Applied Entomology and Zoology
https://doi.org/10.1007/s13355-022-00786-6

ORIGINAL RESEARCH PAPER

Capture effect of yellow sticky traps covered with meshes of different colors and sizes on *Bemisia tabaci* (Hemiptera: Aleyrodidae) and nontarget organisms

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Received: 28 January 2022 / Accepted: 25 May 2022

Abstract

Management of *Bemisia tabaci* (Gennadius) (Hemiptera: Aleyrodidae) populations is a key strategy to reduce the transmission of viruses to crops. Yellow sticky traps are widely used tools to monitor and/or reduce *B. tabaci* populations. Nevertheless, these traps also allow the collection of debris and nontarget organisms including *B. tabaci* natural enemies. Covering the surface of the traps with a mesh is an alternative to mitigate those unwanted effects. Two field experiments were carried out to determine the color and size effect of the mesh on the capture of *B. tabaci* and nontarget organisms. The color experiment showed that among the 13 colors evaluated, only the yellow mesh did not reduce statically the number of *B. tabaci* captured compared with the uncovered traps. On the size experiment, among the three sizes evaluated, no statistical effect on the number of *B. tabaci* captured was exhibited. For the capture of nontarget organisms, the significative lowest values were showed in the small diamond and hexagon grooves. Those mesh traits were validated with two additional field experiments. The results of this study indicate that yellow sticky traps covered with a yellow mesh reduce the collection of nontarget organisms without affecting the capture of *B. tabaci*.

Keywords Trapping · Monitoring · Control · Whitefly · Integrated pest management

Introduction

The whitefly *Bemisia tabaci* (Gennadius) (Hemiptera: Aleyrodidae) is one of the most important insect pests limiting of the agriculture worldwide (Basu 2019; Kanakala and Ghanim 2019; Naranjo et al. 2010). This insect causes direct and indirect damage through the feeding and transmissions of plant viruses, respectively (Jones 2003; Palaniswami 2020). The economical relevance of *B. tabaci* reside on the fact that plant viruses have no known cure (Gilbertson et al. 2011). Therefore, growers emphasize the management of these diseases in the reduction of vectors (Castle et al. 2009).

The effective measurement of *B. tabaci* populations is crucial for a successful management; the counting of *B. tabaci* adults over nymphs and/or eggs has been highly recommended due to its convenience by being easy to perform and low time-consuming (Ohnesorge and Rapp 1986). Different techniques to monitor adults have been performed such as image systems, direct counts, vacuum sampling, and yellow sticky traps (Horowitz 1986; Qiao et al. 2008). Among these alternatives, the sticky traps have been widely adopted as monitoring tools on different agroecosystems due to their low cost and high effectiveness at detecting *B. tabaci*, especially at low densities (Ohnesorge and Rapp 1986; Qiao et al. 2008; Shin et al. 2020). Additionally, the capture ability of the sticky traps has been used as a control method to suppress *B. tabaci* populations alone or combined with other strategies such as biological control (Gu et al. 2008; Lu et al. 2012; Nair et al. 2021). However, the combination of these strategies has been partially effective due to the lack of specify of the traps, leading to a massive capture of debris and nontarget organisms including regulator insects of *B. tabaci* such as lady beetles and lacewings (Kheirodin et al. 2020; Maredia et al. 1992; Parajulee and Slosser 2003).

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So far, a limited number of alternatives have described to reduce those unwished effects without affecting the capture of the wanted organism. Covering the sticky traps with a mesh have been reported as an alternative to mitigate the collection of debris and capture of nontarget organisms; however, the traits of the mesh such color and size influence those parameters and the capture of the wanted organism (Sétamou et al. 2019). To date, there are no studies designed to evaluate the capture effect of yellow sticky traps covered with meshes of different colors and sizes on *B. tabaci*. The objective of the present work was to determine the effectiveness of yellow sticky traps covered with meshes of different colors and sizes on the capture of *B. tabaci* adults and the reduction on the collection of debris and nontarget organisms.

Materials and methods

Study establishment

The evaluation of mesh-covered sticky traps to *B. tabaci* was conducted in a field of stacked jalapeno pepper (*Capsicum annuum* L.) at the Experimental Station of the Faculty of Agronomy of the Autonomous University of Sinaloa, located in Culiacan, Sinaloa, Mexico (24° 37′ 27″ N, 107° 26′ 28″ W, 21 m above sea level) during January–February 2021. Pepper plants were planted in rows 80 m long and 1.30 m between rows, with a separation between plants of 0.25 m. The total area of the study was approx. 4500 m^2. The study was carried out at fruiting stage. No insecticide was used during the trials.

Manufacture of the traps

Rectangular sticky traps (Nair et al. 2021) were made from yellow carboards (20 × 12.5 cm) (José Luis Mondragón y Compañia S. A. de C. V.), sealed with clear laminating film (polyethylene terephthalate [PET]) (3 mil [0.076 mm]), and covered with entomological adhesive (Imex-Adhesive). After the adhesive dried, traps were covered with tulle nylon mesh (Skytex México S.A. de C.V.). Mesh characteristics varied among trials.

Experimental design

Every of the following trials carried out in the current work were established as a completely randomized design with ten replications for each treatment where a single sticky trap was considered as a replication. The treatments characteristics and their number varied among trials according with their goal as described below. Uncovered traps were consider in every trial to be used as control. Traps were attached to wooden stakes and placed at the plant canopy of the crop with a separation of 5.2 m among traps.

Mesh color trial

A 1-week trial under field conditions was conducted to determine the effect of covering yellow sticky traps with meshes of different colors on the capture of *B. tabaci*. Thirteen colors (white [5810L01], black [5810L19], red [5810L36], orange [5810L61], purple [5810L83], light blue [5810L21], dark blue [5810L27], crimson [5810L37], pink [5810L50], gray [5810L11], light green [5810L46], dark green [5810L47], and yellow [5810L72]) of mesh (diamond shape with 3 mm long each diagonal) (Skytex México S.A. de C.V.) were selected to cover one side of the traps (Table 1). After 7 days, traps were removed from the field and taken to the plant protection laboratory for *B. tabaci* adults counting with a dissecting microscope.

Mesh size trial

To determine the effect of covering yellow sticky traps with meshes of different size on the capture of *B. tabaci* adults and their cleanliness (scale 1–9), traps were covered with three different mesh groves size: diamond shape measuring 1 mm long each diagonal (area of 0.5 mm^2, model 5833L72) and 3 mm long each diagonal (area of 4.5 mm^2, model 5820L72), and hexagon shape with 1 mm long each (area of 2.6 mm^2, model 5820L72) (Skytex México S.A. de C.V.). To evaluate the cleanliness of the traps after 1 week, the rating scale of Sétamou et al. (2019) with modifications was used, where 1 = clean with 0–20% of trap area covered with organisms and debris, 3 = 20–40% of trap area covered,

Table 1 Mesh colors evaluated with their corresponding CMYK values

No	Color	CMYK values
/	Unmeshed (Control)	/
1	White	0.00, 0.00, 0.00, 0.00
2	Black	0.00, 0.00, 0.00, 0.97
3	Red	0.00, 1.00, 1.00, 0.00
4	Orange	0.00, 0.73, 1.00, 0.00
5	Purple	0.12, 0.65, 0.00, 0.69
6	Light blue	0.76, 0.14, 0.00, 0.00
7	Dark blue	0.62, 0.56, 0.00, 0.58
8	Crimson	0.00, 0.89, 0.81, 0.42
9	Pink	0.00, 0.27, 0.10, 0.00
10	Gray	0.00, 0.00, 0.00, 0.16
11	Light green	0.45, 0.00, 0.45, 0.00
12	Dark green	0.77, 0.00, 0.96, 0.64
13	Yellow	0.00, 0.03, 0.98, 0.00

5 = 40–60% of trap area covered, 7 = 60–80% of trap area covered, and 9 = 80–100% of trap area covered. The procedure of this trial was similar as the previous trial described above.

Multiple host crops' trial

With the goal to provide supportive data of the effectiveness of mesh-covered traps on the capture of *B. tabaci* adults and cleanliness of the traps, a validation field trial was conducted in five neighboring commercial *B. tabaci* host crops (Basu 2019) for 1 week (Table 2). After the period, the traps were taken to the laboratory to record the number of *B. tabaci* adults caught and cleanliness of the traps (scale 1–9).

Long-term validation study

A second validation trial was carried out during four consecutive weeks to evaluate the traps efficiency over a long term. The trial was conducted in the stacked jalapeno pepper field at the experimental station of the faculty. Number of *B. tabaci* adults caught and cleanliness of the traps (scale 1–9) were evaluated weekly. Additionally, on the last evaluation, debris and nontarget organisms were recorded. Nontarget organisms were only categorized by type.

Statistical analysis

Data from the trials (number of insects captured and cleanliness of the traps) did not comply with the statistical assumptions of normality of variances according with Kolmogorov–Smirnov test, and homogeneity of variances in accordance with Levene's test. Therefore, a nonparametric analysis of variances was applied. For the mesh color and size trials, the Kruskal–Wallis and Dunn median tests with Bonferroni correction were carried out to exhibited significance among treatments ($p < 0.05$). Regarding the validation trials, because only were compared meshed traps with uncovered ones, the Mann–Whitney *U* test was used. The calculations were performed with SPSS version 26.

Results

Effect of mesh color

The mesh color exhibited a significant effect on the number of *B. tabaci* adults captured at 7 days after exposure ($H = 53.676$, df = 13, $p = 0.001$). Among the 13 colors used, only yellow traps covered with yellow mesh had no significant reduction on the adults captured compared with uncovered traps (Fig. 1). Yellow mesh was chosen for subsequent trials.

Effect of mesh size

The mesh grooves sizes evaluated exhibited nonsignificant effect on the number of *B. tabaci* captured ($H = 6.937$, df = 3, $p = 0.074$) at 7 days after exposure (Fig. 2A). However, a significative effect on the cleanliness of the traps was found $H = 28.507$, df = 3, $p < 0.001$). Small diamond and hexagon grooves had the lowest score followed by the large diamond which in turn had significantly lower score compared with the uncovered control (Fig. 2B). The mesh with hexagon grooves was chosen for subsequent trials.

Multiple host crops' trial

To validate the effectiveness of the traps covered with yellow-hexagon grooves mesh on the capture of *B. tabaci* adults and their cleanliness, the traps were compared to the uncovered control on five different *B. tabaci* host crops under field conditions for 7 days. For the number of adults caught, cover-mesh traps did not differ significantly from uncovered control on either of the crops evaluated (Table 2). On the other hand, cleanliness of the mesh-cover traps was significantly different on every evaluation from uncovered control (Table 2).

Table 2 Respond of mesh-covered and uncovered yellow sticky traps to *Bemisia tabaci* and cleanliness (scale 1–9) (+SD) 7 days after exposure on five different crops under field conditions

Crop	Growth stage	No. of *B. tabaci*		*p* value	Cleanliness of the traps		*p* value
		Meshed	Uncovered		Meshed	Uncovered	
Capsicum chinense	Fruiting	17.7±7.23	12.5±3.72	0.089	2.6±1.99	5.6±2.5	0.019
Citrullus lanatus	Vegetative	30.8±9.65	26.1±4.58	0.190	1.4±0.84	4.0±1.05	<0.001
Phaseolus vulgaris	Fruiting	5.6±1.35	4.6±0.97	0.165	2.4±1.7	7.0±1.33	<0.001
Physalis ixocarpa	Flowering	11.7±6.11	8.4±1.51	0.190	2.0±1.05	6.6±1.84	<0.001
Solanum lycopersicum	Fruiting	46.9±34.6	30.1±12.17	0.393	1.0±0	3.8±1.03	<0.001

Treatments with *p* value < 0.05 were statistically different (Mann–Whitney *U* test)

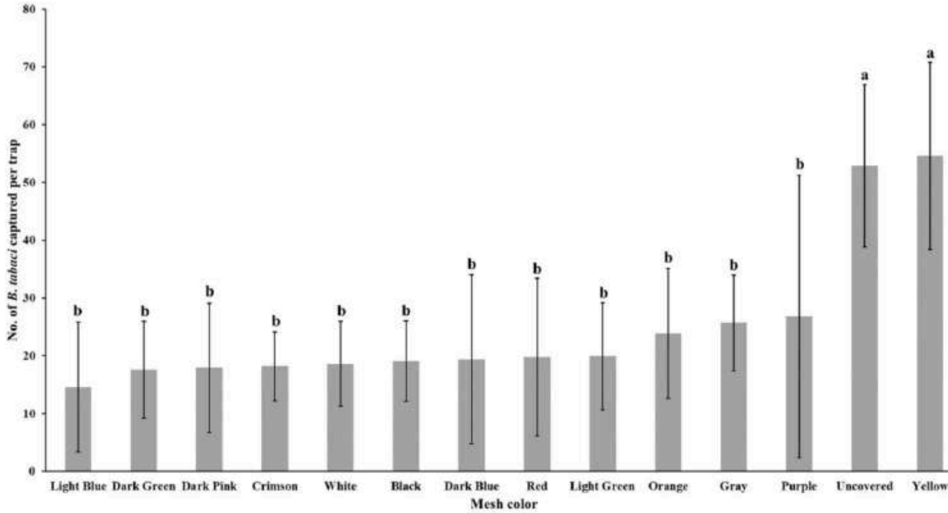


Fig. 1 Mean (+SD) number of *Bemisia tabaci* adults caught on yellow sticky traps covered with meshes of 13 colors plus uncovered traps under field conditions 7 days after exposure. Means with same letter indicate no significance difference according to Dunn's median test with Bonferroni correction ($p=0.003$)

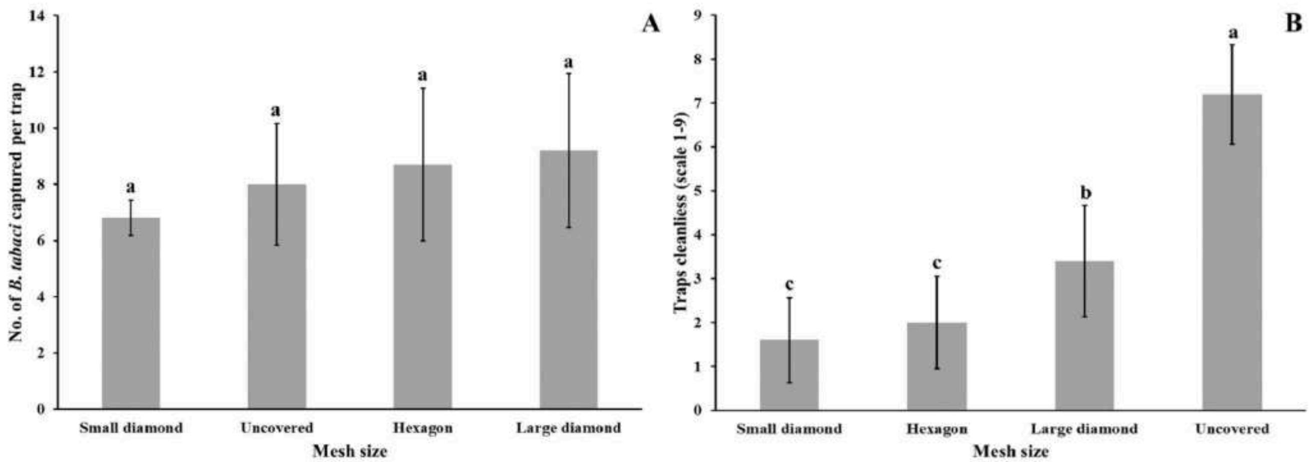


Fig. 2 Mean (+SD) number of *Bemisia tabaci* adults caught per trap (**A**) and cleanliness of the traps (**B**) on yellow sticky traps covered with yellow meshes of three sizes plus uncovered traps under field conditions 7 days after exposure. Means with same letter indicate no significance difference according to Dunn's median test with Bonferroni correction ($p<0.001$)

Long-term trial

Yellow-hexagon mesh-covered traps were compared to uncovered control weekly for 4 weeks to validate the traps effectiveness through time. For adult's capture, on the first week, there was no significant difference ($H=3.752$, $df=1$, $p=0.053$). However, at the second ($H=7.846$, $df=1$, $p=0.005$), third ($H=14.044$, $df=1$, $p<0.001$), and fourth ($H=14.318$, $df=1$, $p<0.001$) week, the mesh-covered traps significantly caught more *B. tabaci* adults than uncovered control (Fig. 3A). Regarding the cleanliness of the traps, mesh-covered traps differ significantly from uncovered control in the first ($H=14.675$, $df=1$, $p<0.001$), second ($H=13.705$, $df=1$, $p<0.001$), third ($H=13.868$, $df=1$, $p<0.001$), and fourth ($H=14.014$, $df=1$, $p<0.001$) week (Fig. 3B). Additionally, on the last evaluation, debris and nontarget organisms were recorded. A significant reduction on the number of debris and nontarget organisms was exhibited on the mesh-covered sticky traps (Table 3).

Discussion

The use of meshes to cover sticky traps has proved to reduce the capture of debris and nontarget organisms without reducing their effectivity of capturing the wanted organism (Sétamou et al. 2019). However, the mesh traits such as color and size influenced those parameters and there are no studies designed to identify those traits of the meshes on the capture of *B. tabaci*.

The color of the mesh used to cover yellow sticky traps influences significatively the capture of *B. tabaci* adults (Fig. 1). Covering the traps with a mesh modifies the perception of the insects to the traps (Sétamou et al. 2019). Out of

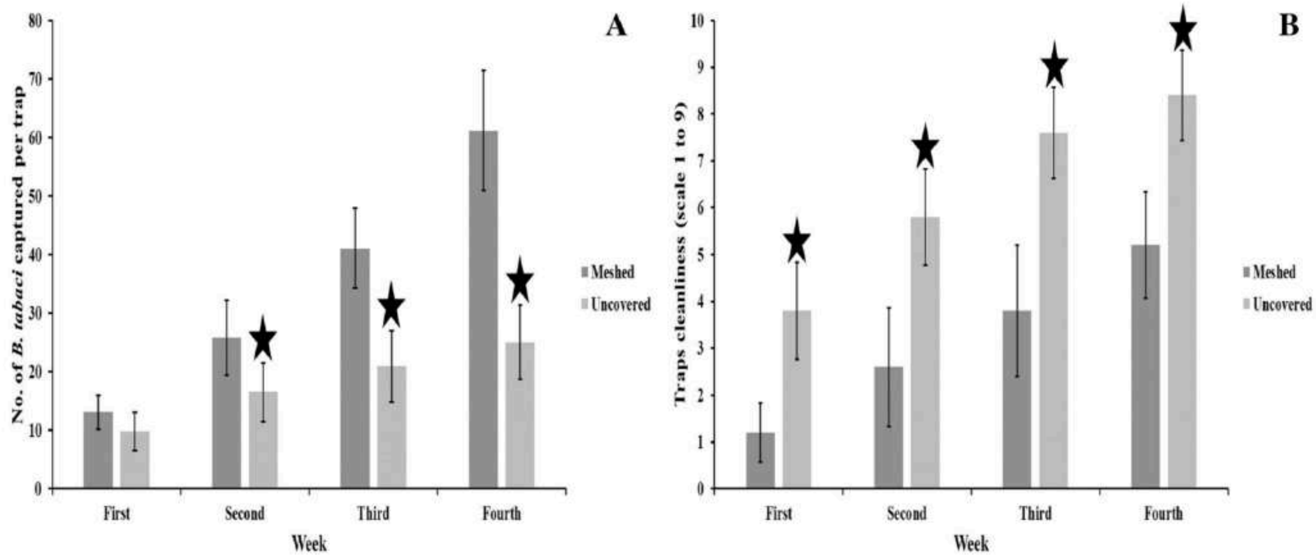


Fig. 3 Mean (+ SD) values of *Bemisia tabaci* caught on yellow-hexagon mesh-covered sticky traps plus uncovered traps (**A**) and traps cleanliness (**B**) under field conditions for 4 weeks. Stars indicate a significance difference between mesh-covered and uncovered traps according to Mann–Whitney *U* test ($p<0.05$)

Table 3 Capture of debris and nontarget organisms on mesh-covered and uncovered yellow sticky traps (+ SD) after 4 week *Bemisia tabaci* field trial

Variable	Trap		*p* value
	Meshed	Uncovered	
Lady beetles	0.2 ± 0.42	1.2 ± 0.42	< 0.001
Small beetles (Coleoptera members)	5.7 ± 2.50	9.1 ± 2.89	0.017
House and compost flies	5.6 ± 2.21	45.9 ± 10.35	< 0.001
Leafhoopers	2.3 ± 1.42	5.9 ± 3.25	0.004
Small bugs (Hemiptera members)	0.2 ± 0.42	1.2 ± 0.42	< 0.001
Bees	0.0 ± 0	0.2 ± 0.42	0.146
Hornest	0.0 ± 0	0.2 ± 0.42	0.146
Moths	0.0 ± 0	0.3 ± 0.48	0.067
Lacewings	0.0 ± 0	1.0 ± 0.42	< 0.001
Spiders	0.0 ± 0	0.2 ± 0.42	0.146
Feathers	0.0 ± 0	0.2 ± 0.42	0.146
Plant debris	0.2 ± 0.42	1.3 ± 0.42	< 0.001

Treatments with *p* value < 0.05 were statistically different (Mann–Whitney *U* test)

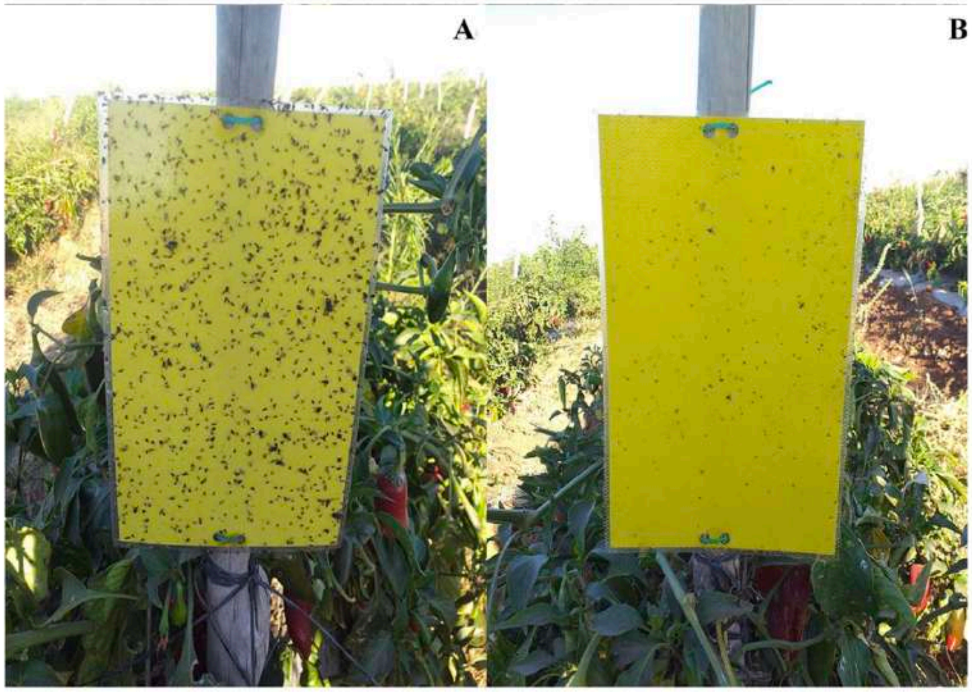
the 13 colors used in the current study, only the yellow mesh exhibited no significant decrease on the number of *B. tabaci* adults captured in comparison with uncovered yellow traps. These results are due to colored meshes apart from yellow have a great contrast with the yellow traps, affecting the perception of the insects. This effect of the mesh is particularly important in insects with a strong visual reaction such as *B. tabaci* (Kim and Lim 2011; Nair et al. 2021).

The covering of the traps with a mesh originates superficial grooves that limited the effective surface of the traps, affecting the capture of insects (Sétamou et al. 2019). For *B. tabaci,* out of the three groove sizes evaluated, the number of adults caught did not differ from uncovered control (Fig. 2A). These results are due to *B. tabaci* adults are small (approx. 0.8–1.0 mm of length) and soft insects, besides there is no need of the entire body of the insects to get stick (Basu 2019; Sétamou et al. 2019). This also explains why the cleanliness of the traps decreases as the size of the grooves increases (Fig. 2B).

To validate the traits of the mesh selected on the present study, two additional trials were performed to validate them. On the first trial, out of the five *B. tabaci* host crops evaluated, the number of *B. tabaci* adults caught did not differ among covered and uncovered traps (Table 2). The data provided by this trial indicate that the effectiveness of the traps is consistent, and the technology is applied on different *B. tabaci* host crops at different population densities. This is particularly important, due to the widely use of yellow sticky traps as monitoring tools of *B. tabaci* populations, especially at low densities (Ohnesorge and Rapp 1986; Qiao et al. 2008). Additionally, the difference on the cleanliness of the traps remained significatively at each crop (Table 2). The reduction of the debris and nontarget organisms at the mesh-covered traps increases the accuracy and reduces the time consumption at the counting of the wanted organism (Sétamou et al. 2019).

On the long-term trial, the number of *B. tabaci* differs among mesh-covered and uncovered traps from the second week (Fig. 3A). This difference may be due to the reduction

Fig. 4 Uncovered (**A**) and mesh-covered (**B**) traps after 4 week exposition to *Bemisia tabaci*, debris, and other organisms at stacked jalapeno pepper field at the Experimental Station of the Faculty of Agronomy of the Autonomous University of Sinaloa, Culiacan, Sinaloa, Mexico



on the effective surface and/or perception of *B. tabaci* to the uncovered control due to their lack of cleanliness (Fig. 3B). Mesh-covered traps kept cleaner after 4 weeks exposure than uncovered ones (Fig. 3B) (Fig. 4). The increasing on the life of the mesh-covered traps is particularly relevant to agroecosystems where yellow sticky traps are used as control tools on *B. tabaci* management programs (Gu et al. 2008; Lu et al. 2012). The potential reduction on the number of sticky traps needed to be deploy by growers would make this control method more profitable, leading to a better adoption. Additionally, yellow sticky traps are often used with biological control, the significative reduction on the capture of *B. tabaci* predators such as lady beetles and lacewings on the mesh-covered traps would allow a better combination of these two control strategies (Table 3). On the other hand, despite the number of bees captured on the uncovered traps did not differ from covered ones, perhaps due to their low population density and/or their low attraction to yellow (Rodriguez-Saõna et al. 2012), the result of null catch of bees on the meshed traps evaluated is particularly interesting to agroecosystems where bees are released by growers in high densities (e.g., cucumbers), leading to a better integration of these two agronomic strategies. Moreover, the height of the trap installation on the crop is a fundamental factor that influence the capture of *B. tabaci* adults (Mao et al 2018; Rodriguez-Saõna et al. 2012; Shin et al. 2020). Covering the traps with a mesh reduced the capture of debris produced by plants which is particularly important in crops where is recommended the installation of the traps at the plant canopy or below to capture the highest number of *B. tabaci* possible.

In summary, yellow sticky traps covered with yellow mesh reduced the collection of debris and nontarget organisms without affecting the capture of *B. tabaci*, making them valuable tools in management programs designed to monitor and control *B. tabaci* populations.

Acknowledgements Authors would like to thank Consejo Nacional de Ciencia y Tecnología (CONACYT) for the scholarship granted to Walter Arturo Rubio-Aragón to carry out his Doctoral Studies.

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