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Attraction of thrips (Thysanoptera: Thripidae and Aeolothripidae) to colored sticky cards in a California avocado orchard

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Abstract

Yellow, white, and blue sticky cards were tested in an avocado orchard for their attractiveness to *Scirtothrips perseae*, *Frankliniella occidentalis* and *Franklinothrips orizabensis*. Clear pieces of plastic coated with adhesive were used as controls to determine rates of random interception of thrips independent of color. Yellow was most attractive to *S. perseae* and white cards captured mostly *F. orizabensis* and *F. occidentalis*. Capture rates on blue cards declined across the course of four trials for *S. perseae* and *F. occidentalis*; this trend was not observed for *F. orizabensis*. Cardinal direction of traps did not significantly effect capture rates of thrips suggesting south westerly prevailing winds did not influence patterns of aerial dispersal. © 2002 Elsevier Science Ltd. All rights reserved.

Keywords: *Scirtothrips perseae*; *Frankliniella occidentalis*; *Franklinothrips orizabensis*

1. Introduction

In June 1996, an unknown species of thrips was discovered damaging foliage and fruit of "Hass" avocado, *Persea americana* var. *drymifolia* Blake (Lauraceae), in Ventura County, California, USA. By July 1997, the thrips had spread to all coastal avocado growing areas of California and it now infests >95% of productive acreage (Hoddle & Morse, 1997, 1998). This pest has subsequently been described and named *Scirtothrips perseae* Nakahara (Thysanoptera: Thripidae) (Nakahara, 1997), and foreign exploration efforts for natural enemies of this pest indicate that *S. perseae* is of Central American origin (Hoddle & Morse, 1997, 1998; Hoddle et al., 2001a).

Scirtothrips perseae adults and larvae have only been recorded as economic pests of avocados and host plant surveys suggest this species feeds exclusively on immature avocado leaves and fruit (Hoddle et al., 2001a). Feeding damage to young leaves causes distortion, premature defoliation, and brown scarring along the midrib and veins on the undersides of leaves becomes increasingly visible as retained leaves mature. Feeding by low densities of *S. perseae*, approximately three larvae on young fruit (<5 cm in length) can scar the entire fruit surface, while localized feeding produces discrete brown scars that elongate as fruit matures (Hoddle, unpublished).

Avocados are an economically important crop in California and the harvest in 1996–1997 was worth $259 million (US) (California Avocado Commission, 1997). Economic losses incurred because of disfiguration by thrips feeding results in harvested fruit being either culled or down-graded in packinghouses. The cost of *S. perseae* management and fruit loss due to feeding damage in 1998 was estimated to be between $7.6 and $13.4 million (US) (Hoddle et al., 1999).

Colored sticky traps may potentially be a rapid, cost-effective tool for monitoring *S. perseae* population densities and phenology in California avocado orchards. Sticky traps provide a simple method of obtaining relative estimates of thrips population densities with little effort. Sticky traps may measure pest populations more readily than labor-intensive absolute monitoring methods, as traps continuously catch and retain specimens without constant human management (Southwood, 1978). The utility of sticky traps as tools for monitoring pestiferous thrips have been evaluated for

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efficacy in greenhouses (Brødsgaard, 1989; Gillespie and Vernon, 1990), and annual (Lewis, 1959; Yudin et al., 1987) and perennial field crops (Beavers et al., 1971; Childers and Brecht, 1996; Coli et al., 1992; Moffitt, 1964; Moreno et al., 1984; Walker, 1974; Wilde, 1962).

Trap attractiveness and capture rates of thrips vary according to species or guild groupings (Kirk, 1984), trap color (Beckham, 1969; Childers and Brecht, 1996; Cho et al., 1995; Vernon and Gillespie, 1990; Walker, 1974; Yudin et al., 1987), U.V. remittance and fluorescence (Vernon and Gillespie, 1990), trap size and shape (Cho et al., 1995; Coli et al., 1992; Moreno et al., 1984; Lewis, 1959), placement height of traps (Gillespie and Vernon, 1990), sunlight degradation of colors (Childers and Brecht, 1996; Samways, 1986; Grout and Richards, 1990), cardinal direction (Beavers et al., 1971), and geographic latitude (Grout and Richards, 1990). Methods for estimating thrips densities on sticky cards have been developed that may involve either counting a section of a trap (Heinz et al., 1992), or by determining the presence–absence of thrips in grids laid over sticky traps (Steiner et al., 1999).

The purpose of the work presented here was to determine the preference of *S. perseae* to sticky traps that were blue, yellow, or white, colors with known attractiveness to thrips (Cho et al., 1995; Vernon and Gillespie, 1990; Childers and Brecht, 1996; Terry, 1997). Clear pieces of plastic coated with sticky adhesive were used as controls to determine rates of random interception independent of trap color. We also sought to determine color preferences of *Franklinothrips orizabensis* Johansen (Thysanoptera: Aeolothripidae), the key predator of *S. perseae* (Hoddle et al., 2000, 2001b) and *Frankliniella occidentalis* (Pergande) (Thysanoptera: Thripidae), a common and economically unimportant thrips found in avocado flowers and on weeds in California avocado orchards. Thrips densities have been previously monitored in avocado orchards by inspecting fruit for pest presence (Dennill and Erasmus, 1992). Our study is the first of which we are aware that has evaluated sticky card color preference for a pest thrips and its key natural enemy in an avocado orchard.

2. Materials and methods

2.1. Study site

Studies were conducted in a 40 ha commercially managed "Hass" avocado orchard in Bonsall California, USA. A 0.61 ha site on a south-facing hill with an 11° slope was selected within the orchard. This site comprised 105 top-worked trees 2–3 m in height with prolific leaf flush. Mean larval *S. perseae* densities were high for the duration of this study at 6–27 larvae per 3/4 expanded immature avocado leaf (Hoddle unpublished). During the course of this work no pesticides were applied for *S. perseae* control.

2.2. Sticky card selection, plexiglass controls, and spectral analysis

Commercially available double-sided sticky cards of three different colors were tested for attractiveness to *S. perseae*, *F. occidentalis*, and *F. orizabensis*. We tested white (Gempler's™, Belleville, MI 53508, USA), blue and yellow (both Disposable Stiky Strips™, Olson Products, Medina, OH 44285, USA). These colors were selected for their known attractiveness to various thrips species (Cho et al., 1995; Vernon and Gillespie, 1990; Childers and Brecht, 1996). Clear plexiglass rectangles were coated with Tangle-Trap (The Tanglefoot Company, Grand Rapids, MI 49504, USA) and used as controls to determine capture rates of thrips due to random aerial interception. All sticky cards and plexiglass controls were 155 cm^2 (10 cm wide × 15.5 cm high) in size.

Reflectance of colored sticky cards, clear plexiglass controls, and immature and mature avocado leaves was determined using a Li-Corr LI-1800 Portable Spectroradiometer® with a LI-1800-12 integrating sphere. Sample reflectance was measured at 10 nm intervals from 350 to 700 nm.

2.3. Experimental design

Sticky cards and plexiglass controls were deployed four times at the study site: April 25–May 2, 1999; May 6–13, 1999; May 27–June 3, 1999, and June 15–22, 1999. Wooden stakes 2 m in height with 2 m wooden perpendicular cross arms attached 1.75 m from the base were used to deploy colored sticky cards and plexiglass controls between rows of trees. With this arrangement, thrips could only be captured on traps if they were attracted to trap color while moving between rows of trees.

For each trial, a total of 96 stakes were positioned at the study site, 24 facing in each cardinal direction. Three different colored cards and one plexiglass control were attached to cross arms with binder clips at 0.5 m intervals from the center of the cross arm for a total of four traps per cross arm. Twenty-four trap combinations based on linear placement on cross arms were set up (see Table 1 for combinations) for each trial. Each of the 24 sticky card color combinations in Table 1 was replicated four times and positioned between tree rows to simultaneously face each cardinal direction to give a total of 96 stakes bearing colored sticky cards each time a trial was run.

After seven days, traps were removed from cross arms, placed in clear plastic bags, and returned to the laboratory. Numbers of each thrips species of interest

Table 1
Sticky trap combinations on cross arms deployed at the study site where C were clear plexiglass controls coated with Tangle-Trap, and W, Y, and B, were white, yellow, and blue sticky cards, respectively. Each trap combination was replicated in each cardinal direction, and both sides of each trap were coated with adhesive

Stake 1	**Stake 2**	**Stake 3**	**Stake 4**	**Stake 5**	**Stake 6**
CWYB	WYBC	BCYW	YBWC	WBCY	CBWY
Stake 7	**Stake 8**	**Stake 9**	**Stake 10**	**Stake 11**	**Stake 12**
BWYC	YCWB	CBYW	YWCB	WBYC	BYWC
Stake 13	**Stake 14**	**Stake 15**	**Stake 16**	**Stake 17**	**Stake 18**
WCYB	CWBY	BYCW	YWBC	WCBY	CYBW
Stake 19	**Stake 20**	**Stake 21**	**Stake 22**	**Stake 23**	**Stake 24**
YBCW	BCWY	CYWB	WYCB	YCBW	BWCY

were recorded for each trap color according to placement combination in each cardinal direction.

2.4. Data analysis

All statistical analyses were undertaken using Generalized Linear Modeling software (GLIM 4, Royal Statistical Society, London (Crawley, 1993)). Color preference was evaluated by inspecting the proportion of thrips captured on each colored card for each color combination. Proportional data were analyzed using a binomial probability link function (equivalent to arcsine square root transformation) and weighed for sample size. Means separation was determined by pair-wise comparisons using *t*-tests. To preserve the experiment-wise error rate of 0.05, significance was evaluated by multiplying each pair-wise comparison by the total number of comparisons made in each analysis. For instance, a significant color preference was only reported when the *t*-test probability between two colors remained <0.05 when multiplied by the number of color comparisons made.

Analyses were conducted to determine: (1) if *S. perseae*, *F. occidentalis*, and *F. orizabensis* exhibited significant preferences for specific trap colors, (2) whether trap color preference for target thrips varied across the four trials, and (3) if cardinal direction influenced trap capture rates.

3. Results

3.1. Spectral analysis and thrips color preferences

Percentage reflectance of light from immature and mature avocado leaves was similar and did not exceed 10% for mature leaves but reached 18% for immature leaves at 700 nm, and generally percentage reflectance for avocado leaves was lower than the clear plastic controls (Fig. 1). Peak reflectance was observed at 430, 480, and 570 nm for white, blue, and yellow cards, respectively (Fig. 1). Trap color had a significant effect on the mean proportion of *S. perseae* ($\chi^2 = 4707$, df = 3, $p<0.005$), *F. occidentalis* ($\chi^2 = 9141$, df = 3, $p<0.005$), and *F. orizabensis* ($\chi^2 = 569$, df = 3, $p<0.005$) caught after correcting for date and color sequence. Significantly more *S. perseae* were captured on yellow sticky cards (Fig. 2A), while white cards were most attractive to *F. occidentalis* (Fig. 2B) and *F. orizabensis* (Fig. 2C).

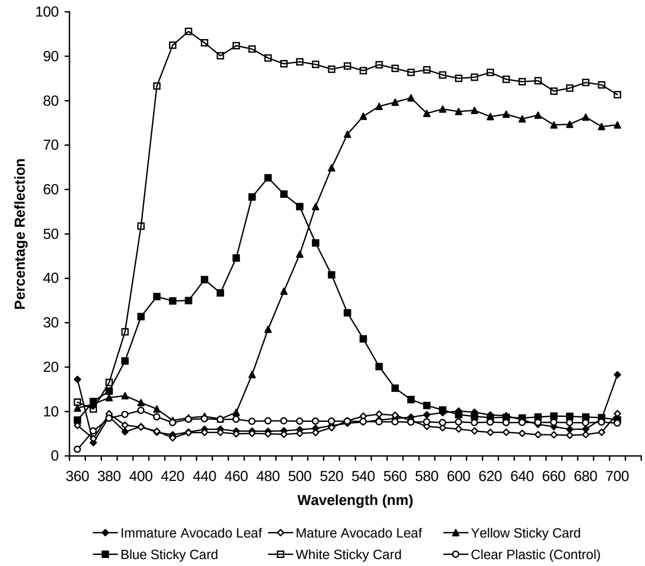

Fig. 1. Percentage of reflectance of light from surfaces of colored and clear plastic traps as measured with a Li-Corr LI-1800 portable spectroradiometer®.

3.2. Shifts in species color preferences with time

Significant differences in trap color preference through time for the four trials were observed for *S. perseae* ($\chi^2 = 291$, df = 12, $p<0.005$) and *F. occidentalis* ($\chi^2 = 1567$, df = 12, $p<0.005$). Significant changes in color preference were not observed for *F. orizabensis* ($\chi^2 = 7.2$, df = 3, $p = 0.07$). Yellow sticky cards became more attractive to *S. perseae* with a corresponding decline in capture rates on blue sticky cards (Fig. 3A). A declining preference for blue sticky cards was observed for *F. occidentalis* and a significant concurrent increase in captures on white sticky cards was recorded (Fig. 3B).

3.3. Cardinal direction and species capture rates

Cardinal direction did not have a significant effect on mean proportion of *S. perseae* ($\chi^2 = 4.15$, df = 3, $p<0.25$) (Fig. 4A), *F. occidentalis* ($\chi^2 = 3.52$, df = 3,

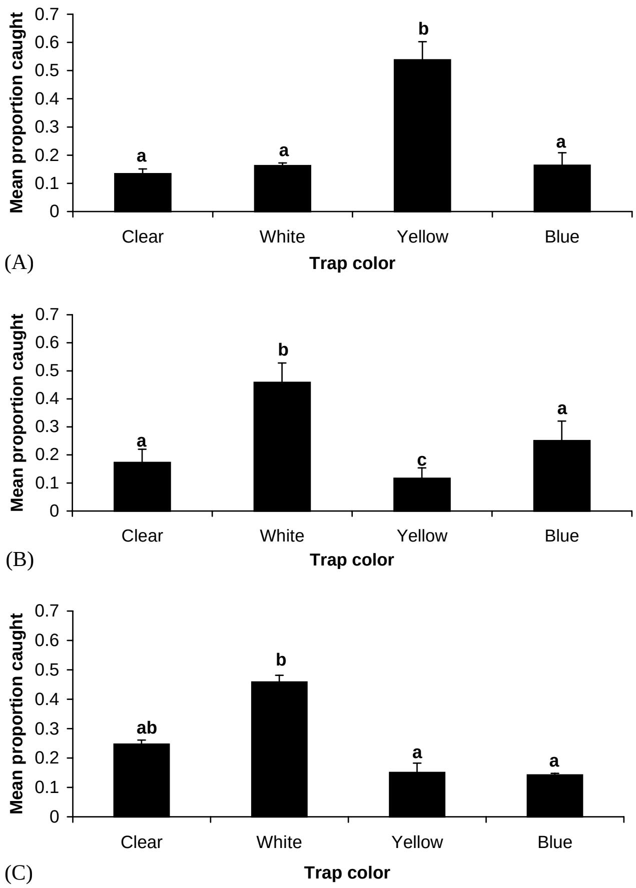

Fig. 2. Untransformed mean proportion (± SE) of *Scirtothrips perseae* (A), *Frankliniella occidentalis* (B), and *Franklinothrips orizabensis* (C) caught on different colored sticky cards. Means with different letters are significantly different at the 0.05 level.

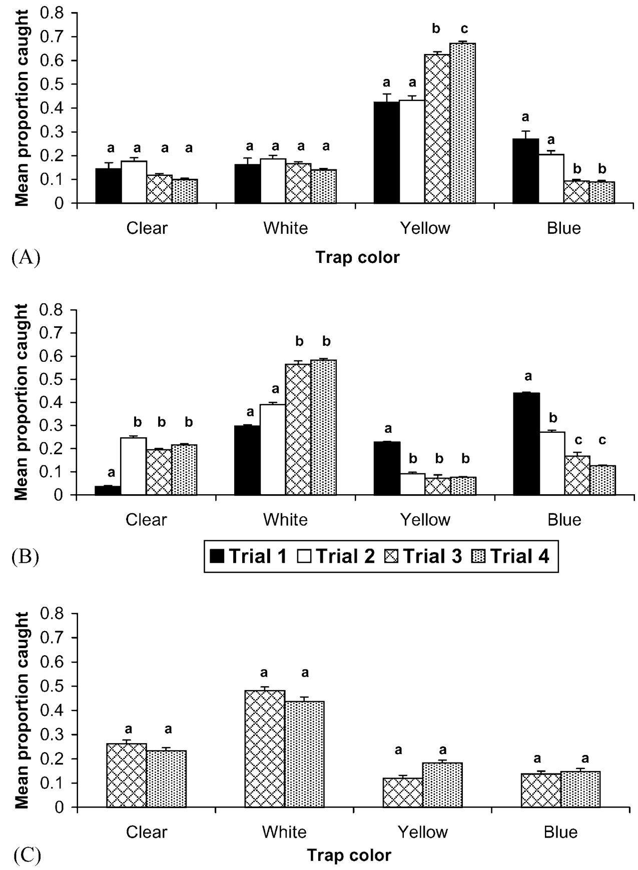

Fig. 3. Untransformed mean proportion (± SE) of *Scirtothrips perseae* (A), *Frankliniella occidentalis* (B), and *Franklinothrips orizabensis* (C) caught on different colored sticky cards for each of the four trials. Data for *F. orizabensis* were collected for trials 3 and 4 only. Means with different letters are significantly different at the 0.05 level within trap colors.

$p<0.32$) (Fig. 4B), or *F. orizabensis* ($\chi^2 = 4.24$, df = 3, $p<0.24$) (Fig. 4C) caught.

4. Discussion

Yellow sticky cards with peak reflectance at 570 nm were highly preferred by *S. perseae* while its key natural enemy, *F. orizabensis*, was most attracted to white sticky cards with maximal reflectance at 430 nm as was *F. occidentalis*, a common non-pestiferous pollen feeding species in avocado orchards. Yellow has been identified as the preferred color for trapping *Scirtothrips* spp in citrus (Moreno et al., 1984; Samways, 1986), while white is most preferred by *F. occidentalis* in some field situations (Moffitt, 1964; Yudin et al., 1987; Terry, 1997).

Integrated pest management programs for pestiferous thrips in tree crops are rare because population monitoring is difficult because of tree size, effective coverage with insecticides can be hampered by canopy density, and natural enemy releases are often not economically feasible. Furthermore, cultural practices used to control thrips such as crop rotation and fallow periods are impossible with perennial crops (Parker and Skinner, 1997). As a monitoring tool, sticky cards need to be attractive to the target pest and capture rates need to be highly correlated with thrips populations on crop plants. Colored sticky cards can be used as an early warning method for detecting increases in aerial numbers of thrips adults in perennial crops (Childers and Brecht, 1996), and capture rates can be used to initiate control measures to prevent economic crop damage and reduce prophylactic applications of insecticides (Samways, 1986).

As part of an IPM program being developed for *S. perseae* in California, monitoring of low density pest populations and determination of population phenology with yellow sticky cards could be a very useful tool for timing selective insecticide sprays (e.g., abamectin, spinosad, or sabadilla) to immature foliage during the pre-bloom period. This pesticide application strategy is

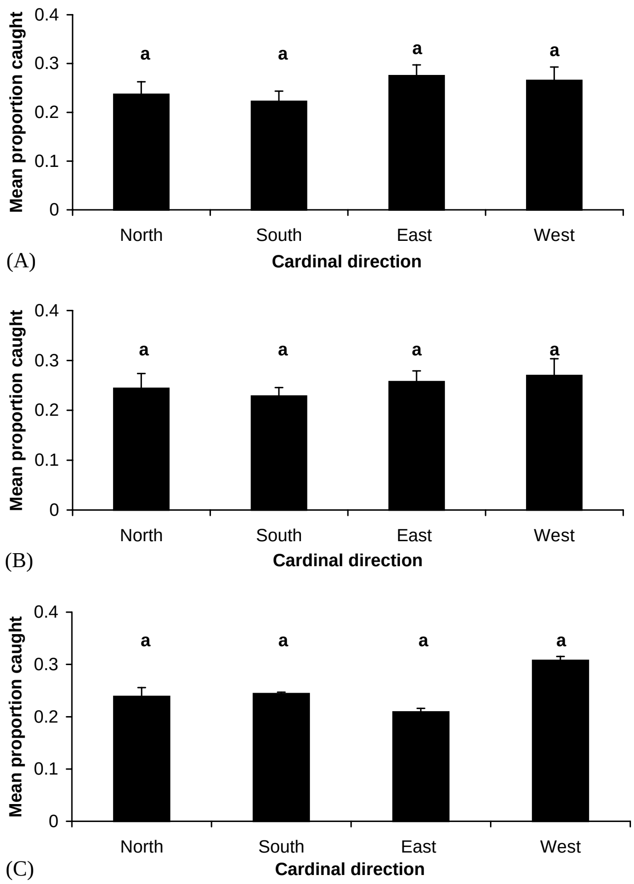

Fig. 4. Untransformed mean proportion (± SE) of *Scirtothrips perseae* (A), *Frankliniella occidentalis* (B), and *Franklinothrips orizabensis* (C) caught on sticky cards independently of color facing in each cardinal direction. Means with different letters are significantly different at the 0.05 level.

currently being investigated for its potential to prevent the development of economically damaging thrips populations on immature leaves prior to fruit set, as it is during fruit set that immature fruit are most susceptible to *S. perseae* feeding damage. Additionally, commercial insectaries in California are mass-rearing *F. orizabensis* for early season augmentative releases against *S. perseae* and use of white sticky cards to monitor densities and phenology of this natural enemy could become an integral part of a biologically based pest management program for *S. perseae*. Field evaluations of *F. orizabensis* for control of *S. perseae*, and phenology monitoring of both thrips with sticky cards are currently on-going. Additional concurrent studies across a variety of avocado growing conditions in California are needed to correlate *S. perseae* and *F. orizabensis* capture rates on yellow and white sticky cards, respectively, with observed densities counted on immature avocado leaves. Development of a rapid sampling program relating sticky card counts to economically damaging pest densities could be used to initiate control actions based on trap counts.

Trap color preferences exhibited by *S. perseae* and *F. occidentalis* changed significantly over the course of the trial. Both of these phytophagous thrips showed declining attraction towards blue traps while capture rates for *S. perseae* and *F. occidentalis* increased on yellow and white traps, respectively. One possible reason for these recorded preference shifts could be due to changes in the visual characteristics of vegetation that *S. perseae* and *F. occidentalis* were utilizing for feeding and oviposition. These visual characteristic changes may result from temporal differences in radiant light quality or in the physical and physiological qualities of the vegetation.

As plants change through time (e.g., leaf and flower development) host switching in response to resource availability could result in differential responses to spectral cues, especially in polyphagous thrips species like *F. occidentalis*, which utilizes weed species and avocado flowers in orchards. This may explain varying color preferences by *F. occidentalis* in different field studies where white (Moffitt, 1964; Yudin et al., 1987), or yellow (Cho et al., 1995) have been demonstrated to be most preferred, while in greenhouses, *F. occidentalis* is most attracted to blue colored traps (Gillespie and Vernon, 1990; Vernon and Gillespie, 1990).

Cardinal direction did not have significant effects on trap captures of the three thrips species monitored, although south-westerly winds were predominant at the trial site over the course of this study. Thrips flying activity and directionality of flight is strongly influenced by atmospheric conditions, and some species fly under conditions when flight can be controlled (Lewis, 1997). *Scirtothrips perseae*, *F. occidentalis*, and *F. orizabensis* may have engaged in dispersal when weather conditions permitted controlled flight and orientation to and landing on sticky traps of preferred colors.

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