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Evaluation of the Visual Attraction of *Scaphoideus titanus*, *Metcalfa pruinosa* and *Phlogotettix cyclops* to Color Traps in the Field (Hemiptera: Cicadellidae, Flatidae)

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Simple Summary

The monitoring of invasive pests is of crucial importance. For several true hopper (Auchenorrhyncha) pests, yellow traps are used for monitoring; however, information on the color preferences of the respective species is scarce. In the current study, we evaluated the visual attraction of three important invasive true hopper species, *Scaphoideus titanus* Ball, *Metcalfa pruinosa* (Say) and *Phlogotettix cyclops* (Mulsant et Rey), to color traps in field experiments. For *M. pruinosa* and *P. cyclops* no previous data were available regarding color preference, whereas previous results on the color preference of *S. titanus* are contradictory. In our experiments, *S. titanus* and *P. cyclops* showed a similar preference for yellow, greenish-yellow and orange traps, whereas *M. pruinosa* did not show a preference for any of the tested colors. Catches of *S. titanus* and *P. cyclops* were male-biased; nevertheless, both sexes showed similar preferences. The results may contribute to a more comprehensive understanding of the importance of colors in the foraging of these species and, consequently, to the development or improvement of monitoring methods.

Abstract

Invasive pests pose a significant threat to agriculture globally; effective monitoring methods utilizing attractive stimuli are thus essential for their management. Yellow traps are routinely used for pest monitoring, but other colors have been found to be more attractive for several species. The current study focused on the visual attraction of the invasive agricultural pests *Scaphoideus titanus* Ball, *Metcalfa pruinosa* (Say) and *Phlogotettix cyclops* (Mulsant et Rey) (Hemiptera: Cicadellidae) to color traps. Despite red traps having previously been reported to be highly attractive to *S. titanus*, contradictions remain about its color preference, whereas no reports on the color preference of *M. pruinosa* and *P. cyclops* are available. Field experiments were therefore conducted, testing seven different colors of sticky traps as well as transparent traps. Catches of different colors differed significantly for *S. titanus* (Kruskal–Wallis chi-squared = 45.361, $p < 0.0001$) and *P. cyclops* (Kruskal–Wallis chi-squared = 38.417, $p < 0.0001$). Our results contradict previous reports on the preference of *S. titanus* adults for red traps, showing an attraction to greenish-yellow, orange and yellow traps instead. Similar preferences were found in *P. cyclops*. For both species, catches were strongly male-biased, but both sexes showed similar color preferences. Interestingly, transparent traps performed similarly to yellow traps for *S. titanus*. On the other hand, no significant difference was found in the catches of different colors for *M. pruinosa* (Kruskal–Wallis chi-squared = 9.4661, $p = 0.149$, and Kruskal–Wallis chi-squared = 8.5541, $p = 0.2003$, for experiments 2 and 3, respectively). Implications of the ecological relevance of the findings and perspectives for potential practical applications are discussed.

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Keywords: color preference; colored sticky traps; invasive species; phytoplasma vectors; Cicadellidae; Flatidae

This paper is an expanded version of our preliminary conference paper published in Hungarian [1]. With novel results, the current manuscript includes a re-analysis of the data regarding the sex-specific preferences of *Scaphoideus titanus* for different colors (Experiment 1 in the current paper), as well as additional experiments and additional species (*Metcalfa pruinosa* and *Phlogotettix cyclops*).

1. Introduction

Invasive pests pose a great threat to agriculture globally and a major challenge to integrated pest management [2]. The number of invasive pests differs greatly among trophic and taxonomic groups; a large proportion of invasive insects are phytophagous, and several invasive species belong to the order Hemiptera [3]. For the effective management of invasive pests, appropriate methods for monitoring are essential [4]. Besides inflicting direct damage, many hemipteran pests also act as vectors transmitting diseases, for instance, phytoplasmas [5]. The detection and monitoring of vectors using attractant traps is thus crucial to make their management more efficient, with less pesticide use [6]. In order to achieve the maximum efficacy of traps, the use of the most attractive stimuli is key, be it visual (i.e., color) or olfactory, for example. Yellow traps are routinely used for pest monitoring [7]. However, for some important pest species, different colors are more attractive; for example, blue was found to be more attractive than yellow to *Lygus rugulipennis* Poppius (Heteroptera: Miridae) [8], green to *Limotettix vaccini* (Van Duzee) (Hemiptera: Cicadellidae) [9], blue to *Matsumuratettix hiroglyphicus* (Matsumura) and *Yamatotettix flavovittatus* Matsumura (Hemiptera: Cicadellidae) [10] and red to *Anoeconeossa bundoorensis* Taylor et Burckhardt and *Glycaspis brimblecombei* Moore (Hemiptera: Psylloidea) [11] within the Hemiptera order. Furthermore, yellow traps often attract non-target beneficial insects [12].

Scaphoideus titanus Ball (Figure 1A) is an invasive Nearctic leafhopper (Hemiptera: Cicadellidae), with outstanding economic importance due to the transmission of the grapevine 'Flavescence dorée' (FD) phytoplasma [13]. FD is a severe disease in vineyards, and its management relies on the monitoring of its primary vector, *S. titanus* [6]. *S. titanus* has now been identified in several countries showing a continuous spread [14], with subsequent epidemic FD outbreaks, as reported recently in Northern Italy [15].

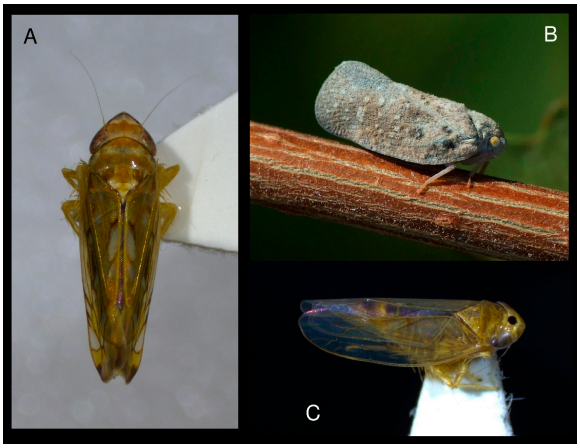


Figure 1. The studied true hopper (Auchenorrhyncha) species. (**A**): Adult *Scaphoideus titanus* Ball. (**B**): Adult *Metcalfa pruinosa* (Say). (**C**): Adult *Phlogotettix cyclops* (Mulsant et Rey).

For adult monitoring, suction sampling and colored sticky traps can be used. However, suction sampling is rather labor-intensive and may collect vast amounts of arthropods and plant material; therefore, considerable sorting is necessary for catch evaluation [16]. Thus, sticky traps may offer a more viable, cost-effective alternative [17], and in order to achieve optimal efficacy, the application of the most attractive color should be favored. As for several other pests, yellow traps are routinely used for the monitoring of *S. titanus* [18], but there are contradictions in relation to its color preference [16,19]. A previous study [20] reported that red traps were significantly more attractive to *S. titanus* than yellow traps. Furthermore, the authors reported remarkable differences in color preference between the sexes, with females showing a much less distinct color preference [20]. Males were more attracted to red than to yellow and white traps, which performed better than blue traps. For females, on the other hand, red traps only performed better than blue traps, and the catches of red, white and yellow traps did not differ significantly from one another [20]. However, a later study did not unambiguously confirm the increased attraction of *S. titanus* to the red color, and also reported a distinct color preference for females in laboratory and field experiments [21]. In laboratory choice experiments, *S. titanus* males preferred yellow over red, whereas females preferred red over yellow [21]. Interestingly, in consecutive field experiments, yellow traps were preferred over red and blue traps by both sexes [21]. In a preliminary report of a field experiment performed in Hungary, the outstanding attraction of *S. titanus* adults to red traps was not confirmed either; however, no sex-specific results were provided [1]. In addition to studies on the color preference of adults, experiments were also performed with the larval/nymphal stages of *S. titanus* [19,22]. A brief overview of previous studies on the color preferences of different sexes and stages of *S. titanus* is presented in Table 1.

Table 1. Color preferences of different sexes and stages of *Scaphoideus titanus* based on literature data (+—tested, no reported preference, ++—preferred relative to one or more alternatives, +++—highest/reported strongest response within the respective study, n.t.—not tested) * in laboratory tests by Mazzoni et al. [21]. Binary comparisons were made, and preference results are thus put in parentheses.

Life Stage	Sex	Method	Yellow	Red	White	Green	Blue	Brown	Reference
adult	male	field trapping	++	+++	++	n.t.	+	n.t.	[20]
adult	male	field trapping	+++	++	n.t.	n.t.	+	n.t.	[21]
adult	male	Y-tube	(+++)	(++)	n.t.	(++)	(+)	n.t.	[21] *
adult	female	field trapping	+	++	+	n.t.	+	n.t.	[20]
adult	female	field trapping	+++	++	n.t.	n.t.	+	n.t.	[21]
adult	female	Y-tube	(++)	(++)	n.t.	(++)	(+)	n.t.	[21] *
larva/nymph	–	choice test	++	+	n.t.	+	n.t.	+	[22]
larva/nymph	–	choice test	+++	+	n.t.	++	+	n.t.	[19]

Metcalfa pruinosa (Say) (Figure 1B) is an invasive planthopper species (Hemiptera: Flatidae) of Nearctic origin, mostly spread by the trade of goods [23]. It has spread to several European countries [24], showing a continuous expansion [25], and has also been found in the Eastern Palaearctic [26]. The species is highly polyphagous and may damage several crops [24]. Besides direct feeding damage, it transmits the aster yellows phytoplasma [27] and the bacterial canker of kiwi [28]. Yellow sticky traps were found to be ineffective for monitoring [29]; nevertheless, to our knowledge, no data are available on its color preference.

Phlogotettix cyclops (Mulsant et Rey) (Figure 1C) is a species of increasing concern as a potential vector of FD, which has been identified from field-collected individuals [30,31]. Although the presence of a pathogen in an insect does not necessarily reflect vector capabilities, the high abundance of the species in infected areas may further suggest its possible

role in spreading the pathogen [5]. This was documented for *P. cyclops* in Austrian vineyards [32]. To our knowledge, the transmission of FD has not been reported for *P. cyclops* so far; however, based on similar observations made previously for another invasive leafhopper species, *Orientus ishidae* (Matsumura), for which the laboratory transmission of FD was documented [33], a potential vector role of *P. cyclops* should not be neglected. Recent studies highlight the potential importance of alternative vectors and host plants in FD phytoplasma epidemics [34]. *P. cyclops* has been present in Europe for a long time and is considered to be invasive [35], undergoing a potential range expansion [36]. It was reported from Hungary at the end of the 19th century (as *Thamnotettix* [37]) and has been known to be present in several European countries for decades [38], which might be the case of a native species becoming invasive [39].

In the current paper, our aim was to study the visual attraction of *S. titanus*, *M. pruinosa* and *P. cyclops* to color traps in the field. We assumed that if a respective species showed color preference, the numbers of attracted individuals should differ among different color traps; if the results indicated a preference among the tested colors, we also investigated sex-specific differences in the attraction of the respective species to the different colors.

2. Materials and Methods

2.1. Colored Traps

For the field experiments, sticky traps of 10 × 16 cm in size, coated with glue (TangleFoot Co., Grand Rapids, MI, USA), were used. The traps had holes near the middle of the upper and lower edges of the sheet in order to facilitate positioning in the canopy with wires. For experiments 1–3 surface-painted color traps were tested. Surface-painted traps were prepared by PáMe Bt. (Pári, Hungary) as follows: 0.2 mm-thick transparent PVC sheets were painted with standard colors including blue, greenish-yellow (often termed 'fluorescent yellow'), green, orange, red, white, and yellow colors and coated with glue. Colors were chosen as follows: yellow traps were chosen as a color routinely used for monitoring purposes [18]; red traps were chosen based on previous results on the increased attraction of *S. titanus* [20]. Greenish-yellow and blue traps were found to perform better than yellow traps in previous studies on Hemiptera and Thysanoptera species [8,40], and white traps were found to perform similarly to yellow traps in a psyllid species [41]. Green traps were chosen as a potential neutral color, and orange traps were tested as a novel stimulus, functioning as a potentially 'intermediate' color between yellow and red traps.

Surface-painted greenish-yellow traps were observed to show color loss after several weeks of field exposure. Thus, in Experiment 4, surface-painted and material-colored yellow and greenish-yellow traps were tested along with transparent traps to assess the potential effects of color loss on catches. Material-colored sticky traps were prepared by PáMe Bt. (Pári, Hungary) from color-impregnated PVC sheets with similar reflectance properties to surface-painted traps (as per the manufacturer), but without any color loss observed. These traps were coated with the same glue (TangleFoot Co., Grand Rapids, MI, USA) as the surface-painted traps. Transparent sticky traps were prepared from 10 × 16 cm sticky liners of CSALOMON RAG delta-sticky traps (Csalomon Kft., Budapest, Hungary) covered with the same glue layer as the colored sticky traps. Transparent sticky traps were fixed in the canopy by punching holes near the middle of the upper and lower edges of the traps, in order to facilitate the same positioning method in the canopy with wires as that used for other traps.

The light reflectance of the sticky traps was measured with a USB2000+ spectrophotometer (Ocean Optics Inc., Orlando, FL, USA) using an R200-7-UV-VIS reflection probe, PX-2 pulsed Xenon lamp, and a WS-1 diffuse reflectance white standard (Ocean Optics Inc., Orlando, FL, USA). Before the measurements, in order to provide a smooth surface,

the excess glue was removed. Measurements were made by choosing five random points on a sticky trap of each color. Reflectance intensity was measured at 0.38 nm wavelength units, and a moving average was calculated for 25 measurement units. Mean values of light reflectance intensity per wavelength were calculated and are presented as percentage intensity as a function of wavelength (Figure 2). The overall reflectance intensity of the traps was also compared (Supplementary Figure S1).

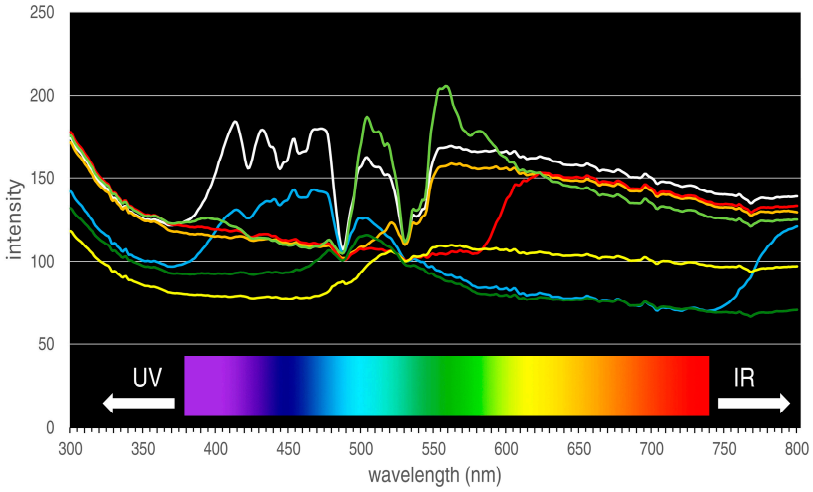


Figure 2. The light reflectance spectra of the colored sticky traps tested in the experiments. Tested standard colors included blue, greenish-yellow (indicated as light green), green (indicated as dark green), orange, red, white, and yellow. The light reflectance of the colored traps was measured with an Ocean Optics USB2000+ spectrophotometer (arrows indicate the ultraviolet (UV) and infrared (IR) regions, respectively).

2.2. Field Experiments

Field experiments were performed at four sites in Hungary; the sites were selected based on previous observations of the high abundance of *M. pruinosa* or *S. titanus*.

Sticky traps of a respective color were set out in pairs, in a vertical position, back-to-back, with the sticky surfaces of the traps facing outwards at the foliage level. Traps were positioned at the foliage level but in positions where the sticky traps were sunlit (Supplementary Figure S2). Catches of back-to back trap pairs were summed. In all experiments, traps were set out in a randomized complete block design, that is, one pair of each color was incorporated into a block in a randomized order, so that individual treatments were 5–8 m apart. The distance between blocks was 10–15 m. To prevent the sticky surfaces from becoming covered with insects or debris, large caught insects and plant debris were removed from the traps during inspection, and the traps were replaced with new ones regularly. As a rule, traps were replaced every 3–4 weeks; however, for Experiment 1, due to the sandy soil and frequent winds at the experimental site, the traps were replaced on a fortnightly basis. To avoid potential positional effects, during trap replacement, new traps were set out in a randomized order within each block.

The details of each experiment are as follows:

Experiment 1 was conducted in an unmanaged vineyard (coordinates: 46°34′44″ N, 19°22′3″ E, cultivar 'Kékfrankos') in the vicinity of Soltvadkert (Bács-Kiskun county, Hungary) with a high abundance of *S. titanus*. Tested colors included blue, greenish-yellow, green, orange, red, white, and yellow. Traps were set out at approximately 1.5–1.8 m in height, at foliage level. The experiment was run from 11 July to 26 September 2012, in ten blocks. A brief preliminary report on the catches of *S. titanus* by different colors based on this experiment was presented previously [1]; however, no data on the sex-

specific attraction of *S. titanus* were provided in that study. Thus, data were reanalyzed in this respect.

Experiment 2 was conducted in a conventionally managed vineyard (coordinates: 46°45′11″ N, 17°40′23″ E, cultivar 'Szürkebarát') in the vicinity of Balatonlelle (Somogy county, Hungary) with a high abundance of *M. pruinosa*. Tested colors included blue, greenish-yellow, green, orange, red, white, and yellow. Traps were set out at approximately 1.5–1.8 m in height, at foliage level. The experiment was run from 18 July to 11 October 2012, in ten blocks.

Experiment 3 was conducted at the edge of an alfalfa field (coordinates: 47°22′37″ N, 18°49′6″ E) in the vicinity of Pusztazámor (Pest county, Hungary) with a high abundance of *M. pruinosa*. Tested colors included blue, greenish-yellow, green, orange, red, white, and yellow. Traps were set out at approximately 0.3–0.5 m in height on wires, at the edge of the field. The experiment was run from 24 August to 11 October 2012, in five blocks.

Experiment 4 was conducted at an organically managed vineyard (coordinates: 47°42′58″ N, 18°47′48″ E) in the vicinity of Kesztölc (Komárom-Esztergom county, Hungary). The vineyard consisted of two neighboring plots featuring two different cultivars (cultivars 'Chardonnay' and 'Grüner Veltliner') under the same management protocol. Surface-painted yellow, surface-painted greenish-yellow, material-colored yellow, material-colored greenish-yellow, and transparent traps were tested. Five blocks were set in each plot. Traps were set out at approximately 1.5–1.8 m in height, at foliage level. Traps were replaced twice during the experiment: on 5 August and 2 September. Besides randomizing trap positions during trap replacement, the traps were also rotated on a fortnightly basis. The experiment was run from 15 July to 30 September 2022.

For all experiments, the traps were inspected on a weekly basis, and the captured insects were gently removed from the sticky traps with fine forceps and placed into paper envelopes labeled with the collection date, treatment, and block code. The collected material was taken to the laboratory, where the insects were sexed and identified to the species level under a stereomicroscope based on the relevant taxonomic works [42–44].

2.3. Statistics

From the catch data, inspections with no or very low catches, accounting for less than 5% of the total catches of a given species in the respective experiment, were excluded from the analysis. The data were tested for normality using the Shapiro–Wilk test. Since the experimental data were not normally distributed, the catch data were analyzed using the Kruskal–Wallis test, and the differences between treatments were evaluated using a pairwise Wilcoxon test with Benjamini–Hochberg correction. If the catches of a respective species differed between treatments, the analysis was also performed for each sex separately. As relatively few *P. cyclops* females were caught, the catches of individual treatments were checked to determine whether they differed significantly from zero using a Wilcoxon test ($p = 0.05$). Statistical procedures were conducted using the software R, version 4.3.2 [45].

3. Results

3.1. Visual Attraction of Scaphoideus titanus to Color Traps

In Experiment 1, a total of 1088 *S. titanus* adults were caught; the treatments differed significantly (Kruskal–Wallis chi-squared = 45.361, $p < 0.0001$). Both males and females were caught; however, the catches were strongly male-biased (female ratio 23.6%).

The catches of different colors differed significantly for both sexes. Greenish-yellow, orange and yellow traps caught significantly more *S. titanus* males than all other treatments, among which white traps caught more than green ones, the catches of which did not differ

from those of blue and red traps. Catches of greenish-yellow, orange, and yellow traps did not differ significantly (Figure 3A).

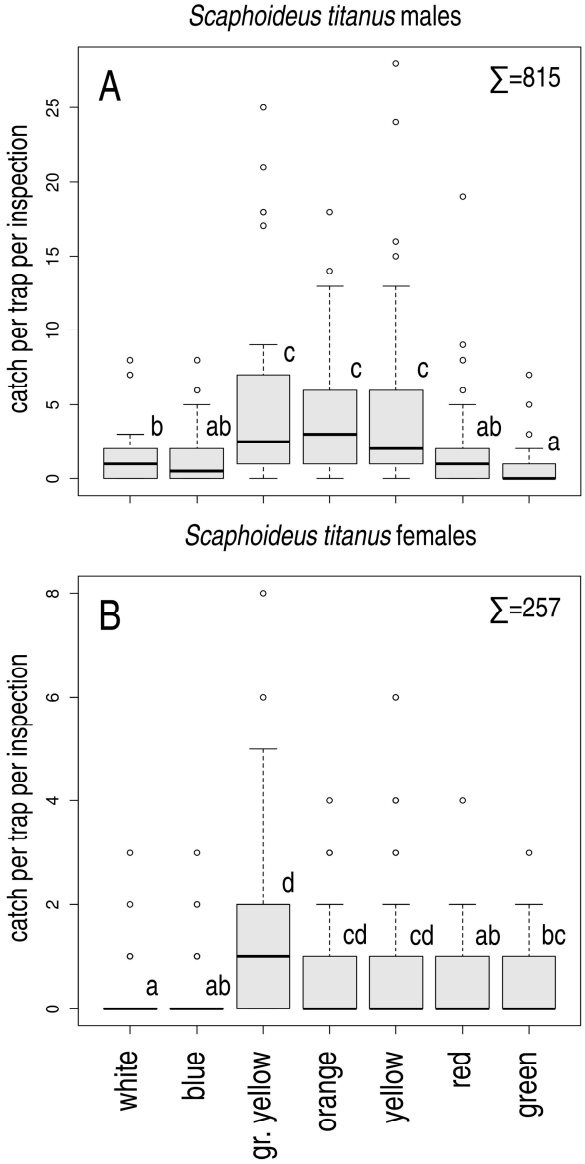


Figure 3. Catches of *Scaphoideus titanus* males (**A**) and females (**B**) on colored sticky traps (Experiment 1). Treatments marked with the same letter are not significantly different (Kruskal–Wallis test, pairwise comparison by a Wilcoxon test with Benjamini–Hochberg correction at $p = 0.05$). $\sum$ indicates the total catches of the respective sex in the experiment (gr. yellow: greenish-yellow).

For females, yellow and orange traps caught more individuals than red, blue, and white traps. Greenish-yellow traps caught more females than all other treatments, except for the yellow and orange traps, from which catches did not differ significantly (Figure 3B).

3.2. Visual Attraction of Metcalfa pruinosa to Color Traps

Metcalfa pruinosa was caught in sufficient numbers for statistical evaluation in Experiments 2 and 3. In Experiment 2, altogether, 183 *M. pruinosa* adults were caught, both males and females (female ratio 42.1%); however, the treatments did not differ significantly (Kruskal–Wallis chi-squared = 9.4661, $p = 0.149$).

In Experiment 3, a total of 126 *M. pruinosa* adults were caught, both males and females (female ratio 46.8%); however, the treatments did not differ significantly (Kruskal–Wallis chi-squared = 8.5541, $p = 0.2003$, Figure 4A).

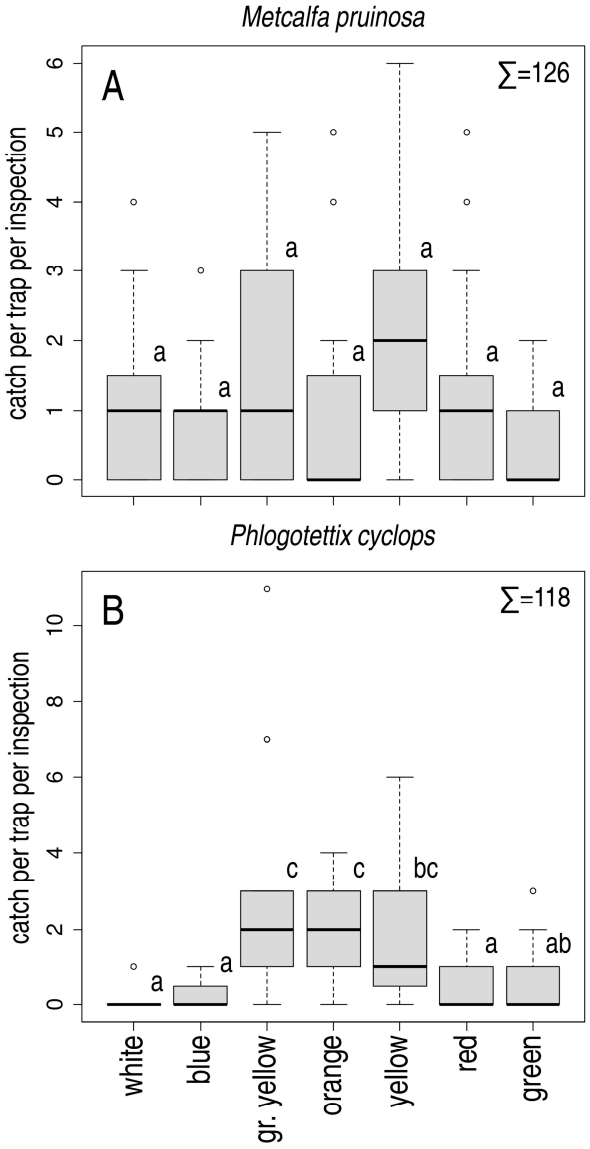


Figure 4. (**A**): Catches of *Metcalfa pruinosa* on colored sticky traps (Experiment 3). (**B**): Catches of *Phlogotettix cyclops* on colored sticky traps (Experiment 3). Treatments marked with the same letter are not significantly different (Kruskal–Wallis test, pairwise comparison by Wilcoxon test with Benjamini–Hochberg correction at $p = 0.05$). ∑ indicates the total catches of the respective species in the experiment (gr. yellow: greenish-yellow).

3.3. Visual Attraction of *Phlogotettix cyclops* to Color Traps

Phlogotettix cyclops adults were caught in sufficient numbers (118 individuals) for statistical evaluation in Experiment 3; the treatments differed significantly (Kruskal–Wallis chi-squared = 38.417, $p < 0.0001$), and the catches were male-biased (female ratio 30.5%). Yellow traps caught significantly more individuals than white, blue, and red traps, and greenish-yellow and orange traps caught significantly more than all other treatments, except for yellow. The catches of greenish-yellow, orange, and yellow traps did not differ significantly (Figure 4B).

For the males, yellow traps caught more than white traps, orange traps caught more than blue and white traps, and greenish-yellow traps caught more individuals than all other treatments except for orange and yellow (Figure 5A). Only greenish-yellow, orange, and yellow traps caught significantly more *P. cyclops* males than white traps, which did not catch any individuals.

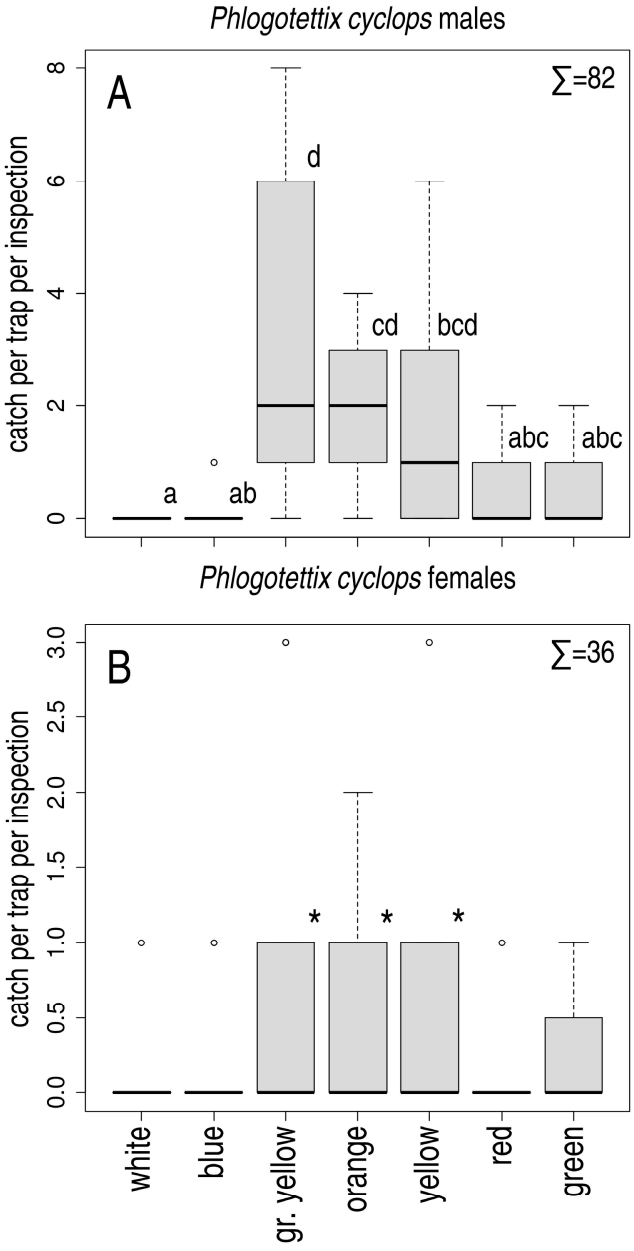


Figure 5. Catches of *Phlogotettix cyclops* males (**A**) and females (**B**) on colored sticky traps (Experiment 3). Male catches of treatments marked with the same letter in (**A**) are not significantly different (Kruskal–Wallis test, pairwise comparison by a Wilcoxon test with Benjamini–Hochberg correction at $p = 0.05$); female catches of treatments marked with an asterisk in (**B**) are significantly different from zero (Wilcoxon test at $p = 0.05$). $\sum$ indicates the total catches of the respective sex in the experiment (gr. yellow: greenish-yellow).

Relatively few females were caught in the experiment; however, the treatments differed significantly (Kruskal–Wallis chi-squared = 14.162, $p = 0.028$). Greenish-yellow, orange and yellow traps tended to catch more individuals than the other treatments, and only the catches of these treatments were significantly different from zero (Figure 5B).

3.4. Differences Between Surface-Painted, Material-Colored, and Transparent Traps

In Experiment 4, all three species were caught; however, only *S. titanus* was captured in sufficient numbers for statistical evaluation. A total of 230 *S. titanus* adults were caught; the treatments differed significantly (Kruskal–Wallis chi-squared = 42.084, $p < 0.0001$). Both males and females were caught, but the catches were male-biased (female ratio 39.3%).

No significant differences were found between the catches of surface-painted and material-colored yellow traps, whereas material-colored greenish-yellow traps caught significantly more *S. titanus* adults than the surface-painted ones (Table 2). Material-colored greenish-yellow traps caught significantly more individuals than the other treatments, which did not differ significantly for the females and total catches. For the males, the catches of material-colored greenish-yellow traps were the highest and transparent traps caught significantly more than surface-painted greenish-yellow traps, the catches of which did not differ from material-colored and surface-painted yellow traps (Table 2).

Table 2. Mean catches of *Scaphoideus titanus* per trap per inspection on yellow, greenish-yellow, and transparent sticky traps (Exp. 4). Colored traps were tested as surface-painted and material-colored traps. Treatments marked with the same letter within one column are not significantly different (Kruskal–Wallis test, pairwise comparison by Wilcoxon test with Benjamini–Hochberg correction at $p = 0.05$).

	Scaphoideus titanus		
Treatment	**Males (Mean ± SE)**	**Females (Mean ± SE)**	**Total Catch (Mean ± SE)**
surface-painted yellow	0.13 ± 0.05 ab	0.22 ± 0.06 a	0.43 ± 0.09 a
material-colored yellow	0.18 ± 0.07 ab	0.22 ± 0.06 a	0.43 ± 0.1 a
surface-painted greenish-yellow	0.07 ± 0.03 a	0.1 ± 0.05 a	0.3 ± 0.09 a
material-colored greenish-yellow	1.27 ± 0.24 c	0.5 ± 0.09 b	1.8 ± 0.27 b
transparent traps	0.28 ± 0.07 b	0.17 ± 0.06 a	0.6 ± 0.16 a

More *S. titanus* were caught in cultivar 'Chardonnay' than in 'Grüner Veltliner'. The difference was significant for the males (Wilcoxon W = 13,309, $p < 0.001$), the females (Wilcoxon W = 12,418, $p = 0.0227$) and the total catches (Wilcoxon W = 14,074, $p < 0.001$).

4. Discussion

We found distinct differences in the attraction to color traps in *S. titanus* and *P. cyclops*; however, no such difference was found in *M. pruinosa*. For *S. titanus*, a preference of both sexes for greenish-yellow, orange, and yellow traps was found. Our results did not confirm previous reports on the increased preference of *S. titanus* adults for red compared to yellow [20]; instead, our results are in line with previous results indicating a higher preference for yellow than for red traps [21]. The ability to see red colors is a very rare trait in insects and is not known in the order Hemiptera [46]. The differences in perceived wavelengths in insect vision highlight the importance of analyzing light reflectance spectra in color preference [47]. Thus, the similarities or differences reported in color preferences could also be due to differences in the specific trap colors used. According to the brief description of the dominant wavelength components of the colors tested for *S. titanus* adults [20,21], the respective colors used in the current experiments were possibly more similar to those used by Mazzoni et al. [21]; however, based on the data provided, a detailed comparison of the reflectance spectra of the traps used was not possible.

The results of previous field experiments [20] indicate considerable sex-specific differences in the color preference of *S. titanus*, with a high prevalence of males and a less pronounced preference in females. Nevertheless, other experiments found a distinct color

preference in both males and females, without a remarkable male bias in the catches [21]. In the current experiments, the catches of *S. titanus* were male-biased, and both sexes showed clear color preferences. Males had a preference for greenish-yellow, orange, and yellow traps, which attracted significantly more individuals than other colors, including red. The catches of females showed similar tendencies, with greenish-yellow, orange, and yellow traps being the most attractive. Possibly due to the lower catches, the differences among the treatments were less pronounced. In summary, colors are important stimuli for both male and female *S. titanus*. This is promising for the development of monitoring methods, since the number of females provides valuable information on population dynamics. Furthermore, since males have higher transmission rates [16], their numbers are also important from the perspective of FD epidemics. According to the observations of previous studies, *S. titanus* shows a distinct preference between different grapevine cultivars [16]. The results of the current study are in accordance with these findings, as significantly more *S. titanus* individuals were caught on the cultivar 'Chardonnay' than on 'Grüner Veltliner' in neighboring plots despite the same sampling effort.

In the current study, *P. cyclops* showed a distinct color preference for greenish-yellow, orange, and yellow traps, with both males and females showing similar tendencies. In the case of the males, greenish-yellow traps performed the best, with catches not being significantly different from those of orange and yellow traps. For the females, the catches of only greenish-yellow, orange, and yellow traps were significantly different from zero. To our knowledge, this is the first report on the color preference of *P. cyclops*.

The higher ratios of male *S. titanus* and *P. cyclops* catches do not necessarily result from sex-specific differences in color preferences; this could possibly reflect the higher mobility of males [20]. The higher mobility of *S. titanus* males poses further epidemiological risks, as males have higher transmission rates, and the proportion of phytoplasma-infected males in vineyards is higher than that of females [16]. In summary, both sexes of *S. titanus* and *P. cyclops* showed similar preferences for greenish-yellow, orange, and yellow sticky traps, which could prove to be valuable in the development of novel methods for their detection and monitoring. The application of appropriate methods for monitoring is essential for the effective management of pests, including invasive species [4]. The advantage of greenish-yellow traps is that they are also highly attractive to the vine thrips, *Drepanothrips reuteri* Uzel [40]. As was pointed out by Bocca et al. [48], the monitoring of *S. titanus* may also be important in the late season, as the species can pose risks during this period. Although the current study focused on the color preference of the target invasive pest species, the attraction of non-target species to color traps is an important aspect of monitoring that should be considered in the development of novel monitoring methods.

We also compared colored sticky sheets prepared with different technologies (Exp. 4). As surface-painted greenish-yellow traps showed a variable degree of color loss after several weeks of field exposure, material-colored traps were compared with surface painted ones. Material-colored greenish-yellow traps caught significantly more *S. titanus* than the surface-painted ones; however, no such difference was found between material-colored and surface-painted yellow traps, where such color loss was not observed. These results indicate that the color loss detected may have significantly affected the attraction of *S. titanus* adults. Material-colored greenish-yellow sheets were found to perform well in the case of other insect pests as well [49]. Another interesting finding of the current study is that the transparent traps showed a similar performance to the yellow traps for *S. titanus*, which have been found to be attractive in several previous studies and also in the current experiments. Nevertheless, it is important to note that transparent traps should not be considered a blank control; instead, as they were positioned in the foliage, they possibly served as an imitation of a complex background—in this case, grapevine foliage. Thus, the imitation of a

complex natural background performed similarly to a homogenous surface of a generally known attractive color. This may suggest that heterogenous patterns mimicking foliage in combination with an attractive color may result in increased attraction, but this hypothesis should be tested in further experiments.

Previous studies reported the inefficiency of yellow traps for monitoring *M. pruinosa* [29]; however, other colors have been found to be more attractive than yellow for certain insect species [8]. In the present study, we did not find a preference of *M. pruinosa* for any of the seven colors tested. The difference in color preferences between the studied species is somewhat unexpected. All three species are phloem-feeders and there are partial overlaps in their host spectra; for instance, all three species have been observed feeding on grapevine. In our tests, *S. titanus* and *P. cyclops* were attracted to yellowish colors, that is, yellow, greenish-yellow, and orange. The latter was tested as a potential 'intermediate' color between yellow and red; however, no preference was found for *M. pruinosa*. Yellowish colors are thought to be attractive by indicating fresh, young leaves with a higher nitrogen content [47]. Thus, a potential explanation for our observations could be that while *S. titanus* and *P. cyclops* feed on leaves [16,35], *M. pruinosa* feeds on various plant parts and is often observed feeding on plant stems and twigs [25]; consequently, leaf colors may be of lesser value in its foraging. Therefore, since the current results could not detect a color preference, it seems likely that instead of colors, other stimuli, such as chemical stimuli, may play a key role in the host-seeking of *M. pruinosa*. This hypothesis regarding the potential importance of semiochemicals is supported by a recent study reporting electroantennographic responses of *M. pruinosa* to plant volatiles [50].

5. Conclusions

The results of the current study did not confirm an increased attraction of *S. titanus* adults to red; however, greenish-yellow, orange, and yellow traps attracted more individuals than red traps in our experiments, indicating their potential for monitoring this important pest. Both males and females were attracted, which is advantageous for monitoring their population dynamics. Greenish-yellow, orange, and yellow traps also attracted both sexes of *P. cyclops*, a potential vector species. To our knowledge, this is the first report on the color preference of this species. On the other hand, no significant color preference was detected under the conditions of the current experiments for *M. pruinosa*, indicating that other, yet unknown stimuli may be important in the host-seeking of this important, invasive pest.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/biology15222060/s1, Figure S1: The reflectance intensity of the colored sticky traps tested in the experiments; Figure S2: Yellow sticky trap positioned in the foliage.

Author Contributions: S.K. and M.T. conceptualized and designed the experiments. Z.G. and S.K. performed and analyzed light reflectance measurements of traps. S.K. and J.K.J. managed the field experiments. S.K. determined the collected individuals. All authors have read and agreed to the published version of the manuscript.

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