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Phototactic behavior of yellow stemborer and rice leaf folder moths to surface mount device-light emitting diodes of various wavelengths

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ABSTRACT

Many nocturnal insect pests exhibit positive phototaxis to the artificial lights of a certain wavelength. Identifying the phototaxis of pests is potentially useful for integrated pest management. This study examined the phototactic response of two major insect pests of paddy crops, yellow stemborer (YSB), *Scirpophaga incertulas*, and rice leaf folder (LF), *Cnaphalocrocis medinalis* moths (Lepidoptera: Pyralidae). Four monochromatic and three bichromatic surface mount device-light emitting diodes strips - ultraviolet (365 ± 5 nm), violet (400 ± 5 nm), blue (465 ± 5 nm), green (525 ± 5 nm), ultraviolet-violet (365 + 400 nm), violet-blue (400 + 465 nm), and ultraviolet-blue (365 + 465 nm) are used for the study. Based on the laboratory and field experiments, YSB moths showed the strongest attraction to ultraviolet (365 ± 5 nm) and LF attraction was highest to violet (400 ± 5 nm) lights. In bichromatic phototactic experiments, both species exhibited the strongest attraction to ultraviolet-violet (365 + 400 nm) lights. The influence of luminance intensity, adaption time in darkness, and light exposure time on the phototactic behavior of these moths are also tested. YSB and LF moths attraction rate increased with an increase in luminance intensity and violet (400 ± 5 nm) at 70 lx showed the strongest attraction. The light attraction rate of YSB was highest at 60 min of dark adaptation and 45 min of light exposure time, LF has a higher attraction rate at 60 min of dark adaptation and 30 min of light exposure time.

Keywords: Light trap, Surface mount device-light emitting diodes, Phototactic response, Rice leaf folder, Yellow stemborer.

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1. INTRODUCTION

Yellow stemborers and rice leaf folders are destructive pests of rice (*Oryza sativa*) in India (Amit et al., 2012). YSB causes severe yield loss in the paddy fields (Khan, 1991) as its larvae bore at the base of the plant leading to drying of its central shoot (dead heart). LF larvae fold the paddy leaves around them and then feed on the leaves resulting in the reduction of the photosynthesis process of the plants. Chemical insecticides are extensively used for control which is increasing environmental pollution (Antignus, 2000; Yang, 2002). The presence of yield affecting pests in the field must be identified at the early stage so that they can be controlled effectively. Light traps are a good choice in pest monitoring as they are easy to construct and deploy. In the case of insects with no known pheromones, light traps are the most preferred option. The light attraction of the insects differs with various characteristics of light, like light wavelength, and light exposure time (Sambaraju and Phillips, 2008; Park and Lee, 2017). Furthermore, the attraction level of insects is related to their dark adaption time, light exposure time, age, etc (Liao et al., 2017; Kim et al., 2018).

Gas lamps, incandescence lamps, fluorescent lamps, and light-emitting diodes (LED) are the various types of artificial light sources used in the light traps. LED light traps have become more popular in monitoring insect pests (Yeh and Chung, 2009; Zheng et al., 2014) due to better luminous efficiency, low power consumption (operable with battery), low cost, and durability. Light wavelengths used in the light trap usually range from 350 to 700 nm (Peitsch et al., 1992; Briscoe and Chittka, 2001; Bishop et al., 2004). The ultraviolet (UV), blue and green-sensitive photoreceptors are typical for many insects (Shimoda and Honda, 2013). Yang et al. (2012) investigated the phototactic response of tobacco cutworm (*Spodoptera litura*) adults to red (625 ± 10 nm), yellow (590 ± 5 nm), green (520 ± 5 nm), and blue (470 ± 10 nm) high-power LEDs. The attraction of the cutworms to LEDs at five different luminance intensities with five different light exposure times was measured in a test chamber with fluorescent light (380 - 800 nm, 50.0%) used as a positive control. Green (520 ± 5 nm) high-power LEDs showed the highest attraction rate (64.3%), whereas blue (470 ± 10 nm, 47.7%) was the second-best at 60 min light-exposure time with 40 lx luminance intensity. Chen et al. (2013) examined the phototactic response of Armand pine bark weevil (*Pissodes punctatus*) to nine monochromatic lights (340 - 689 nm), at five different light intensities (1 lx - 200 lx). Violet light (415 nm) at a light intensity of 10 lx showed the strongest attraction followed by UV light (340 nm) at 5 lx light intensity.

Luo and Chen (2016) studied the nocturnal behavior of a parasitoid wasp (*Scleroderma guani*) of bark-weevil to different monochromatic lights at various light intensities. The wasps were most attracted to blue (450 nm) wavelength light at 100 lx light intensity. As the phototactic response (Chen et al., 2013) of bark weevil also has the same range of spectral sensitivity, light traps in armandii plantation must be utilized only during and after bark weevil peak emergence. (Katsuki et al., 2012) studied the attraction of West Indian sweet potato weevil (*Euscepes postfasciatus*) to direct UV (375 nm), diffused UV, direct green (520 nm), diffused green, and green lights with sweet potato bait. They achieved the best attraction with diffused UV LEDs with sweet potato bait. (Jeon et al., 2014) investigated phototactic attraction of greenhouse whitefly adults (*Trialeurodes vaporariorum*) to red (625 ± 10 nm), yellow (590 ± 5 nm), green (520 ± 5 nm), blue (470 ± 10 nm), UV (365 nm), and infrared (IR) (730 nm) LEDs in a Y-maze chamber. Blue LED light with 30 min exposure time at 40 lx luminous intensity achieved the highest attraction rate (97.3%). Kim and Lee (2014) studied Angoumois grain (*Sitotroga cerealella*) moths phototactic response to red (625 ± 10 nm), yellow (590 ± 5 nm), green (520 ± 5 nm), blue (470 ± 10 nm), UV (365 nm), and IR (730 nm) LEDs. UV LEDs showed the highest attraction rate (67.7%). Yang et al. (2015) examined western flower thrips (*Frankliniella occidentalis*) phototactic behavior to white (450 - 620 nm), red (625 ± 10 nm), yellow (590 ± 5 nm), green (520 ± 5 nm), blue (470 ± 10 nm), and IR (730 nm). After comparing the attraction rate with different light wavelengths, luminance intensities, and exposure times, they identified that yellow light with 80 lx luminous intensity and 90 min exposure was most attractive to western flower thrips.

Wen et al. (2018) examined snout weevils (*Eucryptorrhynchus scrobiculatus*, *Eucryptorrhynchus brandti*) phototactic response to various wavelength lights with respect to starvation, light, and dark exposure times. Laboratory and field experiments were conducted and identified that violet (400 - 410 nm) was most attractive to the weevils. Liu et al. (2018) evaluated the sensitivity of oriental fruit flies (*Bactrocera dorsalis*) of different genders and ages to white, purple (440 nm), red (633 nm), blue (450 nm), yellow (596 nm), and green (522 nm) LED lights. They identified that with the increase in age, positive phototaxis increased significantly. The male adult fruit flies are more sensitive to the test lights than the female adults, and green (522 nm) was the most attractive light to both flies. In this paper, we investigated the phototactic response of the YSB and LF moths to different wavelength lights in laboratory and field conditions. An observation box for laboratory tests and four-light traps for field tests are constructed for the study. The influence of luminance intensity, dark adaption time, and light source exposure time on the phototactic behavior of the moths are also been evaluated.

2. MATERIALS AND METHODS

2.1 Insect Pest Source

YSB and LF moths are collected from the paddy fields using insect nets near Kadur village, Sri City (13°35'06.0"N, 79°57'51.6"E), Andhra Pradesh, India, in July 2020. The active and healthy adults (mixed sex) are selected and kept at room temperature of 25–28°C, with a relative humidity of 65–75% for the study.

2.2 Light Source

Light sources are constructed with surface mount device-light emitting diode (SMD-LED) strips as they are more flexible, energy-efficient, long-lasting, and have a larger beam angle (typically 120º) compared to ordinary through-hole LEDs. The SMD strips are purchased from Monssen Electronics Co., Ltd, and Shenzhen Suntech Co., Ltd (Shenzhen, China). The light sources are made of 2.5 m long SMD-LEDs with 150-LEDs adhered around 10-inch-long cylindrical pipes. Four such monochromatic light sources with light wavelengths of 365 ± 5 nm (ultraviolet (UV)), 400 ± 5 nm (violet (V)), 465 ± 5 nm (blue (B)), and 525 ± 5 nm (green (G)) are used for the study. Bichromatic light sources are made by combining UV-V (365 + 400 nm), V-B (400 + 465 nm), and UV-B (365 + 465 nm). The luminance intensity of V, B, and G light sources are adjusted using potentiometers. For measuring luminance intensity (30.4 cm from the light source), an illuminometer (*Sekonic i-346*) was purchased from Seiko Electric Industries Co., Ltd (Tokyo, Japan).

2.3 Laboratory Experimental Setup

An observation box with dimensions of 3 ft × 3 ft × 1.2 ft was constructed to observe the phototactic response of collected YSB and LF moths. Its interior was covered with black sheets to minimize light reflections. The box is divided into four compartments and its base is divided into three zones, namely insects release zone (neutral zone), sensitive zone, and phototaxis zone. Each zone is further divided into 1-inch-wide sectors and numbered accordingly. Observation box with monochromatic and bichromatic SMD-LED lights are shown in Fig. 1a & 1b. The box is kept in a dark room and its top is covered with an acrylic plastic sheet for observing the moths movements during the experiments. The acrylic sheet has an openable entry at its centre for releasing the moths in the insects release zone. Based on the insect location in the observation box, the phototaxis index was calculated using Equation (1). The greater the phototaxis index, the stronger the phototactic behavior (Wen et al., 2018).

$$\text{Phototaxis index} = \frac{\Sigma(N_{ts} \times N_{st})}{N_s \times N_t} \times 100 \quad (1)$$

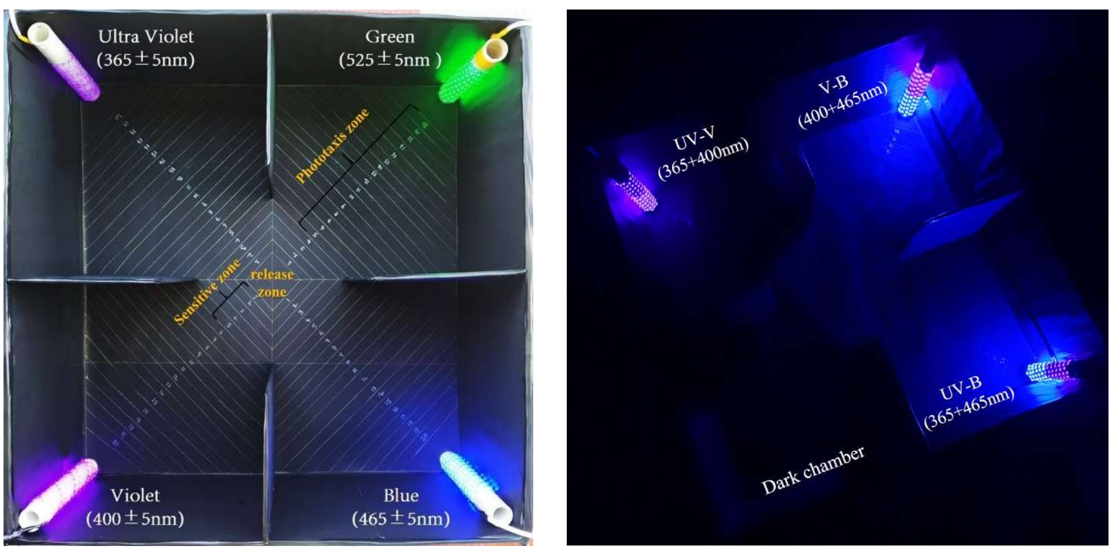
Where N_{ts} is the total number of moths within a specific sector, N_{st} is the total number of sectors with moths, N_s is the total number of sectors in the phototaxis zone ($N_s = 16$), N_t is the total number of moths released in the observation box ($N_t = 25$).

2.4 Field Experimental Setup

The phototactic response of YSB and LF moths for different wavelengths is studied in field conditions to validate the results obtained from the laboratory experiments. Field studies are conducted in the same paddy fields from where the moths are collected for laboratory testing. The designed light traps are 3-feet tall single-pole structures with three components: 1) SMD-LED light source, 2) Plastic funnel, 3) Catch container. The traps are placed on a 3-feet support rod for better visibility to the insects in the field. Four similar light traps are designed for testing the phototactic response of the moths to four wavelength light sources as shown in Fig. 2. The light traps are powered with a 12 V 12 Ah DC battery. The catch container is a 10-liter plastic container with an openable lid at its bottom. During the study period, the nitrogen fertilizer was punctiliously applied and abstained from applying chemical pesticides, which have made both the species sufficiently available during the testing period.

2.5 Statistical Analysis

The significant differences between the means of the repeated experiments are compared with one-way ANOVA in IBM SPSS Statistics software SPSS V25. Tukey's honest significant difference (HSD) test is used for analysing significant differences.



(a) (b)

Fig. 1. Observation box divided into different zones with a) monochromatic b) Bichromatic SMD-LED lights in the corners

Fig. 2. Light traps in the paddy field

3. RESULTS

3.1 Phototactic Behavior of YSB and LF Moths to Different Wavelength Lights Under Different Luminance Intensities

The phototactic behavior of YSB and LF moths to monochromatic violet, blue, and green SMD-LEDs under four luminance intensities (10 lx, 30 lx, 50 lx, and 70 lx) are examined. In every test, four similar wavelength light sources are used with different luminance intensities by adjusting the potentiometer connected in series with the lights. For each experiment, moths are released in the observation box for 90 min. Based on the location of the moths after the experiment, the phototactic attraction rate (mean ± standard error of the mean (SEM)) % is calculated. The YSB and LF moths attraction towards light sources increased with an increase in light intensity and they showed the highest attraction at 70 lx luminance intensity as shown in Table 1 and Table 2. Since UV (365 ± 5 nm) luminance intensity cannot be measured using an illuminometer, they are excluded from the luminance tests.

3.2 Phototactic Behavior of YSB and LF Moths to Different Wavelength Lights in Laboratory Conditions

The four monochromatic lights are fixed at the corners of the observation box for conducting the experiments. YSB exhibited strongest attraction towards UV with attraction rate of 47% followed by violet with 31% attraction among all the repeated experiments (df = 15, F = 39.360, $p < 0.05$). LF showed strong attraction towards violet light with 42% attraction rate followed by UV with attraction rate of 39% (df = 15, F = 82.080, $p < 0.05$). As the wavelength increased the attraction rate of YSB drastically reduced, whereas the LF has shown good attraction towards both UV and violet lights. The attraction of both species towards the green light was very poor. The phototactic response of YSB and LF moths in the laboratory conditions is shown in Fig. 3. In the graph, the error bar specifies the standard deviation and the same letters above the bars indicate no significant difference ($p > 0.05$), according to the Tukey HSD test.

Table 1. Attraction rate of YSB adults to SMD-LEDs under various luminance intensities

Color (Wavelength)	YSB attraction rate ((Means ± SEM, %)			
	Luminance intensity (lx)			
	10	30	50	70
Violet (400 ± 5 nm)	9.6 ± 2.30	19.2 ± 1.79	31.2 ± 1.92	36.8 ± 2.39
Blue (465 ± 5 nm)	7.2 ± 1.92	18.4 ± 1.34	29.6 ± 1.67	31.2 ± 1.30
Green (525 ± 5 nm)	3.2 ± 0.85	16 ± 1.21	20.8 ± 2.60	35.2 ± 3.12

Table 2. Attraction rate of LF adults to SMD-LEDs under various luminance intensities

Color (Wavelength)	LF attraction rate ((Means ± SEM, %)			
	Luminance intensity (lx)			
	10	30	50	70
Violet (400 ± 5 nm)	8.8 ± 1.64	17.6 ± 1.67	29.6 ± 1.14	40.8 ± 2.39
Blue (465 ± 5 nm)	5.6 ± 1.34	19.2 ± 1.48	28 ± 1.22	37.6 ± 2.07
Green (525 ± 5 nm)	6.4 ± 1.16	12.8 ± 0.84	25.6 ± 1.82	29.6 ± 2.190

3.3 The Influence of Light Exposure Time on the Phototactic Behavior of YSB and LF Moths

The effect of light exposure time on the phototactic response of the YSB and LF are evaluated as shown in Fig. 4. In YSB testing, the UV light source is kept in one corner and the remaining corners are dark chambers. Similarly, for LF moths, violet wavelength light is kept in one corner for the experiment. The experiments are conducted for different times (15, 30, 45, and 60 min) and at the end of each experiment, the location of the moths is noted. YSB attraction towards UV increased significantly with 45 min exposure time and no significant improvement beyond that among all the repeated experiments ($df = 11$, $F = 55.851$, $p < 0.05$). LF attraction towards violet light increased significantly with 30 min exposure time ($df = 11$, $F = 26.897$, $p < 0.05$).

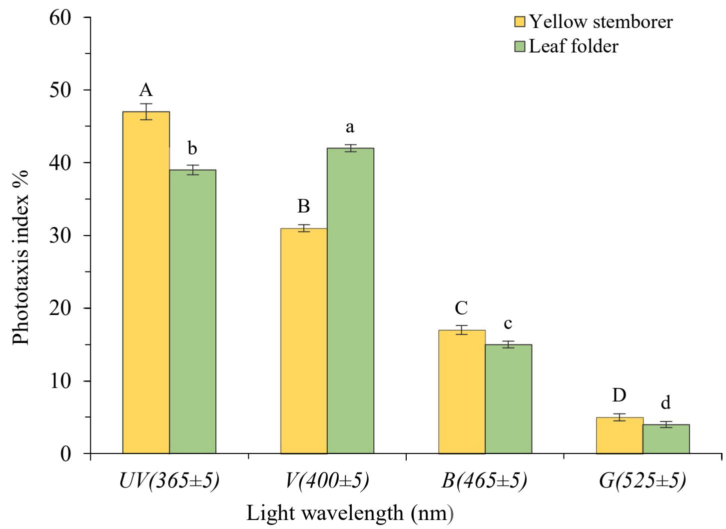


Fig. 3. Phototaxis indexes of YSB and LF moths to different wavelength lights in laboratory conditions

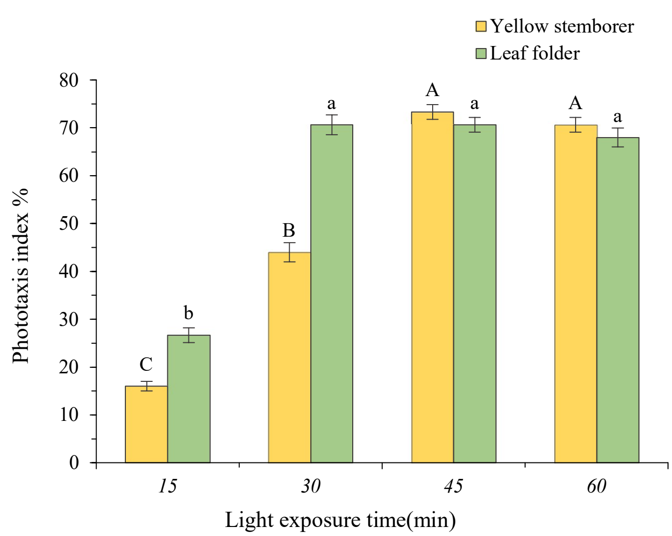


Fig. 4. Effect of light exposure time on the phototaxis indexes of YSB and LF moths

3.4 The Influence of Dark Adaptation Time on the Phototactic Behavior of YSB and LF Moths

The effect of dark adaption time on the phototactic response of the YSB and LF is evaluated as shown in Fig. 5. Both the species are kept in a dark chamber for different timings (0, 1, 2, and 3 hrs) before released into the observation box. UV light is used for YSB and violet light is used for LF as like the light exposure time experiment. An increase in attraction towards the light is observed in both the species after an hour of dark adaptation time (df = 11, F = 17.963, $p < 0.05$; df = 11, F = 27.865, $p < 0.05$). As the dark adaptation time increased beyond an hour, the attraction is reduced.

3.5 Phototactic Behavior of YSB and LF Moths to Light Traps with Different Wavelength Lights in the Paddy Field

The phototactic response of YSB and LF moths to different wavelength lights is studied in field conditions. The light traps are turned on during the night time and the next morning, the trapped moths are separated from the catch container for counting. Trapped insects in the light trap container are shown in Fig. 6a, and separated leaf folder moths from the catch container are shown in Fig. 6b. The average number of YSB and LF moths captured by different light traps is shown in Fig. 7. YSB showed the strongest attraction to UV light. The phototaxis indices for UV light was significantly higher among all the five repeated experiments (df = 19, F = 45.950, $p < 0.05$). The attraction of the YSB reduced drastically as the light wavelength increased. LF showed the strongest attraction to violet light among all the repeated experiments (df = 19, F = 34.088, $p < 0.05$). Both the species exhibited the least attraction to the green light in the field tests.

3.6 Phototactic Behavior of YSB and LF Moths to Different Bichromatic Wavelength Lights in Laboratory Conditions

The phototactic behavior of YSB and LF moths to three bichromatic wavelength lights (UV-V, V-B, and B-UV) is examined. The green light source was not used in the experiments as its attraction to the moths is very poor, so one corner was kept as a dark chamber. The attraction rate of bichromatic lights to YSB and LF is shown in Table 3. The YSB and LF moths shown strong attraction towards UV-V light among all the repeated experiments (df = 11, F = 45.6, $p < 0.05$; df = 11, F = 23.560, $p < 0.05$).

3.7 Phototactic Behavior of YSB and LF Moths to Different Bichromatic Wavelength Lights in the Field Conditions

The phototactic response of the moths to bichromatic light sources is tested in field conditions. The number of YSB and LF trapped in the catch container is counted and the results are tabulated in Table 4. YSB was most attracted to UV-V among five repeated experiments (df = 19, F = 6.118, $p < 0.05$) followed by B-UV lights whereas LF was most attracted to UV-V (df = 19, F = 2.093, $p < 0.05$) followed by V-B lights.

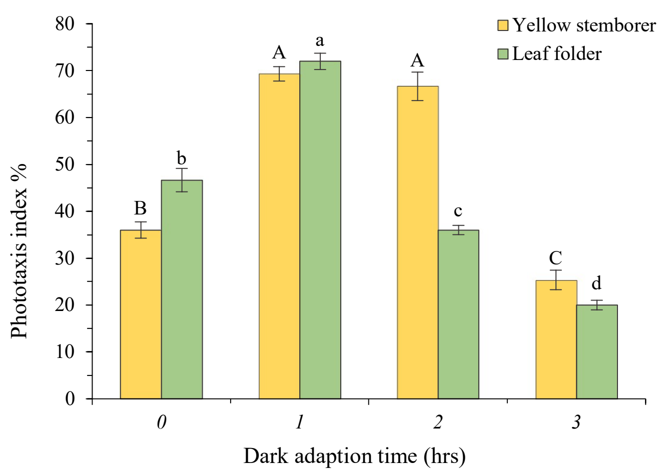


Fig. 5. Effect of dark adaptation time on the phototaxis indexes of YSB and LF moths

Fig. 6. (a) Trapped insects in the light trap container (b) Separated leaf folder moths for counting

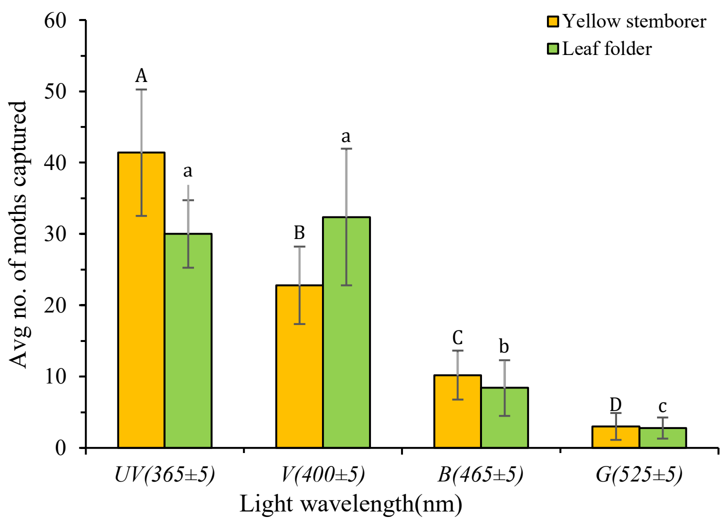


Fig. 7. Average number of YSB and LF moths captured by light traps with different wavelength lights in field conditions

4. DISCUSSION

In agriculture, insect pest monitoring is essential to know whether the economic threshold has been reached and to observe the effectiveness of control measures. For monitoring the insect pests in the field, the light trap is a potential option. To improve the trapping efficiency of the light traps, several hypotheses are presented on insect phototaxis (Kim et al., 2019) over the past years. The insect pest penetration increases in the vegetative stage of a crop and then their population multiplies rapidly in the field due to pests breeding. With the help of light trap sampling data, control measures can be applied quickly to avoid pest procreation. Advances in the studies on the phototactic response of destructive pests for specific crops can help improve the trapping efficiency of the light trap. In paddy crops, YSB and LF moths are major pests in South India that are contributing to severe yield loss.

In the current study, The YSB and LF moths phototactic response to various light wavelengths, luminance intensities, different darkness adaption times, and light exposure times are tested. the phototactic behavior of YSB and LF moths to monochromatic- ultraviolet, violet, blue and green lights, as well as bichromatic- UV-V (365 + 400 nm), V-B (400 + 465 nm), and B-UV (365 + 465 nm) wavelength lights, are investigated. For better accuracy in the results, the wavelength experiments are conducted in the laboratory as well as in the field conditions. The results obtained from both field and laboratory experiments are similar with trivial deviations.

Table 3. The attraction rate of YSB and LF moths to bichromatic SMD-LEDs in the laboratory conditions

Color (Wavelength)	Attraction rate (Mean ± SEM, %)	
	YSB	LF
UV-V (365 + 400 nm)	53 ± 0.957	46 ± 1.291
V-B (400 + 465 nm)	19 ± 1.708	31 ± 0.957
B-UV (365 + 465 nm)	25 ± 1.258	18 ± 1.915

Table 4. The attraction of YSB and LF moths to bichromatic SMD-LEDs in the paddy field.

Color (Wavelength)	Attraction (Means ± SEM)	
	YSB	LF
UV-V (365 + 400 nm)	9.2 ± 1.924	8.4 ± 2.408
V-B (400 + 465 nm)	4.4 ± 2.074	6.6 ± 2.966
B-UV (365 + 465 nm)	5.6 ± 2.702	4.6 ± 3.362

The attraction of YSB moths are strongest towards monochromatic UV (365 ± 5 nm) and bichromatic UV-V (365 + 400 nm) lights. LF are most attracted to V (400 ± 5 nm) and UV-V (365 + 400 nm).

In the luminance intensity tests, the attraction of YSB and LF to violet, blue, and green wavelength lights increased with an increase in the luminance intensities, and both species showed the strongest attraction to violet light at 70 lx luminance intensity. In the light exposure and dark adaptation time experiments, both the species showed notable differences in their attraction. From the observations, it's found that an hour of dark adaptation time is significantly improving both species attraction towards the light source, hence it's preferred to switch on the light trap one hour after the sunset. The light exposure time results indicate that the light traps must be on in the field for at least 45 min for YSB and 30 min for LF moths for better luring. To make effective pest monitoring, researchers must focus on identifying the best-suited wavelength lights with various light properties in the light traps for serious yield affecting pests in various crops.

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