledge the useful comments and suggestions made by Dr. Susan Halbert and two anonymous reviewers on an earlier version of the manuscript. Partial funding of this project is provided by the USDA AFRI National Institute of Food and Agriculture through the grant entitled 'Training the next generation of agricultural scientists: coping with food security and climatic change challenges', award number: 2016-67032-25013.

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