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ORIGINAL RESEARCH ARTICLE

Efficiency of traps with different shape, background color and location to monitor *Bemisia tabaci* (Gennadius) adults on Anaheim pepper (*Capsicum annuum* L.) crop

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Abstract

Sticky traps are widely used for monitoring *Bemisia tabaci* populations, and their efficiency is affected by their design and location within crops. Exist few information about these factors, especially on pepper crops (*Capsicum annuum* L.) under open field conditions, therefore, the objectives of this study were to determine the efficiency of sticky traps with different shapes, background colors, and locations to monitor *B. tabaci* adults within Anaheim pepper. In the first part of this study, two assays with six trap shapes and seven colored backgrounds were evaluated. A significantly higher number of adults were captured on triangular, rectangular, and ellipsoid traps in comparison with the other shapes. The sticky traps with yellow and black backgrounds showed no significant difference on the number of insects between them but they did with the other colors. In the second part, three assays were done to evaluate the effect of four different trap orientations, five side distances from the center of row to the inter-row space and five trap heights. While as trap orientation did not have a significant effect on insects captured, traps installed at 0–40 cm aside from the row center during the early crop growth and 0–60 cm during the reproductive phase caught a significant highest number of adults. Traps placed at a height of 0 cm during the vegetative phase, and at 0–20 cm during the reproductive phase captured the maximum number of adults. This study provides new useful insights for monitoring whiteflies with sticky traps in open field conditions.

Keywords Whitefly · Monitoring · Sticky traps · Integrated pest management · Insect behavior

Introduction

Peppers (*Capsicum annuum* L.) are one of the most important crops worldwide (FAO, 2023). Anaheim morphotype is one of the most important peppers morphotype and is currently cultivated in many countries, especially in the tropical and subtropical regions (Hashem et al. 1991; Walker and Funk 2014; Al-Aloosi et al. 2020). Pepper production in these regions is limited by several factors, highlighting the wide diversity of phytophagous insects (Weintraub 2007).

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Among these insect pests, the whitefly *Bemisia tabaci* (Gennadius) (Hemiptera: Aleyrodidae) spotlight as a major yield limiting due to its ability to transmit plant viruses and their severity is related with its population size (Hernandez-Espinal et al. 2018; Retes-Manjarrez et al. 2018; Ghosh and Ghanim 2021).

The implementation of appropriate pest management measures requires a reliable identification and monitoring of the insect pest, especially of virus vectors such as *B. tabaci* because is essential for decision-making in an Integrated Pest Management Program. The estimation of *B. tabaci* densities using adult counts over the other biological stage is highly recommended and widely adopted due to a higher ease to perform and cost effectiveness (Ohnesorge and Rapp 1986). Comparative studies of multiple sampling methods exhibit the use of yellow sticky traps as one of the most sensitive strategies to estimate *B. tabaci* population size,

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establishment and spread within crops over other techniques such as vacuum sampling and image systems (Horowitz 1986; Qiao et al. 2008).

Sticky traps consist of a cardboard or plastic surface covered with a viscous substance used as adhesive such as oil or a specialized glue (Singh and Sood 2020). The effectiveness of the sticky traps to capture insects is highly influenced by different factors such as the traps design and their location within the crops. For the design, factors such as shape and background color have been shown to modify the traps effectivity of different insects (Moreno and Gregory 1984, Döring et al. 2004, Mainali and Lim 2010, Nair et al. 2021) and for the location within the crops, factors such as trap orientation, side distance from the center of row to inter-row space and height crop type and its vegetative stages have been reported to be fundamental aspects to consider (Atakan and Canhilal 2004; Mao et al. 2018; Pobozniak et al. 2020; Shin et al. 2020). However, there is a very limited number of studies designed to evaluate the effectiveness of different yellow sticky traps shapes, the additions of a background colors and location to monitor *B. tabaci* populations in open field crops such as Anaheim pepper. Therefore, the objectives of this study were to evaluate the efficiency of sticky traps with different trap shapes, background colors, and locations factors, such as orientation, side distance from the center of row to inter-row space and height to monitor *B. tabaci* adults within Anaheim pepper crop in open field conditions.

Materials and methods

Study establishment

The current study was conducted in a commercial staked Anaheim pepper (*Capsicum annuum* L.) field in Angostura, Sinaloa, Mexico (25°9'15"N, 109°54 '34"W). Wooden stakes and nylon ropes were used to keep the plants erected. The rows design was as follow: width of the rows 0.6 m, distance among rows (center to center) 1.6 m and distance among plants 0.3 m. The study was divided in two parts and each part was carried out twice. The total area for each part was approx. of 3,275 m^2 and 2,460 m^2, respectively. No pesticides were used during the study.

First part of the study: trap shapes and background color

This phase of the study was carried out during April and May 2021 at fruiting stage with the goal of evaluating the efficiency of different trap shapes and background colors for capturing *B. tabaci*. The sticky traps used were made from cardboard, sealed with clear laminating film (polyethylene terephthalate [PET]) (3 mil [0.076 mm]), and covered with entomological adhesive (Imex-Adhesive). Only one side of the traps was glued. For the shape assay, the yellow cardboard was cut into six geometrical shapes of 250 cm^2: triangle (22.0 cm base and 22.6 cm height), ellipse (12.0 and 6.6 cm axis), rectangle (20.0 cm long and 12.5 cm width), diamond (22.3 cm and 22.3 cm diagonals), circle (8.9 cm radius) and square (15.8 cm per side) (Fig. 1A). Due to their common use and commercial availability the rectangle shape was considered as control treatment. Regarding the background assay, yellow rectangles (250 cm^2 [20.0 cm long and 12.5 cm width]) were attached in the center of yellow, red, white, black, green, purple, and blue rectangles (500 cm^2 [27.9 cm long and 17.9 cm width]), the resulting traps were sealed, and the adhesive was applied only to the small-yellow rectangle (Fig. 1B). Due to the background and trap color were similar, yellow background was considered as control treatment. For both assays, the bottom edge of the traps was placed at the plant canopy level.

Second part of the study: traps orientations, side distances from the row center to the inter-row space, and height

This part was performed during October-March 2021–2022 with the goal of evaluating the efficiency of different orientations, side distances from the row center to the inter-row space, and height placements of the traps during the crop development. Rectangular-yellow traps (250 cm^2 [20.0 cm long and 12.5 cm width]) were used on the following assays. To evaluate the effect of the orientation, the traps were located facing North, South, East, and West. For the row side distance, the sticky traps were installed from the center of the row to the center of the inter-row space at intervals of 20 cm, leading a total of five treatments 0, 20, 40, 60 and 80 cm aside of the row center (Fig. 2). Two row side distance assays were carried out. The trap orientation and the first-row side distance assays were performed during the first week after transplanting the seedling, and the second-row side distance assay was carried out when the crop reached flowering. For the three previous assays, the bottom edge of the traps was placed at the plant canopy level. Regarding the height, the bottom edge of the traps was placed at 0, 20, 40, 60 and 80 cm above the row top and a total of seven evaluations were made from the first week after the transplanting at intervals of fifteen days for the first six evaluations and the last evaluation was made one month after the sixth evaluation as a validation assessment. For the first four evaluations (vegetative stage) traps were placed 40 cm from the row center to the inter-row space and for the remaining (flowering and fruiting) traps distance mas

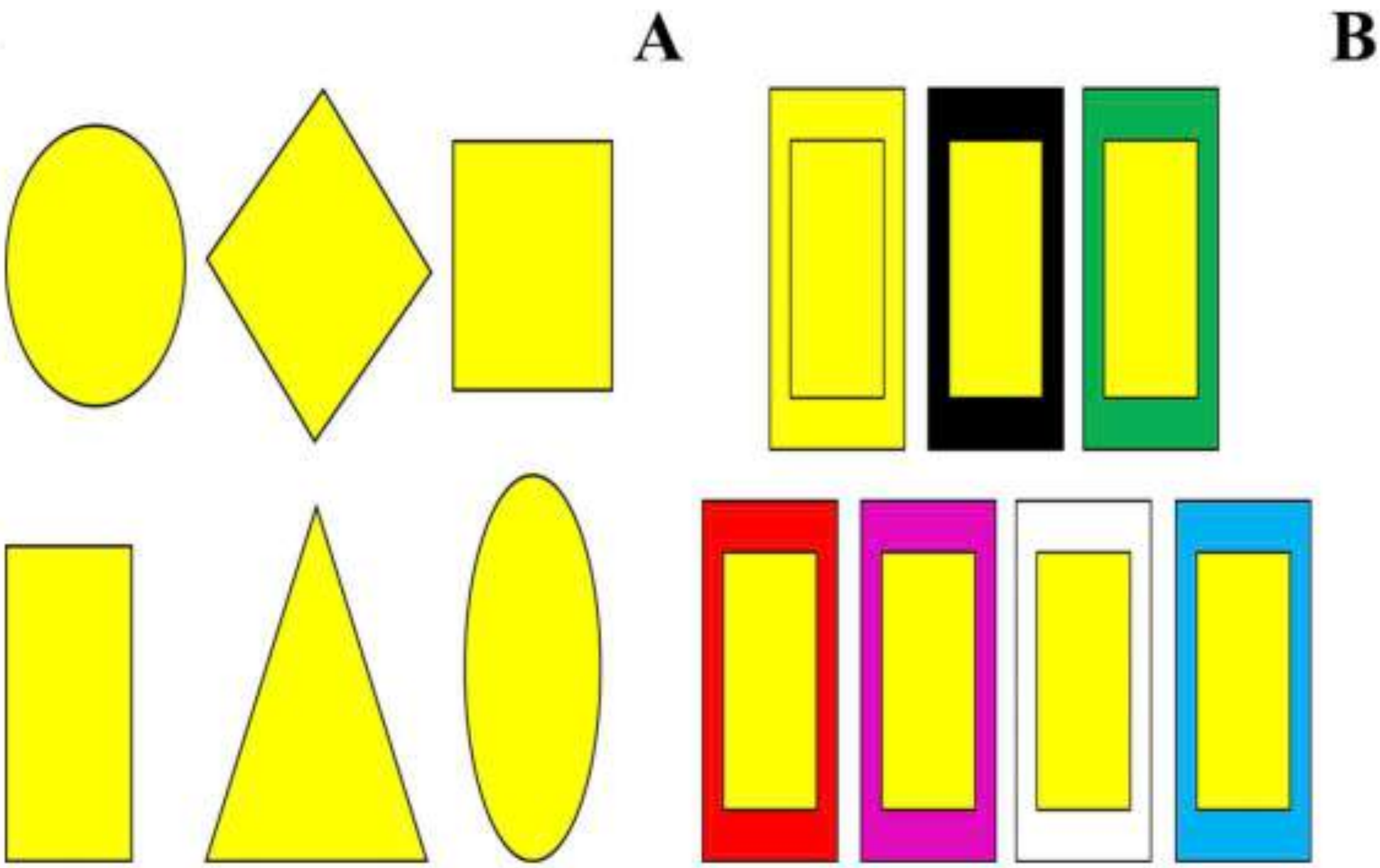

Fig. 1 Diagram representing the shape (**A**) and background color (**B**) of the yellow sticky traps used in the first experiment

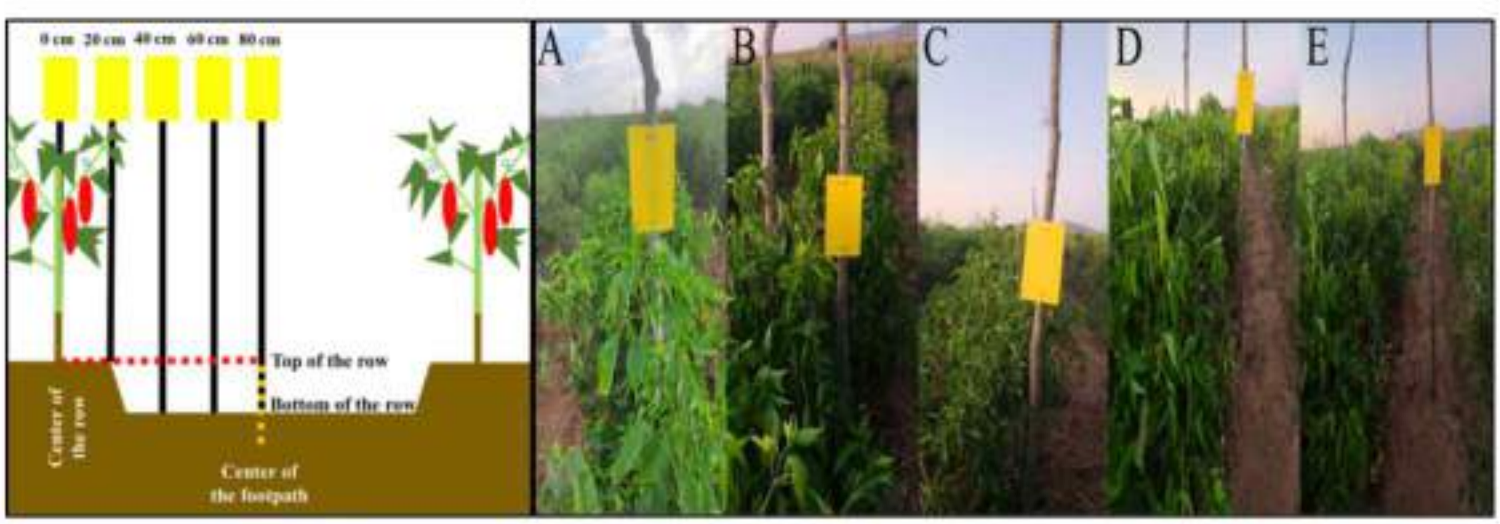

Fig. 2 The diagram for yellow sticky traps installed at the pepper plants canopy. Right pictures show the traps installed at the five different distances evaluated 0 cm (**A**), 20 cm (**B**), 40 cm (**C**), 60 cm (**D**) and 80 cm (**E**) aside from the row center to the inter-row space

modified 60 cm aside from the row center. When it was necessary the plants branches were carefully manipulated using the nylon ropes to avoid obstruction among the traps and the insects.

Experimental design and data analysis

Every of the assays performed in both parts of the study was established as a completely randomized design with ten replications per treatment and a trap separation of 6.4 m. Each trap was considered as a replication and the traps were left in the field for three days. After the period, the traps were removed for insects counting with a dissecting microscope.

Data generated from both replications of each assay was combinate since there was no statistical difference among the number of insects captured in all the evaluations involved ($P>0.05$). The data did not comply the statistical assumptions of normality and homogeneity of variances according with the Kolmogorov-Smirnov and Levene´s tests, respectively, therefore, a nonparametric variance analysis with the Kruskal-Wallis and Dunn median tests was used to determine significance among treatments ($P\leq0.05$). All analysis were performed with the statistical software SPSS version 26.

Results

First part of the study: trap shapes and background color

There was a significative effect of the trap shape on the capture of *B. tabaci* (H = 43.507; gl = 5; $P\leq0.001$). Among the six shapes evaluated, triangle, rectangle, and ellipse had the statistical highest number of *B. tabaci* with an average trap catch of 59.5 ± 4.3, 56.8 ± 3.5 and 55.7 ± 3.7 adults captured per trap, the remaining shapes had 40.9 ± 1.8 to 35.2 ± 2.2 (Fig. 3A). As no shape had a significant higher number of insects caught than the control, rectangle shape was chosen for subsequent assays.

In the trap background color, there was also a significant difference in the number of *B. tabaci* adults among treatments (H = 73.745; gl = 6; $P\leq0.001$). Yellow and black were the most effective colors capturing insects followed by green and red with an average trap catch of 34.5 ± 3.1, 29.8 ± 2.8, 19.3 ± 2.2 and 19.0 ± 1.9 insects, respectively, the remaining colors had 11.9 ± 1.4 to 8.1 ± 1.0 (Fig. 3B). As no background color had a significant higher number of insects caught than the yellow control, no colored frame was added, and a simple monochromatic yellow-rectangle design was used for subsequent assays.

Second part of the study: traps orientations, side distances from the row center to the inter-row space, and height

No significant difference was found in the number of insects caught by the sticky traps placed at the different cardinal orientations (North, South, East, and West); the range of the average adults caught per trap was from 12.9 ± 1.0 to 18.4 ± 2.74 (H = 2.783; gl = 3; $P\leq0.426$).

In the row side distance assays, there was a significant difference exhibited among treatments in both assays. In the first assay (H = 13.954; gl = 4; $P=0.007$), among the five distances evaluated, the traps placed at 0, 20 and 40 cm aside from the row center to the inter-row space had the statistical highest number of insects caught with an average trap catch of 8.7 ± 1.3, 12.0 ± 1.2 and 7.8 ± 0.5 insects per trap, the reaming treatments had 6.0 ± 1.2 and 3.9 ± 0.7 (Fig. 4A). In the second assay (H = 12.775; gl = 4; $P=0.012$), the distances with the significant higher average trap catch were 0, 20, 40 and 60 cm with 22.9 ± 2.1, 26.0 ± 3.6, 27.4 ± 2.0 and

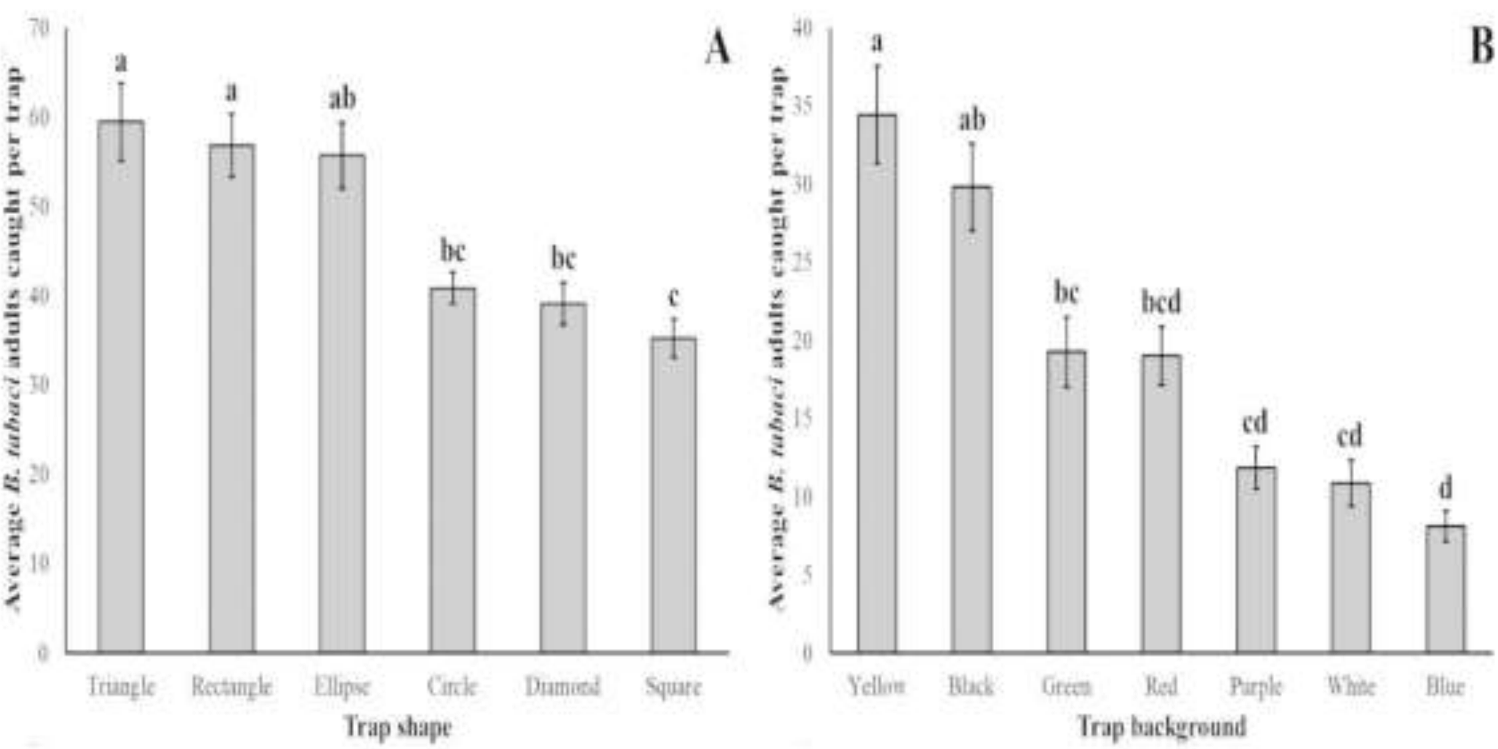

Fig. 3 Average (±SE) number of *Bemisia tabaci* caught per yellow sticky trap with different shapes (**A**) and background colors (**B**). Columns with different letters are statistical different according with the Dunn test (P ≤ 0.001)

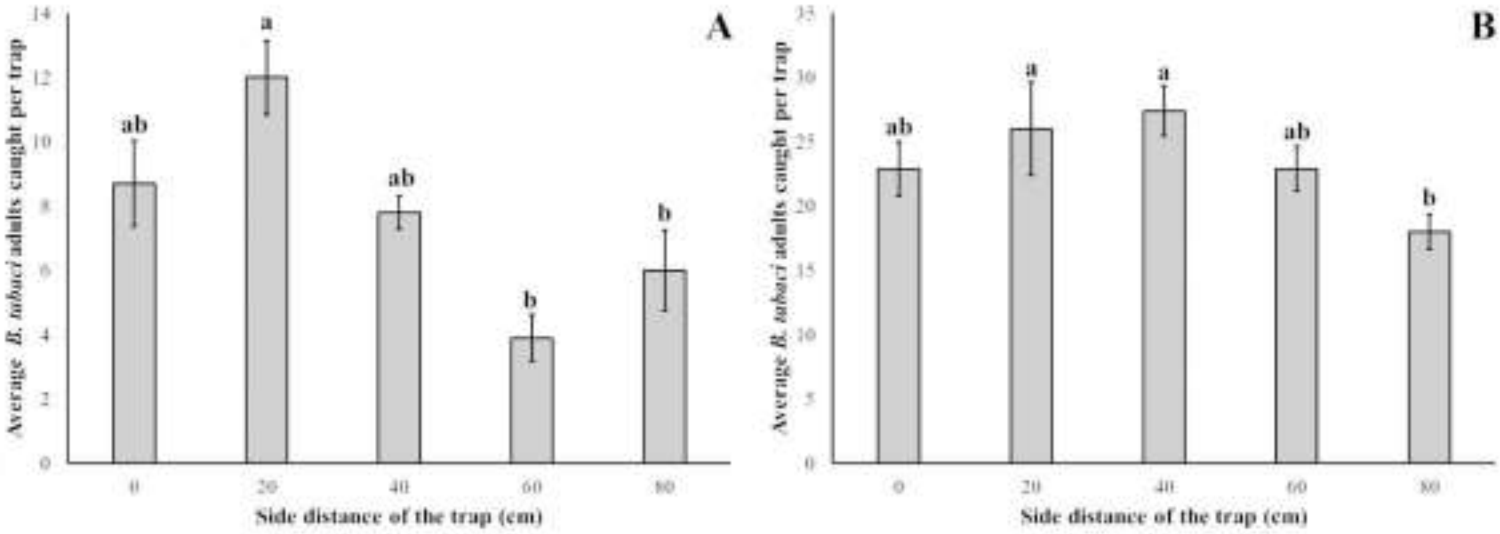

Fig. 4 Average (±SE) number of *Bemisia tabaci* caught per yellow sticky trap placed at different side distance from the row center to the inter-row space carried out one week after the transplanting of the seedlings (**A**) and in the flowering stage (**B**). Columns with different letters are statistical different according with the Dunn test (P ≤ 0.05)

Table 1 Average (±SE) number of *Bemisia tabaci* caught per yellow sticky traps placed at different heights from the row top through the development of the crop

Heights (cm)	Vegetative				Flowering	Fruiting	
	1	2	3	4	5	6	7
0	20.0 ± 3.3 a	29.4 ± 2.7 a	18.0 ± 1.5 a	25.6 ± 2.4 a	30.6 ± 2.4 a	20.6 ± 2.4 a	32.6 ± 3.4 a
20	11.9 ± 1.5 b	18.0 ± 1.5 b	12.1 ± 1.1 b	13.6 ± 1.6 b	23.8 ± 1.8 ab	16.9 ± 1.3 a	28.9 ± 2.3 a
40	5.7 ± 0.8 c	8.1 ± 1.0 c	4.4 ± 0.9 c	6.0 ± 1.6 c	9.9 ± 1.6 c	8.9 ± 1.0 b	23.4 ± 2.6 b
60	4.5 ± 0.6 c	8.1 ± 1.2 c	1.3 ± 0.4 c	4.8 ± 2.5 c	7.9 ± 1.7 c	6.3 ± 1.2 b	18.5 ± 1.6 bc
80	3.4 ± 0.8 c	5.4 ± 0.8 c	0.9 ± 0.4 c	1.1 ± 0.5 c	6.1 ± 1.5 c	2.8 ± 0.6 c	14.8 ± 1.8 c

Means with different letters in columns are statistical different according with the Dunn test ($P \leq 0.001$)

22.9 ± 1.8, respectively, the remaining treatment only had 17.0 ± 1.4 adults (Fig. 4B).

For the trap height, a significative difference among treatments was showed in the seven evaluations performed. In the first (H = 28.839; gl = 4; $P \leq 0.001$), second (H = 30.539; gl = 4; $P \leq 0.001$), third (H = 32.801; gl = 4; $P \leq 0.001$), and fourth (H = 28.266; gl = 4; $P \leq 0.001$) evaluation, the distance with the statistical highest average trap catch was 0 cm with an average trap catch of 20.0 ± 3.3, 29.4 ± 2.7, 18.0 ± 1.5 and 25.6 ± 2.4 adults followed by 20 cm with 11.9 ± 1.5, 18.0 ± 1.5, 12.1 ± 1.1 and 13.6 ± 1.6, the remaining treatments averaged 4.5 ± 0.4, 7.2 ± 0.6, 2.2 ± 0.5 and 4.0 ± 0.9 insects, respectively for each evaluation ($P \leq 0.001$). In the fifth evaluation (H = 30.821; gl = 4; $P \leq 0.001$), the treatments 0 and 20 cm had the statistical highest number of insects with an average trap catch of 30.6 and 23.8 insects, the remaining treatments averaged 7.8. In the sixth (H = 31.943; gl = 4; $P \leq 0.001$) and seventh (H = 29.011; gl = 4; $P \leq 0.001$) evaluation also the treatments 0 and 20 had the significant highest number of insects with an average trap catch of 20.6 and 16.9, and 32.6 and 28.9 adults, followed by the treatments 40 and 60 cm with 8.9 and 6.3, and 23.4 and 18.5, the remaining treatment had 2.8 and 14.8, respectively for each evaluation (Table 1).

Discussion

Monochromatic yellow, white, and blue sticky traps with a rectangle shape are the most commercially common traps available for growers worldwide to monitor insects (Koppert 2023, BioBee 2023) and for *B. tabaci* yellow is highly recommended over other colors (Simmons 2003; Shah et al. 2020; Rubio-Aragón et al. 2022). However, a recent study exhibited that yellow sticky traps with a triangle, diamond and circle shapes are efficient to capture *B. tabaci* in acrylic cages under controlled conditions (Kim et al. 2011). Based on this information, it is suggested that these kinds of studies need to be performed by production systems, crops, ecosystems, and even per species because it is well known that the behavior of the insects can vary among or within the same species.

Our results indicate that *B. tabaci* exhibited a significantly preference to triangle, rectangular and ellipsoid shapes over circle, diamond, and square shapes (Fig. 3A). It is known that insects might relate the traps shapes with different parts of the plants (Moreno et al. 1984; Vernon and Gillespie 1995), and in this particular case under our conditions the insects could related the triangle, rectangle and ellipse trap shapes with plant leaves and not with other parts of the plants. Since *B. tabaci* only feeds and oviposit on plant leaves, this insect might develop a preference for these shapes over circle, diamond and square ones which are more likely to be perceived as reproductive structures (Mainali and Lim 2010). Our results did not agree with those obtained by Kim et al. (2011) who found no statistical difference among the triangle with the diamond and circle shapes in acrylic cages under controlled conditions and this contrast between the results of both studies may be related with the different environment conditions, methodology, crop, and insect populations that these studies had during their execution.

Regarding the sticky traps with different background color, the yellow and black backgrounds showed not significantly difference between them, but they did with the other colors on the number of whiteflies captured. This result agrees with Kim et al. (2011), who found that the black color was the treatment with more *B. tabaci* captured and sticky traps with blue, white, and green backgrounds were less preferred by the whitefly adults. Different studies have demonstrated that the addition of a colored background changes the perception of the insects to the traps (Vernon and Gillespie 1995). The combination of a background of the same color as the trap does not provide a colored contrast but only increase the total area of the traps which might allowed them to be perceived by the insects from a farther distance and it has been reported that the size of the yellow sticky traps significantly influences the number of *B. tabaci* caught and the higher number is exhibited in the bigger traps (Hou et al. 2006). On the other hand, the addition of a dark background such as black originates a high contrast with the remaining area of the trap and may help the insects to perceive the reflectance with minimum interception from other source of reflectance (Döring et al. 2004; Mainali and Lim 2010).

In the second part of this study, the efficiency to capture *B. tabaci* with yellow sticky traps are no influenced by their orientation placement in any of the four main cardinal directions (North, South, East, and West). This result agrees with Hou et al. (2006) and Saleh et al. (2010) who found no differences on the preference of *B. tabaci* regarding the location of the traps. A plausible explanation could be that new adults disperse to all directions from their emergence site (van Lenteren and Noldus 1990).

To the best of our knowledge, no studies have considered the side distance of the traps in the inter-row space as a relevant location factor to improve the effectiveness of the sticky traps in open field conditions. Commonly, growers set up the sticky traps in the row center omitting this factor. According with our results, the location of 0, 20 and 40 cm (distance from the row center to the inter row space) captured a significant higher number of *B. tabaci* in comparison with the 60 and 80 cm locations during the vegetative stage at the beginning of the crop, while during the reproductive stage of flowering all the locations (0, 20, 40 and 60 cm) showed a significantly higher number of insects captured in comparison with the 80 cm location. These results agree with Shin et al. (2020) who reported in a strawberry greenhouse with high-raised beds that the significant catching zone of different phytophagous insects can be extended horizontally over the plant foliar area and the cultivation row. The increase of the significant catching zone from 0 to 40 cm aside from the row center to the inter-row space in the beginning of the crop to 60 cm aside in the reproductive phase might be explained by the increase in the total leaf area of the pepper plants. For Anaheim pepper, the current study is the first one to consider this location factor (Fig. 5).

Height is another major factor affecting the efficiency of the sticky traps to catch *B. tabaci*. In the first fourth assessments during the vegetative phase of the crop (1 to 9 weeks after transplanting the seedling), the best place to install the trap was at 0 cm from the row top, and for the fifth to seventh evaluation carried out during reproductive phase of the crop (11–17 weeks after transplanting the seedling) the optimal height increased up to 20 cm (Table 1). These results agree with Atakan and Canhilal (2004) who determinate that the crop developmental stages influence the effectiveness of the yellow sticky traps to capture *B. tabaci*. A plausible explanation of why the statistical highest number of *B. tabaci* adults is caught at the lower heights could be due the adults in the bottom leaves are more attracted to the closest traps of their emergence places and the newly adults from the upper zones also can be exposed to the lower heights due to the branches hanging (van Lenteren and Noldus 1990). These might also explain why the significant height to capture a higher number *B. tabaci* adults increased from 0 to 20 cm height in the reproductive phase of the crop where the plants had their maximum height.

In summary, yellow sticky traps with a triangular, rectangular, and ellipsoid shape with or without a black background color are efficient designs to capture *B. tabaci* adults. Traps installed up to 40 cm aside from the row center to the inter-row space and 0 cm height from row top regardless their orientation are efficient locations to capture *B. tabaci* adults throughout the entire developmental stages of the Anaheim pepper crop; this catching zone represent a valuable opportunity to standardize the monitoring protocol to capture *B. tabaci* adults with sticky traps during the entire crop development, lowering the installation and evaluation time consumption and expense which might lead into a greater adoption of this technique.

Fig. 5 Yellow sticky trap installed at 60 cm aside from the row center to the inter-row space and 20 cm height from the row top

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Declarations

Conflict of interest Authors declare no conflict of interest.

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