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NOTE

Phototactic behavior 7: phototactic response of the maize weevil, *Sitotroga zeamais* motsch (Coleopter: Curculionidae), to light-emitting diodes

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Abstract Phototactic responses of maize weevil, *Sitotroga zeamais*, adults to five light-emitting diodes (LEDs) were evaluated and compared with the commonly used luring lamp (BLB). Under optimal light conditions, the red LED (625 ± 10 nm) exhibited the highest attraction rate (59.8 %), followed by the yellow LED (590 ± 5 nm, 52.3 %), the infrared LED (730 nm, 51.9 %), the green LED (520 ± 5 nm, 46.7 %), the blue LED (470 ± 10 nm, 45.3 %), the ultraviolet LED (365 nm, 32.7 %), and the BLB (27.3 %). Moreover, the red LED was approximately 2.19 times more attractive than that of the BLB. These results indicate that a red LED trap may be useful to control *S. zeamais* adults.

Keywords Attractive responses · Light-emitting diodes (LEDs) · Luring lamp (BLB) · Phototactic responses · *Sitotroga zeamais*

Introduction

Stored agriculture products are damaged by more than 1000 species of beetle pests, moths, and mites, resulting in quantitative and qualitative losses (Rajendran 2002; Rajendran and Sriranjini 2008). Stored product insects contribute to contamination of food commodities through the presence of live insects and insect products (chemical excretions, dead insects, and insect body fragments) (Thomas and James 2010). The major insect in stored agriculture products is the maize weevil, *Sitotroga zeamais* (Dobee 1974). *S. zeamais* is a common insect of economic importance on maize in warm areas and causes losses in stored grain weight of up to 18.3 % (Adams 1976). Therefore, controlling these insects relies heavily on the use of synthetic insecticides and fumigants, such as methyl bromide and phosphine (Rajendran and Sriranjini 2008). The number of synthetic insecticides for insect control has decreased drastically because of problems with ozone depletion (i.e., methyl bromide), exposure to applicators, and insect resistance (Paul and Zlatko 2000). Thus, there is a growing need for alternative pest control methods for *S. zeamais* (Hidalgo et al. 1998). Insect light traps have long been used to control stored grain insects, such as *Lasioderma serricorne* and *Plodia interpunctella* (Papadopoulou and Buchelos 2002; Sambaraju and Phillips 2008; Jeon et al. 2012). Light-emitting diode (LEDs) traps have been extensively used to control insect pests more recently (Zheng et al. 2014). LEDs have some specific properties, such as small size, low weight, low temperature, sensitivity, high mechanical stability, high reliability, long operating life, and low cost, that makes them attractive (Schubert 2003). These advantages make LEDs a good alternative to synthetic pesticides for insect control (Zheng et al. 2014). Therefore, in this study, the effects of LEDs on attracting *S. zeamais* under laboratory conditions were investigated and compared with the commonly used BLB.

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Materials and methods

Insects

The maize weevil, *S. zeamais,* adult culture was obtained from the National Academy of Agricultural Science, RDA

(Korea). They were reared on rice grain without exposure to any known insecticides in the laboratory in plastic cages (30 × 30 × 20 cm) at 27 ± 1 °C, 65 ± 5 % relative humidity, and a 12 h light/12 h dark photoperiod.

Light sources

The light sources were produced by Kodenshi Auk Co. Ltd (Korea). The types of LEDs used for testing were UV LED (365 nm), blue LED (CL-1W-UBB, 15.0 ± 3.1 lm, 470 ± 10 nm), green LED (CL-1W-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-1W-UBB, 350.0 ± 1.2 lm, 625 ± 10 nm), and IR LED (730 nm). The LED circuit board (70 × 140 mm) consisted of 40 LEDs of each color and was attached to a control circuit board (300 × 150 mm) in a phototactic chamber. The phototactic responses of *S. zeamais* adults were compared with those to a BLB (315–400 nm, F8T5 BLB: Sankyo-Denki Co. Ltd., Tokyo, Japan), which served as a control.

Test chamber

The Y-maze chamber for analyzing the phototactic responses was designed by Oh and Lee (2011). The Y-maze chamber consisted of an opaque acrylic body (W400 × D400 × L200 mm) and two hyaloid acrylic boards that were placed at both ends of the boundary outside of the light arm on the Y-maze chamber, which was equipped with the light side at a distance of 250 mm (Fig. 1). The insect entrance hole (100 mm in diameter, covered with nylon netting cloth) was created at a point between the light arm and the dark. The experiments were conducted in a chamber kept at 27 ± 1 °C and 65 ± 5 % relative humidity in complete darkness.

Bioassay

The phototactic responses of *S. zeamais* adults were measured in the Y-maze under different light conditions, such as different wavelengths, luminance intensities, and light durations. The luminance intensities of the LEDs positioned 700 mm from the light source were measured using an illuminometer (LM-322; AS ONE Co., Ltd., Osaka, Japan). Thirty *S. zeamais* adults were collected using a tiny brush and were released into the insect entrance hole of the Y-maze. The numbers of insects in the light and dark zones of the modified Y-maze were determined to evaluate the attraction of the *S. zeamais* adults to the LEDs. All experiments were repeated at least six times. Attraction rate (%) = (a number of *S. zeamais* in a rage of 200 mm from light sources/total *S. zeamais*) × 100.

Statistical analysis

SPSS ver. 18.0 software (SPSS Inc., Chicago, IL, USA) used for the data analysis. The attraction test results were subjected to one-way analysis of variance, and Tukey's standardized range test was performed to detect significant differences among the mean values at $p < 0.05$.

Results and discussion

The attraction effects of *S. zeamais* adults to the LEDs were examined under conditions in which particular wavelengths, light intensities, and light-exposure times were varied in the Y-maze chamber. The phototactic responses of the *S. zeamais* adults to four visible (blue, green, yellow, and red) LEDs under four luminance intensities (25, 50, 75, and 100 lx) over 24 h are shown in Table 1. The blue (470 ± 10 nm), green (520 ± 5 nm), yellow (590 ± 5 nm), and red (625 ± 10 nm) LEDs were highly

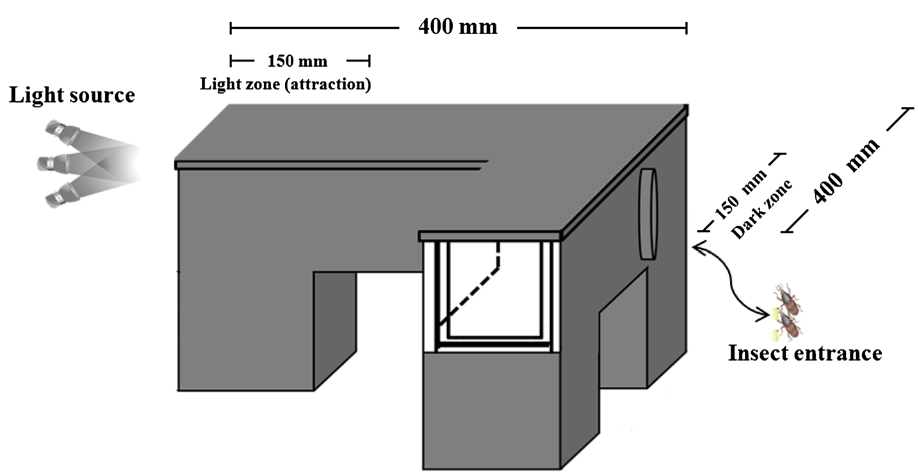

Fig. 1 Model of Y-maze phototactic chamber designed by Jeon et al. (2012)

Table 1 Attraction rate of *S. zeamais* adults to light-emitting diodes under various luminance intensities (lx)[1]

Wavelengths (nm)	Attraction rate (%)[2]			
	Luminance intensity (lx)			
	25	50	75	100
470 ± 10 (blue)	32.6[bc]	32.3[bc]	28.7[bc]	26.6[c]
520 ± 5 (green)	33.3[bc]	33.3[bc]	25.5[c]	23.8[c]
590 ± 5 (yellow)	36.8[b]	30.1[bc]	30.1[bc]	24.3[c]
625 ± 10 (red)	48.2[a]	42.3[ab]	31.3[bc]	29.4[bc]

The significance of letters are Duncan's multiple range

[1] Each value is the average of 6 determinations after a 24 h exposure, with 30 adult insects per replication

[2] Attraction rate (%) is the average percentage of the 30 *S. zeamais* adults attracted to various light intensities

attractive to *S. zeamais* adults at 25 lx (32.6, 33.3, 36.8, and 48.2 %, respectively). Furthermore, the attractive effects of *S. zeamais* adults using various light-exposure times (12, 24, 36, and 48 h) were further examined by calculating the attractive rate of the *S. zeamais* adults to the four visible (blue, green, yellow, and red) LEDs, the IR (730 nm) LED, and the UV (365 nm) LED (Table 2). The UV, blue, green, yellow, red, and IR LEDs exhibited the highest attraction rate to *S. zeamais* adults after 48 h. No significant difference was observed in the percentage of attracted *S. zeamais* adults as exposure duration was increased above the optimal exposure time. Based on these results, the effects of the six LEDs on attracting the *S. zeamais* adults were examined under optical conditions and compared with those of the BLB as a positive control (Table 3). Under optimal light conditions, the red LED exhibited the highest attraction

Table 2 Attraction rate of *S. zeamais* adults to light-emitting diodes at various light-exposure times (h)[1]

Wavelengths (nm)	Luminance intensity (lx)	Attraction rate (%)[2]			
		Light exposure duration (min)			
		12	24	36	48
365 (UV)	–[3]	19.7[c]	26.3[bc]	32.7[bc]	32.7[bc]
470 ± 10 (blue)	25	30.8[bc]	32.6[bc]	43.3[ab]	45.3[ab]
520 ± 5 (green)	25	31.7[bc]	33.3[bc]	45.3[ab]	46.7[ab]
590 ± 5 (yellow)	25	36.8[bc]	36.8[bc]	49.8[ab]	52.3[ab]
625 ± 10 (red)	25	45.3[ab]	48.2[ab]	51.8[ab]	59.8[a]
730 (IR)	–[3]	40.7[b]	48.2[ab]	50.8[ab]	51.9[ab]

The significance of letters are Duncan's multiple range

[1] Each value is the average of 6 determinations at each light-exposure time, with 30 adult insects per replication

[2] Attraction rate (%) is the average percentage of the 30 *S. zeamais* adults attracted to various light intensities

[3] Each value is the average of 6 determinations per each light-exposure time at 8 W, with 30 adult insects per replication

Table 3 Attraction rate of *S. zeamais* adults to light-emitting diodes under optimal conditions[1]

Wavelengths (nm)	Luminance intensity (lx)	Time (h)	Number of adults (mean ± SEM)		Attraction rate (%)[2]	Relative attraction[3]
			Light side (attraction)	No choice		
365 (UV)	–[4]	48	9.81 ± 0.88[c]	20.19 ± 0.92	32.7[c]	1.20
470 ± 10 (blue)	25	48	13.59 ± 1.47[bc]	16.41 ± 1.59	45.3[bc]	1.66
520 ± 5 (green)	25	48	14.01 ± 1.92[b]	15.99 ± 1.53	46.7[b]	1.71
590 ± 5 (yellow)	25	48	15.69 ± 0.74[ab]	14.31 ± 8.24	52.3[ab]	1.92
625 ± 10 (red)	25	48	17.94 ± 1.03[a]	12.06 ± 1.32	59.8[a]	2.19
730 (IR)	–[4]	48	15.57 ± 0.87[ab]	14.43 ± 1.23	51.9[ab]	1.90
BLB (control)	–[4]	48	8.19 ± 1.98[c]	21.81 ± 2.04	27.3[c]	1.00

The significance of letters are Duncan's multiple range

[1] Each value is the average of 6 determinations after a 48 h exposure, with 30 adult insects per replication

[2] Attraction rate (%) is the average percentage of the 30 *S. zeamais* adults attracted to various light intensities

[3] Each value is the average of 6 determinations per each light-exposure time at 8 W, with 30 adult insects per replication

[4] Relative attraction = attraction rate of each wavelength/attraction rate of BLB

rate (59.8 %) to *S. zeamais* adults, followed by the yellow LED (52.3 %), the IR LED (51.9 %), the green LED (46.7 %), the blue LED (45.3 %), the UV LED (32.7 %), and the BLB (27.3 %). Based on these results under optimal conditions, the red LED was approximately 2.19× more attractive than that of the commonly used BLB. Therefore, the maze weevils were effectively controlled by the red LED and the yellow LED at night time, but not by natural light time. Most insects have two types of photoreceptive organs such as compound eyes and ocelli (Shimoda and Honda 2013). Compound eyes consist of a lot of light-sensitive unit called ommatidia (Shimoda and Honda 2013). Ommatidia include an elongated bunch of photoreceptor cells each of which has specific spectrum sensitivities (Land and Nilsson 2002). The ommatidia are arranged in the hexagonal array in order to cover a broad visual field with certain spatial resolution and to recognize the movement of object (Land and Nilsson 2002). LEDs affect insect behavior in various ways that can be separated into several categories, such as attraction, repulsion, light adaption, circadian rhythms, photoperiodicity, and light toxicity (Meyer-Rochow et al. 2002; Saunders 2012; Kim et al. 2013; Shimoda and Honda 2013; Jeon et al. 2014). However, the physiological mechanism of phototaxis remains unclear (Yang et al. 2003). Previous studies have reported that insect behavioral responses are related to photoreceptor physiology and the visible light wavelengths detectable by insects which are determined by the spectral sensitivities of the photoreceptors (Menzel and Blakers 1976; Menzel and Greggers 1985). The spectral ranges of photoreceptors differ widely between species (Briscoe and Chittka 2001). Katsuki et al. (2012) reported that the sweet potato weevil, *Euscepes postfasciatus,* is attracted to UV LED. In addition, Jeon et al. (2012) noted that rice weevil, *Sitophilus oryzae,* adults are attracted to blue and green LEDs. Taken together, our results show that light traps equipped with red and yellow LEDs could be helpful for attracting and trapping *S. zeamais* adults for integrated pest management. However, further studies should be conducted to evaluate the efficacy of these LEDs in a broad range of granary conditions.

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