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Selection of colour of sticky trap for monitoring adult bean thrips, *Caliothrips fasciatus* (Thysanoptera: Thripidae)

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Abstract: Adult bean thrips, *Caliothrips fasciatus* (Pergande), overwintering inside the navel of navel oranges shipped from California to Australia, are an actionable pest for the importing country, i.e. infested lots are fumigated with methyl bromide. Strict quarantine regulations regarding *C. fasciatus* prompted studies on the best colour sticky trap that might be used to monitor for bean thrips populations in the vicinity of California citrus groves prior to harvesting fruit for export. Preliminary experiments identified the most attractive trap of each of four colours (blue, green, white, yellow) commonly used to sample adult Thysanoptera. Three trials of a field study were conducted, comparing *C. fasciatus* capture on the best card of each colour using asparagus ferns naturally infested with high levels of this pest. Based on significantly higher catch on green sticky cards, this colour trap is recommended for potential use in California's bean thrips mitigation plan designed to reduce thrips levels on citrus exported to Australia.

Keywords: Australia; export pest mitigation; navel oranges; quarantine pest; trapping

1 INTRODUCTION

Bean thrips, *Caliothrips fasciatus* (Pergande), was listed as the type species when the genus *Caliothrips* was described in 1904.[1] Pergande[2] first described bean thrips as *Heliothrips fasciata* on the basis of the collection of two specimens from an orange leaf in Yuba County, California, in November 1894. The region of origin of bean thrips is unknown but has been speculated to be California,[3] Florida[4] or Brazil,[5] and a single specimen was collected by Steinweden and Moulton[6] in Foochow, China. Bailey[7–9] reports this species as also present in Alabama, Arizona, Colorado, Idaho, Louisiana, Mississippi, Nebraska, Nevada, Oregon, South Carolina, Texas, Utah, Wyoming, Argentina and the west coast of Mexico.

Bean thrips is not considered a pest on citrus in California except that it contaminates shipments of navel oranges bound for Australia. Bean thrips became a problem for California growers shipping fruit to Australia during the 1996–1997 season when 28 of 982 navel orange shipments (estimated value of all shipments was $6.9 million) from California were found to be infested. Infested loads were fumigated with methyl bromide, which is damaging to the fruit and costly to the importer, but a larger concern was potential loss of the Australian citrus market if interception levels were not reduced. Mound and Houston[10] reported two species of *Caliothrips* as present in Australia, but, to date, established populations of *C. fasciatus* have not been detected there. They indicate that there are 19 known species in this genus, seven from North America, and the majority of species are found in the tropics. Owing to a long history of regular interceptions of *C. fasciatus* in Australia, Hoddle *et al.*[11] surveyed areas around airports, seaports, public recreational parks and major agricultural areas in the states of Queensland, New South Wales, Victoria, South Australia and Western Australia. Although a total of 4675 thrips encompassing at least 76 species from 47 genera were detected, *C. fasciatus* was not found. Hoddle *et al.*[11] concluded that *C. fasciatus* has not yet become established in Australia, in spite of the long history of California navel oranges being shipped to that country.

Caliothrips fasciatus has been found on at least 40 crop plants in California.[12] Of these, Bailey[12] reported that it has been known to cause reduction in yield on alfalfa, beans, cantaloupes, cotton, lettuce, pears and peas, although it is notable that no reports of serious crop damage appear after 1940, leading one to question how serious a pest this species ever was. It has also been found on more than 60 genera of wild and ornamental plants. The preferred hosts of *C. fasciatus* are prickly lettuce (*Lactuca serriola* L.) and sow thistle (*Sonchus oleraceus* L.), weeds of European origin occurring commonly in valleys and irrigated areas throughout California.

Bean thrips begin life as a white, bean-shaped egg, approximately 0.2 mm long, deposited within the

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leaf tissue of the female's host plant.[12] They pass through two larval instars and a prepupal and pupal stage. Bean thrips are gregarious and have several overlapping generations during the summer, allowing them to build to high numbers on suitable hosts. Adults cease egg-laying in early October and begin to search for hibernation sites around the end of that month, migrating to plants that are still green, including citrus trees. They seek out sheltered parts of the plant and become inactive; common hibernation sites include curled leaves, pine cones, empty scale insect covers, debris on the ground and inside the navel of navel oranges.[12]

Past studies on the attractiveness of different coloured trap cards to other species of thrips have yielded varying results. Hoddle *et al*.[13] compared blue, yellow and white cards for their efficacy in trapping avocado thrips (*Scirtothrips perseae* Nakahara), western flower thrips [*Frankliniella occidentalis* (Pergande)] and a principle predator of avocado thrips, *Franklinothrips orizabensis* Johansen. They found yellow cards to be most attractive to *S. perseae*, and white cards to be most attractive to *F. occidentalis* and *F. orizabensis*. White traps also proved more effective than yellow, red or orange traps at attracting *Frankliniella bispinosa* (Morgan) in Florida citrus groves;[14] yellow traps outperformed blue and white traps in catching *F. tritici* (Fitch) and *F. occidentalis* in tomato fields,[15] and caught more pear thrips [*Taeniothrips inconsequens* (Uzel)] than dark-red, dark-blue, dark-green or white traps in New England pear groves.[16] However, Chen *et al*.[17] caught significantly more *F. occidentalis* on blue traps than on yellow or white traps in greenhouse experiments, and Chu *et al*.[18] found 'true blue' and white to be the most effective of nine colours (white, rum, red, yellow, lime green, spring green, woodland green, true blue and black) at trapping the same species in fields of several different crops in the southwestern USA, India, and China. Complicating matters, *F. occidentalis* has shown differential attraction to colour, depending on sex, whether or not thrips are engaged in swarming behaviour associated with mating[19] or time of year.[12]

Starting in November 2002, USDA-APHIS imposed an 'Australian Export Bean Thrips Mitigation Plan' (http://citrusent.uckac.edu/bean_thrips.htm) on all California growers shipping navel oranges to Australia. One of the components of this plan was that growers shipping to Australia must monitor field bean thrips levels with yellow or blue sticky cards. Regulations were modified for the 2004–2005 shipping season, specifying the use of one yellow or white card per 2.02 hectares (i.e. per five acres with a minimum of four cards per citrus block) left in the field for 28 ± 7 days, and blocks having more than 20 bean thrips per card were ineligible for shipment to Australia. Prior to the present study, published data indicating which colour card would be best for monitoring bean thrips were not available, and yellow or blue cards were chosen on the basis of an examination of published literature, as summarized above, on the colour of cards used to monitor other thrips species. White cards were later added to the protocol (and blue cards dropped) on the basis of white cards being readily available to growers, and owing to unpublished grower data suggesting that they were effective. The objective of the study reported here was to determine which of the coloured sticky traps available to California navel orange growers might be most effective in bean thrips detection. The results will be used to confirm or suggest revisions to the Australian Export Bean Thrips Mitigation Plan for monitoring bean thrips in California citrus groves with coloured sticky cards.

2 MATERIALS AND METHODS

2.1 Spectral analysis

In order to detect differences between cards of similar colour that might be apparent to the eyes of an insect, the reflectance of all sticky cards that were tested, with their normal adhesive, was measured using a Li-Cor LI-1800 portable spectroradiometer with an 1800-12 integrating sphere (Li-Cor Biosciences, Lincoln, NE). Readings were taken at 10 nm intervals from 350 to 1100 nm.

2.2 Preliminary experiments

Preliminary monitoring was conducted from September to October 2003 and from August to September 2004 in a three-year-old (in 2003) asparagus planting in field 15C at the University of California, Riverside Citrus Experiment Station, where sweep-net sampling had established the presence of a heavy natural infestation of *C. fasciatus*. The field consisted of 18 plots of each of three cultivars of asparagus, UC 115, UC 157 F1 and 'Purple Passion', planted on 25 May 2000. UC 115 is an experimental asparagus variety scheduled for release by the University of California, Riverside, in 2006. Both UC 157 F1 and 'Purple Passion' are commercial asparagus varieties available from California Asparagus Seed and Transplants, Inc. (Davis, CA; http://www.calif-asparagus-seed.com/index.html).

The 54 plots of asparagus were arranged in a nine plot per row by six row wide Latin square for an experiment on fungicides conducted in the summer of 2000, and were untreated since then. For the purposes of the present study, advantage was taken of the presence of these nearby mature asparagus ferns harbouring high levels of bean thrips, in spite of the fact that the field was planted for another purpose. Each plot was originally planted with 19 asparagus plants within a 6 m long, 52 cm wide and 10 cm high raised bed with 1 m bare soil between each plot within a row and 104 cm of bare soil between each raised bed row, running east to west. Thus, the entire planting of 54 plots was 62 m long (east to west, down the rows) by 8.3 m wide. At the time the studies were run, the asparagus plants had grown out to fill all available

space, so there was a contiguous mat of plants that were difficult to walk between.

Preliminary experiments were conducted to select the single best yellow, blue and white cards for later comparison against the single brand of green card that was available. Three brands of yellow cards, Yellow 3 × 5″ Sticky Card (Olson Products, Medina, OH), Yellow Plastic Card (Advanced Pheromone Technologies (APT), Inc., Marylhurst, OR; formerly IPM Tech, Inc., Portland, OR) and Sticky Aphid/Whitefly Trap (Seabright Enterprises, Emeryville, CA), were compared in three trials, each over a 10 day period in September–October 2003. All cards were of equal size (7.6 by 12.7 cm). Cards were hung from 'T'-shaped posts 1.5 m above the soil, at a height approximately level with the tops of the mature asparagus ferns. The 'T' of the post was 1.22 m long and was oriented north to south, perpendicular to the row of asparagus. For each of the three yellow card trials, 18 posts were used, distributed over six plots of each of the three cultivars, with one card of each brand on each post, and each possible ordering of the three brands (SIO, SOI, IOS, ISO, OSI and OIS, where S = Seabright, I = APT and O = Olson) applied once in each cultivar. Cards were held on the posts using binder clips, with the two surfaces of the cards facing east and west. The 18 plots chosen for this study used six contiguous plots across the six asparagus rows with three per row, using alternate plots. Thus, there was 12 m between 'T'-shaped posts down a row but only 34 cm between the ends of the 'T's across the rows.

Two blue cards, Blue Plastic Card (APT) and Sticky Thrips/Leafminer Trap (Seabright), and two white cards, Intercept SC (APT) and Scale Trap (Trécé Inc., Adair, OK), were tested once each during consecutive 7 day periods in August 2004, using 24 posts divided among eight patches of each of the three cultivars, each post holding two cards of each brand. The 24 plots chosen for this study used six contiguous plots across the six asparagus rows with four per row, using alternate plots. All cards were of equal size (7.6 by 12.7 cm) except for the Seabright cards, which were cut to match the size of the other brands. Bean thrips on both surfaces of the cards were identified using the keys in Kono and Papp,[20] and all other thrips species on the cards were ignored. No statistical significance tests were used for the preliminary trials, as it was necessary to select one card of each colour for the four-colour sticky card trial regardless of whether the differences between the brands were statistically significant.

2.3 Four-colour sticky card experiment

For the experiment comparing four trap colours, the brands of yellow (Seabright), blue (Seabright) and white (Trécé) cards that captured the highest mean number of bean thrips during the preliminary experiments were compared with green cards of the same size cut from unfolded green Intercept D Traps (APT; these traps are normally folded into triangular boxes open at one end, typically used to trap lepidopteran pests). Again, 24 posts were used, with one card of each of the four colours on each post. One post was placed in each of eight plots of each of the three asparagus cultivars, using the same arrangement as described for the blue and white cards. Three trials (repeated over time) of this experiment were performed in September 2004. Originally, each trial was intended to run for 7 days; however, the second trial ran for 10 days owing to an interruption in access to the experimental site.

2.4 Statistical analysis

A generalized linear model was used to analyse data from the four-colour sticky card experiment. The number of thrips caught by a card was modelled as a Poisson random variable, and the logarithm of the Poisson mean was assumed to be a linear function of the main effects and interactions of the primary factor, colour, and three other factors: the trials (performed over time), the cultivars of asparagus and the positions of the cards on the posts (the inner two cards on each post were hung directly over the asparagus row, while the outer two were hung over the gaps between rows, one on each side of the row). The maximum likelihood estimates were computed for the effects, and analysis of deviance was used to test for significance.

3 RESULTS AND DISCUSSION

3.1 Spectral analysis

Peak reflectances were observed at 580 nm for APT yellow cards, 570 nm for Olson yellow, 360 nm for Seabright yellow, 350 nm for APT white, 1100 nm for Trécé white, 860 nm for Seabright blue, 470 nm for APT Blue and 940 nm for APT green (Figs 1–3). Reflectance curves were similar within each colour card. However, Seabright blue had a secondary peak at 470 nm, while APT blue had one at 820 nm; APT green also showed a similar curve to the blue cards, with a secondary peak at 520 nm. Trécé's white secondary peak fell at 350 nm, and APT's white at 1100 nm.

The largest differences in percentage reflectance between cards of the same colour were observed among the three yellow cards (Fig. 1), and the smallest between the two white cards (Fig. 2). The overall reflectance curve for APT green was similar to that of the two blue cards (Fig. 3).

3.2 Preliminary experiments

In the preliminary experiments, the highest mean numbers of bean thrips were found on the Seabright yellow, Seabright blue and Trécé white cards respectively (Table 1). These traps were selected for later comparison against each other and the APT green cards. Note that preliminary trials with the three brands of yellow cards were run from September to October 2003, and preliminary trials with blue and white cards were both run in August 2004,

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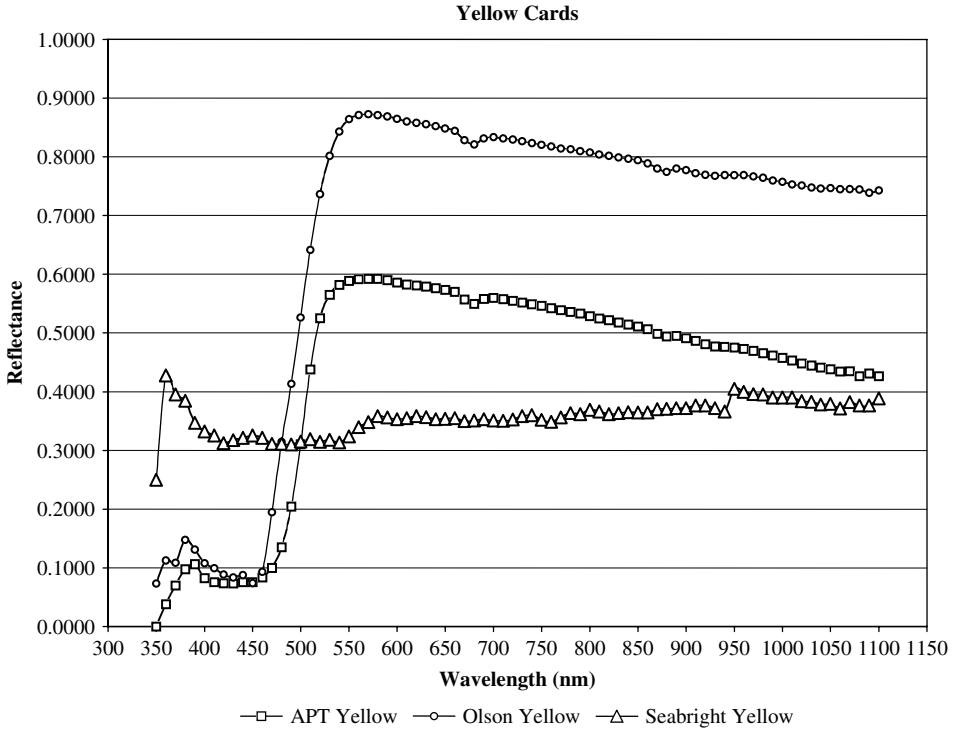

Figure 1. Reflectance readings for the three brands of yellow sticky cards compared for bean thrips capture.

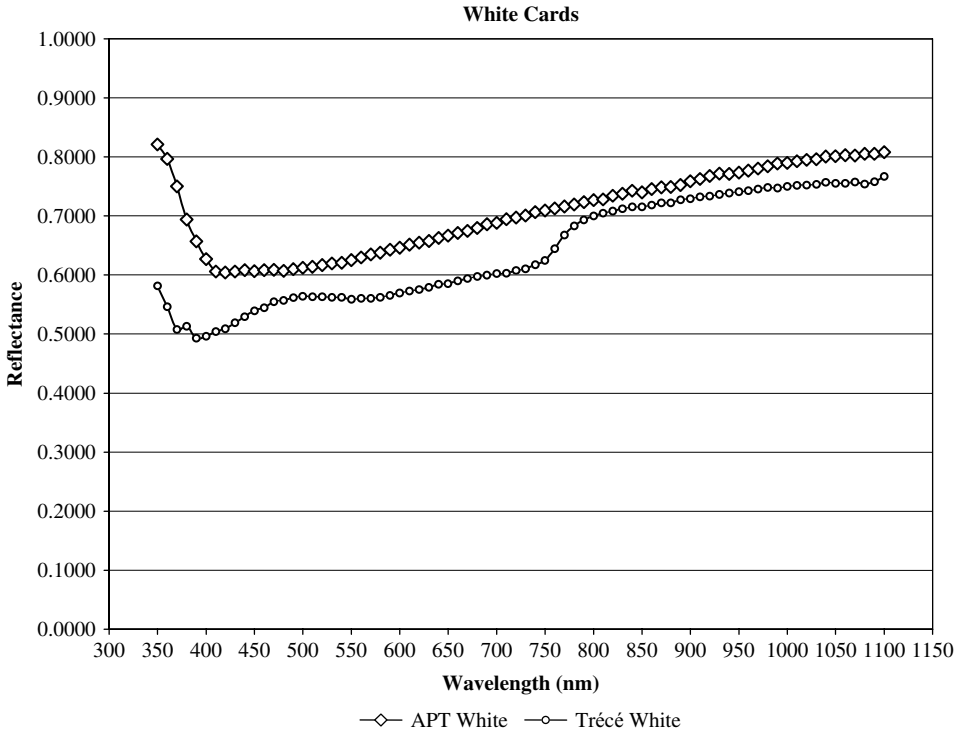

Figure 2. Reflectance readings for the two brands of white sticky cards compared for bean thrips capture.

nearly a year later. However, the authors have no reason to believe that adult bean thrips would respond differently to trap colour from year to year, and the same planting of asparagus in a similar stage of growth was used during both years in which the preliminary studies were run.

No immature bean thrips were caught on the traps in either the preliminary or later trials, and no other species of thrips were counted. Based on casual observation, the most common species of thrips other than bean thrips was western flower thrips, *F. occidentalis*. The dark black bean thrips were easy to recognize on the cards and the only other thrips species of similar appearance was the occasional specimen of the dark phenotype of *F. occidentalis*;[21] the vast majority of this species were of the light colour morph.

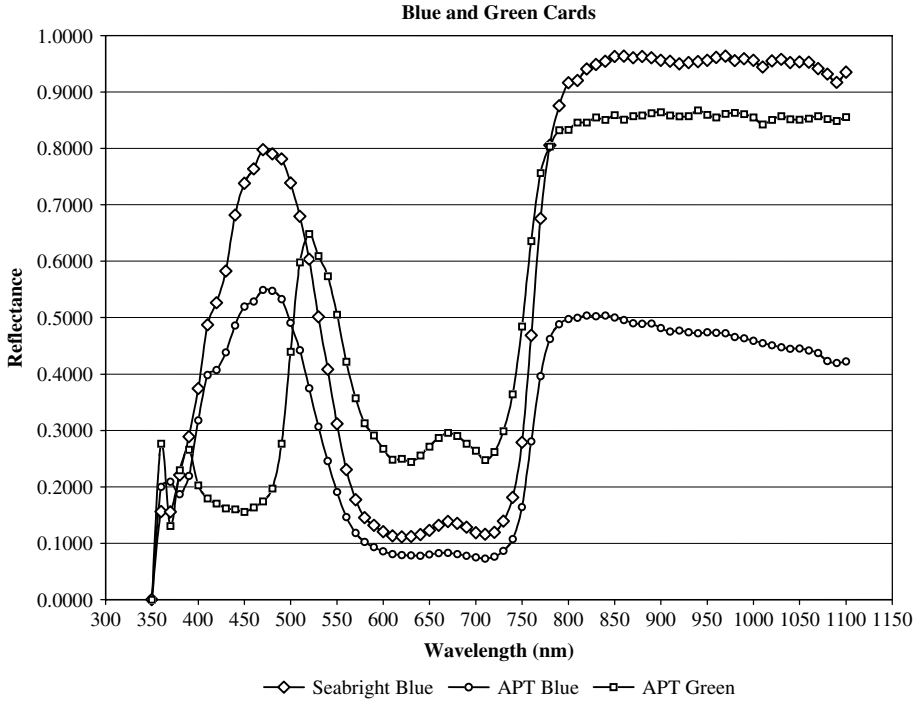

Figure 3. Reflectance readings for the two brands of blue and one brand of green sticky cards compared for bean thrips capture.

Table 1. Mean (± standard error) adult bean thrips captured per sticky card in preliminary experiments[a] at 1.5 m height above asparagus ferns

Brand	Yellow	Blue	White
Olson	10.2 (±1.3)	–	–
Seabright	15.6 (±2.6)	5.0 (±0.5)	–
APT	6.4 (±0.8)	1.9 (±0.3)	4.0 (±0.7)
Trécé	–	–	4.9 (±0.8)

[a] Three trials (over time) of the experiment comparing the three yellow cards were run from September to October 2003. The two blue cards were compared against each other in a single trial in August 2004, and later that same month a single trial was run comparing the two white cards.

Table 2. Mean adult bean thrips captured per card in the four-colour sticky card experiment at 1.5 m height above asparagus ferns

Colour	Trial 1	Trial 2	Trial 3	Total
Blue	14.9	28.2	12.5	18.5
Yellow	7.3	8.8	4.9	7.0
White	5.8	11.0	4.5	7.1
Green	43.4	62.6	23.8	43.3

3.3 Four-colour sticky card experiment

In all trials of this study, the highest mean numbers of bean thrips were found on the APT green cards; the second highest were found on the Seabright blue card. Seabright yellow and Trécé white caught roughly equal numbers, well below those of the green and blue traps (Table 2). The superiority of green cards for *C. fasciatus* monitoring is notable as previous studies[13–19] failed to mention this colour as being effective in monitoring.

Not surprisingly, more bean thrips (2629) were caught in the longer (10 day) second trial than in the first (1712) or third (1086) trials. The lower number caught in the third trial was also consistent with expectations, as the weather was cooler and wetter during that trial than during the previous two trials. It seems reasonable that *C. fasciatus* would be less likely to fly, and therefore to be caught on sticky cards, at lower temperatures. There was also variation in the numbers of thrips caught on the various cultivars of asparagus: cards in plots of cultivar A (UC 157) yielded a total of 1562 bean thrips over the course of the experiment, while those in plots of cultivars C (UC 115) and B ('Purple Passion') yielded 1693 and 2172 respectively.

3.4 Statistical analysis

In the largest model, containing all main effects and interactions, no effects of position were significant and only the main effects of colour, trial, cultivar and the interaction of colour and cultivar were significant at the 5% level (Tables 3 and 4). In a smaller model that

Table 3. Analysis of deviance for the proposed overdispersed log-linear model with an estimated overdispersion parameter $\varphi = 16.84$. The approximate F statistic is deviance/(φ*df)

Factor	df	Deviance	Residual df	Residual deviance	F	P value
Null	–	–	287	8209.7	–	–
Trial	2	668.6	285	7541.1	19.85	0.0000
Colour	3	3049.5	282	4491.7	60.35	0.0000
Cultivar	2	111.4	280	4380.3	3.31	0.0381
Colour/ cultivar	6	375.4	274	4004.9	3.71	0.0014

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Table 4. Effect estimates for trials, sticky card colour and asparagus cultivar[a]

Parameter	Estimate	Standard error	*t* statistic	*P* value
θ_{GA1}	3.177	0.186	17.12	0.0000
α_2	0.429	0.127	3.37	0.0009
α_3	−0.455	0.159	−2.86	0.0046
β_{GB}	0.896	0.198	4.53	0.0000
β_{GC}	0.506	0.211	2.40	0.0171
β_{BA}	−0.005	0.236	−0.02	0.9833
β_{BB}	−0.599	0.280	−2.14	0.0330
β_{BC}	−0.499	0.271	−1.84	0.0663
β_{WA}	−1.354	0.367	−3.69	0.0003
β_{WB}	−1.212	0.347	−3.49	0.0006
β_{WC}	−1.263	0.354	−3.56	0.0004
β_{YA}	−1.153	0.340	−3.39	0.0008
β_{YB}	−1.286	0.358	−3.60	0.0004
β_{YC}	−1.440	0.380	−3.79	0.0002

[a] θ_{GA1} is the logarithm of the expected number of bean trips given colour green, cultivar A and trial 1, which is the baseline condition for the model; α_k is the effect for trial k; β_{ij} is the effect for colour i and cultivar j.

contained only these significant effects, the logarithm of the expected number of thrips caught by a card is

$$\theta_{ijk} = \theta_{GA1} + \beta_{ij} + \alpha_k$$

with $\alpha_1 = 0$ and $\beta_{GA} = 0$. If $\beta_{ij} > 0$, then a card with colour i placed in cultivar j is expected to catch more thrips than a card with colour G (green) placed in cultivar A, whereas $\beta_{ij} < 0$ indicates that a card with colour i placed in cultivar j is expected to catch fewer thrips. The main trial effect α_k can be interpreted similarly. The analysis of deviance is shown in Table 3. The maximum likelihood estimates, associated with standard errors, t statistics, and P values, are shown in Table 4.

Green cards caught significantly more thrips than yellow and white cards on all cultivars. Green also outperformed blue, but the difference was significant at the 5% level only on cultivar B and at the 10% level on cultivar C. Significant effects of trial are seen from the estimate of α_k, where more thrips were caught in trial 2 and fewer in trial 3 than in trial 1. When green cards are focused upon, from the estimates of β_{Gj}, cultivar has a significant effect in that more thrips were caught on cultivars B and C than on cultivar A. Based on results on asparagus, it is suggested that green sticky cards be evaluated on citrus as an alternative to the yellow and white traps currently recommended for use in the Australian Export Bean Thrips Mitigation Plan. Studies should be done on citrus during the fall of the year when cards would normally be deployed by growers (i.e. during the 4 week trapping interval specified by APHIS) as it is possible that results on asparagus during summer and fall might be different from those on citrus during fall. If results on citrus in the fall were found to be similar to those on asparagus in the present study, then it is suggested that the Australian Export Bean Thrips Mitigation Plan should switch to use of green cards. This would likely result in improved detection of bean-thrips-infested navel orange groves, which should be excluded from shipment to Australia, leading to a lower likelihood that bean thrips might be introduced into and establish in Australia.

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