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ORIGINAL CONTRIBUTION

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Trap colour and aggregation pheromone dose affect the catch of western flower thrips in blackberry crops

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Abstract

Frankliniella occidentalis causes significant damage to berry crops in Mexico. Traps may be used for monitoring or mass-trapping thrips populations. Generally, colour traps are used for monitoring thrips, but sometimes a chemical stimulus can be added to the traps. However, there is conflicting information about what colour is the most attractive and efficient for capturing *F. occidentalis*. In this study, we first evaluated six colours of adhesive traps for catching *F. occidentalis* in blackberries grown in tunnels or in an open field. Subsequently, using the most attractive trap colour, we assessed the biological activity of neryl (*S*)-2-methylbutanoate and (*R*)-lavandulyl acetate, components of the pheromone aggregation of *F. occidentalis*. Finally, we examined the effect of neryl (*S*)-2-methylbutanoate dosage rates on the number of captured thrips. We found that blue (tunnel) and yellow (open field) followed by violet traps captured a significantly greater number of *F. occidentalis* compared with the white, black and green traps. Our results confirm that neryl (*S*)-2-methylbutanoate is the only component necessary for enhancing the performance of coloured traps. Blue and yellow traps baited with 200–400 μg of neryl (*S*)-2-methylbutanoate increased the capture 2.5–3 times compared to unbaited traps. In all experiments, traps captured more females than males in blackberries grown in tunnels, whereas the opposite was found in blackberries cultivated in the open field. These results constitute the first step in the development of a monitoring system for *F. occidentalis* in soft fruit crops in Mexico.

KEYWORDS
chemical cues, *Frankliniella occidentalis*, mass trapping, monitoring, Rosaceae, *Rubus ulmifolius*, Thripidae, visual cues

1 | INTRODUCTION

The western flower thrip, *Frankliniella occidentalis* (Thysanoptera: Thripidae), is native to North America, although it currently has a worldwide distribution (Abdullah, Ficken, Greenfield, & Butt, 2015; Kirk & Terry, 2003; Kirk, 2002). This insect feeds on approximately 500 plant species, some of them of economic importance (Badillo-Vargas et al., 2012; Margaria et al., 2014; Morse & Hoddle, 2006; Ogada, Maiss, & Poehling, 2013; Tzanetakis, Guzmán-Baeny, VanEsbroeck, Fernandez, & Martin, 2009). In Mexico, this species is considered one of the main insect pests of avocado (Bravo-Pérez et al., 2018; Ramírez-Dávila, Solares-Alonso, Figueroa-Figueroa, & Sánchez-Pale, 2013) and soft fruits (Ayala-Ortega et al., 2019; Cubillos-Salamanca et al., 2020). Adults and larvae scrape and suck the cell fluids on the surface of leaves and flower petals, causing visible streaks and discolourations, and necrosis of the flower petals, respectively (Castañeda-González, Johansen-Naime, Hernández-Vásquez, & Aparicio-Parra, 2011; Castresana et al., 2008). Likewise, they feed on all flower parts, including ovaries, styles, petals and developing fruits (Castañeda-González et al., 2011; Rhodes & Liburd, 2017). This damage can reduce fruit production and cause atrophy, abortion and fruit deformation (Liburd, Arevalo, & Rhodes, 2005).

The use of insecticides has been the main control method of *F. occidentalis*; however, this method has limitations, including the high costs of insecticides, the ability of *F. occidentalis* to develop resistance and the adverse effects of insecticides on the environment and human health (Bielza, Quinto, Contreras, et al., 2007; Bielza, Quinto, Fernandez, Gravalos, & Contreras, 2007b; Castresana et al., 2008; Espinosa, Bielza, Contreras, & Lacasa, 2002; Gao, Lei, & Reitz, 2012). Fortunately, there are other alternatives for managing this pest. One of these options is the use of traps for monitoring or mass-trapping thrips. *F. occidentalis* uses visual stimuli and chemical compounds in different aspects of its behaviour. Matteson, Terry, Ascoli-Christensen, and Gilbert (1992), using an electroretinogram, reported that *F. occidentalis* has two types of photoreceptors: one at 365 nm (UV) and another at 540 nm (green-yellow). Several studies have reported that *F. occidentalis* can discriminate between different trap colours, showing a preference for blue, violet, white or yellow traps over green, orange, red or black ones (Brødsgaard, 1989; Gillespie & Vernon, 1990; Kirk, 1984; Matteson & Terry, 1992; Vernon & Gillespie, 1990). However, there are contrasting results regarding which colour is the most attractive and efficient for monitoring *F. occidentalis*. Thus, while some studies have shown that more *F. occidentalis* are captured by blue traps (Brødsgaard, 1989; Matteson & Terry, 1992), other studies have reported more captured by yellow or white traps (Cho, Eckel, Walgenbach, & Kennedy, 1995; Hoddle, Robinson, & Morgan, 2002). Some studies have even shown that blue traps capture more females, while yellow traps capture more males (e.g. Gillespie & Vernon, 1990).

In addition, it is known that *F. occidentalis* is attracted to floral and non-floral volatiles such as benzaldehyde, p and o-anisaldehyde, geraniol, nerol, linalool, (+)-citronellol, (*S*)-(−)-verbenone, 1,8-cineole, methyl isonicotinate and ethyl isonicotinate, among other compounds (Abdullah et al., 2015; Abdullah et al., 2014; Chermenskaya et al., 2001; Koschier, De Kogel, & Visser, 2000). Likewise, it has been reported that *F. occidentalis* males release an aggregation pheromone that comprises neryl (*S*)-2-methylbutanoate and (*R*)-lavandulyl acetate (Hamilton, Hall, & Kirk, 2005; Kirk, 2017; Kirk & Hamilton, 2004). A number of studies have shown that the aggregation pheromone enhances sticky trap captures of *F. occidentalis* (Broughton, Cousins, & Rahman, 2015; Kirk, 2017; Sampson & Kirk, 2013). For instance, experiments performed in glasshouse-grown roses using yellow sticky traps baited with commercial aggregation pheromone lures caught 1.2–4 times more *F. occidentalis* compared with unbaited traps (Broughton et al., 2015).

The objective of this study was to begin to optimize a monitoring system for *F. occidentalis* in blackberries grown in tunnels and in an open field in Mexico. First, we evaluated six colours of adhesive traps for catching *F. occidentalis* in blackberries (*Rubus ulmifolius*, Rosaceae) grown in tunnels or in an open field. Subsequently, using the most attractive trap colour, we assessed the biological activity of neryl (*S*)-2-methylbutanoate and (*R*)-lavandulyl acetate. Finally, we evaluated the dose effect of neryl (*S*)-2-methylbutanoate on the number of captured *F. occidentalis*.

2 | MATERIALS AND METHODS

2.1 | Experimental area

Three experiments were performed in two different cultivated areas of blackberries. In the first area, blackberries are grown in tunnels that belong to Koppert Development Institute Berries, located in Tiripetío, Municipality of Morelia, Michoacán (19°31'55''N, 101°22'10''W). The experimental area is 3 ha surrounded by other blackberry crops. For the management of thrips, farmers use the predatory mite *Neoseiulus cucumeris* (Thripex, Koppert Biological Systems, Mexico) released at 100 mites/m^2 every seven days. In the second area, blackberries are cultivated in open fields that belong to the Domillo orchard, located in Barrio Alto Taretan, Michoacán (19°20'54.155''N, 101°55'46.9''W). The experimental area is 5 ha surrounded by other blackberry crops. SpinTor (Corteva Agriscience, Guadalajara, Jalisco, Mexico), Proxy and Protecprid (Koor Intercomercial, S.A. Morelos, Mexico), potassium neem soap and Bio A6 (Echeri Tzippity, Michoacán, Mexico) are regularly applied to control *F. occidentalis* in this area. In both experimental areas, blackberry plants had flowers and green and ripe fruits when the experiments were performed. The experiments were conducted in both experimental areas between October 2019 and January 2020, when the populations of *F. occidentalis* increase in these regions. At both study sites, plants were 7 months from transplanting, the plant height was about 2 m, and the row spacing was 1.7 m.

2.2 | Experiments

We performed three experiments in this study. In the first, we evaluated the effect of colour on the number of captured *F. occidentalis*. We used adhesive traps constructed with coloured cardboard (21.59 x 27.94 cm). We evaluated the following colours: yellow (R: 241; G: 249; B: 110), blue (R: 133; G: 195; B: 233), white (R: 257; G: 251; B: 252), black (R: 31; G: 30; B: 28), green (R: 24; G: 88; B: 6) and violet (R: 118; G: 46; B: 230) (https://imagecolorpicker.com/es/). We placed the trap inside a transparent poly paper bag, and on it, we distributed homogeneously an adhesive SPIDER®Plus El Vergel (butylene phenolic adhesive resin 55%, Mexico). This adhesive allowed us to remove captured insects without damage. After each sampling date, we removed the bags from the traps and took them to the laboratory for identification, sexing and recording the number of captured insects.

In the second experiment, we evaluated the biological activity of (*R*)-lavandulyl acetate and neryl (*S*)-2-methylbutanoate on the number of captured *F. occidentalis*. We evaluated four treatments:

one treatment only contained neryl (*S*)-2-methylbutanoate (1:0), while the other three treatments were binary blends of neryl (*S*)-2-methylbutanoate and (*R*)-lavandulyl acetate at the ratio of 0.5:1, 1:1 and 1:1.5, respectively. Squid Biological and Pheromones S. A. de C. V., Mexico, provided the compounds. The purity of neryl (*S*)-2-methylbutanoate and (*R*)-lavandulyl acetate was 96.9% and 92.6%, respectively, according to the supplier. We prepared the solutions in high-performance liquid chromatography (HPLC)-grade hexane (Sigma-Aldrich, Toluca, Mexico); we placed 400 μg of each blend in red rubber septa. In this experiment, we used blue and yellow traps for blackberries grown in tunnels and in an open field, respectively. We made the traps with cardboard (21.59 x 27.94 cm) and treated them as described above.

Finally, we evaluated the effect of the neryl (*S*)-2-methylbutanoate dose on captured *F. occidentalis*. In this experiment, we used blue and yellow traps for blackberries grown in tunnels and in an open field, respectively. We made the traps with cardboard (21.59 x 27.94 cm) and treated them as described above. We evaluated seven neryl (*S*)-2-methylbutanuate doses: 30, 50, 100, 200, 400, 600 and 1,000 μg. We prepared the solutions in HPLC-grade hexane (Sigma-Aldrich, Toluca, Mexico). We placed the different solutions on red rubber septa. We used an unbaited trap as a negative control; we used a trap baited with a commercial pheromone, neryl (*S*)-2-methylbutanoate (ISCAlure, Feromix, Mexico) as a positive control.

2.3 | Experimental design

We used the same experimental design in both experimental areas. We placed the traps following a randomized complete block design; each block contained all treatments (six treatments per block in the first experiment, four in the second experiment and nine in the third experiment). We used six replicates in each experiment. The distance between blocks was 30 m, and the distance between traps was 15 m. We placed the traps 1.5 m above the ground and within the crop with the help of wooden stakes. We recorded trap catches every third day. There were a total of 12 observational dates for the first experiment and 9 observational dates for the second and third experiments. We removed the poly paper bags from traps and transported them to the Chemical Ecology Laboratory of the Institute of Ecology, Pátzcuaro, Michoacán, to identify, sex and count the captured thrips with a stereomicroscope (Leica EZ4, Leica Microsystems, Morrisville, USA). We then reintroduced traps in new poly paper bags and applied the adhesive. We rotated the traps every third day within the same block to eliminate position bias.

2.4 | Statistical analysis

We analysed the obtained data with the statistical software R version 3.6.1 (R Core Team, 2019). We analysed catches as the number of thrips captured per trap per day using a repeated measures analysis of variance (ANOVA). Prior to analyses, we verified the assumptions of normality and homoscedasticity of the data; when necessary, we square root transformed the data. We compared means with the Tukey test ($\alpha = 0.05$) and confidence intervals. We evaluated sex differences in the number of captured flies (both species) with the chi-square test with Yates correction.

3 | RESULTS

In the first experiment, we found that the colour of the trap affected the number of *F. occidentalis* captured in blackberries grown in tunnels ($F = 67.82$; $df = 5{,}426$; $p < .001$). The blue traps captured significantly more *F. occidentalis* compared to the other coloured traps. Yellow and violet traps caught significantly more thrips than white-, black- and green-coloured traps (Figure 1a). In the blackberries cultivated in open fields, the colour of the traps also affected the number of captured *F. occidentalis* ($F = 64.87$; $df = 5{,}426$; $p < .0001$). The yellow-coloured traps captured significantly more *F. occidentalis* compared with white-, black-, green- and violet-coloured traps. The number of thrips captured by blue traps was intermediate to and not significantly different from those captured by yellow or violet traps (Figure 1b). The traps with white, black and green colours captured the fewest thrips in both growth conditions (Figure 1a,b). Overall, traps captured more females (56.37%) than males (43.63%) in blackberries grown in tunnels ($\chi^2 = 596.9$, $p < .001$), whereas the opposite (46.13% females and 53.87% males) was found in blackberries cultivated in the open field ($\chi^2 = 338.5$, $p < .001$).

In the second experiment, the addition of (*R*)-lavandulyl acetate to neryl (*S*)-2-methylbutanoate affected the number of *F. occidentalis* captured in blackberries grown in tunnels ($F = 49.15$; $df = 3{,}212$; $p < .001$; Figure 2a) and in the open field ($F = 15.93$; $df = 3{,}212$; $p < .001$; Figure 2b). The number of thrips captured by traps baited with neryl (*S*)-2-methylbutanoate was significantly higher compared with the binary blends (Figure 2a, b). Overall, traps captured more females (52.02%) than males (47.98%) in blackberries grown in tunnels ($\chi^2 = 87.9$, $p < .001$), whereas the opposite (48.17% females and 51.83% males) was found in the blackberries cultivated in the open field ($\chi^2 = 118.1$, $p < .001$).

In the third experiment, the number of *F. occidentalis* captured in blackberries grown in tunnels ($F = 17.64$; $df = 8{,}477$; $p < .0001$; Figure 3a) and in the open field ($F = 6.83$; $df = 8{,}477$; $p < .0001$; Figure 3b) was affected by the dose of neryl (*S*)-2-methylbutanoate. Traps baited with 400 μg neryl (*S*)-2-methylbutanoate caught more thrips than unbaited traps and those baited with 30 and 50 μg of neryl (*S*)-2-methylbutanoate, and commercial pheromone lure in tunnels. There were no significant differences in the number of *F. occidentalis* captured by traps baited with 100, 200, 400, 600 and 1,000 μg of neryl (*S*)-2-methylbutanoate (Figure 3a). For the blackberries grown in the open field, traps baited with 400 μg neryl (*S*)-2-methylbutanoate captured significantly more thrips than the other evaluated treatments, except traps baited with 600 μg neryl (*S*)-2-methylbutanoate. The number of thrips captured by traps baited with other doses of neryl (*S*)-2-methylbutanoate was

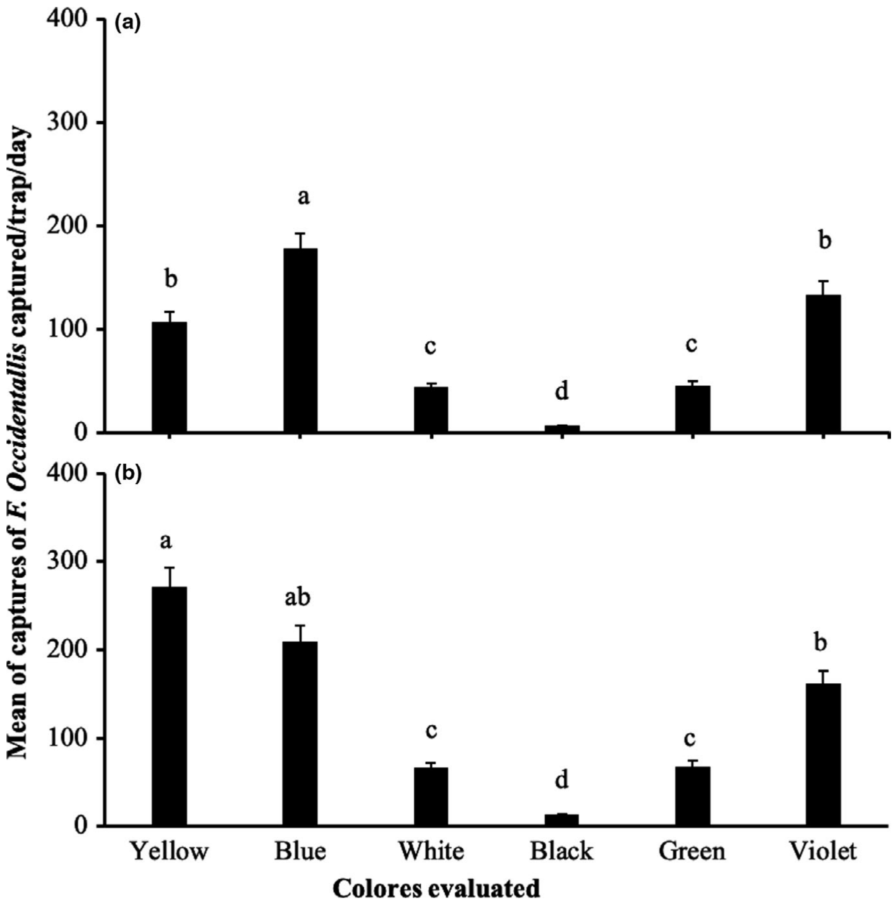

FIGURE 1 Mean ± standard error (*SE*) number of western flowers thrips captured by adhesive colour traps placed in blackberry crops. A = crop growing in tunnels; B = crop growing in the open field. Different letters indicate significant differences (Tukey test, $\alpha = 0.05$)

not significantly different from those captured by unbaited traps and traps baited with the commercial aggregation pheromone lure (Figure 3b). Overall, traps captured more females (51.32%) than males (48.68%) in blackberries grown in tunnels ($\chi^2 = 96.5$, $p < .001$), whereas the opposite (48.14% females and 51.86% males) was found in the blackberries cultivated in the open field ($\chi^2 = 249$, $p < .001$).

In the first experiment, 6%–9% of the insects captured by coloured traps were non-target organisms (Diptera, Prostigmata and Hemiptera). Specifically, non-target organisms were captured mainly by yellow and white traps. In the other two experiments, the percentage of non-target organisms captured by traps decreased to 2%–3%; in general, only non-target dipterans were captured in these experiments.

4 | DISCUSSION

In this study, we found that the trap colour affected the number of captured western flower thrips. Blue, yellow and violet traps captured a greater number of *F. occidentalis* compared with the other tested colour traps. We also found that only neryl (*S*)-2-methylbutanuate increased trap captures for trips: the addition of this compound to the blue or yellow traps at the appropriate load rates (400 μg) may double the number of captured *F. occidentalis*.

It is known that attraction of *F. occidentalis* to coloured traps is governed by the colour hue, intensity and saturation (Vernon & Gillespie, 1990). A number of studies have reported that *F. occidentalis* can discriminate among colours (Brødsgaard, 1989; Czencz, Holman, Pelikan, Dixon, & Weisman, 1987; Gillespie & Vernon, 1990; Lewis, 1959). Overall, yellow and blue are the most attractive colours for this thrip species (Kirk, 1984; Mouden, Sarmiento, Klinkhamer, & Leiss, 2017). In agreement with previous studies (Gillespie & Vernon, 1990; Matteson & Terry, 1992; Vernon & Gillespie, 1990), we found that blue and yellow traps captured the highest number of *F. occidentalis* in blackberries grown in tunnels and in the open field. However, blue traps captured significantly more thrips in tunnels, while yellow and blue traps showed higher captures in the open field. Sunlight has a lower penetration in tunnels, so the light level was lower. By contrast, in an open field the plants are in direct sunlight, which increases the light intensity. Therefore, the reflectance intensity likely varied from one experiment to another because the light level in the blackberry growing systems was different. This factor probably explains the difference in the number of thrips captured by traps of the same colour under the two production system. These data would confirm that reflectance intensity affects the attraction of *F. occidentalis* to traps, as reported in previous studies (Gillespie & Vernon, 1990; Matteson & Terry, 1992; Vernon & Gillespie, 1990). For instance, Vernon and Gillespie (1990) found that brightly coloured traps compared with those of opaque colours captured more *F. occidentalis* in cucumber growing in open fields. Röth, Galli, Tóth, Fail, and Jenser, (2016) also reported that fluorescent yellow traps captured more thrips than non-fluorescent yellow traps, due to the

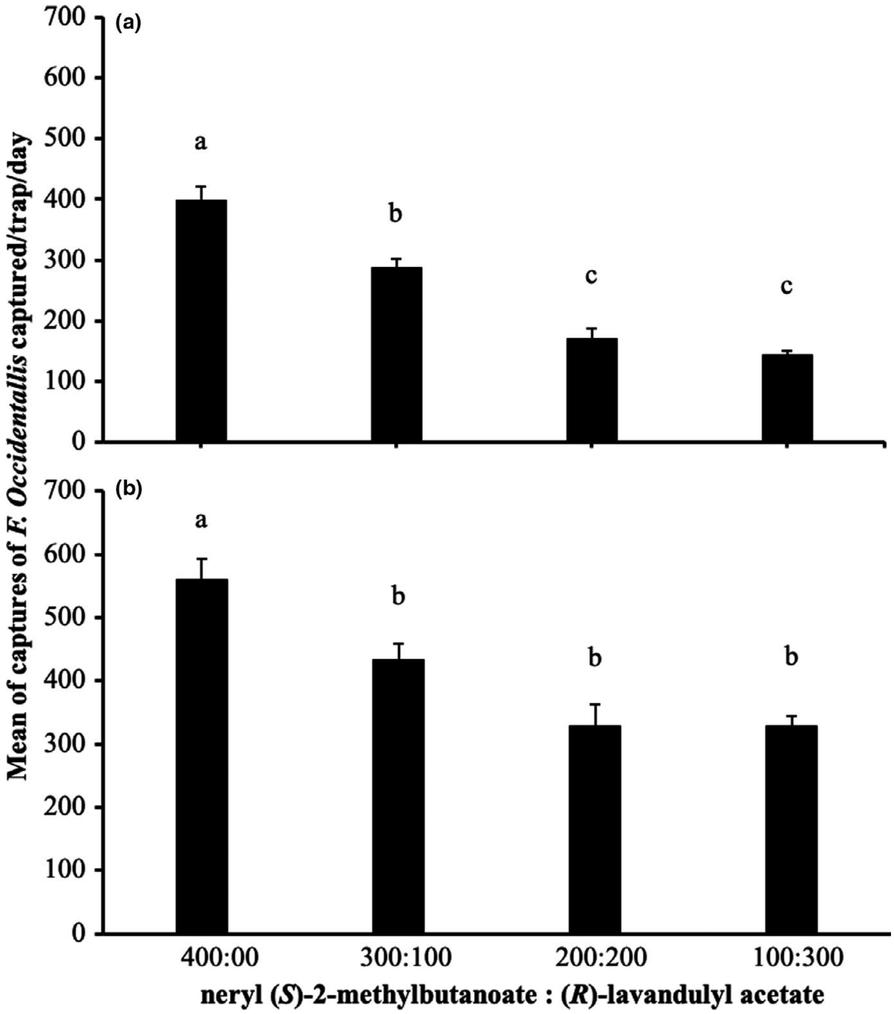

FIGURE 2 Mean ± standard error (*SE*) number of western flowers thrips captured by blue (crop growing in tunnels) and yellow (crop growing in the open field) traps baited neryl (*S*)-2-methylbutanuate single; a blend of (*R*)-lavandulyl acetate and (*R*)-lavandulyl acetate; or *R*)-lavandulyl acetate alone. A = crop growing in tunnels; B = crop growing in the open field. Different letters indicate significant differences (Tukey test, $\alpha = 0.05$)

higher reflectance of the fluorescent colour. However, it is important to note that reducing the reflectance intensity of non-attractive colours did not affect the number of captured *F. occidentalis* (Vernon & Gillespie, 1990). Other variables that may affect the capture of *F. occidentalis* are the trap shape, trap size and colour contrast (Vernon & Gillespie, 1995).

We also found that (*R*)-lavandulyl acetate did not increase the number of *F. occidentalis* captured in blackberries growing in either culture system. The decrease in the number of *F. occidentalis* captured by traps baited with the binary mixtures may be related to the decrease in the dose (Figure 3a,b). Our results agree with those previously reported, namely that (*R*)-lavandulyl acetate is not a key compound in the attraction of *F. occidentalis*. The function of (*R*)-lavandulyl acetate may be related to mediating interspecific interactions of *F. occidentalis* and other related thrips. In fact, it has recently been reported that this compound mediates the aggregation of *F. occidentalis* and *Frankliniella intosa* (Geng, Li, Zhang, Zhang, & Lu, 2017; Li et al., 2019). However, when both species do not coexist, it seems that (*R*)-lavandulyl acetate is not necessary to attract *F. occidentalis* (Kirk, 2017).

The neryl (*S*)-2-methylbutanuate doses that showed effectiveness in attracting *F. occidentalis* in the field differed from that recommended by Kirk (2017), who reported that 30 μg is sufficient to increase the number of thrips captured in adhesive coloured traps, either impregnated in the trap or in a rubber septum. However, our results showed that more than 200–400 μg of this compound is needed using a rubber septum. This difference in the attractive dose between the two studies is possibly due to the fact that our experiment was carried out in an open field and not in greenhouses. Alternatively, traps baited with ISCAlure attractant only had a 23.8%–61.2% increase in the number of captured thrips compared with the control, despite being formulated in rubber septa. This finding suggests that the dose of neryl (*S*)-2-methylbutanoate rather than the release device affects the number of captured *F. occidentalis*. As observed in this study, the number of captured thrips peaked when traps were baited with 400 μg neryl (S)-2-methylbutanoate (Figure 3).

There are previous reports on the increase in the number of captured *F. occidentalis* by adding the aggregation pheromone to colour traps (Broughton & Harrison, 2012; Broughton et al., 2015; Gómez, Garcia, GreatRex, Lorca, & Serna, 2006; Hamilton et al., 2005; Sampson, 2014; Sampson & Kirk, 2013; Sampson, Hamilton, & Kirk, 2012). However, the number of captured thrips observed in our study was 2.5–3 times higher compared with the unbaited traps; that

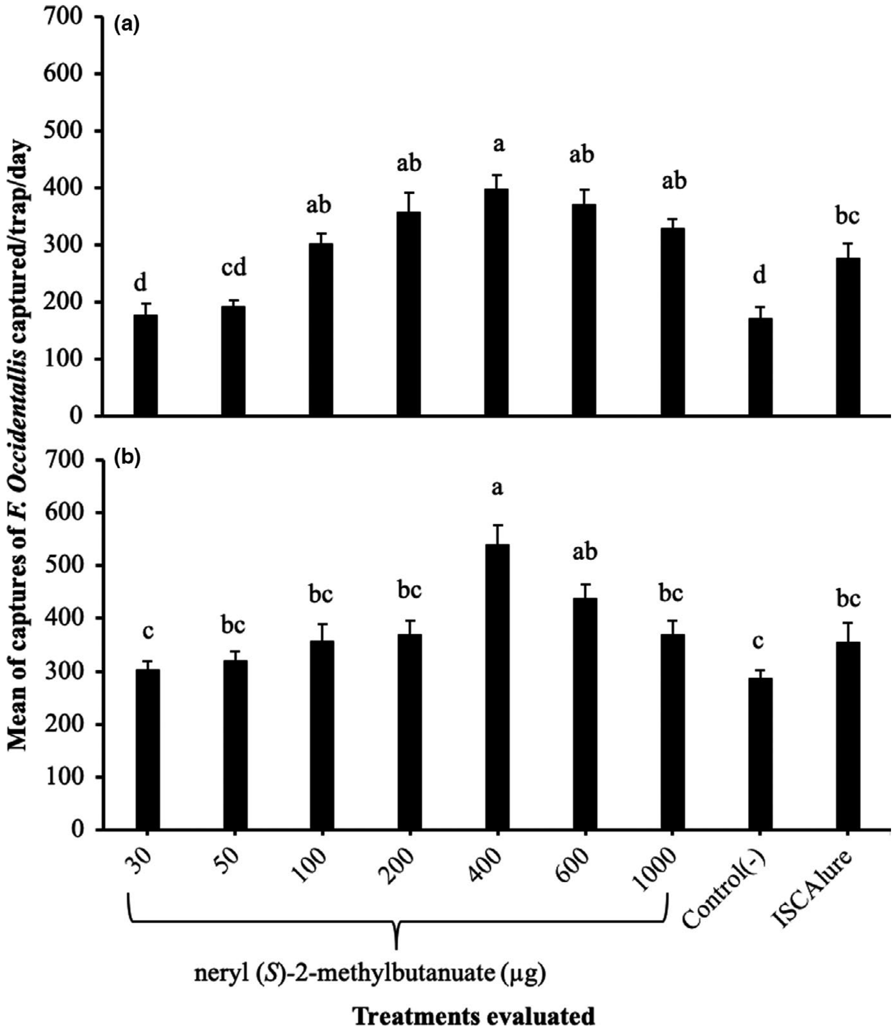

FIGURE 3 Mean ± standard error (SE) number of western flowers thrips captured by blue (crop growing in tunnels) and yellow (crop growing in the open field) traps baited with different doses of neryl (*S*)-2-methylbutanoate or a commercial pheromone (ISCAlure). A = crop growing in tunnels; B = crop growing in the open field. Different letters indicate significant differences (Tukey test, $\alpha = 0.05$)

is, for each thrip captured by the blue and yellow adhesive trap, the same trap baited with neryl (*S*)-2-methylbutanuate captured 2.5–3 times as many thrips. There have been conflicting reports with regard to the extent to which the number of captured *F. occidentalis* is increased with the addition of the pheromone to coloured traps. For example, some studies have shown that there is only a 1.5-fold increase compared with unbaited traps (Broughton et al., 2015; Sampson et al., 2012). In contrast, other studies have reported that pheromone increased the catches of colour traps by 4–14 times compared with unbaited traps (Broughton et al., 2015; Davidson, Butler, Winkler, & Teulon, 2007; Sampson et al., 2012). Our results and those of other studies suggest that chemical cues are an important factor for enhancing western flower thrip capture, as has been reported in other insects (Andrade, Rodriguez, & Oehlschlager, 2000; Blomquist et al., 2010; El-Sayed, Heppelthwaite, Manning, Gibb, & Suckling, 2005; Iglesias, Nyoike, & Liburd, 2014; Vandermoten, Mescher, Francis, Haubruge, & Verheggen, 2012; Zhang, Walker, & Wang, 2015).

Overall, the low number of non-target insects captured in the traps baited with neryl (*S*)-2-methylbutanoate suggests that these insects are not attracted to the pheromone of *F. occidentalis*. Hence, it would be relatively easy to incorporate this system to the integrated management of this pest. Our results agree with previous studies that have reported that the aggregation pheromone of *F. occidentalis* is not attractive to non-target insects (Broughton & Harrison, 2012; Sampson et al., 2012). Non-target insects were caught by the unbaited traps due to colour, which is unavoidable due to the trap design (Sampson & Kirk, 2013). In contrast, traps baited with plant volatiles can increase the number of non-target insects that are captured (Broughton & Harrison, 2012; Teulon et al., 2017). For example, a study showed that blue traps baited with Lurem-TR, a kairomone based on methyl isonicotinate, caught 1.3 times more brown lacewing compared with unbaited traps (Broughton & Harrison, 2012). However, Muvea et al. (2014) found that the addition of Lurem-TR to the sticky traps significantly enhanced the number of captured *F. occidentalis*, *Megalurothrips sjostedti*, *Frankliniella schultzei* and *Hydatothrips adolfifriderici* (Karny), but not their natural enemies. Future experiments will investigate whether the addition of kairomones to the yellow and blue traps baited with neryl (*S*)-2-methylbutanoate increases the number of captured *F. occidentalis* without affecting non-target insects.

In all three experiments, more females than males were captured in the traps placed in the blackberries growing in tunnels, while the opposite occurred when the traps were placed in the blackberries growing in the open field. One possibility is that there were more females than males in the crop growing in tunnels and fewer females than males in the crop growing in the open field. Unfortunately, we did not carry out a manual sampling of leaves and flowers to estimate the sex ratio of thrips on blackberry plants. Higgins (1992) found *F. occidentalis* females and larvae on leaves and flowers of bell pepper and cucumber plants in a greenhouse. Last study did not find many male western flower thrips on plants, but they were captured in high numbers on yellow traps (Higgins, 1992). In contrast, more males than females were trapped by blue traps placed at the top of carnation growing in glasshouses, whereas more females than males were found on flowers (Mateus, Araújo, & Mexia, 2003). Gillespie and Vernon (1990) found that blue traps captured more females while yellow traps captured more males. Matteson and Terry (1992) reported that more *F. occidentalis* males than females were captured during swarming compared to non-swarming behaviour periods. However, this eventuality would not explain our results because the traps remained for days during which both swarming and non-swarming periods likely occurred.

In conclusion, the blue and yellow adhesive traps were the most effective in attracting and capturing *F. occidentalis* in blackberries growing in tunnels and in the open field. The addition of *F. occidentalis* pheromone at 400–600 μg can increase the number of captured *F. occidentalis* in tunnels and in open fields by 2- to 3-fold. Yellow or blue traps baited with neryl (*S*)-2-methylbutanoate can be used to develop a monitoring, mass trapping or push–pull system. This system can be combined with biological control agents (natural enemies) for the management of thrip populations in blackberry crops.

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CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

AUTHORS' CONTRIBUTIONS

SCE and JCR conceived the research. PHL and SCE conducted field samplings and identified and counted the insects. SCE conducted the statistical analysis. SCE and JCR wrote the manuscript. All authors commented on the manuscript. All authors read and approved the manuscript.

DATA AVAILABILITY STATEMENT

Raw data are accessible as supplementary file: Raw data supplementary material S1.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section.

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