NORTH-WESTERN JOURNAL OF ZOOLOGY 12 (1): 40-49 ©NwjZ, Oradea, Romania, 2016
Article No.: e151104 http://biozoojournals.ro/nwjz/index.html

The hypothesized visual system of *Thrips tabaci* Lindeman and *Frankliniella occidentalis* (Pergande) based on different coloured traps' catches

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Received: 05. November 2014 / Accepted: 15. April 2015 / Available online: 29. May 2016 / Printed: June 2016

Abstract. *Thrips tabaci* Lindeman and *Frankliniella occidentalis* (Pergande) are the most studied members of *Thysanoptera: Thripidae*, since these thrips species have already become worldwide spread pests causing serious yield losses. Thrips damage host plants directly through the feeding process and indirectly by transmitting plant viruses. Biological characteristics of these species make them difficult to manage and prevent the damage they cause. This study is aimed to find the most attractive colour of the commonly used sticky traps for mass trapping of these two species, and generate information about the vision system of both specimens by investigating the reflectance spectrum of these traps. The attractiveness of white, yellow, blue and fluorescent yellow sticky traps for *T. tabaci* was investigated in a white cabbage field during summer production. The order of attractiveness of yellow, blue and fluorescent yellow traps was also investigated for *F. occidentalis* in a greenhouse during the pollination season of selected cauliflower plants. In this study number of captured thrips specimens was significantly affected by trap's colour in open field for *T.tabaci* ($\chi2(3)=147,4$; $p<0,001$) and also in the greenhouse for *F.occidentalis* ($\chi2(2)=457,8$; $p<0,001$). No significant differences were found between the numbers of the specimens of *T. tabaci* caught by the yellow (average 36,03 specimens per trap) and white (average 33,25 specimens per trap) coloured traps (Mean dif. 2,06; SE 3,79; Bonferroni sig. p=1,000), while the blue colour (average 18,1 specimens per trap) proved to be the least attractive. Fluorescent yellow coloured traps caught the highest number of the specimens (average 82,88 specimens per trap) of *T. tabaci*. The highest numbers of *F. occidentalis* were also caught with fluorescent yellow sticky traps (average 47,88 specimens per trap), followed by blue (average 21,67 specimens per trap) and yellow (average 9,29 specimens per trap). Thereby, fluorescent yellow traps proved to be the most effective in this study for monitoring thrips species both in the field and in the greenhouse. The light reflectance of the coloured sticky traps used in this study and the petals of cauliflower flowers were also measured both in the UV and visible light ranges. The proportion of captured thrips specimens of the two species (*T. tabaci* and *F. occidentalis*) and the light reflectance spectrum of the most preferred coloured traps suggest that these thrips species might have different photoreceptor systems. Results of this study also suggest that light reflectance in the yellow region and in the UV range has the most important effect on host plant selection of *T. tabaci* and *F. occidentalis*.

Key words: fluorescent yellow, *Thrips tabaci, Frankliniella occidentalis,* white cabbage, cauliflower, thrips vision

Introduction

Since the 1980s, the onion thrips *Thrips tabaci* Lindeman, 1889 has become the most common pest on cultivated white cabbage plants in continental climatic conditions. Western flower thrips, *Frankliniella occidentalis* (Pergande, 1895) is one of the most destructive insect pests in greenhouses, feeding on a wide variety of horticultural crops, including crop plants in the family *Brassicaceae*. These thrips species have several generations per year, a rapid life cycle and an enormous reproductive capacity. Both larvae and adults are plant feeders, attacking leaves, flowering stalks, buds, flowers and pods. Thrips feeding results in a proliferation of injured cells on some plant tissues, what looks like a brownish-grey growth on the surface. In many cases the damaged area may wither or die on other plant tissues. In the case of cabbage, the damaged head leaves become unacceptable for fresh and processing markets, causing huge commercial loss, loss of quality premiums and increased labour costs for the growers to peel off the injured leaf layers.

For the monitoring of flight activity of *T. tabaci,* blue (Bognár & Shanab 1969, Villeneuve et al. 1997, Liu & Chu 2004), yellow (Teulon & Penman 1992, Jenser 1993, Jenser et al. 2001), and white (Kahrer 1992, Jenser et al. 2009) and for *F. occidentalis* mainly blue (Matteson & Terry 1992, Roditakis et al. 2001, Chu et al. 2006, Allsop 2010), blue and white (Larrain et al. 2006) coloured water and sticky board traps were proposed and used in practice. It was previously demonstrated in comparative experiments that the attractiveness of coloured traps and capture rates of *T. tabaci* and *F. occidentalis* vary according to species and trap colour (Kirk 1984a, Brødsgaard 1989, Czencz 1987, Jenser et al. 2001). Behavioural studies of the colour preference of *T. tabaci* and *F. occidentalis* have provided variable results, but there is general agreement that greater numbers of thrips are caught by low UV-reflective white, blue, and yellow traps than are caught by green, red, black, and high UV-reflective white traps (Hoddle et al. 2002, Chu et al. 2000, Chen et al. 2004).

In the interest of reliable monitoring of *T. tabaci* under field conditions and of *F. occidentalis* in greenhouses, the attractiveness of fluorescent yellow, yellow, blue, and white colour sticky boards were compared in this study. Possible explanations for the colour preference are also discussed.

Materials and Methods

The colour preference of *T. tabaci* was investigated in the field of different white cabbage varieties at the Syngenta trial station in Ócsa (Hungary) during the summer of 2011. Plants were seeded on 19th of April and seedlings were transplanted to field plots on 26th of May. Four coloured traps were tested: yellow, white, blue and fluorescent yellow from the CSALOMON® trap family produced by the Plant Protection Institute (Hungarian Academy of Sciences, Budapest, Hungary; www.julianki.hu/traps).

Plots of four different white cabbage varieties were selected in the field experiment ('Quisor' and 'Bloktor' from Syngenta, 'Ferro' from Seminis, 'Lennox' from Bejo) and the four different coloured traps (1 trap of each colour with sticky surface on both sides) were randomly placed on reed-sticks about 60 cm above ground in each plot. Quisor (more susceptible for thrips damage) and Ferro (more resistant for thrips damage) are summer varieties for fresh market with about 90-95 growing days after transplanting; Lennox (susceptible) and Bloktor (resistant) are storage varieties requiring a longer growth period (120-140 days). Each plot size was 15.6 m^2 with 3.33 plants/m^2 density. Sampling was repeated four times at two weeks intervals. The first sampling period was from 5th of July to 19th of July, the second – from 19th of July to 2nd of August, the third – from 2nd to 16th of August, and the fourth – from 16th to 30th of August.

The attractiveness of blue, yellow and fluorescent yellow coloured traps for *F. occidentalis* was also compared on selected cauliflower plants in a 500 m^2 greenhouse section during pollination season (December 2011 – April 2012). Five traps of each colour were randomly placed on reed-sticks at a height of 60 cm from ground level. All traps were changed four times at two weeks intervals: the first sampling period was from 20th of December to 04th of January, the second – from 05th to 20th of January, the third – from 25th of January to 08th of February, the forth – from 08th to 23rd of February, the fifth – from 23rd of February to 08th of March. From 13th of March to 09th of May only fluorescent yellow traps (5 traps per replication) were placed in the greenhouse to monitor the abundance of *T. tabaci*.

The size of the sticky sheets used was 10 × 16 cm. The sticky material (TangleFoot C. Palo Alto, MS) was spread in ca. 1-2 mm thickness over both surfaces of the sheet. When changing the traps both sides were covered by plastic sheaths and transferred to the laboratory for counts of the captured thrips by Wild stereo-microscope at ×60 magnification.

The extent of thrips damage in cabbage heads was assessed both by counting the number of injured leaf layers and by estimating the severity of the damage on a scale, where 0: no damage at all, 9: over 90% of the leaf is damaged. Six heads were tested at each assessment.

A Poisson loglinear model was used for statistical analysis which provides likelihood ratios to test the significance of each factor (differently coloured sticky traps, varieties, period). Comparisons of individual parameters within each effect were performed using Wald's Chi-Square. Proc GENLIN in IBM SPSS Statistics version 20.0 (IBM Corp. Armonk, NY, USA) was used for all calculations.

The light reflectance of the sticky sheets and petal of the cauliflower flowers was recorded by an Ocean Optics USB 2000+ portable spectrophotometer using R200-7-UV-VIS reflection probe, PX-2 pulsed Xenon lamp (220-750 nm) and WS-1 diffuse reflectance white standard. Ten measurements were performed at different spots and the means were calculated and presented. Light reflectance spectra were recorded from 230 nm to 700 nm at 0,2 nm intervals and data were processed by the software SpectraSuite.

Results

In the white cabbage field, number of captured thrips specimens was significantly affected by trap's colour ($\chi2(3)=147{,}4$; $p<0{,}001$). The highest numbers of *T. tabaci* were caught with fluorescent yellow coloured sticky traps in all sampling periods (Table 1; Fig. 1). Number of thrips captured on fluorescent yellow traps was significantly higher than number of specimens captured on yellow traps, the second most preferred colour by thrips (Mean dif. 39,11; SE 5,1; Bonferroni sig. $p<0{,}001$). There was no significant difference between white and yellow traps (Mean dif. 2,06; SE 3,79; Bonferroni sig. $p=1{,}000$), while the blue trap was the significantly less attractive for *T. tabaci* than yellow trap in all samplings (Mean dif. 19,06; SE 3,74;

Table 1. Estimated marginal means of captured *T. tabaci* on different coloured sticky traps in the sampling periods. The values not followed by the same letter in the Significance column are significantly different (p<0.05). This reflects the 'P' values of Bonferroni test after the pairwise comparisons of estimated marginal means.

Time period	Colour of the trap	Mean	Std. Error	95% Wald Confidence Interval		Significance
				Lower	Upper	
5-19 July	Blue	30.3	5.0	21.9	41.7	**b**
	White	42.2	5.9	32.2	55.5	**b**
	Yellow	43.5	5.9	33.3	56.9	**b**
	Fluorescent yellow	110.0	9.5	92.9	130.2	**a**
19 July-2 August	Blue	21.6	4.2	14.5	31.2	**c**
	White	53.0	6.6	41.6	67.6	**b**
	Yellow	57.3	6.8	45.3	72.3	**bc**
	Fluorescent yellow	137.0	10.6	117.8	159.4	**a**
2-16 August	Blue	1.0	0.9	0.2	5.9	**b**
	White	15.5	3.6	9.9	24.3	**a**
	Yellow	13.8	3.3	8.5	22.2	**a**
	Fluorescent yellow	31.5	5.1	23.0	43.2	**a**
16-30 August	Blue	19.5	4.0	13.1	29.1	**b**
	White	22.3	4.3	15.3	32.4	**b**
	Yellow	29.5	4.9	21.3	40.9	**ab**
	Fluorescent yellow	53.0	6.6	41.6	67.6	**a**

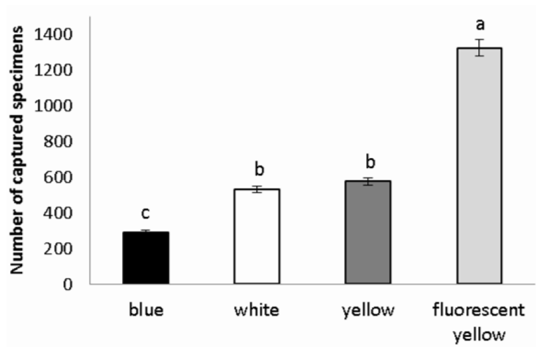

Figure 1. Cumulated number of captured *T. tabaci* specimens [(SUM±SE)/traps] on different coloured sticky traps in the field of all sampling periods. Significance differences are indicated with small letters above the columns (p<0.001). This reflects the 'P' values of Bonferroni test after the pairwise comparisons of estimated marginal means.

Bonferroni sig. p<0,001).

The fluorescent yellow traps caught 2.5 times more onion thrips than yellow and white traps, and 4.6 times more than blue traps. The yellow and white traps caught 2 times more onion thrips than blue traps.

The spectral reflectance curves of the tested sticky traps are shown in Fig. 2. The fluorescent yellow sticky sheet showed the lowest reflectance in the UV range followed by blue, yellow and white, respectively. There was almost no difference in the pattern of reflectance curves in the UV range for the different traps. The difference was more characteristic in the visible range. The blue sticky sheet used here had a broad peak between 400 and 500 nm, the yellow sticky sheet reflectance plateau started at about 520 nm, and the white trap had a reflectance plateau in the whole visible spectrum. The fluorescent yellow sheet had a very high peak between 500 and 530 nm in the green portion and another peak at 550-560 nm in the yellow range. Yellow and fluorescent yellow had low reflectance at short wavelengths. A significant positive correlation (r(62)=0,57; p<0,001) was demonstrated with Spearman's test between the average light reflectance of the sticky traps in the 540-590 nm region and the number of captured *T.tabaci* specimens.

There was no significant 'variety effect' detected: no significant difference was found between the numbers of *T. tabaci* specimens captured on any coloured trap ($\chi2(3)=0,272$; p=0,965), placed in the plots of different varieties (Table 2, Fig. 3), in spite of huge varietal differences in the susceptibility to thrips (Fig. 4). Comparing the summer cabbage varieties, Quisor proved to be more susceptible regarding the number of injured leaf layers and also the severity of the damage on

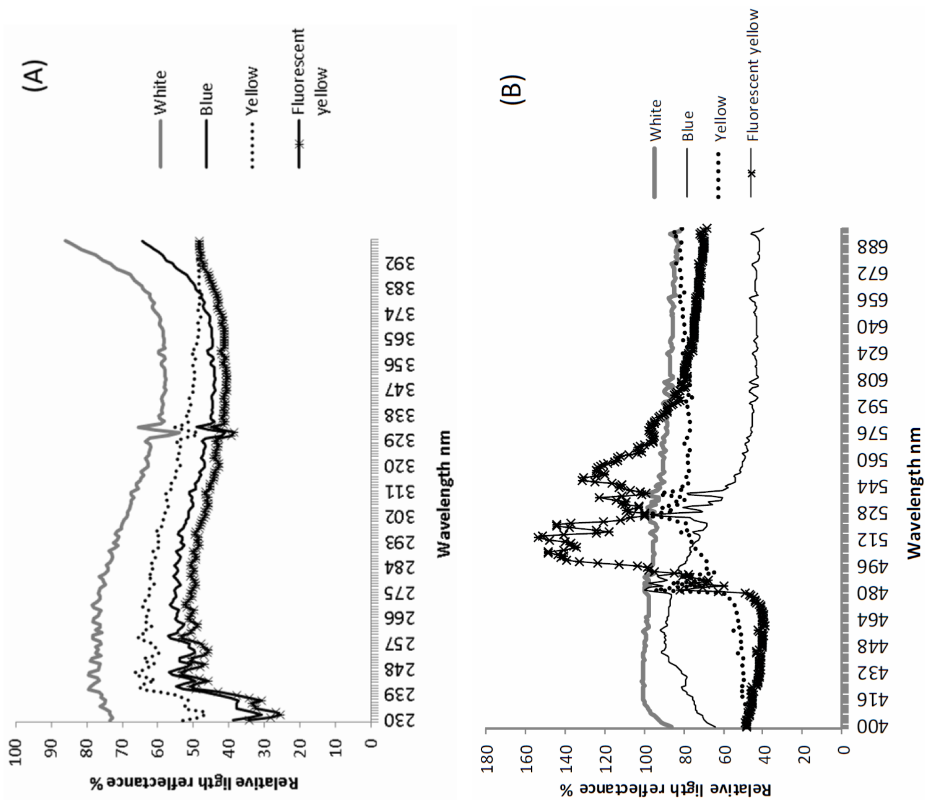

Figure 2. Light reflectance spectrum of the coloured sticky traps from 230 to 400 nm in the UV region (A) and from 400 to 700 nm in the visible (B) region.

Table 2. Number of *T. tabaci* specimens captured on different white cabbage varieties, combined for all four traps and all four sampling events. The values within the column not followed by the same letter are significantly different (p<0.05). This reflects the 'P' values of Bonferroni test after the pairwise comparisons of estimated marginal means.

Variety	Number of thrips captured (SUM±SE)/variety
Bloktor	670 ± 39.9 **a**
Quisor	702 ± 33.1 **a**
Lennox	678 ± 37.1 **a**
Ferro	672 ± 37.1 **a**

the leaves, while less damage was observed on the head leaves of Ferro (Fig. 4). This difference increased with the development of the plants. These summer varieties reached harvest maturity at the end of August, while the first date of damage assessment (August 3) was 69 days after transplanting when the heads were not yet filled.

In case of storage type varieties no damage was observed on Bloktor until the third week of September and the extent of damage remained very low even after whole maturity of the heads. In the variety Lennox, more than 20 leaf layers were injured by thrips at the end of head formation, and the damage was much more severe, scored up to 50% damage of the whole leaf surface.

A significant time effect ($\chi 2(3)=166{,}9$; $p<0{,}001$) was detected in the open field trial on the captured *T.tabaci* specimens in the four examined periods (Fig. 3; Table 3). The number of captured flying thrips considerably decreased in the third sampling period, probably due to the colder and rainy weather conditions in that time. The number of captured thrips increased again in the subsequent two weeks period.

The attraction of different coloured sticky traps to *F. occidentalis* was also investigated on flowering cauliflower plants in a greenhouse during the pollination season and significant trap colour effect was proved in statistical analysis

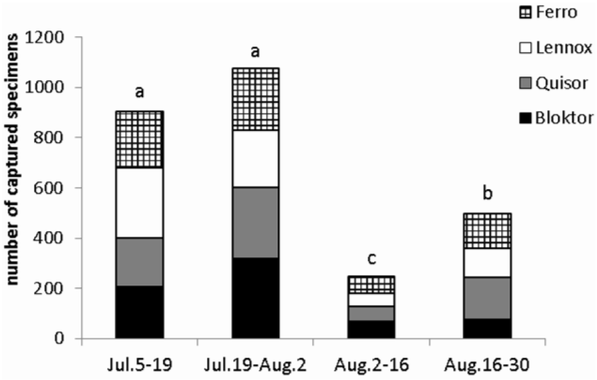

Figure 3. Cumulative numbers of captured *T. tabaci* specimens in the four examined periods on the traps were placed in the field of the four cabbage varieties. Significance differences are indicated with small letters above the columns (p<0.001). This reflects the 'P' values of Bonferroni test after the pairwise comparisons of estimated marginal means.

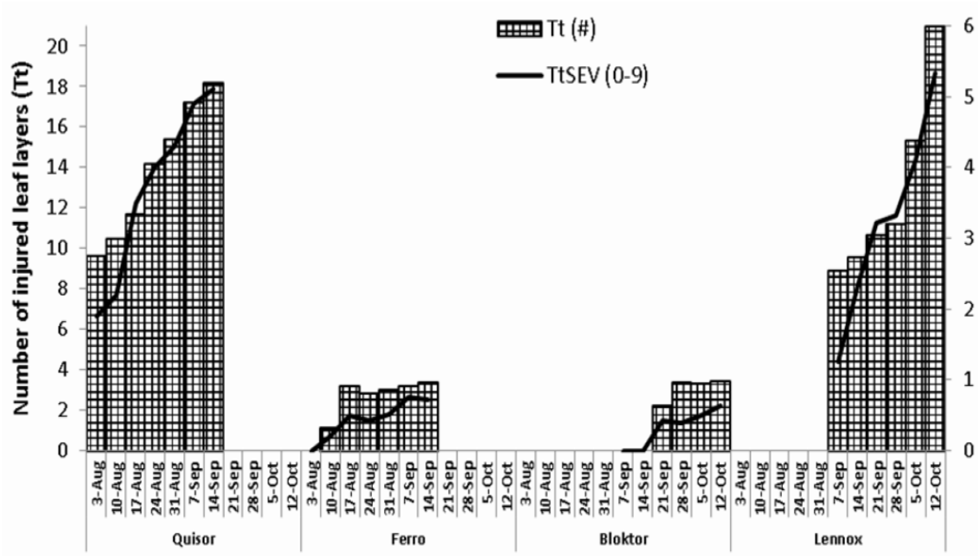

Figure 4. Number of injured leaf layers (Tt) and severity of the thrips damage (TtSEV) of the examined white cabbage varieties during head formation. Each data point represents the mean of the examined 6 cabbage heads.

Table 3. Estimated marginal means of captured *T. tabaci* in the four sampling periods. The values not followed by the same letter in the Significance column are significantly different (p<0.001). This reflects the 'P' values of Bonferroni test after the pairwise comparisons of estimated marginal means.

Time period	Mean	Std. Error	95% Wald Confidence Interval		Significance
			Lower	Upper	
5-19 July	49.73	3.346	43.59	56.74	**a**
19 July - 2 August	54.52	3.707	47.72	62.29	**a**
2-16 August	9.05	2.21	5.61	14.61	**b**
16-30 August	28.7	2.501	24.19	34.04	**c**

($\chi 2(2)=457{,}8$; p<0,001). The highest number of *F. occidentalis* was caught with fluorescent yellow sticky traps (average 53,2 specimens per trap), followed by blue (average 23,16 specimens per trap) and yellow (average 9,12 specimens per trap) (Table 4). Capture on fluorescent yellow sticky traps was significantly higher than on the blue traps (Mean dif. 54,28; SE 4,35; Bonferroni sig. p<0,001). The blue traps also caught significantly higher number of thrips compared to yellow traps (Mean dif. 18,98; SE 2,23; Bonferroni sig. p<0,001).

A significant positive correlation (r(73)=0,64;

Table 4. The number of *F. occidentalis* specimens captured by different coloured sticky traps in the sampling periods. Significance differences are indicated within dates and between colours with small letters; within colours and between dates with capital letters ($p<0.001$). This reflects the 'P' values of Bonferroni test after the pairwise comparisons of estimated marginal means.

Date	Trap colours	Average number of the catched adults	Standard deviation	Significance level within date between trap colours	Trap colours	Date	Significance level within trap colours between dates
Dec.20-Jan.04	yellow	0	0	c	yellow	Dec.20-Jan.04	B
	blue	20.8	7.36	b		Jan.05-Jan.20	B
	fluorescent yellow	117.4	41.16	a		Jan.25-Feb.08	B
Jan.05-Jan.20	yellow	3.23	2.3	b		Feb.08-Feb.23	B
	blue	39.37	20.3	a		Feb.23-Mar.08	A
	fluorescent yellow	51.79	5.98	a	blue	Dec.20-Jan.04	ABC
Jan.25-Feb.08	yellow	5	1.87	a		Jan.05-Jan.20	A
	blue	6.2	2.17	a		Jan.25-Feb.08	C
	fluorescent yellow	11.6	4.98	a		Feb.08-Feb.23	BC
Feb.08-Feb.23	yellow	6.6	5.13	a		Feb.23-Mar.08	AC
	blue	15.4	5.46	a	fluorescent yellow	Dec.20-Jan.04	ABC
	fluorescent yellow	24.6	10.21	a		Jan.05-Jan.20	A
Feb.23-Mar.08	yellow	31.6	17.85	a		Jan.25-Feb.08	C
	blue	26.6	8.08	a		Feb.08-Feb.23	BC
	fluorescent yellow	34	17.71	a		Feb.23-Mar.08	B

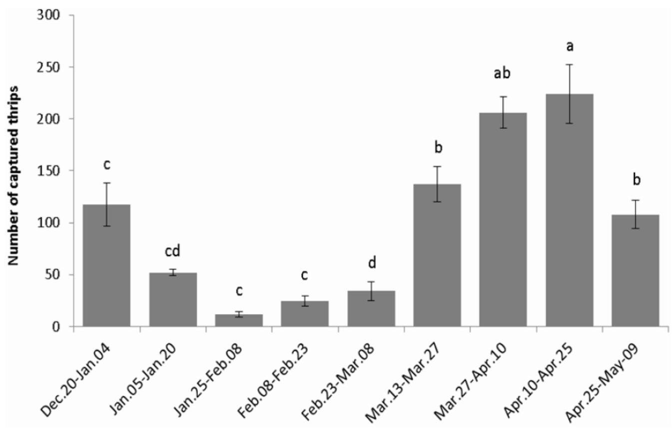

Figure 5. The number of *F. occidentalis* specimens captured by fluorescent yellow sticky traps in the greenhouse from December 2011 until May 2012. Significance differences are indicated with small letters above the columns ($p<0.001$). This reflects the 'P' values of Bonferroni test after the pairwise comparisons of estimated marginal means.

$p<0,001$) was demonstrated with Spearman's test between the average light reflectance of the sticky traps in the 490-510 nm region and the number of captured *F. occidentalis* specimens.

A surprisingly large number of thrips specimens were detected at the end of December. Afterwards, this number stayed low during all winter and then a big increase was observed in March when the spring and warmer weather arrived (Fig. 5).

Important difference can be found comparing the order of the two thrips species' most preferred colours. Yellow coloured traps caught significantly more *T. tabaci* specimens than the blue coloured traps in 2 of the 4 sampling periods, while the blue coloured traps proved to be more attractive for *F. occidentalis* than the yellow coloured traps in 4 of the 5 sampling periods.

Discussion

T. tabaci and *F. occidentalis* are polyphagous thrips species with extremely wide host-plant range. *T. tabaci* is one of the main pest species of white cabbage production in open field, while the spring population of *F. occidentalis* detected also in this study in March causes the biggest problem for plant breeding processes every year during the pollination season by attacking the flowering stalks, flowers, pods and by feeding on and transferring pollen grains (Kirk 1984b, Wäckers et al. 2007). Avoiding this huge pressure of western flower thrips is critical for the success of pollinations in protected facilities. Factors affecting these thrips species' host-plant selection are not identified yet. Several plant characteristics are assumed to play a significant role in this interaction between the plant and insects. Different types of information from surrounding environment can be detected and analysed by the senses of thrips, and the effects of these factors for the host-plant selection are still unknown. Some of the assumed plant characteristics involved in this process have been studied and proved to be correlated with thrips populations on economically important crops, like epicuticular wax content for *T. tabaci* (Trdan et al. 2008), and different volatile plant compounds in case of *F. occidentalis* (Koschier et al. 2000) and *T. tabaci* (Koschier et al. 2002). Antixenotic resistance in some white cabbage varieties against *T. tabaci*, and reflectance of the cabbage leaves as one of the factors playing role in antixenotic resistance were reported (Fail et al. 2008). Because visual cues seem to play a role in the host selection of thrips, different coloured sticky traps can be useful tools not just in the daily practice of crop protection but also in research studies. Coloured traps are used in pest management against thrips for several purposes: for monitoring the presence or absence of a species, for early detection of infestation and in some cases for control by mass trapping especially under greenhouse conditions. Obviously, the most attractive colour is the most appropriate to use for all of these situations.

Colour preference of different Thysanoptera species has been investigated in several studies in different crops. The contradictory results of these studies might be explained by some influential factors on colour preference. The host-plant type could significantly influence the response of some Thysanoptera species to colours (Kirk 1984a). Background colours of traps can also increase or decrease the attractiveness of a trap depending on trap colour and thrips species (Czencz 1987). It is more than likely based on the previous studies that individual thrips species can discriminate the colours of the traps. It was also shown that differences in the shades of the same colour and the interaction between thrips and their host plants, may account for differences in colour preference for a given thrips species in different experiments (Brødsgaard 1989). Therefore, it is extremely important to identify and present the reflectance spectrum of coloured traps used in the widest possible wavelength, rather than simply describing the colour of the trap. The exact physical characterization of the traps used, especially by their reflectance curves, is extremely important since many shades of colour are currently available and could be generated in the future and might have differences in attractiveness. In our case, for instance, over 100% relative light reflectance was detected and shown in Fig. 2 since every measurement was taken after the sticky material had been spread on the sheets that made the surface shiny. The appearance of the colour does not only depend on the particular combination of reflected wavelength, but also on other physical characteristics (shininess and smoothness in this case) of a given surface. The use of an independent light source is also important to avoid the possible deviations of sunlight during the measurements. The Xenon lamp used in this study has 220-750 nm spectral output that makes measurements possible not only in the visible but also in the UV range.

The differences in shades of the colours as well as background colours, might explain the various attractiveness of similar coloured surfaces reported in different studies. In most of the studies the colour spectrum of the traps used for catching thrips species is only partially recorded or not recorded at all. In this study the reflectance spectrums of the sticky traps were recorded not just in the human visible region but also in the UV range of light, considering the proven ability of *F. occidentalis* and the hypothesized ability of *T. tabaci* to detect UV light.

It has been shown earlier that intense reflectance in the UV range has a repellent effect on many thrips species (Terry 1997). Therefore, the lowest light reflectance of the fluorescent yellow traps in the UV range might play a part in the attractiveness of these traps to thrips. Although, the visible yellow range seems to play the most critical role in the attraction of thrips in this study, since the brightness of traps in this region of light and the number of thrips caught is strongly correlated. This correlation is supported with the peak spectral efficiency of the photoreceptor of western flower thrips (around 540 nm), the only thrips species studied (Matteson et al. 1992).

In earlier studies the white coloured traps (without diffuse UV reflectance) were suggested by Moffit (1964) and Yudin et al. (1987) for monitoring *F. occidentalis.* In the detailed experiments of Brødsgaard (1989) blue colour proved to be the most attractive, but it seems to be obvious that different shades of blue show differences in attractiveness. In our study *F. occidentalis* was attracted the most to fluorescent yellow sticky board traps among the studied colours; however, the difference was not significant between the colours in all sampling periods.

To understand the preference of a given thrips species to different colours it is necessary to know its visual system and its spectral sensitivity for key wavelengths. Sticky coloured traps are suitable tools to study the response of insects to visual stimulus since they exclude the effect of other stimuli (biochemical, physiological, etc.), which may also modify insect behaviour.

Vernon and Gillespie (1990) suggested that western flower thrips have a photosystem with three photoreceptors, similar to bees, based on behavioural response to coloured traps. The existence of two photoreceptors has been proven by physiological data for western flower thrips (Matteson et al. 1992). Information about the photoreceptor system of onion thrips based on physiological studies is not available yet, but Bálint et al. (2013) suggest that the reflectance of the host-plant (cabbage) both in UV and in visible region has a role in the host-plant selection of *T. tabaci*.

Comparing the brightness of the traps (Fig. 2) and the number of captured thrips, the strongest positive correlation was found in the greenish-yellow region (540-570 nm) for *T. tabaci* (Fig. 1), whereas for *F. occidentalis*, in the bluish-green region of light, around 500 nm. Based on these correlations our suggestion is that reflectance in the yellow region elicits the strongest response of onion thrips, but western flower thrips is more influenced by reflectance in the blue region than in the yellow region. Although both of them are polyphagous species, and both could feed on leaves and pollen as well, *T. tabaci* may have a preference towards vegetative parts of host plants, whereas *F. occidentalis* is considered more of an anthophilous, flower feeding pest. The different response of these species to the same colour may be explained by their feeding site preference and their slightly different adaptation could have resulted in differences in their visual system.

This study indicates that the fluorescent yellow colour of CSALOMON® trap family has a distinguished attractiveness on these two thrips species. In concordance with this study, fluorescent yellow traps proved to be effective for monitoring grape thrips (*Drepanothrips reuteri* UZEL), as well (Jenser et al. 2010). The character of the light reflection curve of the trap and the preferred part of the host-plant might explain this high attractiveness. Comparing the reflection of the cabbage head forming leaves presented by Bálint et al. (2013) to the reflection of the different colours used in this study, it is concluded that the fluorescent yellow colour has the most similar curve to one of the studied host-plant' leaves. The reflectance is low in the UV range, has a peak around 550 nm, and brightness decrease at longer wavelengths.

The flowers of cross-pollinated plants attractive for insects often have blue, violet and yellow colour in the nature. The whole area of the petals in these flowers often looks homogenous for the human eye, but their UV reflection is usually different on the internal and external area of the petal.

In general, the external area has higher reflection than the internal area closer to the centre of the flower, giving the so called bull's eye pattern for these petals in the UV. Although not all cross-pollinated plant species have the typical bull's-eye UV pattern in their flowers (Rørslett 2006), the studied cauliflower definitely has (Fig. 6). Light reflectance measured on the internal and external area showed obvious differences, the external area has higher reflectance except in a small part of the UV-C region (245-280 nm). It has most likely no effect on thrips's vision since UV photoreceptors in insects typically have a peak sensitivity in the UV-A region (Tovée 1995, Stavenga & Arikawa 2006, Briscoe 2008) and even *Caliothrips phaseoli*, the only thrips species that is known to detect and respond to UV-B light, have no sensitivity in the UV-C region (Mazza et al. 2010).

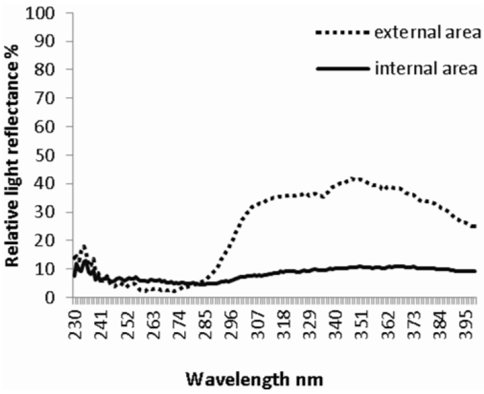

Figure 6. Light reflectance spectrum of the internal and external area of a cauliflower flower petal from 230 to 400 nm in the UV region.

Our assumption based on these findings is that onion thrips have at least two different light receptors: one with peak spectral sensitivity in the greenish-yellow (540-570 nm), and another in the UV-A region (350-360 nm). Western flower thrips possess either trichromatic vision with peak spectral sensitivities in the greenish-yellow (540-570 nm), bluish-green (440-450 nm) and also in the UV-A region (350-360 nm), or dichromatic vision with peak sensitivities in the greenish-yellow (540-570 nm) and in the UV-A region (350-360 nm) and blue colour is perceived through the simultaneous excitation of both receptors, as suggested by Matteson et al. (1992). The light reflectance of the most effective fluorescent yellow coloured sticky trap has the most similar reflectance spectrum to the light reflectance of general host plants' leaves (see also Richardson & Berlyn 2002, Pandey & Gopal 2011). This colour would be the best choice for mass trapping of these species both in open field and greenhouses.

Acknowledgements. We are grateful to Rico Linders and Charles Baxter (Syngenta) for useful recommendations and corrections of the manuscript. Author J. Fail was supported by the National Development Agency (NDA) and the Hungarian Scientific Research Fund (OTKA MB08A-81156) co-funded by EU FP7 Marie Curie Actions.

References

Al-Ayedh, H., Al-Doghairi, M. (2004): Trapping efficiency of various coloured traps for insects in cucumber crop under greenhouse condition in Riyadh, Saudi Arabia. Pakistan Journal of Biological Sciences 7: 1213–1216.

Allsop, E. (2010) Seasonal occurrence of Western Flower Thrips, *Frankliniella occidentalis* (Pergande), on table grapes in the Hex River Valley, South Africa. South African Journal of Enology and Viticulture 31: 49–57.

Bálint, J., Nagy, B.V., Fail, J. (2013): Correction: Correlations between Colonization of Onion Thrips and Leaf Reflectance Measures across Six Cabbage Varieties. PLoS ONE 8(9): art.10.

Bognár, S., Shanab, L.M. (1969): Investigation on onion thrips (*Thrips tabaci* Lind.) populations. Acta Phytopathologica Acadeamiae Scientiarum Hungaricae 4: 153-161.

Briscoe, A. D. (2008): Reconstructing the ancestral butterfly eye: focus on the opsins. Journal of Experimental Biology 211(11): 1805-1813.

Brødsgaard, H.F. (1989): Coloured sticky traps for *Frankliniella occidentalis* (Pergande) (Thysanoptera, Thripidae) in glasshouses. Journal of Applied Entomology 107: 136-140.

Chen, T.Y., Chu, C.C., Fitzgerald, G., Natwick, E.T., Henneberry, T.J. (2004): Trap Evaluations for Thrips (Thysanoptera: Thripidae) and Hoverflies (Diptera: Syrphidae). Environmental Entomology 33(5): 1416-1420.

Chu, C.C., Ciomperlik, M.A., Chang N.T., Richards, M., Henneberry, T.J. (2006): Developing and evaluating traps for monitoring *Scirtothrips dorsalis* (Thysanoptera: Thripidae). Florida Entomologist 89: 47-55.

Chu, C.C., Pinter, P.J., Henneberry, T.J., Umeda, K., Natwick, E.T., Wei Y.A., Reddy, V.R., Shrepatis, M., (2000): Use of CC Traps with Different Trap Base Colors for Silverleaf Whiteflies (Homoptera: Aleyrodidae), Thrips (Thysanoptera: Thripidae), and Leafhoppers (Homoptera: Cicadellidae). Journal of Economic Entomology 93(4): 1329-1337.

Czencz, K. (1987): The role of coloured traps in collecting thrips fauna. In: Population Structure, Genetics and Taxonomy of Aphids and Thysanoptera. pp. 426-435. In: Holman, J., Pelikán, J., Dixon, A.F.G., Weisman, L. (eds.), Population Structure, Genetics and Taxonomy of Aphids and Thysanoptera. SPB Academic Publishing, The Hague.

Fail, J., Zana, J., Pénzes, B. (2008): The role of plant characteristics in the resistance of white cabbage to onion thrips: Preliminary results. Acta Phytopathologica et Entomologica Hungarica 43: 267-275.

Hoddle, M.S., Robinson, L. Morgan, D. (2002): Attraction of thrips (Thysanoptera: Thripidae and Aeolothripidae) to colored sticky cards in a California avocado orchard. Crop Protection 21: 383-388.

Jenser, G. (1993): Studies on the vertical distribution of some Thysanoptera species in an oak forest. Journal of Pure and Applied Zoology 4: 233-238.

Jenser, G., Almási, A., Kazinczi, G., Takács, A., Szénási, Á., Gáborjányi, R. (2009): Ecological background of the epidemics of Tomato spotted wilt virus in Central Europe. Acta Phytopathologica et Entomologica Hungarica 44: 213-223.

Jenser, G., Szénási, A., Zana, J. (2001): Investigation on the colour preference of *Thrips tabaci* Lindeman (Thysanoptera: Thripidae). Acta Phytopathologica et Entomologica Hungarica 36: 207-211.

Jenser, G., Szita É., Szénási, Á., Voros, G., Tóth, M. (2010): Monitoring the population of vine thrips (*Drepanothrips reuteri* Uzel) by using flurescent yellow sticky traps. Acta Phytopathologica et Entomologica Hungarica 45: 329-335.

Kahrer, A. (1992): Monitoring the timing of peak flight activity of *Thrips tabaci* in cabbage fields. Bulletin OILB SROP (France) 15: 28-35.

Kirk, W.D.J. (1984a): Ecologically selective coloured traps. Ecological Entomology 9: 35-41.

Kirk, W.D.J. (1984b): Pollen feeding in thrips (Insecta: Thysanoptera). Journal of Zoology 204(1): 107-117.

Koschier, E. H., De Kogel, W. J., Visser, J. H. (2000): Assessing the attractiveness of volatile plant compounds to western flower thrips *Frankliniella occidentalis*. Journal of Chemical Ecology 26(12): 2643-2655.

Koschier, E. H., Sedy, K. A., Novak, J. (2002): Influence of plant volatiles on feeding damage caused by the onion thrips *Thrips tabaci*. Crop Protection 21(5): 419-425.

Larrain, S.É., Valere, U.F., Quiroz, E.C., Grana, S. (2006): Effect of trap colour on catches of *Frankliniella occidentalis* (Pergande) in sweet peppers (*Capsicum annum* L.). Agricultura Técnica 66: 306-311.

Liu, T.X., Chu, C.C. (2004): Comparison of absolute estimates of *Thrips tabaci* (Thysenoptera: Thripidae) with field visual counting and sticky traps in onion field in South Texas. Southwestern Entomologist 29(2): 83-89.

Mainnalim, B.P, Lim, U.T. (2011): Behavioral response of Western Flower Thrips to visual and olfactory cues. Journal of Insect Behavior 24: 436-446.

Matteson, N., Terry, I. (1992): Response to color by male and female *Frankliniella occidentalis* during swarming and non-swarming behaviour. Entomologia Experimentalis et Applicata 63: 187-201.

Matteson, N., Terry, I., Ascoli-Christensen, A., Gilbert, C. (1992): Spectral efficiency of the western flower thrips, *Frankliniella occidentalis*. Journal of Insect Physiology 38: 453-459.

Mazza, C.A., Izaguirre, M.M., Curiale J., Ballaré, C.L. (2010): A look into the invisible: ultraviolet-B sensitivity in an insect (*Caliothrips phaseoli*) revealed through a behavioural action spectrum. Proceedings of the Royal Society B: Biological Sciences 277: 367-373.

Moffitt, H.R. (1964): A colour preference of the western flower thrips, *Frankliniella occidentalis*. Journal of Economic Entomology 57(4): 604-605.

Pandey, J.K., Gopal, R. (2011): Laser-induced chlorophyll fluorescence and reflectance spectroscopy of cadmium treated *Triticum aestivum* L. plants. Spectroscopy: An International Journal 26(2): 129-139.

Richardson, A.D., Berlyn, G.P. (2002): Spectral reflectance and photosynthetic properties of *Betula papyrifera* (Betulaceae) leaves along an elevational gradient on Mt. Mansfield, Vermont, USA. American Journal of Botany 89(1): 88-94.

Rørslett, B. (2006): Flowers in ultraviolet arranged by plant family. <http://www.naturfotograf.com/UV_flowers_list.html>

Stavenga, D.G., Arikawa, K. (2006): Evolution of color and vision of butterflies. Arthropod Structure & Development 35(4): 307-318.

Terry, L.I., Lewis, T. (1997): Host selection, communication and reproductive behaviour. pp. 65-118. In: Lewis, T. (eds.), Thrips as Crop Pests. CAB International, Cambridge.

Teulon, D.A.J., Penman, D.R. (1992): Colour preferences of New Zealand thrips (Terebrantia: Thysanoptera). New Zealand Entomologist 15: 8-13.

Tovée, M.J. (1995): Ultra-violet photoreceptors in the animal kingdom: their distribution and function. Trends in Ecology & Evolution 10(11): 455-460.

Trdan, S., Valič, N., Andjus, L., Vovk, I., Martelanc, M., Simonovska, B., Jerman, J., Vidrih M., Žnidarčič, D. (2008): Which plant compounds influence the natural resistance of cabbage against onion thrips (*Thrips tabaci* Lindeman)?. Acta Phytopathologica et Entomologica Hungarica 43(2): 385-395.

Vernon, R.S., Gillespie, D.R. (1990): Spectral responsiveness of *Frankliniella occidentalis* (Thysanoptera, Thripidae) determined by trap catches in greenhouses. Environmental Entomology 19: 1229-1241.

Villeneuve, F., Bosc, J.P., Letouze, P., Levalet, M. (1997): Flight activity of *Thrips tabaci* in leek fields and the possibility of forecasting the period of attack. Infos CTIFL IOBC/WPRS Bulletin 19: 25-32

Yudin, L.S., Mitchell, W.C., Cho, J.J. (1987): Colour preference of thrips (Thysanoptera: Thripidae) with reference to aphids (Homoptera: Aphididae) and leafminers in Hawaiian lettice farms. Journal of Economic Entomology 80: 51-55.

Wäckers, F.L., Romeis, J., van Rijn, P. (2007): Nectar and pollen feeding by insect herbivores and implications for multitrophic interactions. Annual Review of Entomology 52: 301-323.