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Phototactic behavior 10: phototactic behavioral effects of *Plodia interpunctella* (Hübner) (Lepidoptera: Pyralidae) adults to different light-emitting diodes of seven wavelengths

Jun-Hwan Park[1] **· Hoi-Seon Lee**[1]

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Abstract Phototactic behavioral responses of the Indian meal moth, *Plodia interpunctella* (Hübner), adults were determined to different light-emitting diodes (LEDs) of seven wavelengths, and their behavioral responses were compared to that using a commercial luring lamp (BLB) under laboratory conditions. Based on the attractive responses under optimal light conditions (60 lx luminance intensity and 30 min light exposure time), the green LED (520±5 nm) showed the highest attractive rate (520±5 nm, 52.2 %), followed by the blue LED (470±10 nm, 33.9 %), the yellow LED (590±5 nm, 32.2 %), BLB (28.9 %), UV LED (365 nm, 22.8 %), the red LED (625±10 nm, 14.5 %), the white LED (450–620 nm, 10.6 %), and IR LED (730 nm, 9.5 %). In addition, the green LED to *P. interpunctella* adults was approximately 1.81 times more attractive than BLB. These results indicate that the green LED could be most useful for monitoring of *P. interpunctella* adults.

Keywords Light-emitting diodes · Light exposure time · Luminous intensity · Phototactic behavioral responses · *Plodia interpunctella*

Introduction

The insect control of stored food product is very important to maintain the quality of foods/grains. This is particularly true in grain storages and food processing plants, where detection of an insect infestation in foods/grains for human consumption can accrue enormous losses for the producer (Phillps, 2006; Kishan et al. 2008). The Indian meal moth, *Plodia interpunctella* (Lepidoptera: Pyralidae), is a wide-spread insect pests of stored grains and value-added food products (Zhu et al. 1999; Nansen and Phillips 2004). The *P. interpunctella* adults attack stored food/grain products of different nutritional values and physical condition and development is mainly affected by the diet upon which it feeds during the larval stage (Lecato 1976; Na and Ryoo 2000). *P. interpunctella* larvae can invade packaged foods and feed on a wide diversity of foods such as cereals, nuts, dried fruits, and some spices (Na and Ryoo 2000; Sauer and Shelton 2002; Perez-Mendoza and Aguilera-Peña 2004). Current pest management of the stored foods/grains has depended on the use of chemicals, such as chlorfluazuron and methyl bromide (Mohandassa et al. 2007; Ebadollahi et al. 2010). Methyl bromide is commonly used fumigant in the management of the stored-product pests. However, Montreal Protocol, an international agreement (Anonymous 2004) will certainly further affect management for *P. interpunctella*, accelerating the demand for effective control strategies (Phillips et al. 2000). Recently LED traps are extensively used to control insect pests (Zheng et al. 2014). LEDs have some advantage including low temperature, small size, low cost, sensitivity, high reliability, and long operating life time (Chen et al. 2004; Jeon et al. 2014). Therefore, the aim of our study was to determine the phototactic behavior of *P. interpunctella* adults in response to LED, and it was compared with that of a commercial BLB.

Hoi-Seon Lee (✉)
E-mail: hoiseon@jbnu.ac.kr

[1]Department of Bioenvironmental Chemistry, College of Agriculture & Life Science, Chonbuk National University, Jeonju 54896, Republic of Korea

Materials and Methods

Stored insect pest

A culture of Indian meal moth adults was obtained from the National Academy of Agricultural Science, RDA (Korea). They were reared on an artificial diet consisting of 480 g corn meal, 120 g flour, and 70 mL glycerol. The culture was maintained at

65±4 % relative humidity (RH), 27±2 ºC, and a 14 h light/10 h dark photoperiod.

Light source and test chamber

The light sources were produced by Kodenshi Auk Co. Ltd (Korea). The types of LEDs used in our study as follow: UV LED (365 nm), blue LED (CL-1 W-UBB, 15.0±3.1 lm, 470±10 nm), green LED (CL-1 W-UPGB, 45.0±3.5 lm, 520±5 nm), yellow LED (PP592-8L61-AOBI, 40.0±10.0 lm, 590±5 nm), red LED (CL-1 W-UBB, 350.0±1.2 lm, 625±10 nm), white (CL-1W-URB, 450−620 nm), and IR LED (730 nm). The LED modules board (70×140 mm) is composed of 40 LEDs of each color and was attached to a control circuit board (300×150 mm) in the chamber. The phototactic behavioral responses of *P. intrepunctella* adults were compared with those to a BLB (315−400 nm, F8T5 BLB: Sankyo-Denki Co. Ltd., Tokyo, Japan), which served as a control. The phototactic test chamber for analyzing the phototactic behavioral responses of *P. interpunctella* adults was designed by Oh and Lee (2010). The test chamber consisted of an opaque acrylic body (500×1,500×300 mm) and two transparent acrylic walls that were fitted inside on both ends of the test chamber. An insect entrance hole (100 mm in diameter, covered with nylon fishnet cloth) was placed at a point between the light arm and the dark. The experiments were conducted in a chamber kept at 27±2 ºC and 65±4 % RH in darkness.

Bioassay

The phototactic behavioral responses of *P. intrepunctella* adult were measured under different light conditions, such as different luminance intensities, wavelengths, and light durations. The luminance intensities of the LEDs was measured using an illuminometer (LM-322; AS ONE Co. Ltd., Osaka, Japan) positioned 700 mm from the light source. Thirty *P. intrepunctella* adults were collected using aspirator and were released into the insect entrance hole of chamber. The behavioral responses of *P. intrepunctella* adults to LEDs were evaluated by counting the number of located insects in the 'light' and 'dark' zone of the chamber. These results were compared with those of BLB. Attractive rate (%) = (A number of *P. intrepunctella* adults in a rage of 500 mm from light sources/total *P. intrepunctella*) × 100. All experiments were repeated at least five times. The statistical analysis was performed by analysis of variance (ANOVA) to compare the number of *P. intrepunctella* adults attracted to each LED using SPSS ver. 18.0 software (SPSS Inc., Chicago, IL, USA). Results are expressed as mean ± SE (standard error).

Results and Discussion

To evaluate the behavioral responses of *P. intrepunctella* adults to the LEDs, the attractive effects to seven monochromatic light, five luminous intensities, and light exposure times were compared to that of a BLB, which served as a positive control. The attractive rate of *P. intrepunctella* adults to five (blue, green, yellow, red, and white) LEDs under five luminous intensities (20, 40, 60, 80, and 100) are shown in Table 1. The blue (470±10 nm), green (520±5 nm), yellow (590±5 nm), red (625±10 nm), and white (450−620 nm) LEDs showed the highest attractive response at 60 lx (33.9, 52.2, 32.2, 14.5, and 10.6 %, respectively). Basic on the test results of luminance intensities, the attractive responses of *P. intrepunctella* adults to varying time of light exposure (10, 20, 30, 40, 50, and 60 min) were investigated with the seven LEDs (UV, blue, green, yellow, red, white, and IR LEDs) (Table 2). At 30 min exposure time, all light sources were highly attractive to *P. intrepunctella* adults; the percentage of attracted *P. intrepunctella* adults declined with increasing exposure time. The attractive effects of LEDs was investigated under optimal light conditions (60 lx luminance intensity and 30 min light exposure time), and were compared with that of a BLB (Table 3). Under optimal light conditions, the green LED (520±5 nm, 52.2 %) was the most attractive to *P. intrepunctella* adults, followed by blue LED (470±10 nm, 33.9 %), yellow LED (590±5 nm, 32.2 %), BLB (28.9 %), UV LED (365 nm, 22.8 %), red LED (625±10 nm, 14.5 %) white LED (450−620 nm, 10.6 %), and IR LED (730 nm, 9.5 %). The attractive effects of green, blue, and yellow LED were approximately 1.11 to 1.81 times higher to *P. intrepunctella* adults than those of a BLB, which is used in commercial electric traps. Previous studies on the electroretinogram have demonstrated that *P. intrepunctella*

Table 1 Attractive rate of *P. intrepunctella*adultsto five LEDsunder various luminance intensities (lx)[1)]

Wavelength (color)	Attractive rate (%)[2)]				
	Luminance intensity (lx)				
	20	40	60	80	100
470±10 nm (Blue)	7.2±0.67[c]	9.4±0.81[c]	33.9±1.84 [ab]	8.9±0.71[c]	22.2±1.47[bc]
520±5 nm (Green)	17.2±1.42[bc]	20.6±1.39[bc]	52.2±2.14[a]	45.0±1.97 [a]	26.1±1.68 [ab]
590±5 nm (Yellow)	3.9±0.47[c]	5.6±0.52 [c]	32.2±1.77[ab]	7.8±0.74[c]	21.4±1.34[bc]
625±10 nm (Red)	10.6±1.08[c]	11.1±1.14[c]	14.5±1.57[bc]	12.8±1.32[bc]	6.1±0.55[c]
450-620 nm (white)	1.7±0.24[c]	5.0±0.38[c]	10.6±1.11[c]	2.2±0.27[c]	2.8±0.31[c]

[1)]Each value is the average of 6 determinations after a 30 min exposure, with 30 adult insects per replication
[2)]Attractive rate (%) is the average percentage of the 30 *P. interpunctella*adults attracted to various light intensities

Table 2 Attractive rate of *P. intrepunctella*adults to seven LEDs at various light exposure times (h)[1)]

Wavelength (color)[3)]	Attractive rate (%)[2)]					
	Light exposure time (min)					
	10	20	30	40	50	60
365 nm (UV)	9.4±1.07[c]	20.6±1.48[bc]	22.8±1.46	18.9±1.43[bc]	19.4±1.73[bc]	18.3±1.44[bc]
470±10 nm (Blue)	31.1±1.67[ab]	31.7±1.69[ab]	33.9±1.87[ab]	26.1±1.75[ab]	24.4±1.62[bc]	22.8±1.91[bc]
520±5 nm (Green)	31.7±1.79[ab]	22.8±1.74[bc]	52.2±2.18[a]	35.6±1.84[ab]	30.0±1.62[ab]	21.1±1.37[bc]
590±5 nm (Yellow)	20.6±1.57[bc]	26.1±1.77[ab]	32.2±1.73[ab]	25.6±1.66[bc]	24.4±1.41[bc]	19.4±1.52[bc]
625±10 nm (Red)	3.8±0.44[c]	5.0±0.51[c]	14.5±1.57[bc]	4.4±0.43[c]	3.8±0.66[c]	2.8±0.38[c]
450-620 nm (white)	6.1±0.74[c]	8.9±0.88[c]	10.6±1.27[c]	10.0±1.27[c]	8.9±0.83[c]	9.4±1.08[c]
730 nm (IR)	4.4±0.53[c]	7.2±0.79[c]	9.4±1.22[c]	7.8±0.96[c]	3.9±0.41[c]	5.0±0.58

[1)]Each value is the average of 6 determinations after a 30 min exposure, with 30 adult insects per replication
[2)]Attractive rate (%) is the average percentage of the 30 *P. interpunctella*adults attracted to light-exposure time
[3)]Each value is the average of 6 determinations per each light-exposure time at 8 W or 60 lx

Table 3 Attractive rate of *P. intrepunctella*adultsto seven LEDsand a BLB under optimal conditions[1)]

Wavelength (color)[2)]	Number of insect (Mean ± SE)		Attractive rate (%)[3)]	Relative attraction[4)]
	Light choice	No choice		
365 nm (UV)	6.83±1.03[bc]	18.83±1.79	22.8[bc]	0.79
470±10 nm (Blue)	10.17±1.37[ab]	6.67±1.19	33.9[ab]	1.17
520±5 nm (Green)	15.67±1.62[a]	6.33±1.14	52.2[a]	1.81
590±5 nm (Yellow)	9.67±1.24[ab]	11.83±1.44	32.2[ab]	1.11
625±10 nm (Red)	4.33±0.67[bc]	20.83±1.82	14.5[bc]	0.50
450-620 nm (white)	3.17±0.51[bc]	14.67±1.23	10.6[c]	0.37
730 nm (IR)	2.83±0.47[c]	5.67±0.69	9.5[c]	0.32
BLB	8.67±1.19[bc]	20.33±1.84	28.9[b]	1.00

[1)]Each value is the average of 6 determinations at optimal conditions (60 lx and 30 min), with 30 adult insects per replication
[2)]Each value is the average of 6 determinations per each light-exposure time at 8 W
[3)]Attractive rate (%) is the average percentage of the 30 *P. interpunctella*adults attracted to light-exposure time
[4)]Relative attraction = attractive rate of each wavelength/attractive rate of BLB

eyes respond to blue (450 nm) and green (550 nm) wavelengths range, with the greatest responses to green light (Marzke et al. 1973; Kishan et al. 2008; Cowan and Gries 2009). Moreover, behavioral studies have demonstrated by Stremer (1959) that *P. intrepunctella* adults showed the highest attractive effect to UV (365 nm) and green (580 nm) lights. In our study, the green LED was more attractive than blue and UV LEDs to *P. intrepunctella* adults. These results contrast with those suggested by Cowan and Gries (2009) that the blue light is more attractive than green light to *P. intrepunctella* adults (both of males and gravid females). These contrasting results may be connected with difference of experiment designs. Contrary to our experiment design, Cowan and Gries (2009) in choice experiments tested the blue, green, orange, and red light as 2- or 4-choice test stimuli at 15 μW/cm^2.

Previous studies have reported that the attractive effect of the green LED to insect pests. For example, Nakamoto and Kuba (2004) reported that the green LED (536 nm) was more attractive than blue LED (470 nm) to West Indian sweet potato weevils (females) in a sweet potato field. In addition, Chen et al. (2004) reported that the yellow sticky card (YC) equipped with lime green LED (530 nm) traps captured more leafhoppers and western flower thrips than YC in greenhouse. Taken together, the results of our study indicate that light traps equipped with the green LED (520±5 nm) could be a new control strategy against *P. intrepunctella* adults. However, further research is needed to control of *P. intrepunctella* adults in a broad range of granary conditions to find methods for increasing the efficiency.

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