4-11-2014

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Recommended Citation

Sétamou, M., Sanchez, A., Saldaña, R. et al. Visual Responses of Adult Asian Citrus Psyllid (Hemiptera: Liviidae) to Colored Sticky Traps on Citrus Trees. J Insect Behav 27, 540–553 (2014). https://doi.org/10.1007/s10905-014-9448-2

For Submission to:

Journal of Insect Behavior

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Visual Responses of adult Asian citrus psyllid (Hemiptera: Liviidae) to colored sticky traps on citrus trees

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Abstract The effects of five differently-colored sticky traps in capturing adult *Diaphorina citri* were evaluated in citrus orchards. Trap catches of *D. citri* were monitored fortnightly on blue, green, red, white and yellow sticky cards placed on three citrus varieties during *D. citri* active flight period from April to July in south Texas. Evaluation of mean trap catches of each color by repeated measures analysis of variance produced three separate groups: yellow traps caught significantly more *D. citri* adults than the other four traps; red and green traps caught significantly more *D. citri* than blue and white traps, which were not significantly different. Although the number of adult psyllid captured on all trap types significantly increased with time during the trapping period, the performance of traps did not change with time. Trap catches were also significantly influenced by the citrus species; traps placed on lemon trees captured more *D. citri* than those placed on sweet orange and grapefruit, suggesting that plant preference exhibited by *D. citri* may influence the performance of traps. The ratio of trap reflectance between the 680- to 700 nm and the 450 nm was significantly correlated with total trap catches in all host species studied. Thus, this index was a good indicator of the attractiveness of adult *D. citri* to colored traps. Additionally, we compared the reflectance values of young versus mature flush shoots of the three host plants used in this study as related to densities of *D. citri* recorded in colored traps. We discussed the importance of visual cues in the host finding behavior of adult *D. citri*.

Key words**:** *Diaphorina citri* – citrus greening – colored traps – visual cues –reflectance

Introduction

The Asian citrus psyllid, *Diaphorina citri* Kuwayama (Hemiptera: Liviidae), is recognized as a great menace to U.S. citriculture. *D. citri* has invaded all U.S. citrus producing states in the last decade (French et al. 2001, Halbert and Manjunath 2004, Grafton-Cardwell et al. 2013). Because of its ability to transmit the bacteria *Candidatus* Liberibacter–the putative causal agents of the deadly citrus greening disease Huanglongbing–*D. citri* is an important pest of citrus (Bové 2006, Gottwald et al. 2007). Huanglongbing is considered one of the deadliest diseases known to citrus in the world. In 2005, Huanglongbing was detected in Florida (Halbert 2005), and over the last 6 years has emerged as a damaging disease to the Florida citrus industry causing significant economic losses in excess of $3.6 billion (Hodges and Spreen 2012). Due to the lack of any known cure, the nonspecific nature of disease symptoms that resemble many other disorders, the prolonged latency of the disease in infected trees, and the difficulty of early detection, Huanglongbing is a very difficult disease to manage (da Graça 1991). Limiting the spread of the disease through vector control is one the viable approaches being implemented for Huanglongbing management (Grafton-Cardwell et al. 2013). Effective management of *D. citri* would however require efficient detection and monitoring tools to be used to determine the presence of infestations and efficacy of control methods.

Several methods for monitoring *D. citri* populations have been reported such as visual observation (Sétamou et al. 2008), trapping, tap sampling (Hall and Hentz 2009, Flores et al. 2009), and vacuum sampling and sweep nets (Thomas 2012). Although no consensus exists on the most effective method, colored sticky traps are widely used for *D.*

citri detection and population monitoring in field studies. Colored traps are passive methods of insect population studies that lure mobile stages of the insect onto a visual target and their sticky surface arrest the insect. Their effectiveness is based on the visual response of the target insect to the trap color. Insects use both visual and chemical stimuli in locating their host plants (Bernays and Chapman 1994). The importance of each type of cues depends on the insect species. However for herbivorous insects, plant spectral quality comprising hue and intensity seems to be the most important factor for their alignment and selection of living plants (Prokopy and Owens 1983).

The importance of visual stimuli in the behavior of *D. citri* and its response to light and trap color has been reported (Hall et al. 2007, Wenninger et al. 2009, Sétamou et al. 2012). The preferences of different hues of green and yellow traps have been evaluated by Hall et al. (2010). Furthermore Hall et al. (2007) reported that *D. citri* preferred yellow over blue traps. However, there are no records on the spectral reflectance characteristics that determine trap attractiveness to adult psyllids. Knowing the trap reflectance parameters involved in *D. citri* host selection would facilitate the development of effective traps for monitoring of its populations. Thus, the objectives of this study were to evaluate the response of *D. citri* to a variety of colors, and to determine the relative effect of their spectral reflectance parameters on the host finding behavior of this psyllid.

Materials and Methods

Diaphorina citri population studies in the field

Populations of *D. citri* adults were monitored using sticky traps in three contiguous citrus blocks located at the TAMUK-Citrus Center from April to July 2007, to cover the first two major flush cycles in citrus. The citrus blocks separated by 10-m intervals of bare soil, were managed using similar grove care practices. In each of the three rectangular citrus blocks, respectively planted with grapefruit, lemon, or sweet orange, four replicates of each of six color traps were used. Traps were made out of identical Oxford® paper folder (Office Depot, Inc.) of assorted colors (black, blue, green, red, white and yellow), laminated with clear plastic and coated on one side with tanglefoot® (Tanglefoot Co., Grand Rapids, MI) for capture of adult psyllids. One trap per color was placed along each perimeter of each citrus block for a total of 4 traps per color. Thus, a total of 24 traps were deployed per citrus block. Between rows, traps were randomly assigned to the first tree of six contiguous rows per citrus block, and along the rows traps were placed on every 5th tree. Traps were attached directly on a twig at the outer canopy of citrus trees at ≈ 1.5 m above ground with the sticky surface facing outside; the between-row distance was 4 m and the within-row distance between traps was 8 m. Traps were replaced with new ones every two weeks for the entire duration of study. During replacement, traps were rotated and re-randomized to account for possible positional bias due to hotpots or variation in psyllid field distribution. Recovered traps were brought to the laboratory and evaluated under a stereomicroscope. The numbers of adult *D. citri* were counted and recorded per trap and sampling date.

Measurement of trap and flush shoot spectral reflectance

The reflectance of each color trap, and of newly emerged and mature flush shoots of the three citrus species evaluated, namely grapefruit, lemon and sweet orange was measured using a FieldSpec dual VNIR spectroradiometer sensitive in wavelengths extending from 350 to 1100 nm with a ViewSpec Pro software (Analytical Spectral Devices, Inc., Boulder, CO). Each wavelength had a 10 nm bandwidth. A remote cosine receptor was used to measure incident irradiation for calibration. Reference measurements were taken on a Spectrolon (Analytical Spectral Devices, Inc., Boulder, CO) plate just prior to measuring reflectance of traps, and converted to % reflectance. Measurements of trap reflectance were made on four ready to be deployed traps per color on clear sunny day on 3 April 2007 between 10:00 and 13:00, while reflectance of three flush shoots for each growth stage per host plant species were measured individually on 8 May 2007 between 10:00 and 12:00. The spectroradiometer sensor had an 18° field-of-view and measurements were made by holding the sensor probe vertically ca. 5 cm above the trap or leaf surface that was held horizontally flat on bare ground. Care was taken to prevent any shadow on the illuminated area of the trap during measurement. Measurements of spectral reflectance were evaluated only from 300 to 900 nm because this range covers the sensitivity of conventional color.

Data analysis

A repeated analysis of variance was run to evaluate the effects of trap color, citrus host species, time, and their interactions on *D. citri* trap catches using the PROC MIXED of SAS (Littell et al. 1996). With the occurrence of significant *F*-values, the least square means of trap color and type of host plant were separated using Tukey test. Potential relationships between cumulative trap catches for each color across all host plants and the reflectance data at specific wavelengths and the indices derived were investigated by calculating Pearson's correlation coefficients using the PROC CORR of SAS (SAS Institute, 2001).

Reflectance values were derived and summarized for several wavelengths of the electromagnetic spectrum including the 450 nm (visible blue), 550 nm (visible green), 680 nm (visible red), 700 nm (visible red edge) and 850 nm (near-infra red). In addition, three indices comprising (1) the normalized total pigment to chlorophyll a ratio index NPCI (NPCI = R680-R430)/(R680 + R430) (Peñuelas et al. 1994), (2) the simple ratio between the visible red and the visible blue (R680/R450), and (3) the ratio between the edge of visible red and the visible blue (R700/R450) were calculated. In plants, both the NPCI and the R680/R450 are indices used to describe plant nutritional status. NPCI varies with the ratio of total pigments to chlorophyll, indicative of plant phenology and physiological status (Peñuelas et al. 1994), while the simple red-blue ratio index is the ratio of carotenoid to chlorophyll content, and generally used as a measure of plant stress (Carter 1994).

To determine the effect of trap color on reflectance values at specific wavelengths (450, 550, 680, and 850 nm) and the three derived indices (NPCI, R680/R450, and R700/R450) data were subjected to one-way analysis of variance (ANOVA) using SAS (SAS Institute, 2007).

A linear regression analysis was conducted to determine the relationship between the NPCI and R700/R450 indices and total numbers of *D. citri* caught on each color trap per host plant. Numbers of *D. citri* captured were log(x+1)-transformed before analysis, but only back-transformed means are presented.

The reflectance values of flush shoots were subjected to a two-way ANOVA to evaluate the effects of citrus species and flush stage. Whenever significant *F*-values were obtained, trap means were discriminated using the Student Newman Keuls test (Zar 1999).

Results

D. citri responses to colored sticky traps

Because all black traps discolored within a week of exposure in the field, trap catches of this trap color were not considered in the analysis. All remaining traps retained their color during the field exposure period, thus only data from these trap-colors were included in the analysis. Captures of *D. citri* adults significantly varied with time, host plant species on which traps were deployed, and trap color, but the interaction between time and trap color, and trap color and host plant, respectively were not significant. This finding suggests that color preference by adult psyllids did not change with time and host plant (Table 1). Across all sampling dates and host plant species, the yellow trap caught a significantly greater number of adult *D. citri* than any other color as shown by the higher least square means (Table 2). The green and red traps had overall moderate trap catches, although at the peak period of *D. citri* flight, the red and the yellow traps had comparable *D. citri* captures in the lemon grove (Fig. 1). The blue and white traps captured the fewest numbers of *D. citri* adults throughout the study.

Counts of captured psyllids on all trap colors significantly increased with time from April to July representing rapid build-up of *D. citri* populations from spring to summer in Texas (Fig. 1). The significant host plant by time interaction suggested that *D. citri* population dynamics varied with host plants. In this study, the highest *D. citri* captures were observed in mid-July in both grapefruit and sweet orange blocks, while peak captured were made in late-June to early July in the lemon block (Fig. 1). Population fluctuations of *D. citri* are influenced by the flushing pattern of host plant with higher populations observed during flush cycles than between flush cycles (M.S. unpublished data).

The number of psyllid adults captured also varied significantly with the host plant in which the traps were deployed (Table 1). Significantly more psyllids were captured on traps placed in the lemon block compared to grapefruit and sweet orange. Mean psyllid captured on lemon trees was 1.7 to 2.3-fold higher than the mean numbers caught on sweet orange and grapefruit, respectively. The lowest numbers of psyllid caught was on traps deployed on grapefruit trees (Table 2).

Reflectance pattern of traps

The reflectance spectrum of the different traps was very unique for each color (Fig. 2). There was a variation in the intensity of reflectance and the wavelength at which peak reflectance occurred (i.e. hue) with the trap color. The unsaturated white trap had a peak reflectance > 75% at ≈ 420 nm and its reflectance stayed at around 70% between 500 and 1,000 nm. In contrast, the black trap had a very low reflectance value < 10% between 300 and 700 nm, and gradually increased exceeding 70% at 950 nm. The blue trap had a reflection in the range of 350 to 600 nm covering both the UV range (350 – 450 nm) and blue range (450–500 nm) with peak value at 450 nm. There was a reflectance in the 450 and 600 nm range from the green trap with a maximum at around 540 nm. The red trap had reflectance values < 25% between wavelengths of 400 and 560 nm, then its reflectance value gradually increased reaching a maximum value of 100% at 800 nm which remained steady up to 1,000 nm. Reflectance values of the yellow trap gradually increased from 450 nm and reaching a peak value of 80% at 800 nm.

The mean light reflectance of the different traps at the five selected wavelengths and the derived ratios are presented in Table 3. At the visible blue wavelength (450–500 nm), the white trap had the highest reflectance value followed by the blue trap. The green and yellow traps had similar and the lowest reflectance values at 450 nm. In the green range of 500–560 nm, the white, yellow and green traps had an average relative intensity of reflectance higher than 40% while the blue, red and black traps had reflectance values lower than 30%. Within the visible red range (635–700 nm), the red, yellow and white traps had higher reflectance values than the green, blue and black traps. The green and blue traps had comparable reflectance values ranging from 15 to 20% in the visible red range, but their intensity of light reflectance was significantly higher than that of the black trap as shown by the SNK mean comparison method (Fig. 2, Table 3). The pattern of spectral reflectance was similar in the green, blue and black traps at > 700 nm wavelength.

The NPCI ratios of the green, red and yellow traps were positive, while the blue and white traps had negative NPCI ratios. The red and yellow traps had higher NPCI values than the other trap colors. The simple red-blue ratio (R700/450) index was highest for the yellow color followed by the red color and lowest for the blue trap. The R700/450 ratio index for the black and green traps had intermediate values, but was significantly higher than 1, suggesting more visible red than visible blue reflectance in these traps.

Reflectance attributes of flush shoots

Reflectance spectrum of flush shoots varied with the flush stage with younger shoots reflecting more light relative to mature shoots across all visible spectra for all three host plant species (Fig. 3). Within the visible spectrum, peak reflectance of both stages of flush shoots was observed in the green (500-560 nm) and yellow (560-590 nm) regions for all three host plants. A two-way ANOVA of reflectance values at their peak (560 nm) revealed that the effect of host plant species on shoot reflectance varied with the flush shoot developmental stage ($F = 17.43$; df = 2, 12; $P < 0.0001$). With reflectance values > 20% at 560 nm, no significant differences were obtained between the young shoots of the three host plant species, while reflectance values of mature shoots (< 15%) varied significantly with the host species. In mature shoots, lemon had the highest reflectance values in the visible green and yellow regions, while no significant differences were observed between grapefruit and sweet orange (Fig. 3).

Relationship between color trap characteristics and *D. citri* captures

Because trap performance did not vary with host plant background or with time as shown by the non-significant interactions (Table 1), and the same numbers of traps per color were deployed and recovered in the three host plants, cumulative numbers of *D. citri* captured across all host plants during the entire study period were calculated per trap color. A total number of 1,192; 1,195; 1,660; 2,012; and 2,553 *D. citri* adults were caught on the blue, white, green, red and yellow traps, respectively. Total numbers of *D. citri* adults captured on traps were not significantly correlated with any of the individual reflectance spectra at the blue, green, red and near-infra red regions (Table 4), suggesting that it is difficult to use reflectance values at these single wavebands for predictions of the trap performance in capturing *D. citri* adults. In contrast, positive and significant relationships between the three derived indices and cumulative *D. citri* trap catches in all host plants were found (Fig. 4) suggesting that these ratios are good descriptors of trap performance in attracting *D. citri*.

Discussion

This study evaluated the attractiveness of various color traps to *D. citri* adults. Significant differences were observed in the numbers of adults captured on various traps indicating that *D. citri* perceived and distinguished between trap colors. The importance of visual cues in host finding behavior of *D. citri* has been well established (Sétamou et al. 2012, Hall et al. 2010, Wenninger et al. 2009). Throughout the study, the highest trap catches were obtained with the yellow traps, followed by the red traps, while the blue and white traps had the lowest numbers of adults caught and the green trap had moderate values (Table 2). With the exception of the white trap, all effective traps had higher cumulative reflectance values across the visible wavelengths (Fig. 2). Specifically in the orange (590-635 nm) and the red (635-700 nm) wavelength regions (Hall et al. 2010), the reflectance values of the yellow and red were significantly higher than the green and blue traps. In the yellow wavelengths (560-590 nm) where the yellow trap has its peak reflectance in the visible spectrum, reflectance values of the red trap also gradually increased from 16 to 40% (Table 3). The higher numbers of *D. citri* captured on the yellow and red traps suggest that *D. citri* have a preference for trap with high reflectance values at wavelength higher than 560 nm. Hall et al. (2010) reported that *D. citri* trap captures tend to increase with an increase in reflectance values in the yellow, orange and red regions as well as increases in the ratios of red or yellow to blue. In the present study, no significant relationships were obtained between *D. citri* trap catches and reflectance values of any of the primary colors (blue, red and green) suggesting that none of the reflectance values of these primary colors was a good predictor of *D. citri* trapping efficiency. However, the derived ratios i.e. the normalized pigment chlorophyll index (NPCI) and the simple red-blue ratio indices, which are indicators of plant health and stress (Carter 1994, Peñuelas et al. 1994, Lichtenthaler et al. 1996, Peñuelas and Filella 1998) were good descriptors of the attractiveness of color traps to *D. citri*. The positive and significant relationship between the simple red-blue indices (R680/R450 and R700/R450) and the total number of *D. citri* captured on traps suggest that these ratios may play an important role in adult host finding behavior in this insect.

The attractiveness of the red trap tested in this study is hard to explain, however, the increase in reflectance in the yellow region of this trap may be a factor leading to adult *D. citri* attraction to this trap color. Very few studies have reported attraction of hemipteran insects to red traps (Döring and Chittka 2007, Straw et al. 2011, Rodriguez-Saona et al. 2012). In most of those studies where aphids and leafhoppers were attracted to red-colored traps, the red color used had relatively higher reflectance values in the yellow wavelengths as in this study. It is also possible that *D. citri* adults may have photoreceptors that are tuned to red substrate color. An observation of adult psyllid eyes suggests the presence of several red pigments that could be a physiological artifact leading to this insect attraction to red substrate. Color attraction of *D. citri* adults may be associated with their most preferred feeding sites in their host plants. In nature, *D. citri* preferentially select juvenile over mature flush shoots of its rutaceous host plants for feeding and reproduction (Hussain and Nath 1927), and these young shoots have higher reflectance values than mature shoots in the yellow, orange and red wavelengths (Fig. 3).

No studies have been performed on the visual physiology of *D. citri*, but strong positive responses to light (Wenninger et al. 2009, Sétamou et. 2012) and color (Sanchez 2008, Hall et al. 2010) have been reported. The different responses of *D. citri* to various trap colors in this study support the idea visual cues are very important and even necessary in *D. citri* host finding behavior.

The trapping efficiency of the tested traps was also significantly affected by the background crop. Traps deployed on lemon caught the highest numbers of *D. citri* followed by those on sweet orange, while traps placed on grapefruit caught the lowest numbers of psyllid adults. These results are consistent with previous studies that reported higher *D. citri* populations on lime and lemon followed by sweet orange and grapefruit, respectively (Arredondo 2009). One of the obvious differences in comparing various mature and healthy citrus groves is their color appearance. Lemon leaves appear a light yellow-greenish in contrast to the dark green color of sweet orange and grapefruit (Turrell et al. 1961). In the present study, mature lemon leaves had higher reflectance values in the whole visible spectrum than grapefruit and sweet orange (Fig. 3) despite receiving similar management and grove care practices. This variation in appearance of citrus species may lead to differential attraction and colonization of adult psyllids into groves, thus explaining the higher *D. citri* populations in lemon relative to grapefruit and sweet orange. In the eucalyptus psyllids (*Ctenarytaina eucalypti* Maskell and *C. spatulata* Taylor), Brennan and Weinbaum (2001) showed that adult psyllids were more attracted to expanding and expanded juvenile leaves that are yellow-greenish in appearance than the green adult leaves. In addition to color, differential attraction of adult psyllids to the three citrus species could be due to differences in volatile profile emanating from the host plants as *D. citri* has been shown to respond to its volatile cues (Patt and Sétamou 2010).

Higher numbers of *D. citri* were observed in early summer than during spring. Higher numbers of ovipositing females may have been present at the initiation of the late-spring to early summer flush cycle, thus explaining the higher progeny production on this flush cycle. The prevailing hot and humid conditions towards the end of spring and early summer in south Texas may also have led to a greater reproduction, rapid development of

D. citri, and faster population build-up on late spring to early summer flush shoots. The temperature during this period lied within 25-30°C, the range of optimum temperature for *D. citri* (Liu and Tsai 2000, Hall et al. 2011).

Field population biology of *D. citri* in Texas is closely related to the phenology of flush cycles in citrus trees with tree colonization and higher densities observed during flush cycles (M. S., unpublished data). Since young flush shoots have a yellow-greenish appearance than mature flush shoots and leaves, it is possible these young shoots are visually more attractive than mature ones in addition to the attraction associated to their volatiles (Patt and Sétamou 2010). The green traps tested in this study were similar in color to mature leaves of sweet orange or grapefruit, thus probably explaining their lower attractiveness to *D. citri* in comparison to yellow and red traps. The effectiveness of yellow and red colored traps in capturing *D. citri* adults despite being deployed in the highly attractive citrus hosts suggests that these colored traps may serve as suitable tools for monitoring grove infestation and population densities of this pest. However, the high correlation between cumulative trap catches and the NPCI and R700/R450 ratios opens avenues into developing specific trap colors that mimic the color of young flush shoots and that would be most attractive to *D. citri* adults.

Acknowledgements We thank Daniel Davila and Maggie Garcia for their assistance with data collection, and Dr. John V. da Graça and Juan Carlos Melgar and two anonymous reviewers for their comments and suggestions on earlier versions of the manuscript. Partial funding for the study was provided by the Texas Citrus Producers Board.

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Table 1. Repeated measures analysis of variance of adult *D. citri* trap catches as affected by trap color, host plant and time.

Effect	**Numerator DF**	**Denominator DF**	**Type III F**	**P > F**
Color	4	5	13.06	0.007
Host plant	2	10	23.90	0.0002
Time	8	40	94.58	<0.0001
Color × Host plant	8	10	0.70	0.69
Color × Time	32	40	0.77	0.77
Host plant × Time	16	80	1.91	0.038
Color ×Host plant × Time	64	80	1.31	0.13

Table 2. Least square means of the trap color and host plant effects on *D. citri* trap catches

Effects	**Estimates**	**Standard Error**	**DF**	**t-value**	**P > |t|**
		Color Effect			
Blue	22.1	4.1	5	5.35	0.003
Green	31.1	4.1	5	7.54	0.0007
Red	37.3	4.1	5	9.03	0.0003
White	22.1	4.1	5	5.36	0.003
Yellow	47.3	4.1	5	11.46	<0.0001
		Host Plant Effect			
Lemon	47.2	2.9	18	17.0	<0.0001
Grapefruit	20.7	2.9	18	7.5	<0.0001
Sweet Orange	28.0	2.9	18	10.12	<0.0001

Table 3. Mean reflectance values and indices[1] of different traps used to monitor adult *D. citri* populations in citrus orchards

Trap	Narrow bands tested				NPCI[2]	R680/	R700/
color	450 nm	550 nm	680 nm	850nm		R450[3]	R450[4]
Black	6.98 d	6.81 e	8.82 d	62.56 c	0.043 c	1.24 d	1.42 d
Blue	34.23 b	21.32 d	14.78 c	67.78 c	-0.040 e	0.43 e	0.54 f
Green	11.03cd	38.19 c	17.88 c	73.2 ab	0.24 b	1.64 c	2.21 c
Red	10.2cd	6.81e	62.2 b	83.1 a	0.72 a	3.54 b	3.75 b
White	76.53 a	68.93 a	74.7 a	70.3 b	-0.02 d	0.93 d	0.93 e
Yellow	14.3 c	63.9 b	75.4 a	80.0 ab	0.68 a	5.29 a	5.51 a
F-value	333.6	347.4	106.7	8.5	774.79	372.26	417.11
DF	5, 12	5, 12	5, 12	5, 12	5, 12	5, 12	5, 12
P-value	< 0.001	< 0.001	< 0.001	0.0012	< 0.01	< 0.01	< 0.01

[1] Means followed by the same letter within each column are not significantly different at P < 0.05 as separated by the Student Keuls Newman test.

[2] NPCI = (R680 - R430)/(R680 + R430)

[3] Ratio between the reflectance at 680 nm (red) and reflectance at 450 nm (blue)

[4] Ratio between the reflectance at 700 nm (near red edge) and reflectance at 450 nm (blue)

Table 4. Matrix presenting Pearson's correlation values between total numbers of *D. citri* captured per trap, trap spectral reflectance at primary colors and derived indices.

	Total *D. citri*	R450	R550	R680	R850	NPCI	R680/ R450	R700/ R450
Total *D. citri*	1	-0.69ns	0.08ns	0.44ns	0.86ns	0.89*	0.98**	0.997**
R450		1	0.52ns	0.29ns	-0.62ns	-0.58ns	-0.57ns	-0.65ns
R550			1	0.49ns	-0.22ns	-0.03ns	0.13ns	0.09ns
R680				1	0.54ns	0.57ns	0.58ns	0.50ns
R850					1	0.97**	0.87ns	0.88*
NPCI						1	0.90*	0.92*
R680/R450							1	0.99**
R700/R450								1

ns= non-significant ($P > 0.05$), * = significant ($P < 0.05$) and ** = significant ($P < 0.01$).

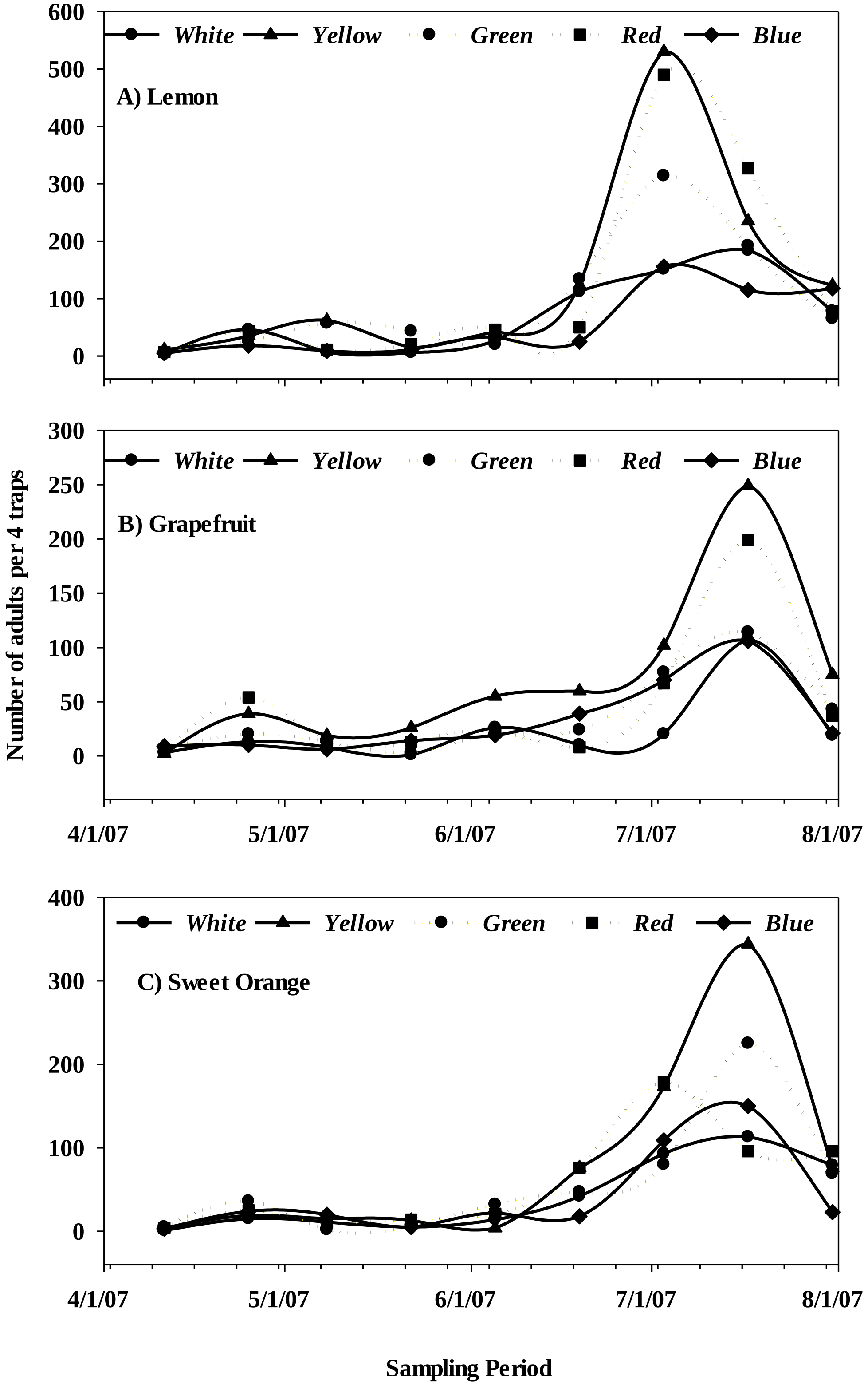
Captions for figures:

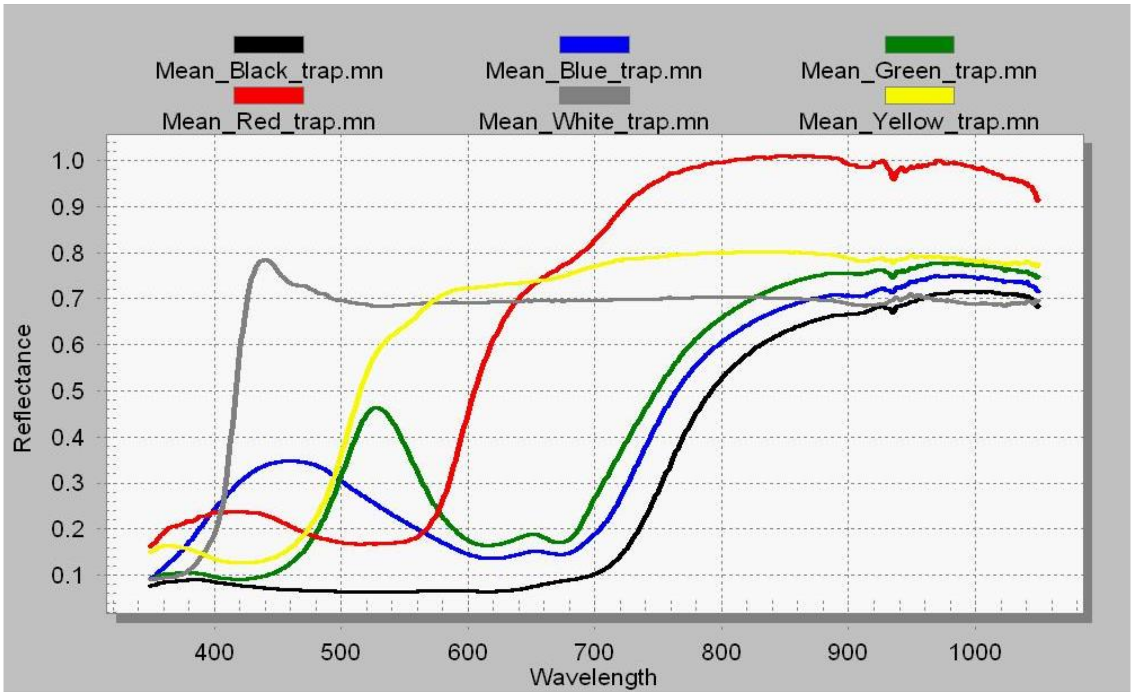
Figure 1. Mean number of *Diaphorina citri* captured on various colored traps deployed in three citrus groves (grapefruit, lemon and sweet orange) in south Texas from April to July 2007. Values represent means of four traps per color in each of the host plant.

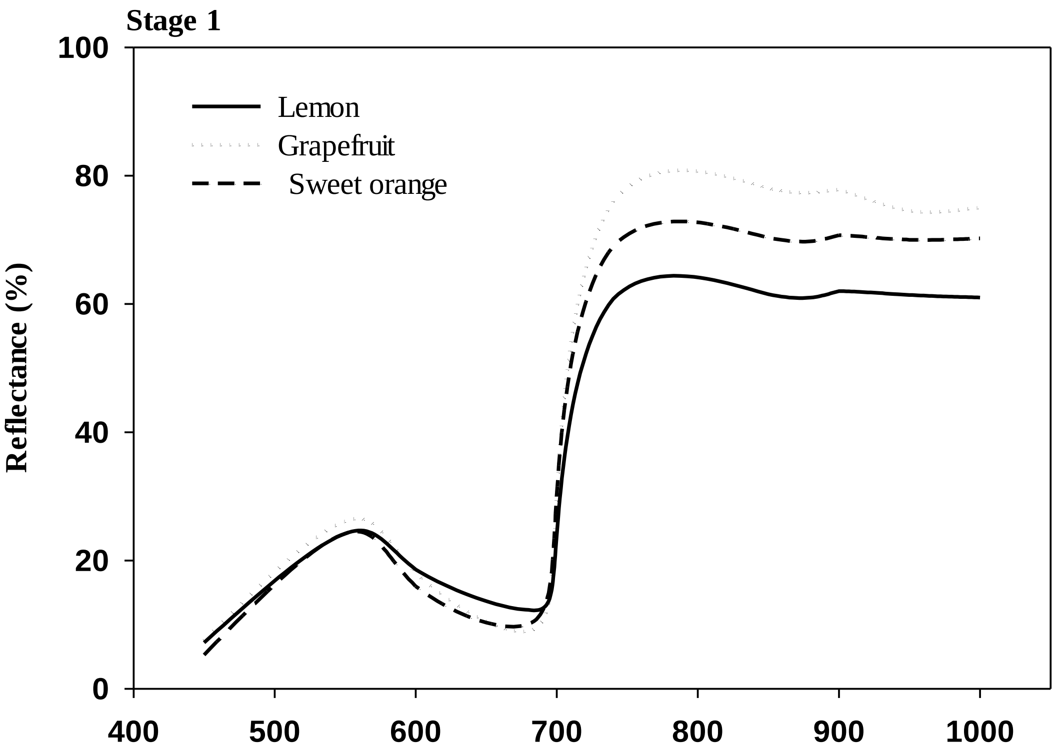
Figure 2. Reflectance spectra of colored traps used in *Diaphorina citri* trapping study in grapefruit, lemon and sweet orange in south Texas, 2007. The spectrum of each color trap is its reflectance relative to a white standard (99% pure Spectralon calibrated reflectance standard). Values are means of four traps measured per color.

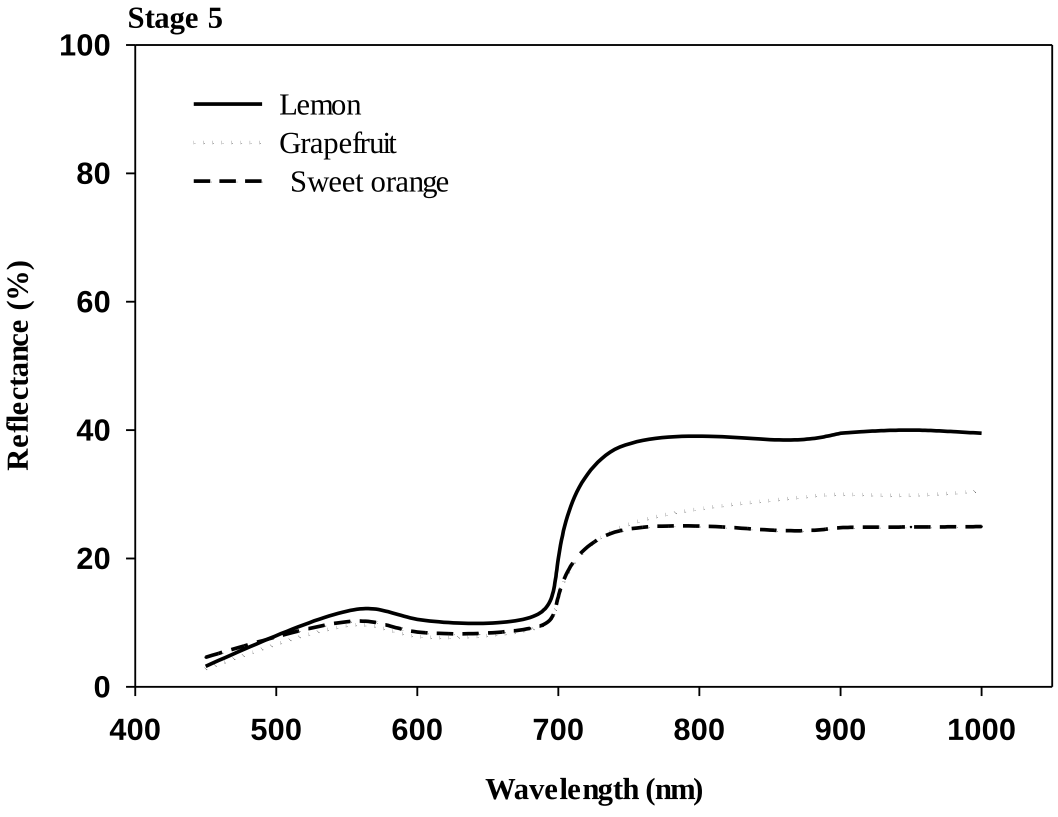
Figure 3. Spectral reflectance curves for young and mature flush shoots of three citrus species (grapefruit, lemon and sweet orange) in which *Diaphorina citri* population dynamics were studied. Values are means of three flush shoots measured for each stage per host plant.

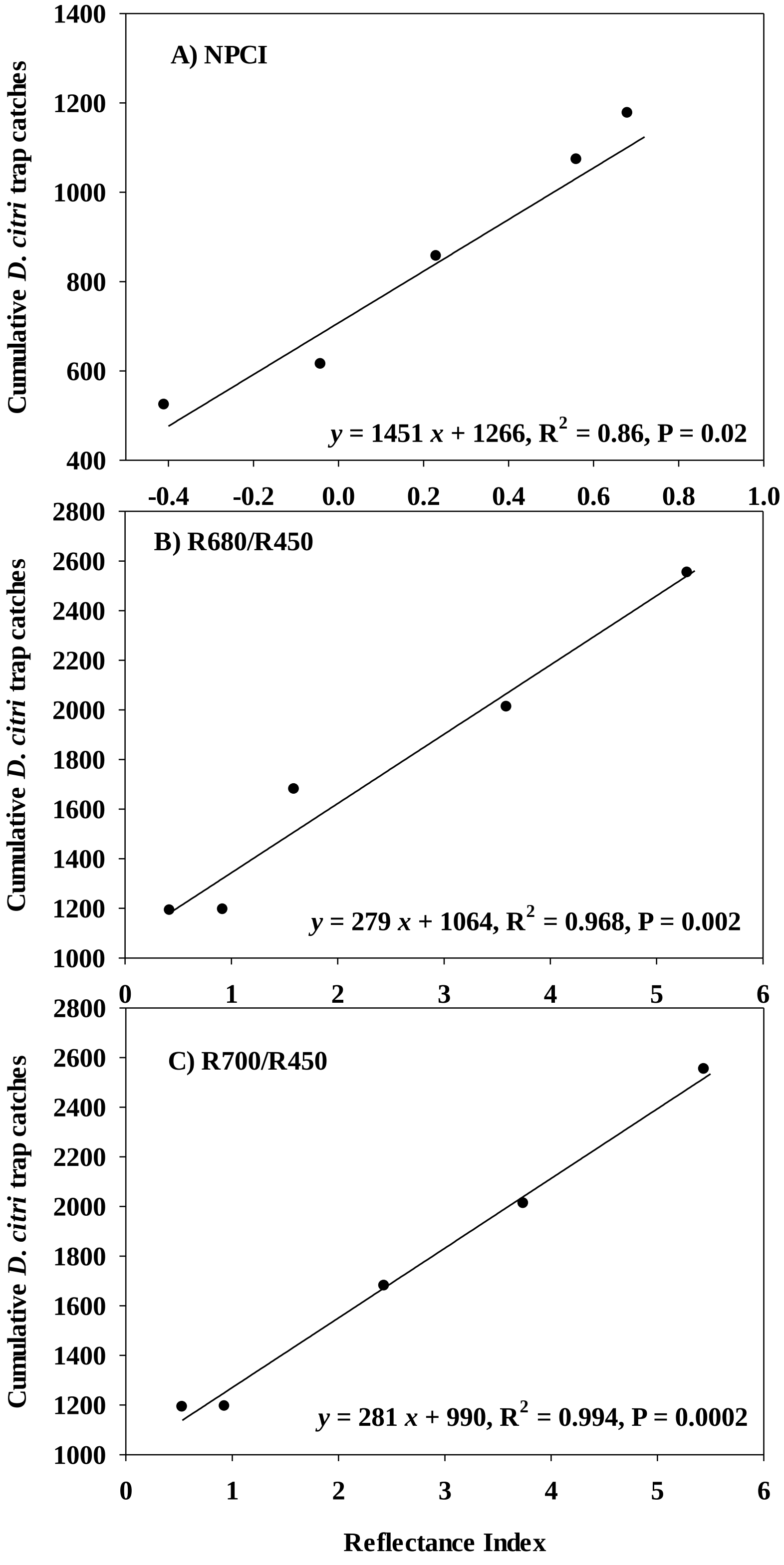
Figure 4. Relationship between total trap catches of *D. citri* and derived spectral reflectance indices of colored sticky cards (NPCI = [R680 - R430]/[R680 + R430], R680/R450 and R700/R450 are the simple ratios between the reflectance values of the visible red (680 nm) and near red edge (700 nm) with the visible (450 nm), respectively.


White
Yellow
Green
Red
Blue
A) Lemon
B) Grapefruit
C) Sweet Orange
600
500
400
300
200
100
0
250
150
50
Number of adults per 4 traps
4/1/07
5/1/07
6/1/07
7/1/07
8/1/07
Sampling Period


Mean_Black_trap.mn
Mean_Blue_trap.mn
Mean_Green_trap.mn
Mean_Red_trap.mn
Mean_White_trap.mn
Mean_Yellow_trap.mn
Reflectance
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
400
500
600
700
800
900
1000
Wavelength


Stage 1
100
80
60
40
20
0
Reflectance (%)
Lemon
Grapefruit
Sweet orange
400
500
600
700
800
900
1000


Stage 5
100
80
60
40
20
0
Reflectance (%)
Lemon
Grapefruit
Sweet orange
400
500
600
700
800
900
1000
Wavelength (nm)


A) NPCI
y = 1451 x + 1266, R2 = 0.86, P = 0.02
1400
1200
1000
800
600
400
-0.4
-0.2
0.0
0.2
0.4
0.6
0.8
1.0
B) R680/R450
y = 279 x + 1064, R2 = 0.968, P = 0.002
2800
2600
2400
2200
2000
1800
1600
1400
1200
1000
0
1
2
3
4
5
6
C) R700/R450
y = 281 x + 990, R2 = 0.994, P = 0.0002
2800
2600
2400
2200
2000
1800
1600
1400
1200
1000
0
1
2
3
4
5
6
Cumulative D. citri trap catches
Reflectance Index