Journal of Pest Science
https://doi.org/10.1007/s10340-024-01752-7

ORIGINAL PAPER

Blue LED trap and commercial lure improve western flower thrips (*Frankliniella occidentalis*) monitoring in cucumber crops

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Received: 19 September 2023 / Revised: 31 December 2023 / Accepted: 19 January 2024

Abstract
Blue sticky traps contribute substantially to monitoring the western flower thrips, *Frankliniella occidentalis* Pergande (Thysanoptera: Thripidae), in greenhouses. Although sticky traps can detect the initial presence of thrips reliably, an estimation of the actual thrips density in the crop by counting number of thrips on the traps is often not accurate. To overcome this issue, we compared blue sticky traps and newly developed sticky LED-enlightened traps in combination with the commercial thrips kairomone Lurem-TR under commercial growing conditions. Therefore, an experiment was conducted in cucumber, *Cucumis sativus* L. (Cucurbitaceae), crop stands in greenhouse cabins investigating the correlation between thrips caught on (LED) traps and the thrips density in the crop for an accurate and reliable thrips monitoring. Additionally, experiments aiming to understand underlying mechanisms of thrips orientation towards traps in different scenarios were conducted under controlled conditions. Results show that thrips catches on sticky LED enlightened coloured traps correlated strongly positive with number of thrips in the crop, especially at low thrips population densities. Adding Lurem to this trap type further improved accuracy of the correlation in the greenhouse cabin experiment. Moreover, LED traps with and without Lurem were more attractive towards thrips in small follow-up experiments compared to standard blue sticky traps. The results are discussed in the context of general orientation of thrips and its behaviour towards visual and olfactory cues when considering different scenarios. Our study shows the successful integration of blue LEDs into an existing trapping system and underlines the advantages compared with standard sticky plates. In conclusion, sticky LED enlightened coloured traps have a potential as an improved thrips monitoring device that might improve pest management decisions.

Keywords Light emitting diode · Insect behaviour · Insect detection · Blue sticky traps · Integrated pest management · Mass trapping · Greenhouse

Key message

- First examination of combining blue LED traps and Lurem-TR for thrips density monitoring in a crop
- Number of thrips caught on LED traps correlates strongly positive with thrips density in the crop
- Lurem-TR further increased accuracy of this correlation in combination with LED traps
- LED traps were much more attractive than blue sticky traps under variable conditions
- Visual rather than olfactory orientation plays a key role for thrips monitoring at short distances

Communicated by Don Weber.

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Introduction

Insect monitoring in the greenhouse has been achieved by using sticky traps for many decades, as it is essential for integrated pest management (IPM). In practice, pest insects, such as aphids (von Moericke 1952; Dieckhoff and Meyhöfer 2023) and whiteflies (Gillespie and Quiring 1987),

Published online: 20 February 2024

are monitored by yellow sticky traps, while blue sticky traps (BSTs) are commonly used for detecting the western flower thrips (WFT), *Frankliniella occidentalis* Pergande (Thysanoptera: Thripidae) (van Tol et al. 2021). Besides detecting the presence of pest insects or beneficials by sticky traps, insect counts can also correlate with the actual insect density present in the crop (Higgins 1992; Muvea et al. 2014; Böckmann et al. 2015; Grupe et al. 2023). This allows integration of action thresholds against pest insects in decision support systems, indication of success of plant protection measures and even indirect monitoring of sessile pests on crops (Böckmann et al. 2015; Grupe et al. 2023). Based on this information, pest management decisions can be improved (Böckmann et al. 2015) and accelerated (Pizzol et al. 2010). Acceleration of pest management decision by using sticky traps is of primary importance for growers, as monitoring on plants is extremely labour intensive (Beers 2012). However, correlations between insects on traps and plants are not always given or reliable (Steiner et al. 1999; Steiner and Goodwin 2005; Broughton and Harrison 2012; Dieckhoff and Meyhöfer 2023). In the last two decades though, insect orientation and monitoring by using enhanced visual cues, such as LED traps (Chu et al. 2003, 2004; McCormack 2015; Stukenberg et al. 2015, 2018, 2020; Otieno et al. 2018; Lopez-Reyes et al. 2022) and attractive olfactory cues, such as *p*-anisaldehyde (Teulon et al. 1993; Koschier et al. 2000; Mainali and Lim 2011; Ren et al. 2020) or methylisonicotinate (MI; Active ingredient of Lurem-TR; Further referred to as "Lurem") (Davidson et al. 2007; Teulon et al. 2007b; Liang et al. 2010; Broughton and Harrison 2012; Muvea et al. 2014; Nielsen et al. 2016; Koschier et al. 2017; Otieno et al. 2018) has been studied. These studies reported (strongly) increased thrips catches by using LED traps and/or semiochemicals. However, studies combining MI and LED traps to detect the WFT are scarce or even missing in case of testing concepts in crop stands. Moreover, no study examined if the combination of MI (Lurem) and a blue LED trap has advantages for decision-making in plant protection compared to standard monitoring. Instead of only catching more thrips with LED traps, earlier detection of WFT on the crop or improved correlations of WFT present on traps and on plants would be an important advantage in practice. Therefore, we investigated the attractiveness of a BST and blue sticky LED–enlightened trap (further referred to as "LED trap") towards WFT in cucumber crops in greenhouse cabins with or without Lurem (MI), respectively. The aim of the study was to characterise the advantages of LED monitoring, i.e. to find out if the combined use of LED traps and Lurem improves monitoring of the WFT and enables predictions more robust and reliable compared to standard monitoring with blue sticky traps. Finally, several experiments under controlled conditions were conducted for a better understanding of the underlying behavioural mechanism, which might help in the future to optimise and automatize monitoring and decision-making in plant protection.

Material and methods

LED traps

For the experiments, traps with eight blue (465 nm) LEDs (NCSB219B-V1 SMD; Nichia Corporation; Anan, Japan) were constructed based on the LED traps used by (Stukenberg 2018) for monitoring the greenhouse whitefly (*Trialeurodes vaporariorum*) (Fig. 1).

A blue coloured plate (size: 11.5 × 16 cm, IVOG biotechnical systems GmbH; Neusäß Vogelsang, Germany) was integrated in the LED trap. Thereby, the coloured plate was enlightened by the blue LEDs to intensify the brightness of the reflection of the trap. This 11.5 × 16 cm big rectangular served as the trapping area by covering it with a plastic sheet covered with insect glue (Insektenleim; Temmen GmbH; Hattersheim-Edersheim, Germany). In case of the standard BSTs, the BSTs (IVOG biotechnical systems GmbH; Neusäß Vogelsang, Germany) were cut into the same size as the LED trap (11.5 × 16 cm) and attached to a dummy LED trap, which was permanently switched off. All LED traps were set to the same light intensity (0.5 µmol/$m^{-2} \times s^{-1}$, measured at a distance of 1 m), using a LED driver (350 mA; LCM-40, MEAN WELL; New Taipei City, Taiwan). Light intensity was measured prior the experiment in complete darkness with a light meter (LI 250 with Quantum Sensor LI-190; LI-COR Biosciences GmbH; Bad Homburg, Germany). Light spectrum of LED traps and BSTs was measured in the greenhouse using a spectrometer (AvaSpec-2048-2;

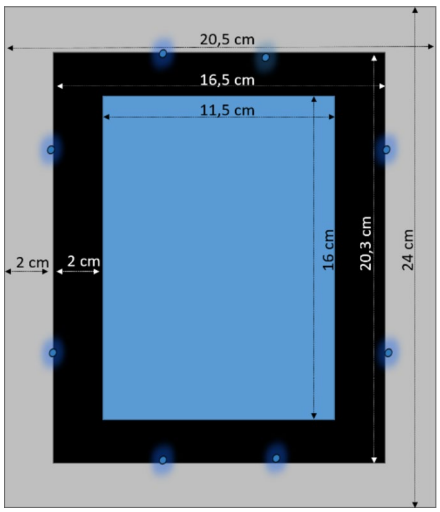

Fig. 1 Schematic of the LED trap equipped with eight blue LEDs (465 nm) that were used in the experiments

Avantes; Apeldoorn, The Netherlands) in combination with the software (AvaSoft 8.9.3.0; Avantes; Apeldoorn, The Netherlands) (Fig. 2).

Insect materials and handling

Frankliniella occidentalis Pergande (Thysanoptera: Thripidae) was transferred from the stock rearing on bean plants (*Phaseolus vulgaris*) at Leibniz Universität Hannover, Germany to cucumber plants (*Cucumis sativus*), cultivar "Cumlaude Bio" (Rijk Zwaan Netherlands B.V.; De Lier, The Netherlands). The WFT were reared on cucumber for at least three generations in custom made wooden cages (approx. 30 × 30 × 40 cm) in a 23 °C climate room before use in any experiment. For collecting WFT from the rearing, a plastic box was held below the plant while tapping the leaves. The plastic box containing the thrips was placed on ice cubes to reduce WFT activity. Western flower thrips were transferred from the box into a glass vial (25 ml; Carl Roth GmbH & Co. KG; Karlsruhe, Germany) using a fine brush (Size: 0; LAT—Labor- und Analysen-Technik GmbH; Garbsen, Germany) for experimental use.

Plant materials

Cucumber seeds, variety "Cumlaude Bio" (Rijk Zwaan Netherlands B.V.; De Lier, The Netherlands) were individually sown in plastic pots (13 cm diameter), containing standard soil substrate (Substrat 1; Klasmann-Deilmann GmbH; Geeste, Germany) for growing. Plants were kept and watered daily in the plant nursery greenhouse at approximately 23 °C without using pesticides or beneficial insects. Plants were taken for the experiments when five to six leaves were present. For data collection during experiments, plants were cut and placed in a plastic bag (MicroSnap-Beutel; Semanedi AG; Ostermundigen, Switzerland) after each experimental repetition. Bags were stored in a freezer at -18 °C for at least 24 h and insects on the plants were counted using a microscope (M26; Leica Camera AG; Wetzlar, Germany).

Experimental setup

Overview. In total, four experiments were conducted in greenhouse cabins to investigate the behaviour of WFT towards visual and olfactory cues under laboratory and semi-greenhouse conditions. Therefore, different trap types, that is LED trap and BST with and without additional Lurem, were investigated in a cucumber crop stand (Experiment 1) for monitoring of WFT and under more standardized conditions (Experiment 2–4). Data loggers (HOBO Pendant®; Onset Computer Corporation; Bourne, MA, USA) were used to monitor the temperature and ambient light (see Fig. A-1 to A-4) during all experiments.

Experiment 1—Thrips monitoring with blue LED traps, BSTs and Lurem in cucumber greenhouse crops. The aim of exp. 1 was to test the advantage of using an LED trap compared to a common sticky trap in practice, as well as a possible effect of Lurem on thrips monitoring. Therefore, two plantings were realized in a greenhouse in 2022. The first planting was grown from February to March (calendar week 7–14) followed by the second planting from April to May (calendar week 16–22). Two greenhouse cabins (63 m^2; 9 × 7 m) were used at the same time. Eighty cucumber plants were transplanted into 10 L containers (31st of January 2022, calendar week 6) filled with standard soil substrate (Substrat 1; Klasmann-Deilmann GmbH; Geeste, Germany) and approximately 50 g of long-term fertilizer (Neudorff Azet® Tomato Fertilizer; W. Neudorff GmbH KG; Emmerthal, Germany). Containers were transferred into the greenhouse cabins (40 containers per cabin) and set up in two double-rows with ten plants per row (Fig. 3).

In accordance with standard horticultural practice, each cucumber plant was grown to a total height of 2.2 m. Plants were watered daily by an automatic dripping system (Gardena "Flexcontrol"; GARDENA GmbH; Ulm, Germany)

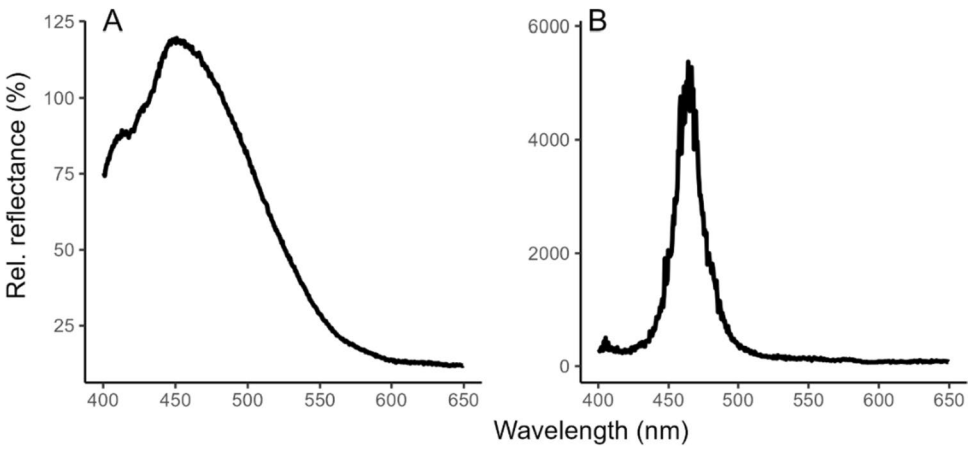

Fig. 2 Measured light spectrum reflected/emitted by the BST **A** and LED trap **B**. Data are based on reflectance relatively to the white reference

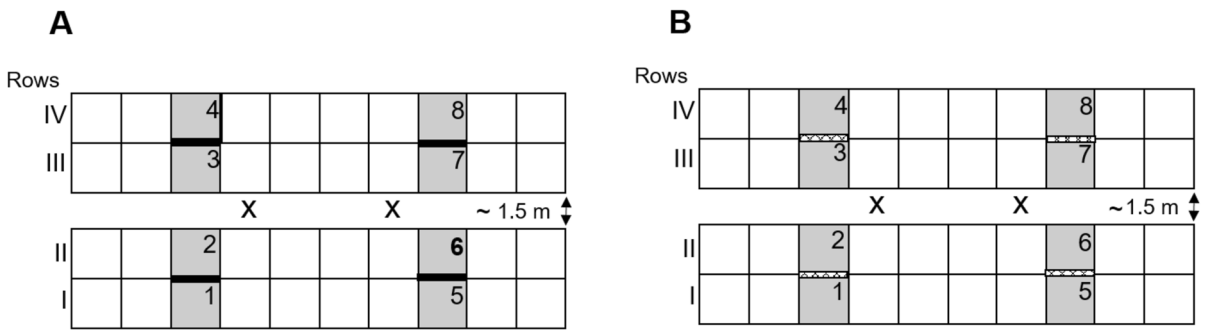

Fig. 3 Schematic of the experimental setup in the two greenhouse cabins with Lurem **B** and without Lurem **A** for the two plantings. Cabin with Lurem was changed from **B** to **A** between the two repeated planting blocks. Squares represent individual cucumber plants set up in two double-rows (I, II and III, IV). X mark the release point of *F. occidentalis* at start of the experiment. Grey fields (1–8) mark the eight sampling plants. The bold lines **A** mark the location of the four traps (LED or BST). Trap one was placed between plant 1 and 2, trap two between plant 3 and 4, trap three between plant 5 and 6 and trap four between plant 7 and 8, respectively. The latticed lines **B** mark the location of the four traps with additional Lurem attached

and manually fertilized (Wuxal® Top N; AGLUKON Spezialdünger GmbH & Co. KG; Düsseldorf, Germany) once per week. During both plantings, fertilizing started two weeks after setting up plants in the greenhouse cabins (first planting: calendar week 8, second planting: calendar week 17). Side shoots and fruits up to the sixth node from the bottom up were removed. Above the sixth node, every third fruit was retained and every side shoot removed until the height of 2.2 m was reached. At 2.2 m, the main shoot was cut off and two side shoots were allowed to grow downwards. During the plant care, plants were also checked for other pest (e.g. spider mites) and diseases (e.g. powdery mildew), but no beneficial insects or pesticides were used.

As initial population 40 WFT, both males (8) and females (32) were released in the middle of each cabin at 9 am on the 4th February 2022 (calendar week 6, first planting) and on the 8th April 2022 (calendar week 15, second planting), respectively. Insect populations were monitored on a weekly basis throughout both plantings, starting in calendar week 7 (9th February) and 16 (13th April), respectively. In total, eight plants per cabin and date were evaluated (Fig. 3). Each sampling plant was sampled in a non-destructive manner. Therefore, plants were visually divided into three equally sized sections (upper, middle and lower section). In each section, three leaves were randomly selected for insect counting (nine leaves per plant in total). Adults and larvae of WFT were counted on both sides of the leaves (abaxial and adaxial side).

Additionally, four traps per cabin were installed on the 9th of February (calendar week 7, first planting) and the 8th April 2022 (calendar week 15, second planting), respectively, to monitor the flying adult WFT. Therefore, two blue LED traps and two BSTs were placed in each cabin within the double-rows next to the sampling plants. All four traps were facing in the same direction, completely randomized every week and adjusted to the height of the plant canopy to a maximum height of 2.2 m. The sticky plastic sheet on the LED traps and the BSTs were removed weekly just before starting insect counting on plants. Number of male and female WFT on the traps were counted in the laboratory under a stereo microscope (Leica M26; Leica Camera AG; Wetzlar, Germany). New BSTs and sticky plastic sheets were installed after finishing insect counting on plants.

During the first planting, Lurem was installed in cabin-2 on the 9th February 2022 by attaching the dispenser with a wire to the LED trap and BST, respectively, while cabin-1 served as control without Lurem. During the second planting, Lurem was installed in cabin-1 on the 14th April 2022 with cabin-2 serving as control without Lurem. To reduce Lurem impact from the one to the other cabin through open windows, another empty greenhouse cabin was located in between cabin-1 and cabin-2, during both plantings. The release of Lurem was monitored by weighting (MXX-412, range: 0.01–410 g; Denver Instrument GmbH; Göttingen, Germany) the lure-dispensers in the laboratory before installing and after removing them from the greenhouse cabin. The average amount of MI released per dispenser was 0.48 ± 0.09 g per week and 0.52 ± 0.11 g per week in the first and second planting, respectively. During the first planting, average temperature in cabin-1 was 25.55 ± 4.11 °C and 24.67 ± 3.28 °C in cabin-2, respectively. During the second planting, temperatures in cabin-1 were 27.49 ± 4.04 °C on average and 26.41 ± 3.82 °C in cabin-2. After the first planting, all greenhouse cabins and equipment were cleaned and sanitized using MennoFlorades (MENNO; Chemie-Vertrieb GmbH; Norderstedt, Germany).

Experiment 2—Attractiveness of traps at different times of the day (no-choice). The second experiment was conducted to investigate the attractiveness of the different trap types in combination with Lurem in a standardised no-choice-setup

without host plants involved. Moreover, daily pattern of WFT attraction to these traps were examined to find out if reducing monitoring efforts to specific daily periods is possible. Two greenhouse cabins were used at the same time for experiments. Lurem was used in one of the cabins and cabins were alternated daily. Two thrips-proof gauze tents (h × l × w: 1.9 × 1.8 × 1.2 m) were installed in each greenhouse cabin (four tents in total) and replaced after each run. A black plastic shield (2 × 2 m) was installed between the tents to avoid light interference between the traps. In each gauze tent, one LED trap or BST (randomized) was placed on a plateau in a height of one metre. Additionally, one Lurem dispenser was attached to each of the two traps using a clothespin. Twenty WFT (10 males and 10 females) were released per run at a distance of one metre from the trap. The experiment was replicated eight times on eight days in June 2022 (8th–10th/14th–18th) at three different daytimes: morning (8–10 am), noon (11 am–1 pm) and afternoon (2–4 pm). The Lurem dispensers were removed and weighed after the third run on each day.

Experiment 3—Attractiveness of traps towards WFT settled on a host plant (choice). The third experiment should reveal a better understanding of the behaviour of recently settled thrips at low population density towards LED traps and BSTs. Two greenhouse cabins were used for the experiment at the same time. As in experiment 1 and 2, Lurem was used in one of the cabins by attaching it to the trap. Four gauze tents were installed per cabin and each equipped with a cucumber plant. Twenty WFT were released from a glass vial directly to the plant at day one at 8 am. Eight hours later the LED trap or BST were placed directly opposite to the host plant in a distance of one metre. Two LED traps and two BSTs were used in each cabin and completely randomized after each run. Each run lasted 24 h from the point the trap was introduced into the gauze tents. The experiment was conducted six times in September 2022 (12th; 14th; 19th; 21st; 23rd and 26th) resulting in 12 replications. The Lurem-dispenser was removed and weighted after each run.

Experiment 4—Preference of WFT for monitoring traps or host plant (choice). The fourth experiment should reveal a better understanding of the behaviour of flying thrips at low population density towards LED traps and BSTs. Four gauze tents were installed in a greenhouse cabin. Two of the four tents were each equipped with a LED trap or BST and a cucumber plant. Trap and host plant (1 m apart) were placed opposite to the release point of thrips at a distance of one metre. Trap and plant positions were interchanged after two days. Placement of trap types (LED/BST) was completely randomized. The experiment was conducted two times per day (9–11 am and 1.30–3.30 pm) on three days in October 2022 (17th–19th) resulting in 12 replications. Twenty WFT were released per run and counted on the plant and trap after two hours, respectively.

Statistical analysis

Data analysis was done in R Studio (Version 4.1.3, RStudio Inc. R Core Team 2022). Linear regression models (LM, R-package: "lme4") were performed to analyse the correlation between number of thrips on the plant and number of thrips on sticky traps. All traps were considered individually and treated as technical, i.e. independent replicates. Number of thrips on the traps were used as the dependent variable and mean number of thrips per plant as the explanatory variable. Kruskal–Wallis Test followed by Dunn´s Test of multiple comparison was performed to compare number of caught thrips by the different treatments, that is BST—(+)Lurem, BST—(−)Lurem, LED—(+)Lurem and LED—(−)Lurem. For the (no-) choice experiments, generalized linear model (GLM, R-package: "lme4") was fitted to the data, assuming quasi-binomial distribution. Thrips on the traps (and plants in experiment 3 and 4) were used as the dependent variable and daytime (experiment 2) and trap type (experiments 2, 3 and 4) were used as explanatory variable. Models were selected by performing an analysis of variance (ANOVA) with F-Test on the model and analysis of goodness-of-fit using the hnp-function (R-package: "hnp") (Moral et al. 2017). The emmeans-function was used for pairwise comparison of the treatments (R-package: "emmeans").

Results

Thrips monitoring with blue LED traps, BSTs and Lurem in cucumber greenhouse crops (Exp. 1)

In general, western flower thrips population density on cucumber plants was similar in both cabins during the first ($p = 0.624$) and second ($p = 0.990$) planting, respectively. However, number of WFT differed significantly between plantings ($p < 0.001$).

In the first planting, correlation analysis revealed a significant correlation between WFT on all trap types in combination with and without Lurem. The strongest correlation was found between WFT on the plants and LED—(+)Lurem ($R^2 = 0.877$, $p < 0.001$), followed by the WFT caught on BST—(+)Lurem ($R^2 = 0.869$, $p < 0.001$), LED—(−)Lurem ($R^2 = 0.657$, $p < 0.001$) and BST—(−)Lurem ($R^2 = 0.603$, $p = 0.002$) (Fig. 4A, Table. A-1).

Most WFT were caught by LED—(+)Lurem (41.9 ± 12.5 mean ± SE) followed by LED—(−)Lurem (21.4 ± 8.9 mean ± SE) (Fig. 5A). Blue sticky trap (+)Lurem (3.2 ± 3.5 mean ± SE) caught significantly less WFT than LED—(+)Lurem ($p = 0.039$), but no significant difference to LED—(−)Lurem and BST—(−)Lurem (1.6 ± 2.4 mean ± SE; $p = 1.00$) was observed. Significantly less WFT were

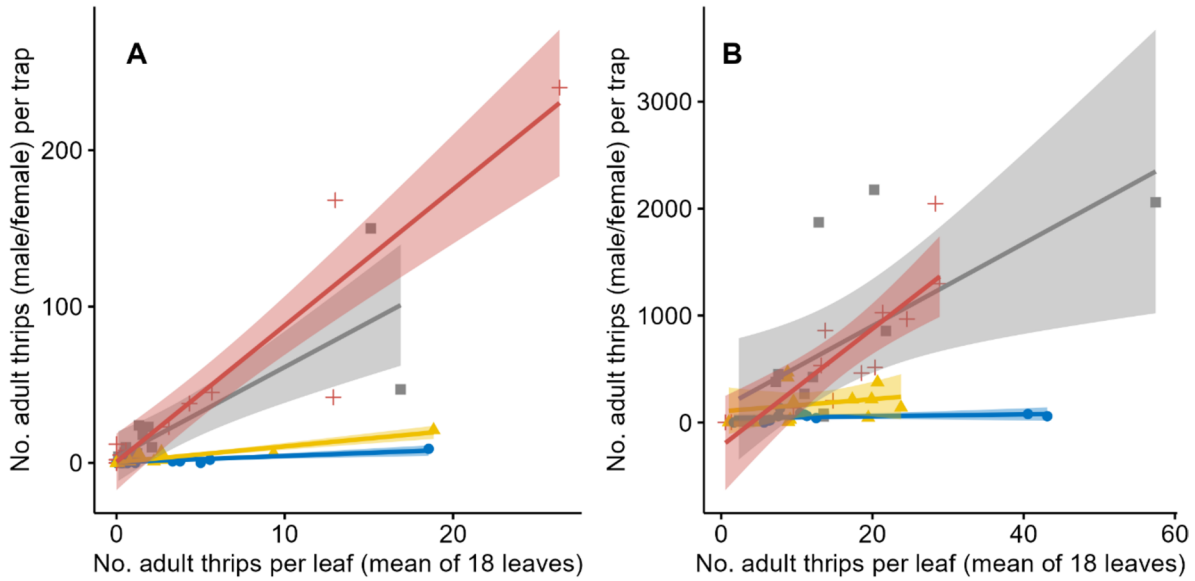

Fig. 4 Linear Regression model to visualize the correlation between adult *F. occidentalis* on LED traps with Lurem (red), LED without Lurem (grey), BST with Lurem (yellow), BST without Lurem (blue) and adult *F. occidentalis* on the plant in the first **A** and second **B** planting of experiment 1. Data for *F. occidentalis* on the traps are based on numbers of insects per trap. Data for *F. occidentalis* on the plants are based on average numbers of adult *F. occidentalis* per leaf (mean, $n = 18$ leaves)

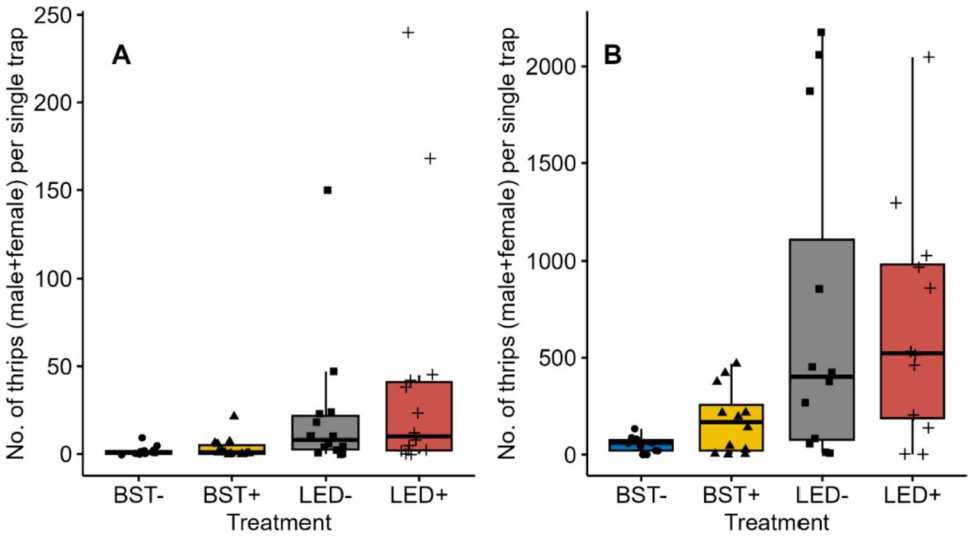

Fig. 5 Number of *F. occidentalis* caught in the first **A** and second **B** rep on LED with Lurem (red, LED+), LED without Lurem (grey, LED−), BST with Lurem (yellow, BST+) and BST without Lurem (blue, BST−) in experiment 1. Data are based on numbers of *F. occidentalis* caught per trap per week ($n = 12$)

caught by BST—(−)Lurem compared to LED—(+)Lurem ($p = 0.010$) and LED—(−)Lurem ($p = 0.033$).

In the second planting, WFT on the plant correlated significantly with WFT on LED—(+)Lurem ($R^2 = 0.715$, $p = 0.001$) and LED—(−)Lurem ($R^2 = 0.453$, $p = 0.017$), respectively. In contrast, number of WFT on the plant and on BST—(+)Lurem ($R^2 = 0.059$, $p = 0.447$) and BST—(−)Lurem ($R^2 = 0.089$, $p = 0.347$) were not correlated (Fig. 4B, Table. A-2). The most WFT were found on the LED—(−)Lurem (720.6 ± 159.6 mean ± SE) followed by LED—(+)Lurem (671.2 ± 154.1 mean ± SE), BST—(+)Lurem (175.9 ± 78.9 mean ± SE) and BST—(−)Lurem (52.9 ± 43.3 mean ± SE) (Fig. 5B). Blue sticky trap (−)Lurem caught significantly less WFT compared to LED—(−)Lurem ($p = 0.032$) and LED—(+)Lurem ($p = 0.009$), but no significant difference to BST—(+)Lurem ($p = 1.00$) was found.

Since insect numbers comprised lower (first planting) and higher (second planting) overall thrips densities, correlation was reassessed with pooled data of both plantings (Fig. 6). The analysis showed a significant correlation between number of WFT on the plant and all treatments (BST—(+)

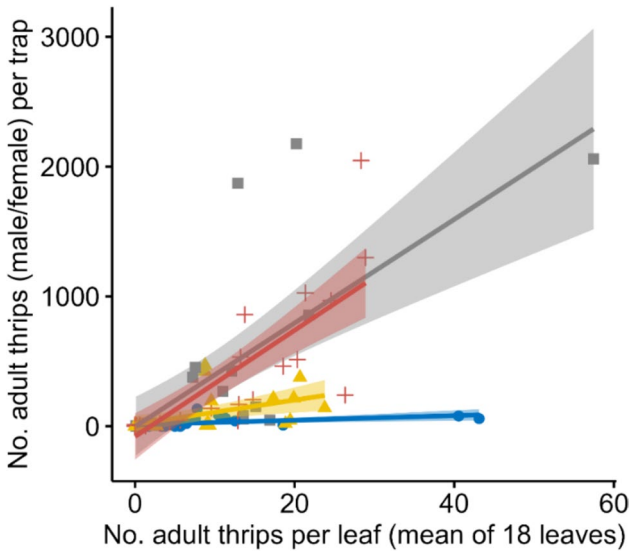

Fig. 6 Linear Regression model to visualize the correlation between adult *F. occidentalis* on LED traps with Lurem (red), LED without Lurem (grey), BST with Lurem (yellow), BST without Lurem (blue) and adult *F. occidentalis* on the plant of experiment 1. Data for *F. occidentalis* on the traps are based on numbers of insects per trap. Data for *F. occidentalis* on the plants are based on average numbers of adult *F. occidentalis* per leaf (mean, $n = 18$ leaves). Data from the first and second planting are pooled in this figure

Lurem: $p = 0.007$; BST—(−)Lurem: $p = 0.005$; LED—(+) Lurem: $p < 0.001$; LED—(−)Lurem: $p < 0.001$). The strongest correlation was found for LED—(+)Lurem ($R^2 = 0.653$), followed by LED—(−)Lurem ($R^2 = 0.544$), BST—(−)Lurem ($R^2 = 0.286$) and BST—(+)Lurem ($R^2 = 0.268$) (Table. A-3).

Attractiveness of traps at different times of the day (no-choice) (Exp. 2)

The recapture rates of thrips ranged between 0 and 70% (mean 17.30 ± 12.95% SD). A significant influence of the treatment ($p < 0.001$) and the daytime ($p = 0.001$), without interaction between treatment and daytime ($p = 0.298$) was observed. There was no significant difference between BST—(+)Lurem and BST—(−)Lurem ($p = 0.981$) and LED—(+)Lurem and LED—(−)Lurem ($p = 0.700$) (Fig. 7), respectively.

LED—(+)Lurem caught 3.06 and 3.44 times more WFT than BST—(+)Lurem ($p < 0.001$) and BST—(−)Lurem ($p < 0.001$), respectively. Even LED—(−)Lurem caught 2.49 and 2.8 times more WFT compared to BST—(+) Lurem ($p < 0.001$) and BST—(−)Lurem ($p < 0.001$), respectively. Significantly more WFT were caught at noon ($p = 0.017$) and afternoon ($p < 0.001$) compared to the morning period. LED trap caught significantly more

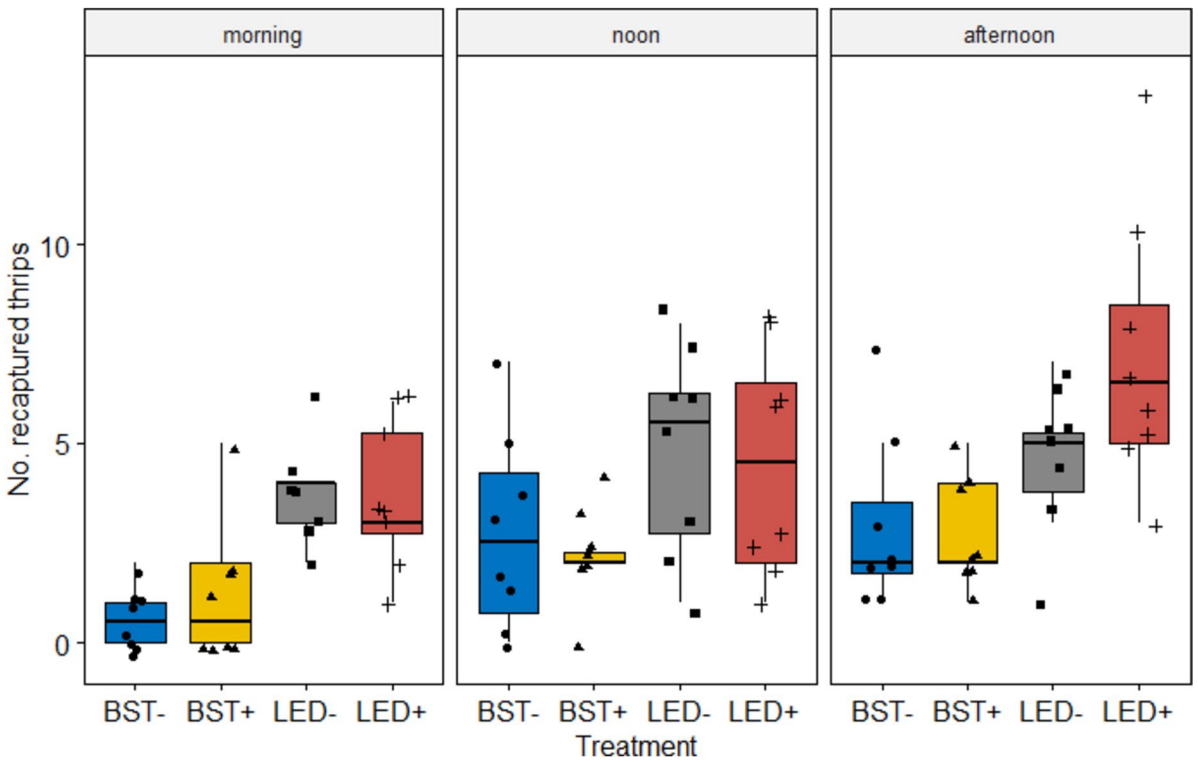

Fig. 7 Number of *F. occidentalis* recaptured on LED with Lurem (red, LED+), LED without Lurem (grey, LED−), BST with Lurem (yellow, BST+) and BST without Lurem (blue, BST−) in experiment 2 at morning, noon and afternoon, respectively. Data are based on numbers of *F. occidentalis* caught per rep at each daytime ($n = 8$)

WFT than the BST regardless of the daytime (morning: $p < 0.001$; noon: $p = 0.006$; afternoon: $p < 0.001$). Females were caught 1.48 times more frequently than males ($p = 0.003$), but interaction between sex and treatment was not significant ($p = 0.333$). Ambient light intensity in the morning (mean ± SD: 4682 ± 1026 Lux) was significantly lower compared to noon (mean ± SD: 16,886 ± 3287 Lux; $p < 0.001$) and afternoon (mean ± SD: 20,597 ± 6718 Lux; $p < 0.001$) but not significantly different between noon and afternoon ($p = 0.052$).

Attractiveness of traps towards WFT settled on a host plant (choice) (Exp. 3)

The recapture rates of thrips ranged between 20 and 100% (mean 59.66 ± 20.14% SD). Significantly more WFT were found on the plants compared to the traps ($p < 0.001$), regardless of the treatment (LED—(+)Lurem, LED—(−)Lurem, BST—(+)Lurem, BST—(−)Lurem) (Fig. 8). Overall, 34.4 times more thrips were found on the plants compared to traps. No significant influence of the treatment on the number of thrips found on either traps or plants was observed ($p = 0.114$).

Preference of WFT for monitoring traps or host plant (choice) (Exp. 4)

The recapture rates of thrips ranged between 5 and 95% (mean 31.20 ± 18.51% SD). On the host plant, 76.9 times more WFT were found compared to the BST ($p < 0.001$) (Fig. 9). No significant difference was observed between WFT on the LED trap and the host plant ($p = 0.097$), where 1.72 times more thrips were found compared to the LED trap. Number of WFT caught on the LED trap was 44.25 times more compared to the WFT caught on the BST ($p < 0.001$).

Discussion

The results clearly indicate that blue LED traps can improve monitoring of WFT in small crop stands. Moreover, the combination of LED traps with the thrips kairomone Lurem can further enhance the accuracy of estimating WFT population densities in greenhouse cabin grown cucumber by trap catches. However, Lurem does not improve WFT catches in all situations.

In general, thrips recapture rates varied strongly between and within the experiments. This variation seems to be within a normal range and can be observed frequently in other studies as well (Davidson et al. 2006; Otieno et al. 2018; Stukenberg et al. 2020).

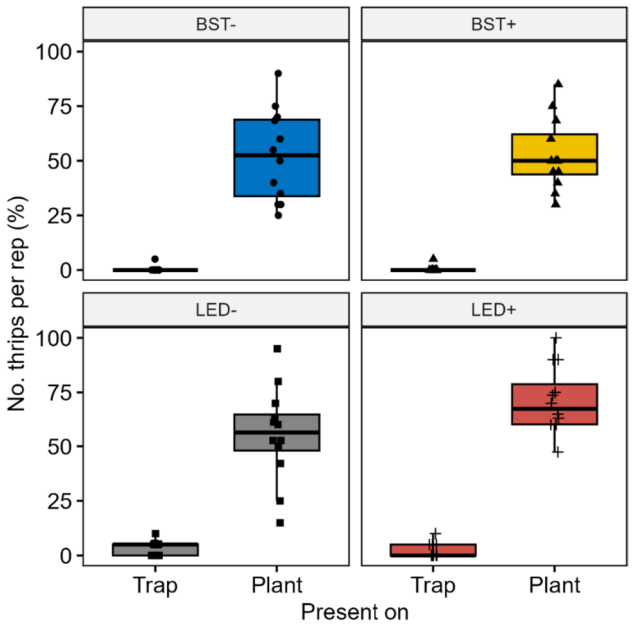

Fig. 8 Percentage number of released *F. occidentalis* found on LED with Lurem (red, LED+), LED without Lurem (grey, LED−), BST with Lurem (yellow, BST+) and BST without Lurem (blue, BST−) or still on the cucumber plant in experiment 3. Data are based on numbers of *F. occidentalis* found per rep ($n = 12$)

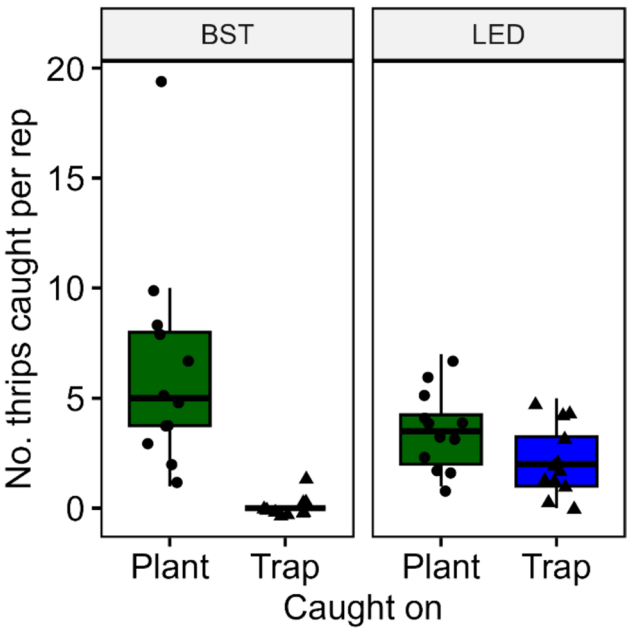

Fig. 9 Number of *F. occidentalis* found on BST (blue, left) or LED without Lurem (blue, right) and on the cucumber plant (green) in experiment 4. Data are based on numbers of *F. occidentalis* found per rep ($n = 12$)

During monitoring of thrips in the cucumber crop (exp. 1), thrips populations developed as expected in both plantings and cabins (data not shown). However, although numbers of initially released thrips were similar, population density was significantly higher in the second planting. This can be explained by external factors that are known to influence thrips development, such as the higher temperature (Nielsen et al. 2021) and longer photoperiod (Whittaker and Kirk 2004) during the second planting. Since also outdoor temperatures increased, number of thrips entering the greenhouse cabins through openings most likely contributed to this observation as well. Nevertheless, at either high or low numbers of thrips on the plants the LED trap showed always far higher thrips catches compared to the BST which also resulted in a more accurate correlation, that is higher explained variance and steeper slope. Especially the higher attractiveness of the LED trap for thrips is also well documented in our study. Two main factors, i.e. light spectrum and light intensity, may have contributed to the increased attractiveness and therefore enhanced thrips monitoring by the LED trap compared to the BST: Light spectrum plays a key role in visual orientation of thrips (Vernon and Gillespie 1990; Otieno et al. 2018; Ben-Yakir, 2020; Stukenberg et al. 2020). Although both trap types emit (LED) or reflect (BST) attractive blue light, the mainly emitted light spectrum is much smaller in the LED trap compared to the light spectrum that is reflected by the BST (Fig. 2). Otieno et al. (2018) and Stukenberg et al. (2020) found that differences of about 15–20 nm significantly influence the attractiveness of traps in the blue light spectrum, which might also account for the lower WFT catches on the BSTs in our experiments. Since the BST reflects great portions of green and yellow light compared to the highly attractive blue light (465 nm), the attractiveness of the BST is negatively affected. Additionally, light intensity plays another key role in thrips visual orientation (Vernon and Gillespie 1990; Otieno et al. 2018). Otieno et al. (2018) found an increasing attractiveness of a blue LED trap with increasing intensity of LED light emitted. The reflected light intensity (and therefore attractiveness) of sticky traps is assumed to be highly variable due to its dependence on the ambient light conditions, such as sunlight (Johansen et al. 2011; Cruz-Esteban et al., 2020; Zhang et al. 2020). This could explain the observed pattern in exp. 2 as BSTs caught significantly less WFT under less sunny compared to sunnier (noon and afternoon) conditions. However, we did not measure light spectrum and intensity reflected/emitted by both trap types continuously during the experiments, but traps were never tested under extreme ambient light intensities (always below 30,000 Lux). Nevertheless, it is most likely that the effect of light intensity can be accounted for the lower WFT catches on BSTs in most experiments (i.e. exp. 1, 2 and 4) since LED traps caught significantly more WFT than BSTs at all daytimes tested. However, we do not know how the light spectrum and intensity of the traps contributed to the results in detail as light conditions always vary greatly during cropping season. These aspects should be further investigated under controlled conditions.

The numbers of thrips caught during monitoring in the crop (exp. 1) and also in the preference test for flying thrips (exp. 4) clearly show the ability of the blue LED trap to compete successfully with the hostplant even in a complex environment. In contrast, BSTs were 76.9 times less attractive than the host plant in a choice situation and much less reliable when it comes to the correlation between WFT on the traps and plants (LED vs. BST: $R^2 = 0.544$ vs. 0.286). Nevertheless, neither trap type was able to attract many thrips while foraging on the host plant, but again the LED trap performed 6.3 times better than the BST (exp. 1 and 3). Even Lurem, which was found to increase take-off behaviour of thrips from leaf discs (van Tol et al. 2012) and number of thrips catches on sticky traps (Broughton and Harrison 2012; Muvea et al. 2014; Teulon et al. 2014; Davidson et al. 2015; Otieno et al. 2018), did not significantly increase number of thrips catches in either experiment. This is in favour of Otieno et al. (2018) and van Tol et al. (2020), who reported reduced attractiveness of an actually attractive trap in combination with Lurem in presence of a host plant. The likely reason for this is that the thrips has no need for leaving a suitable host plant. There are significant resources on the host plant such as food or places for mating and oviposition—especially when considering the low thrips density and, therefore, small interspecific competition in our experiments. Davidson et al. (2006) for example found that WFT responds much less to MI when satiated compared to starved ones. Furthermore, Teulon et al. (2007b) proposed a competition between plant odours and MI in the thrips olfactory system due to structural similarities of these compounds. This would lead to a reduced response of the thrips towards MI when already feeding on a host plant. Moreover, the relatively small distance between the release point and the trap in experiment 1, 2 and 3 might play an important role regarding the low effectiveness of Lurem. It is well accepted that the visual orientation plays an increasing role at decreasing distances, while olfactory orientation is supposed to be more important at longer distances in many insects (Prokopy and Owens 1983; Finch and Collier 2000; Ren et al. 2020). Thus, the olfactory stimulus by Lurem seems to be dominated by the visual stimulus of the LED trap. This might also explain why the addition of Lurem to the LED trap improved correlations between thrips on LED traps and plants in both plantings only moderately. In consequence, the visual enhancement of a trap is more important than the addition of an olfactory cue in small experimental setups and also in the closer neighbourhood of traps in the crop stand in greenhouse cabins. Otieno et al. (2018) could

show this in their experiments, as numbers of WFT catches significantly increased when LEDs attached to BSTs were switched on. However, Otieno et al. (2018) observed also a significant increase in WFT catches due to Lurem in some experiments at small distances (0.7 m). This discrepancies in the effectiveness of Lurem with or without the combination of enhanced sticky traps were found in several studies (Sampson et al. 2012; Nielsen 2013; van Tol et al. 2020) and underline that the increase in thrips catches by visual and olfactory cues are still not fully understood (Berry et al. 2006; van Tol et al. 2020). Other factors, such as temperature (Nielsen 2013), volatile dose (van Tol et al. 2012; Kirk et al. 2021), insect origin (Nielsen 2013) or the presence of plant odours (Visser 1986; Teulon et al. 2007a, 2017) and other unknown intrinsic factors are suggested to play a role in the effectiveness of Lurem (= methyl isonicotinate, MI). Nevertheless, neither of these factors account for the here observed pattern as plants, temperatures and insect origin did not differ within and between cabins. Furthermore, no significant difference in MI release was found between plantings (data not shown). Besides that, no difference was found in the effectiveness of the LED trap and Lurem between plantings, which supports the functionality of Lurem. Therefore, it remains unclear why the correlation on BST was enhanced by the use of Lurem in the first planting but not in the second planting of experiment 1 and why it was always enhanced when combined with LED traps in this experiment. Seasonal effects or ambient light conditions might be accounted for this observation and should be investigated in future studies.

Our study shows the successful integration of blue LEDs into an existing trap design used for greenhouse whitefly monitoring (see Stukenberg 2018). Therefore, LED trap colours can be adjusted to the growers needs, i.e. to the colour preferences of specific target-insects, or might even be combined in one trap to switch colours on and off at specific activity periods of insects. Furthermore, it is worth notable that the blue LED trap attracted also high numbers of the fungus gnat *Bradysia difformis* Frey (Diptera: Sciaridae) compared to BSTs in experiment 1 (data not shown). This shows an additional positive effect of using blue LED traps instead of standard BSTs.

To our knowledge, this is the first study monitoring WFT density in cucumber crop stands using a blue LED trap in combination with Lurem. The blue LED trap shows a very accurate correlation of thrips catches and thrips on cucumbers in the greenhouse cabins at high and low thrips population densities. The addition of Lurem further enhanced the accuracy of the correlation model. However, follow-up studies have to show if blue LED traps are also effective in other crops, locations and seasons, as differences in the attractiveness of different trap colours and lures in different crops are still not fully understood. Nevertheless, the high numbers of thrips caught on LED traps show the impressive potential of this technique, at least in small greenhouse setups. Further studies with different thrips lures, either to attract thrips or to disturb thrips on the host plant (or both in combination) in bigger greenhouses, are necessary to investigate the full range of possible improvements (Athanasiadou and Meyhöfer 2023) since traps were poorly able to attract thrips already settled. Additionally, LED traps mounted on a self-driving platform may further enhance monitoring. This is currently tested in the joint BLE funded project "LichtFalle" (www.hortico40.de).

Authors contribution

BG and RM conceived and designed research. BG conducted experiments. BG analysed data. BG wrote the manuscript. BG and RM reviewed and edited the manuscript. RM involved in funding acquisition. RM involved in supervision. All authors read and approved the manuscript.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s10340-024-01752-7.

Acknowledgements We would like to thank Dr. Andreas Olsowski and Timo Michel for technical support. Furthermore, we thank Eric Mülnikel, Alexander Wilhelm and Nils Bertels for insect counting and support in the greenhouse.

Funding The project was supported by funds of the Federal Ministry of Food and Agriculture (BMEL, FKZ: 2818506B18) based on a decision of the Parliament of the Federal Republic of Germany via the Federal Office for Agriculture and Food (BLE) under the innovation support program.

Data availability The data that support the research findings of this study are available at LUH Data Repository (Grupe and Meyhöfer, 2023): https://doi.org/10.25835/fkiw2etj.

Declarations

Conflict of interest We declare to have no competing interests.

References

M Athanasiadou R Meyhöfer 2023 Blue and UV light-emitting diodes (LEDs) disturb the greenhouse whitefly (*Trialeurodes*

vaporariorum) from its host J Pest Sci https://doi.org/10.1007/s10340-023-01693-7

EH Beers 2012 Effect of trap color and orientation on the capture of *Aphelinus mali* (Hymenoptera: Aphelinidae), a parasitoid of woolly apple aphid (Hemiptera: Aphididae) J Econ Entomol 105 1342 1349 https://doi.org/10.1603/ec12174

N Berry RC Butler DAJ Teulon 2006 Responses of new Zealand flower thrips (*Thrips obscuratus*) to synthetic and natural stimuli (odour and colour) in a wind tunnel N Z J Crop Hortic Sci 34 121 129 https://doi.org/10.1080/01140671.2006.9514396

Ben-Yakir D (2020) Optical manipulation of arthropod pests and beneficials. CAB International; CABI, Oxford, Wallingford, Boston, MA. https://doi.org/10.1079/9781786394705.0000

E Böckmann M Hommes R Meyhöfer 2015 Yellow traps reloaded: what is the benefit for decision making in practice? J Pest Sci 88 439 449 https://doi.org/10.1007/s10340-014-0601-7

S Broughton J Harrison 2012 Evaluation of monitoring methods for thrips and the effect of trap colour and semiochemicals on sticky trap capture of thrips (*Thysanoptera*) and beneficial insects (Syrphidae, Hemerobiidae) in deciduous fruit trees in Western Australia Crop Prot 42 156 163 https://doi.org/10.1016/j.cropro.2012.05.004

CC Chu GC Jackson PJ Alexander K Karut TJ Henneberry 2003 Plastic cup traps equipped with light-emitting diodes for monitoring adult *Bemisia tabaci* (Homoptera: Aleyrodidae) J Econ Entomol 96 543 546 https://doi.org/10.1093/jee/96.3.543

C-C Chu AM Simmons T-Y Chen PJ Alexander TJ Henneberry 2004 Lime green light-emitting diode equipped yellow sticky card traps for monitoring whiteflies, aphids and fungus gnats in greenhouses Entomologica Sinica 11 125 133 https://doi.org/10.1111/j.1744-7917.2004.tb00186.x

S Cruz-Esteban JC Rojas P Hernández-Ledesma 2020 Trap colour and aggregation pheromone dose affect the catch of western flower thrips in blackberry crops J Appl Entomol 144 755 763 https://doi.org/10.1111/jen.12815

MM Davidson RC Butler DAJ Teulon 2006 Starvation period and age affect the response of female *Frankliniella occidentalis* (Pergande) (Thysanoptera: Thripidae) to odor and visual cues J Insect Physiol 52 729 736 https://doi.org/10.1016/j.jinsphys.2006.03.013

MM Davidson RC Butler S Winkler DAJ Teulon 2007 Pyridine compounds increase trap capture of *Frankliniella occidentalis* (Pergande) in a covered crop N Z Plant Prot 60 56 60 https://doi.org/10.30843/nzpp.2007.60.4609

MM Davidson M-C Nielsen RC Butler C Castañé O Alomar J Riudavets DAJ Teulon 2015 Can semiochemicals attract both western flower thrips and their anthocorid predators? Entomol Exp Appl 155 54 63 https://doi.org/10.1111/eea.12284

C Dieckhoff R Meyhöfer 2023 If only you could catch me—catch me if you can: monitoring aphids in protected cucumber cultivations by means of sticky traps Horticulturae 9 571 https://doi.org/10.3390/horticulturae9050571

S Finch RH Collier 2000 Host-plant selection by insects—a theory based on 'appropriate/inappropriate landings' by pest insects of cruciferous plants Entomol Exp Appl 96 91 102 https://doi.org/10.1046/j.1570-7458.2000.00684.x

DR Gillespie D Quiring 1987 Yellow sticky traps for detecting and monitoring greenhouse whitefly (Homoptera: Aleyrodidae) adults on greenhouse tomato crops J Econ Entomol 80 675 679 https://doi.org/10.1093/jee/80.3.675

B Grupe C Dieckhoff R Meyhöfer 2023 Keep an eye on natural enemies: what *Aphidius* on sticky traps tells us about aphid pest population dynamics Entomol Exp Appl 171 722 731 https://doi.org/10.1111/eea.13360

CS Higgins 1992 Western flower thrips (Thysanoptera: Thripidae) in greenhouses: population dynamics, distribution on plants, and associations with predators Hortic Entomol 85 1891 1903 https://doi.org/10.1093/jee/85.5.1891

NS Johansen I Vänninen DM Pinto AI Nissinen L Shipp 2011 In the light of new greenhouse technologies: 2. Direct effects of artificial lighting on arthropods and integrated pest management in greenhouse crops Ann Appl Biol 159 1 27 https://doi.org/10.1111/j.1744-7348.2011.00483.x

WDJ Kirk WJ Kogel de EH Koschier DAJ Teulon 2021 Semiochemicals for thrips and their use in pest management Annu Rev Entomol 66 101 119 https://doi.org/10.1146/annurev-ento-022020-081531

EH Koschier WJ Kogel de JH Visser 2000 Assessing the attractiveness of volatile plant compounds to western flower thrips *Frankliniella occidentalis* J Chem Ecol 26 2643 2655 https://doi.org/10.1023/A:1026470122171

EH Koschier M-C Nielsen B Spangl MM Davidson DAJ Teulon 2017 The effect of background plant odours on the behavioural responses of *Frankliniella occidentalis* to attractive or repellent compounds in a Y-tube olfactometer Entomol Exp Appl 163 160 169 https://doi.org/10.1111/eea.12566

X-H Liang Z-R Lei J-Z Wen M-L Zhu 2010 The diurnal flight activity and influential factors of *Frankliniella occidentalis* in the greenhouse Insect Sci 17 535 541 https://doi.org/10.1111/j.1744-7917.2010.01337.x

K Lopez-Reyes KF Armstrong DAJ Teulon RC Butler C Dooremalen van M Roher RWHM Tol van 2022 Colour response in western flower thrips varies intraspecifically InSects https://doi.org/10.3390/insects13060538

BP Mainali UT Lim 2011 Behavioral response of western flower thrips to visual and olfactory cues J Insect Behav 24 436 446 https://doi.org/10.1007/s10905-011-9267-7

McCormack K (2015) Enhancing the monitoring and trapping of protected crop pests by incorporating LED technology into existing traps. Dissertation, University of Edinburgh. http://hdl.handle.net/1842/22837

Moral RA, Hinde J & Demétrio CGB (2017) Half-Normal Plots and Overdispersed Models in R: The hnp Package. Journal of Statistical Software, 81. https://doi.org/10.18637/jss.v081.i10

V Moericke 1952 Farben als landereize für blattlaeuse (Aphidoidea) Z Naturforschung 7b 304 309 https://doi.org/10.1515/znb-1952-0508

AM Muvea MM Waiganjo HL Kutima Z Osiemo JO Nyasani S Subramanian 2014 Attraction of pest thrips (Thysanoptera: Thripidae) infesting French beans to coloured sticky traps with Lurem-TR and its utility for monitoring thrips populations Int J Trop Insect Sci 34 197 206 https://doi.org/10.1017/S174275841400040X

Nielsen M-C (2013) Factors affecting the response of thrips to an olfactory cue. Dissertation, Lincoln University. https://hdl.handle.net/10182/5890

M-C Nielsen RC Butler DAJ Teulon 2016 Response of *Frankliniella occidentalis* and *Thrips tabaci* to thrips lures in California N Z Plant Prot 69 322 https://doi.org/10.30843/nzpp.2016.69.5928

M-C Nielsen DAJ Teulon RB Chapman RC Butler GM Drayton H Phillipsen 2021 Effects of temperature on survival, oviposition, and development rate of 'greenhouse' and 'lupin' strains of western flower thrips, *Frankliniella occidentalis* Entomol Exp Appl 169 480 490 https://doi.org/10.1111/eea.13032

JA Otieno N Stukenberg J Weller H-M Poehling 2018 Efficacy of LED-enhanced blue sticky traps combined with the synthetic lure Lurem-TR for trapping of western flower thrips (*Frankliniella occidentalis*) J Pest Sci 91 1301 1314 https://doi.org/10.1007/s10340-018-1005-x

J Pizzol D Nammour P Hervouet A Bout N Desneux L Mailleret 2010 Comparison of two methods of monitoring thrips populations in a greenhouse rose crop J Pest Sci 83 191 196 https://doi.org/10.1007/s10340-010-0286-5

R Prokopy E Owens 1983 Visual detection of plants by herbivorous insects Annu Rev Entomol 28 337 364

R Core Team (2022) R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria.

X Ren S Wu Z Xing R Xu W Cai Z Lei 2020 Behavioral responses of western flower thrips (*Frankliniella occidentalis*) to visual and olfactory cues at short distances InSects https://doi.org/10.3390/insects11030177

C Sampson JGC Hamilton WDJ Kirk 2012 The effect of trap colour and aggregation pheromone on trap catch of *Frankliniella occidentalis* and associated predators in protected pepper in Spain Iobc/wprs Bull 80 313 318

MY Steiner S Goodwin 2005 Management of western flower thrips, *Frankliniella occidentalis* (Pergande) (Thysanoptera: Thripidae), in hydroponic strawberry crops: using yellow sticky traps to determine action thresholds Aust J Entomol 44 288 292 https://doi.org/10.1111/j.1440-6055.2005.00466.x

MY Steiner LJ Spohr I Barchia S Goodwin 1999 Rapid estimation of numbers of whiteflies (Hemiptera: Aleurodidae) and thrips (Thysanoptera: Thripidae) on sticky traps Aust J Entomol 38 367 372 https://doi.org/10.1046/j.1440-6055.1999.00114

N Stukenberg 2018 LED based trapping of whiteflies and fungus gnats: from visual ecology to application Diss, Leibniz Univ Hann https://doi.org/10.15488/4144

N Stukenberg K Gebauer H-M Poehling 2015 Light emitting diode (LED)-based trapping of the greenhouse whitefly (*Trialeurodes vaporariorum*) J Appl Entomol 139 268 279 https://doi.org/10.1111/jen.12172

N Stukenberg N Ahrens H-M Poehling 2018 Visual orientation of the black fungus gnat, *Bradysia difformis*, explored using LEDs Entomol Exp Appl 166 113 123 https://doi.org/10.1111/eea.12652

N Stukenberg M Pietruska A Waldherr R Meyhöfer 2020 Wavelength-specific behavior of the western flower thrips (*Frankliniella occidentalis*): evidence for a blue-green chromatic mechanism InSects https://doi.org/10.3390/insects11070423

DAJ Teulon MM Davidson DI Hedderley DE James CD Fletcher L Larsen VC Green NB Perry 2007a 4-pyridyl carbonyl and related compounds as thrips lures: effectiveness for onion thrips and new zealand flower thrips in field experiments J Agric Food Chem 55 6198 6205 https://doi.org/10.1021/jf070389a

DAJ Teulon DR Penman PM Ramakers 1993 Volatile chemicals for thrips (Thysanoptera: Thripidae) host- finding and applications for thrips pest management J Econ Entomol 86 1405 1415 https://doi.org/10.1093/jee/86.5.1405

DAJ Teulon M-C Nielsen DE James S Winkler ARG Mclachlan NB Perry 2007b Combination of two odour chemical lures does not increase thrips capture in field bioassays N Z Plant Prot 60 61 66 https://doi.org/10.30843/nzpp.2007.60.4610

DAJ Teulon C Castañé M-C Nielsen AM El-Sayed MM Davidson R Gardner-Gee J Poulton AM Kean C Hall RC Butler CE Sansom DM Suckling NB Perry 2014 Evaluation of new volatile compounds as lures for western flower thrips and onion thrips in New Zealand and Spain N Z Plant Prot 67 175 183 https://doi.org/10.30843/nzpp.2014.67.5749

DAJ Teulon MM Davidson NB Perry M-C Nielsen C Castañé D Bosch J Riudavets RWHM Tol van WJ Kogel de 2017 Methyl isonicotinate: a non-pheromone thrips semiochemical—and its potential for pest management Int J Trop Insect Sci 37 50 56 https://doi.org/10.1017/S1742758417000030

RWHM Tol van A Bruin de RC Butler MM Davidson DAJ Teulon WJ Kogel de 2012 Methyl isonicotinate induces increased walking and take-off behaviour in western flower thrips, *Frankliniella occidentalis* Entomol Exp Appl 142 181 190 https://doi.org/10.1111/j.1570-7458.2011.01215.x

RWHM Tol van MM Davidson RC Butler DAJ Teulon WJ Kogel de 2020 Visually and olfactorily enhanced attractive devices for thrips management Entomol Exp Appl 168 665 677 https://doi.org/10.1111/eea.12969

RWHM Tol van J Tom M Roher A Schreurs C Dooremalen van 2021 Haze of glue determines preference of western flower thrips (*Frankliniella occidentalis*) for yellow or blue traps Sci Rep 11 15 https://doi.org/10.1038/s41598-021-86105-5

RS Vernon DR Gillespie 1990 Response of *Frankliniella occidentalis* (Thysanoptera: Thripidae) and *Trialeurodes vaporariorum* (Homoptera: Aleyrodidae) to fluorescent traps in a cucumber greenhouse J Entomol Soc B C 87 38 41

JH Visser 1986 Host odor perception in phytophagous insects Annu Rev Entomol 31 121 144

MS Whittaker WDJ Kirk 2004 The effect of photoperiod on walking, feeding, and oviposition in the western flower thrips Entomol Exp Appl 111 209 214 https://doi.org/10.1111/j.0013-8703.2004.00167.x

J Zhang H Li M Liu H Zhang H Sun H Wang L Miao M Li R Shu Q Qin 2020 A greenhouse test to explore and evaluate light-emitting diode (LED) insect traps in the monitoring and control of *Trialeurodes vaporariorum* InSects https://doi.org/10.3390/insects11020094