Synergistic influence of the capture effect of western flower thrips (*Frankliniella occidentalis*) induced by proportional yellow-green light in the greenhouse

Qihang Liu[1†], Xinfa Wang[1†], Mingfu Zhao[1], Tao Liu[2*]

(1. *Henan Institute of Science and Technology, Xinxiang 453003, Henan, China*;
2. *Inner Mongolia Agricultural University, Huhehot 010018, China*)

Abstract: To clarify the influence of yellow, green, and proportional yellow-green light on the capture effect, western flower thrips, *Frankliniella occidentalis* (Pergande), were captured using different self-made light sources in a greenhouse. The bio-activity capture effect of thrips was regulated by light and analyzed to determine the reasons for the changes in their capture by light. The results showed that the thrips' capture effect induced by different light sources with the same brightness was positively correlated with night temperature. When the average night temperature was 27°C (19:00-21:30), the capture effect was optimal, indicating that the coupling effect of light temperature can regulate the capture effect of thrips. Green light intensified and yellow light inhibited the visual trend sensitivity of thrips to yellow-green light of differing proportions. The capture effect trapped by a green-yellow light ratio of 4:1 was optimal (1088.00 individuals in night time), while that of yellow light was the worst (456.67 individuals/night), thus, indicating that visual trend sensitivity of thrips to green light was higher than that of yellow light. Such differences originated from the differences in the photoelectric thermal conversion effect of spectral optical properties, and the spectral photo-thermal effect was the main reason that thrips produced a light-trapped behavior. Night light enhanced the sensitivity of thrips' responses to a white adhesive board during the daytime, and the effect of yellow light intensity was the strongest (1563.00 individuals in the daytime), while that of green light was the weakest (75.33 individuals in the day time). Additionally, yellow light intensified while green light inhibited the regulatory effect of different proportions of yellow-green light on the bio-activity of thrips. However, the capture effect of day and night corresponding to 4:1 green-yellow light was the best (2019.67 individuals in day and night). The function of the photo-thermal effect on the capture effect of thrips was affected by the decrease in night temperature, but the photo-electro-thermal effects of night light intensified the bio-activity of thrips in the daytime and enhanced their color sensitivity. The results provide a theoretical basis for the development of pest light induction equipment.

Keywords: western flower thrips, proportional yellow-green light, synergistic influence effect, capture effect
DOI: 10.25165/j.ijabe.20231601.7562

Citation: Liu Q H, Wang X F, Zhao M F, Liu T. Synergistic influence of the capture effect of western flower thrips (*Frankliniella occidentalis*) induced by proportional yellow-green light in the greenhouse. Int J Agric & Biol Eng, 2023; 16(1): 88–94.

1 Introduction

Western flower thrips (*Frankliniella occidentalis*) belong to the orders Thysanoptera, Thripidae, and Frankliniella, and are a globally invasive pest and a major threat to crops such as vegetables and flowers in China[1]. In the global, chemical control is mainly used to control thrips, but long-term use of chemical pesticides has caused problems such as pesticide resistance, and environmental harm, and has adverse effects on human health[2], thus, attracting interest in their physical control[3]. Shimoda et al.[4,5] considered that light color induction was an effective measure to control thrips. Therefore, a deep understanding of the effects of spectral light on thrips phototaxis will not only help reveal their phototactic regulatory mechanisms, but also provide a theoretical basis for the photoinduced biological changes of thrips, and pest light control technology.

The phototaxis of thrips has been studied by scholars at home and abroad. Researchers have found that thrips have the strongest spectral response in the range of 500-580 nm, which is affected by the intensity of sunlight[6,7], while host plant color, physical structure, sticky plate shape and size, background color, height, and habitat affect the trapping of thrips by the color plate[8,9]. Matteson et al.[10] measured the retinal potential of thrips in a wave range between 400-620 nm, and the peak value at 545 nm was identified. However, the peak value of the spectral behavior of thrips was at 524 nm[11,12]. Fan et al.[13] found that the wavelength of colored light with the highest reaction rate in *F.occidentalis* was 524-590 nm. Yang et al.[14] found that the phototactic response rate of thrips to yellow light (560 nm) was the highest, followed by that of green light (520 nm). These results indicated that the phototactic sensitivity of *F.occidentalis* was significantly correlated with the light spectrum, and showed a preference for the yellow

Received date: 2022-03-30 **Accepted date:** 2023-01-02
Biographies: Qihang Liu, PhD, Associate Professor, research interest: locust capturing technology of optical-mechanical-electrical integration, Email: bjliuqihang@163.com; **Xinfa Wang**, Senior Engineer, research interest: agricultural engineering and intelligent equipment, Email: wangxf2006@qq.com; **Mingfu Zhao**, MSE, Professor, research interest: modern wisdom agriculture, signal processing and control, Email: mingfuzhao@sina.com.
†The authors contributed equally to this article and are co-first authors.
***Corresponding author: Tao Liu**, PhD, Associate Professor, research interest: agriculture and animal husbandry equipment design and machine vision inspection technology. Inner Mongolia Agricultural University, Huhehot 010018, China. Tel: +86-471-4309215, Email: liutao@imau.edu.cn.

and green spectra. However, there are no reports on the factors of yellow and green light that attract *F.occidentalis* in the field, or on the regulatory effect of yellow and green light on the photobiological habits of thrips. And the intensity of yellow and green light changed the visual response effect of *F.occidentalis* to yellow and green light and could regulate the trapping effect of thrips[15]. However, the factors influencing the phototactic effect of thrips induced by yellow and green light are not clear, and the synergistic and regulatory effect of different ratios of combined yellow and green light on trapping thrips have not been reported.

Based on the visual sensitivity of thrips to yellow and green light, light emitting diode (LED) light sources with single yellow and green spectra, and different ratios of yellow and green light were used in trapping experiments of *F.occidentalis*. The trapping results of different light sources were analyzed to reveal the mechanisms and factors influencing the light control for *F.occidentalis*. The biological regulation of yellow and green light on the habitats of thrips was also discussed, providing a basis for the development and application of pest light control technology.

2 Materials and methods

Thrip induction experiments were conducted in a vegetable greenhouse (length×width×height=120 m×11 m×4 m) at the Zhengzhou suburb (34°58′N, 113°14′E) of Henan Province on June 20-26, 2021. The interval mixed plants of pepper and eggplant grew well in the greenhouse, and the growth of each plant was similar, with each plant in the peak fruiting stage at the time of experimentation. 22 rows of pepper and eggplant plants (240 plants/row) were planted along the width of the greenhouse, and plant, row spacing was 0.5 m, respectively. The *F. occidentalis* had been bred for many generations in the same area prior to experimentation.

Experimental light sources: The light sources used for trapping and counting the *F. occidentalis* are shown in Figure 1. The experimental spectra of the light sources are shown in Figure 2.

a. Design model drawing b. Image of the light source

1. Upper box (built-in light rain control system) 2. Support rod 3. Clamping device 4. White sticky board 5. Luminous body 6. Support frame 7. Lower box 8. Air suction device 9. Collection device

Figure 1 Experimental light source

a. Yellow b. Green c. Yellow-green (2:1) d. Yellow-green (1:2) e. Yellow-green (4:1) f. Yellow-green (1:4)

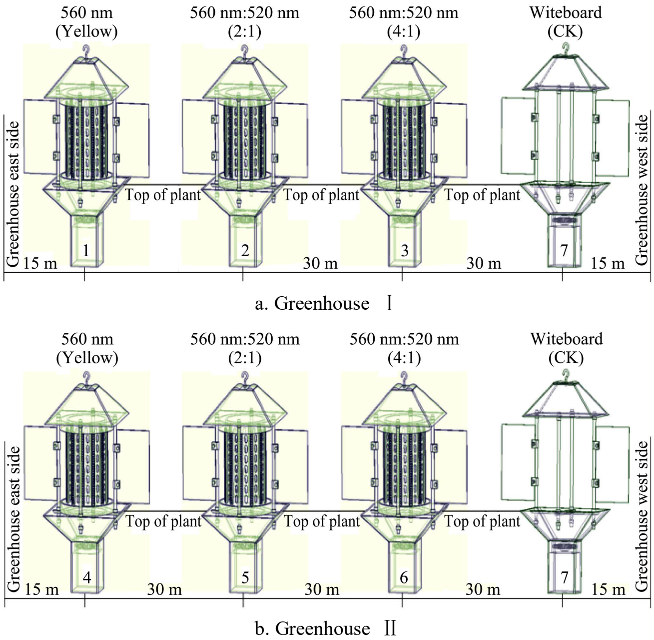
Figure 2 Experimental light spectra used for testing

The light source adopted two capture measures with an air suction device and a white sticky plate (Figure 1). The air suction device (8) was located between the lower box (7) and the collection device (9). The white sticky plate (4) (to catch the flying thrips around the lights at night) was clamped on the support rod (2) by the clamping device (3). The support rod (2) was connected to the upper box and the lower box, and the light source and fan control system was built into the upper box. The lower box (7) presented an inverted shape to suck thrips into the collection device (9). The luminous body (5), was made with LED arrays with different spectral columns (as shown in Figure 2) and was placed on the support frame (6) of the upper and lower box bodies. The upper and lower ends of the LED support cylinder were sealed and opened, respectively, and oval or round holes were arranged on the cylinder body. The experimental spectra of the light source were yellow (560 nm), green (520 nm), and 2:1, 1:2, 4:1, and 1:4 of yellow-green, respectively. According to the spectra, six kinds of light sources were developed, which were labeled 1, 2, 3, 4, 5, and 6, respectively. The illumination of the light sources was calibrated at 12 000 lx and the illumination was 0.01 lx at a distance of 20 m.

Light source arrangement: According to the light distance and the sensitivity of the visual response of thrips to different light qualities, two greenhouses (I and II) were used, and before the experiment, the occurrence of thrips in the two greenhouses was basically the same (population density: 36.4 individuals/plant). Three light sources labeled 1, 2, and 3, as well 7 with a contrast whiteboard, and three light sources labeled 4, 5, and 6, as well 7 with a contrast whiteboard, were suspended in the middle position of the 120 m length of the greenhouse I, and greenhouse II, respectively. The upper edge of the lower box was level with the top of the interval mixed plants of pepper and eggplant, and the distance between them was 30 m. The label corresponds to the fixed position of the suspended lamp (Figure 3).

To avoid the specific influence of light on the biological community of *F.occidentalis*, the tests were completed over 6 d, and after testing at night, the positions of the No. 1-6 light sources were changed in the two greenhouses. The new positions of the

No. 1-6 light sources on days 1-6 were as follows: 1-2-3-4-5-6, 4-5-6-1-2-3, 3-1-2-6-4-5, 6-4-5-3-1-2, 2-3-1-5-6-4, and 5-6-4-2-3-1, ensuring the homogeneity of light sources at different locations. The position of the contrast whiteboard remained invariable throughout the experiment.



Note: Light sources 1-7 are the label numbers of the different spectral light sources and contrast whiteboard (CK), respectively, which correspond to the hanging positions of the light source.

Figure 3 Light source arrangement in greenhouses I and II

Experimental methods: To ensure the consistency of the capture measures of white sticky plate reflecting light and wind sucking thrips, the light sources and the wind suction measures were opened all day and night during the experiments. The 10 h when the light source was on, from 19:00 to 05:00 the next day, was divided into four periods, and at 19:00, 21:30, 0:00 (24:00), 02:30, and 05:00 every day, the white sticky plate and the collecting device were replaced. The number of thrips trapped by the sticky plates and collecting devices during 19:00-21:30, 21:30-24:00, 0:00-02:30, 02:30-05:00, and 05:00-19:00 was counted.

The average value of six replicates for each light source at the four time periods on the six nights was calculated, and the average number was used to reflect the trapping effect of the different light sources at each period of the night. Moreover, the average value of six replicates for the white sticky plate and collecting device of different light sources during the day (05:00-19:00) on the six days was calculated, to determine the trapping effect of the white plate reflecting light during the day after thrips were irradiated by light at night. The temperature during the four periods of every night was recorded by a thermometer suspended in the shed, and the average temperature during the four periods over the six nights was calculated (the relative humidity in the shed was 65.0%±2.5%), as shown in Table 1, to evaluate the influence effect of temperature on the capture effect of thrips.

Data computation and analysis: After each day's test, the number of thrips (n_1) trapped by the different light sources within 24 h (19:00-5:00-19:00), the average numbers of thrips (n_2) trapped by two contrast whiteboards during the daytime, and the number of thrips (n_3) trapped by the different light sources from 19:00-5:00 at night were counted. The total average number of thrips was calculated using the formula $(n_1-n_2)/6$, to reflect the total trapping effects of each light source at night and its white plate reflecting light during the day. Moreover, the total average number of thrips was calculated using the formula $(n_3)/6$, to reflect the trapping effect of each light source in 10 h of night. The average number of thrips calculated by the formula $(n_1-n_2-n_3)/6$ was used to reflect the trapping effects of the white board in the daytime after the light source irradiated the thrips at night. These data were used to analyze the influence of light on the photo-biological effect of thrips and the application effect of different light ratios during the day and at night.

For the tests, a general linear model analysis was used to compare the average number of thrips captured by different light sources. For multiple comparisons, LSD (Least-Significant Difference) tests at p=0.05 were used. The Student's t-test was used to determine the significance of differences between two different time periods and two different light sources. SPSS statistical software for Windows (SPSS, Chicago, IL, USA), version 16.0, and Excel Software for Windows (Microsoft, Redmond, WA, USA) were used for all statistical analyses. The results are expressed as the mean±standard error.

3 Results and discussion

3.1 Synergistic effect of different ratios of yellow-green light on the trapping effect of *F. occidentalis*

The trapping effects of *F.occidentalis* by different light sources at different times of night are listed in Table 1.

Table 1 Trapping effects of *F.occidentalis* by different light sources at different times of night

Data title		Thrips average numbers captured by light source/individuals				*F* value	*p* value
Time period Average Temperature/°C		19:00-21:30 27.0±0.5	21:30-24:00 25.0±0.5	0:00-2:30 23.0±0.2	2:30-5:00 21.5±0.2	df=3	
Wavelength/nm	520:560=4:1	$536.67\pm46.67^{A^{**}\#\#a^{**}}$	$276.67\pm14.53^{A^{*}\,^{**}b^{**}}$	$160.00\pm11.55A^{*}c^{**}$	$114.67\pm2.91^{A^{*}c^{**}}$	56.569	<0.001
	520:560=2:1	$426.67\pm18.56^{B^{**}\,\triangle\triangle a^{**}\,\#\#}$	$226.67\pm12.02^{B\#\#b^{**}}$	$146.67\pm17.64ABc^{\#\#}$	$100.00\pm5.77^{ABc^{**}}$	99.893	<0.001
	520	$376.33\pm8.76^{B^{**}\,\triangle\triangle a^{**}\,\#\#}$	$193.33\pm26.67^{BC^{*}\,\#b^{**}}$	$123.33\pm9.28Cc^{\#\#}$	$98.33\pm4.41^{Bc^{**}}$	70.637	<0.001
	560:520=2:1	$255.00\pm18.93^{C^{**}a^{*}\,^{**}}$	$178.33\pm14.81^{C^{*}\,\triangle b^{*}\,\#}$	$120.00\pm20.82Cc^{**}$	$89.33\pm2.33^{Bc\#\,^{**}}$	20.924	<0.001
	560:520=4:1	$236.67\pm24.04^{CD^{**}\,a^{**}\,\#\#}$	$121.67\pm9.28^{D^{**}\,\#\#\,\#b^{**}}$	$103.33\pm4.41D^{*}c^{\#\#}$	$71.67\pm6.67^{C^{*}c\#\#}$	28.427	<0.001
	560	$190.00\pm20.21^{D\#\#\,\triangle\triangle a^{*}\,^{**}}$	$101.67\pm6.01^{D^{**}\,\#\#\,\#\,\triangle b^{*}}$	$85.00\pm5.00D^{*}c^{**}$	$70.00\pm10.41^{C^{*}c^{**}}$	18.981	<0.01
F value	df=5	26.735	18.052	3.679	8.267		
p value		<0.001	<0.001	<0.05	<0.05		

Note: Data in the table are the means ± standard error. In the same column, different capital letters indicate significant differences (p<0.05). Different capital letters with the same single superscript, or with the same double superscript indicate very significant differences (p<0.01), and extremely significant differences (p<0.001). In the same row, different lowercase letters indicate significant differences (p<0.05), different lowercase letters with the same single superscript, or with the same double superscript indicate very significant differences (p<0.01), and extremely significant differences (p<0.001), respectively.

At different times of night, the difference in thrips trapping by yellow light was significant (p<0.01), while that trapped by the other light sources was extremely significant (p<0.001) (Table 1). Between 00:00-02:30 and 02:30-05:00, the differences in trapping caused by different light sources were not significant (p>0.05), and trapping induced by different light sources at 0:00-2:30 and 02:30-05:00 were lower than that at 19:00-21:30. Between 19:00-21:30 and 21:30-12:00, and 21:30-12:00 and 02:3-05:00, the differences in trapping caused by green light, a green:yellow ratio = 2:1, or a green:yellow ratio=4:1, were extremely significant (p<0.001), while that caused by a green:yellow ratio = 1:2 was very significant (p<0.01). Between 19:00-21:30 and 21:30-12:00, the difference caused by yellow light, a green:yellow ratio = 1:4 light was extremely, very significant, respectively, and between 21:30-12:00 and 02:30-05:00, the difference was significant. Then, as the length of time periods increased at night, the trapping effects gradually decreased, and between 02:30-05:00, the trapping by different light sources was the worst, while between 19:00-21:30, trapping by different light sources was optimal.

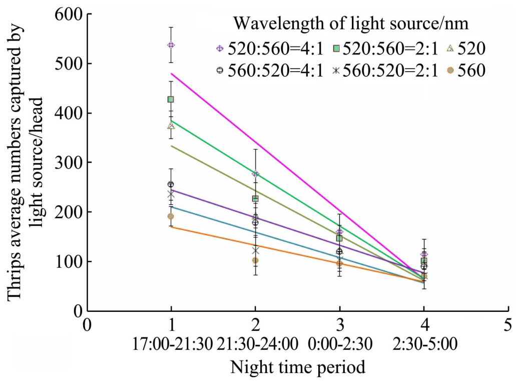


Figure 4 Relationship between thrips capture and night time

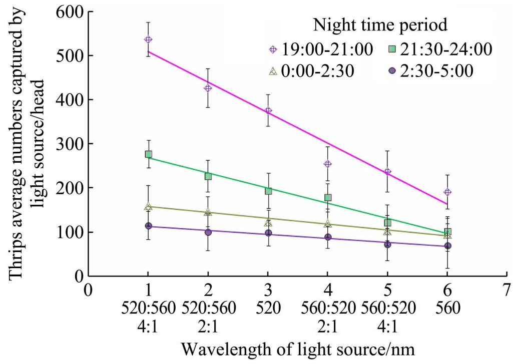


Figure 5 Relationship between thrips capture and light source

Between the different light sources at 19:00-21:30 and 21:30-12:00, the differences in thrips trapping were extremely significant (p<0.001), while between 00:00-02:30 and 02:30-05:00, the difference was significant (p<0.05). However, the difference significance was different between two different light sources at the same night time (Table 1). Additionally, the difference between yellow light and a green:yellow ratio=1:4 was not significant, while the trapping by those lights were lower than that by a green:yellow ratio=1:2. Between a green:yellow ratio=2:1 and green light at 19:00-21:30, the difference was significant, while that between green light and a green:yellow ratio=1:2, the difference was extremely significant. However, at the other same night time, the difference was not significant. Between light with a green:yellow ratio=4:1 and a green:yellow ratio=2:1, the difference at 19:00-21:30 was extremely significant, while at 21:30-12:00, it was significant, and at 00:00-02:30 and 02:30-05:00, the difference was not significant. Those results showed that at the same time period, the trapping of thrips by light with a green:yellow ratio=4:1 light source was optimal, followed by a green:yellow ratio=2:1, while that of yellow light was the worst, that of green: yellow=1:4 light was the second worst, and the trapping effect induced by green light was better than that by green: yellow=1:2 light.

The results in Table 1 show that the nighttime periods significantly affected the trapping of thrips by the same light source, presenting a significant linear correlation (Figure 3). The correlation analysis showed that the average number of thrips trapped by different light sources at night was negatively correlated with the time period ($R_{520:560=4:1}$=–0.944, $R_{520:560=2:1}$= 0.944, R_{520}= –0.929, $R_{560:520=4:1}$= –0.921, $R_{560:520=2:1}$= –0.983, R_{560}= –0.904, p=0.05). Since the relative humidity in the shed was constant, while the temperature decreased with an extension of night time (Table 1), the average numbers of thrips trapped by different light sources at night were positively correlated with the night temperature ($R_{520:560=4:1}$=0.944, $R_{520:560=2:1}$=0.944, R_{520}=0.929, $R_{560:520=2:1}$=0.983, $R_{560:520=4:1}$=0.921, R_{560}=0.904, p=0.05). Simultaneously, at the same time period at night (the temperature was the same), there was a significant linear correlation between the trapping of thrips and the ratio yellow-green light (Figure 4). The correlation analysis showed that the trapping of thrips was negatively correlated with the ratio of yellow-green light ($R_{19:00-21:30}$=–0.978, $R_{21:30-12:00}$=–0.990, $R_{0:00-2:30}$=–0.985, $R_{2:30-5:00}$= –0.976, p=0.05). The results showed that relative to yellow light, green light enhanced trapping, and as the amount of green light increased in the green-yellow ratio, the synergistic effect on trapping was more obvious.

3.2 Influence of yellow-green light on the phototactic trapping of *F. occidentalis*

Relative to the trapping effect captured by the contrast whiteboard, the total trapping effect of thrips induced by different light sources from 05:00-19:00-05:00 (day and night) and from 19:00-05:00 (night) is shown in Figure 6. The comparative results of thrip trapping between all-day (day and night) and night are shown in Figure 7.

Data in the figures are the means±standard error. Different capital letters indicate significant differences (p<0.05, multiple comparison: LSD). Different capital letters with the same single superscript and different capital letters with the same double superscript denote very significant differences (p<0.01) and extremely significant differences (p<0.001), respectively.

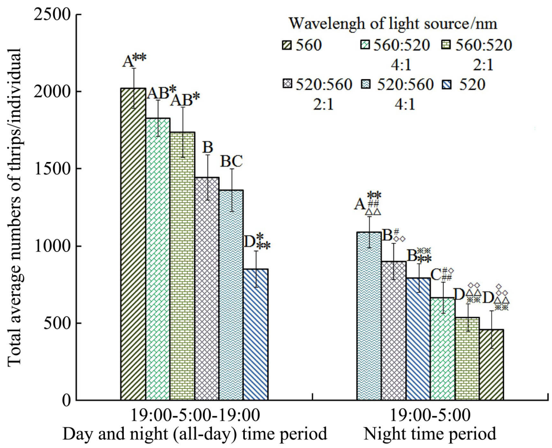


Figure 6 Total capture effect induced by light source

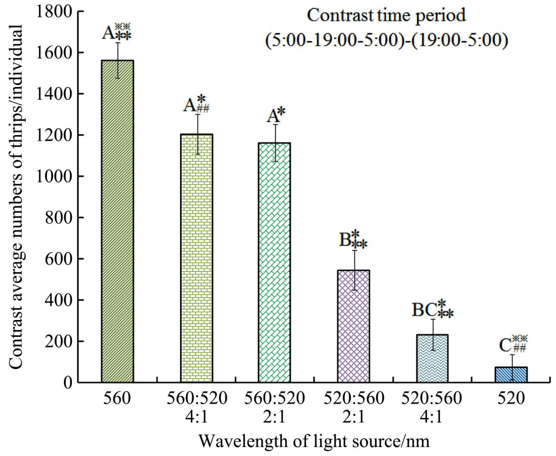


Figure 7 Comparative results of thrips trapping between all-day and night

The differences in the total trapping effect of thrips over the whole day were very significant (F=6.23, p<0.01), and that of yellow light were optimal (2019.67 individuals/all-day), followed by a green:yellow ratio=1:2 (1825.33 individuals/all-day), with that of green light being the worst (846.67 individuals/all-day), that of green:yellow ratio=4:1 light was the second worst (1360.00 individuals/all-day) (Figure 5). Relative to yellow light, green light significantly inhibited the total trapping effect of thrips all day, and as the proportion of green light in the green:yellow ratio increased, the inhibition was stronger.

The differences in the total trapping of thrips at night were extremely significant (F=6.23, p<0.01), but that between a green:yellow ratio=2:1, green light, a green:yellow ratio=1:4, and yellow light was not significant. The differences between green:yellow=1:4 light and green light and between yellow light and green light were significant. Between green:yellow=2:1 light and green:yellow=4:1 light, the difference was extremely significant. Between green:yellow=1:2 light and green:yellow= 2:1 light and between green:yellow=1:2 light and yellow light, the differences were very significant. The results showed that the total trapping of thrips induced by a green: yellow ratio=4:1 at night was optimal (1360.00 individuals/night), followed by a green: yellow ratio=2:1 (900.00 individuals/night), with that induced by yellow light, was the worst (456.67 individuals/night), that induced by green:yellow=1:4 light was the second worst (533.33 individuals/night). Relative to yellow light, green light enhanced the total trapping of thrips at night, and as the proportion of green light in the green-yellow combination increased, the synergistic effect was stronger.

Relative to the trapping effect (193.33 individuals/d) of the contrast whiteboard reflecting sunlight during the day, after thrips irradiated by spectral light, the irradiation effect significantly enhanced the trapping effect of white board reflecting spectral light (p<0.001) (Figure 6). And the trapping effect enhanced by yellow light was the best (1563.00 individuals/day), followed by green:yellow ratio=1:4 light, and that by green:yellow ratio=2:1 light was the third (1163.67 individuals/day). While the trapping effect enhanced by green light was the worst (75.33 individuals/day), that by green:yellow ratio=4:1 light, green:yellow ratio=2:1 light was the second, and third worst, respectively. The results showed that after being irradiated by light source, spectral light irradiation enhanced the visual trend sensitivity of thrips to whiteboard light color. That is, nocturnal light enhanced the bio-activity of thrips in the day, and the enhancement of yellow light was the strongest, while that of green light was the worst, and as the proportion of green light in the green-yellow combination increased, the enhancement effect decreased.

3.3 Discussion

F.occidentalis have compound eyes composed of about 70 ommatidiums and are referred to as apposition eyes. Thrips are diurnal insects and can be active during day and night[16], which presents a good color trend at a short distance, and the color light perception ability provides a good visual guarantee for its behavior[17]. Some studies have shown that different chromatographic ratios can enhance the trapping of thrips, and light intensity (brightness, energy) strongly affects the photo-regulatory phototaxis behavior of thrips[18,19]. Therefore, under the same light source and the same environment in the shed, the influence of yellow and green light, and their different proportions, on response of *F.occidentalis* were studied. The results showed that the sensitivity of thrips to the trap induced by green light was more than that induced by yellow light, which was related to the retinal sensitivity of diurnal insects[20]. Relative to yellow light, however, light with different proportions of yellow-green, and green-yellow, enhanced the effect of the light trap, which was positively correlated with the proportion of yellow and green light in the ratios, respectively. Relative to green light, the different proportions of yellow-green, and green-yellow light inhabited or enhanced the effect of the light trap, respectively, which was negatively and positively correlated with the proportion of yellow, and green light in the ratios, respectively. This finding may stem from the spectral anti-tuning sensitivity of the retinal ganglion cells of thrips being stimulated by green and yellow LED light[21,22]. And the action of the discriminative push-pull strategy of thrips phototactic vision, and the preference response to green light in retinal cells[23], caused green-yellow ratio light with more green light had the stronger synergetic trapping effect, which provides a theoretical basis for the development of thrips pests photoelectric induction machine.

It has been reported that yellow light can attract adults *F.occidentalis* in the daytime, but cannot attract adults at night. Thus, it has been hypothesized that this photoperiod activity rhythm may be related to the physiological rhythm of melatonin in the body[24], however, the resetting influence effects of LED light characteristics and night temperatures on the biological behavior of thrips were not considered. The results of this paper showed that night temperature significantly affected the utility of the light trap, and when the night temperature was 27°C, trapping was the best. As the night progressed and night temperature decreased, the trapping induced by light also decreased, showing that light and temperature can regulate the bio-activity of thrips, and the action effects of temperature and light on the biological habit, courtship, and mating behavior of insects were also found[25]. Thus, the combined effect of light and temperature can effectively improve the utility of the light trap, but under the same light intensity of the light source. The reason for the attraction of thrips to LED light was not clear.

To discuss the influence of optical factors of light source on thrips visual trend, when the illumination of the light source was 12 000 lx, the measured light source power, and light energy parameters are listed in Table 2.

According to the results in Table 1, Figure 5, and Table 2, it can be seen that the intensity of luminous power and the energy of a light source corresponds to the trapping ability of the light source; that is, as the luminous power and the energy of the light source increased, the trapping effect of the light source improved. Thus, luminous power and light energy produced by the luminous photoelectric effect of LED light affected the effect of the light trap effect. Considering the photo-electro-thermal conversion effect of light source giving out light, then, light source with the stronger power and light energy emitted a stronger heat quantity, and the trapping effect captured by light source was stronger. Therefore, the LED spectrum photo-thermal effect was responsible for the trapping effect. Studies have shown that at a certain temperature range at night, Oriental Migratory Locusts tend to be in the light at higher temperatures, and the activity and distribution of adult *F.occidentalis* are affected by the radiant heat from sunlight[26-28]. Thus, considering the differences in the visual sensitivity of thrips to the brightness of spectral light and the difference in spectrum electro-thermal conversion, the spectral photo-electro-thermal effect is the main reason for differences in the light trap on *F. occidentalis*.'

Table 2 Power and energy of different light sources

Wavelength/nm	Power/W	Light energy/mW·cm^{-2}
520:560=4:1	27.78	4.35
520:560=2:1	25.16	3.79
520	23.92	3.18
560:520=2:1	23.02	3.02
560:520=4:1	22.36	2.89
560	20.16	2.10

Note: The power of the light source was obtained by the equation $P=U\times I$. The energy of the single yellow and green light sources was the light energy at 50 mm. The light energy of yellow-green light of different proportions was the light energy of the intersection of the yellow and green light at 50 mm from the light source.

The results in this study showed that at night, the response of thrips to yellow light was the strongest, and that to green light was the weakest, and green light inhibited the response of thrips to yellow-green ratio light. After irradiation by light at night, the radiation light effect enhanced the trapping effect of the color plate on thrips in the daytime, and intensified the bio-sensitive activity of thrips to the color spectrum. In addition, the enhancement effect of yellow light was the strongest. Overall, these are results are consistent with previous results indicating that the insect light stress response is compensated for their bio-activities[29-31], then, the habitat behavior characteristics of thrips can be regulated by light. However, the cause of the differences between the response sensitivity and visual trend sensitivity of thrips to spectral light was not discussed in this paper. Additionally, the effects of light on the biological habits and the push-pull trap mechanism of thrips need to be further studied.

4 Conclusions

The visual trend sensitivity of *F. occidentalis* to green light was stronger than that to yellow light. Relative to yellow light, yellow-green light of different ratios enhanced the phototactic trapping of thrips, and as the proportion of green light increased, the synergistic effect increased. Relative to green light, green:yellow≥2:1 light enhanced while yellow:green≥2:1 light inhabited the trapping effect, and the trapping effect captured by green:yellow = 4:1 light was the best. The visual response of *F. occidentalis* to yellow light was stronger than that to green light. Relative to green light, yellow-green light of different ratios enhanced the total phototactic trapping of thrips all day long, and as the proportion of yellow light increased, the synergistic effect increased. The total trapping effect of yellow light was optimal, while that of green light was the worst. Moreover, after thrips were irradiated by light at night, the irradiation effect of yellow-green light enhanced their visual response sensitivity to the color spectrum in the daytime, and the enhancement effect caused by yellow light was the strongest while that caused by green light was the worst. However, the trapping ability of different light sources on thrips decreased with reductions in night temperature, while the photo-induced thermogenic effect intensified the visual trend effect of thrips. Then, through different light ratios during the day and at night, and the coupling implementation of spectral light, color plate, and thermal measure for thrips, thrips pests can be caught all day to achieve greenhouse pest control.

Acknowledgements

The authors acknowledge that this work was financially supported by the Scientific and technological project in Henan Province, China (Grant No. 212102110139, 212102110229), the Special Project of Xinxiang Science and Technology, China (Grant No.21ZD003), the Agriculture Research System of MOF and MARA (Grant No.CARS-03).

[References]

[1] Lyu Y B, Zhang Z J, Wu Q J, Du Y Z, Zhang H R, Yu Y, et al. Research progress of the monitoring, forecast and sustainable management of invasive alien pest *Frankliniella occidentalis* in China. Chinese Journal of Applied Entomology, 2011; 48(3): 488–496. (in Chinese)

[2] Kirk W D J. The aggregation pheromones of thrips (Thysanoptera) and their potential for pest management. Int. J. Trop. Insect Sci., 2017; 37(2): 41–49.

[3] Han Y, Tang L D, Wu J H. Researches advances on integrated pest management of thrips (Thysanoptera). Chinese Agricultural Science Bulletin, 2015; 31(22): 163–174. (in Chinese)

[4] Kirk W D J, Kogel W J, Koschier E H, Teulon D A J. Semiochemicals for thrips and their use in pest management. Annu. Rev. Entomol., 2021; 66: 101–119.

[5] Abdul A M, Song J H, Seo H J, Choi J J. Monitoring thrips species with yellow sticky traps in astringent persimmon orchards in Korea. Applied Entomology and Zoology, 2018; 53: 75–84.

[6] Tol R, Davidson M M, Butler R C, Teulon D, Kogel W. Visually and olfactorily enhanced attractive devices for thrips management. Entomologia Experimentalis et Applicata, 2020; 168: 665–677.

[7] Zhang A S, Yu Y, Zhuang Q Y, Song Y Q, Men X Y. Effect of spectral sensitivity and intensity on the behavioral response of the *Thrips palmi* female adult. Acta Ecologica Sinica, 2015; 35(11): 3555–3561.

[8] Vernon R S, Gillespie D R. Influence of trap shape, size, and background color on captures of *Frankliniella occidentalls* (Thysanoptera: Thripidae) in a cucumber greenhouse. J Econ Entomol, 1995; 88(8): 288–293.

[9] Yu C, Rui Z J, Zhang C, Wang R Z, Shang C, Gao B Z, et al. Behavioral responses of *Frankliniella occidentalis* to floral volatiles combined with different background visual cues. Arthropod-Plant Interactions, 2018; 12: 31–39.

[10] Matteson N, Terry I, Ascoli CA, Gilbert C. Spectral efficiency of the western flower thrips, *Frankliniella occidentalis*. Journal of Insect Physiology, 1992; 38(6): 453–459.

[11] Otani Y, Wakakuwa M, Arikawa K. Relationship between Action Spectrum and Spectral Sensitivity of Compound Eyes Relating Phototactic Behavior of the Western Flower Trips, *Frankliniella occidentalis*. Jpn. J. Appl. Entomol. Zool, 2014; 58: 177–185.

[12] Murata M, Hariyama T, Yamahama Y, Toyama M, Ohta I. Effects of the range of light wavelengths on the phototactic behaviour and biological traits in the melon thrips, *Thrips palmi* Karny (Thysanoptera: Thripidae). Ethol Ecol Evol., 2017; 22: 101–113.

[13] Fan F, Ren H M, Lu L H, Zhang L P, Wei G S. Effect of spectral sensitivity and intensity response on the phototaxis of *Frankliniella Occidentalis* (Pergande). Acta Ecologica Sinica, 2012; 32(6): 1790–1795.

[14] Yang J Y, Sung B K, Lee H S. Phototactic behavior 8: phototactic behavioral responses of western flower thrips, *Frankliniella occidentalis*, Pergande (Thysanoptera: Thripidae), to light-emitting diodes. Appl Biochem Biotech, 2015; 58(3): 1–5.

[15] Pobozniak M, Tokarz K, Musynov K. Evaluation of sticky trap colour for thrips (thysanoptera) monitoring in pea crops (*Pisum sativum L.*). Journal of Plant Diseases and Protection, 2020; 127: 307–321.

[16] Lewis T, Taylor L R. Diurnal periodicity of flight by insects. Ecol. Entomol., 2010; 116(15): 393–435.

[17] Kishi M, Wakakuwa M, Kansako M, Inuma T, Arikawa K. Action spectrum of phototactic behavior and compound eye spectral sensitivity in yellow Tea Trips, *Scirtothrips dorsalis Hood* (Tysanoptera: Tripidae). Jpn. J. Appl. Entomol. Zool, 2014; 58: 13–16. (in Janpanese)

[18] Wu Q J, Xu B Y, Zhang Y J, Zhang Z J, Zhu G R. Taxis of western flower thrips to different colors and field efficacy of the blue sticky cards. Plant Protection, 2007; 33(4): 103–105. (in Chinese)

[19] Liu Q H, Jiang Y L, Miao J, Gong Z J, Li T, Duan Y, et al. Visual response effects of western flower thrips manipulated by different light spectra. Int J Agric & Biol Eng, 2019; 12(5): 21–27.

[20] Liu Q H, Zhou Q. Influence of the visual reaction effect induced and stimulated by different light on the phototactic behavior in Locusta migratoria. Int J Agric & Biol Eng, 2017; 9(2): 186–194.

[21] Münch T A, Silveira R, Siegert S, Viney T J, Awatramani G B, Roska B. Approach sensitivity in the retina processed by a multifunctional neural circuit. Nature Neuroscience, 2009; 12(10): 1308–1316.

[22] Gong Z, Liu J, Guo C, Zhou Y Q, Teng Y, Liu L. Two pairs of neurons in the central brain control Drosophila innate light preference. Science, 2010; 330(3): 499–502.

[23] Liu Q H, Jiang Y L, Miao J, Gong Z J, Li T, Duan Y, et al. Study on the visual response of *Frankliniella occidentalis* to ultra violet-visible spectroscopy with different wavelength ranges. Journal of Biobased Materials and Bioenergy, 2021; 15: 1–7.

[24] Hu S, XiaoY W, Zhong Q Y, Jian J D. Effects of photoperiod and light intensity on wing dimorphism and development in the parasitoid *Sclerodermus pupariae* (Hymenoptera: Bethylidae). Biological Control, 2019; 133: 117–122.

[25] Cheng L Y, Zhang Y, Chen Z Z, Xu Y Y. Effects of photoperiod and temperature on diapause termination and postdiapause development and reproduction of the green lacewing, *Chrysopapallens* (Neuroptera: Chrysopidae). Acta Entomologica Sinica, 2017; 60(3): 318–327. (in Chinese)

[26] Pei C Y, Zhang Y P, Zheng C Y. Distribution and daily activity of adult western flower thrips *Frankliniella occidentalis* (Pergande)] under solar greenhouse condition. Chin. J. Eco-Agric., 2010; 18(2): 384–387. (in Chinese)

[27] Liu Q H, Wu Y Q, Zhao M F. Photo-induced visual response of western flower thrips attracted and repulsed by their phobotaxis spectrum light. Int J Agric & Biol Eng, 2022; 15(2): 48–57.

[28] Liu Q H, Jiang Y L, Miao J, Gong Z J, Li T, Duan Y, et al. Photoreceptive reaction spectrum effect and phototactic activity intensity of locusts' visual display characteristics stimulated by spectral light. Int J Agric & Biol Eng, 2021; 14(2): 19–25.

[29] Ren X Y, Wu S Y, Xing Z L, Xu R R, Cai W Z, Lei Z R. Behavioral responses of western flower thrips (*Frankliniella occidentalis*) to visual and olfactory cues at short distances. Insects, 2020; 11(3): 177. doi: 10.3390/insects11030177.

[30] Kim K N, Huang Q Y, Lei C L. Advances in insect phototaxis and application to pest management: A review. Pest Management Science, 2019; 75(12): 3135–3143.

[31] Liu Q H, Zhao M Q, Miao J, Fu G C, Wu Y Q. Influences of yellow and green lights on the visual response of western flower thrips and field verification. Int J Agric & Biol Eng, 2022; 15(4): 49–56.