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ORIGINAL ARTICLE

Phototactic Response of the Rice Weevil, *Sitophilus oryzae* Linnaeus (Coleoptera: Curculionidae), to Light-emitting Diodes

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Abstract The phototactic response of the rice weevil, *Sitophilus oryzae* (L.), to light-emitting diodes (LEDs) at five different wavelengths and various light intensities was tested in an LED-equipped Y-maze chamber, and compared with its response to a luring lamp, which is used in commercial traps. Blue (84.3%) was the wavelength most attractive to *S. oryzae*, followed by green (74.3%), red (64.3%), UV (63.3%), and IR (48.7%). Moreover, blue and green wavelengths were 1.5 and 1.3 times more attractive than luring lamp (56.7%), whereas the UV wavelength was slightly less attractive to the weevils than luring lamp. These results suggested that blue and green wavelengths could be more useful than those currently used for monitoring and mass trapping of *S. oryzae*.

Keywords attraction · light-emitting diodes · phototactic response · *Sitophilus oryzae* · visual stimulus

Introduction

The control of insect pests in stored grains is important for managing food products, post-harvest grains, and processed foods (Kim et al., 2010). These insects can have significant adverse effects on the commercial value, quality, seed viability, and weight of stored grains (Dal Bello et al., 2001). Among these pests, the rice weevil, *Sitophilus oryzae* (L.), is one of the most destructive pests and is found in flour mills, grocery shops, stored cereals, and warehouses (Kim et al., 2010). In particular, the eggs, larvae, and pupae of this weevil develop inside the kernels of whole grain in storage, thus making removal of infestation difficult during the grain milling process (Plarre, 1996; Nakakita and Ikenaga, 1997). Fumigants and synthetic insecticides are commonly used as residual grain protectants against *S. oryzae* (Athanassiou et al., 2004). For the past few decades, methyl bromide and phosphine have been used to control stored grain insect pests such as coleopteran pests in stored products (Athanassiou et al., 2004). Although methyl bromide and phosphine are effective control systems, the use of methyl bromide has been restricted due to its ozone-depleting potential (Michaelraj and Sharma, 2006). In addition, many stored-grain pests, including *S. oryzae*, have developed resistance to phosphine due to its repeated application (Ahn et al., 1998; Athanassiou et al., 2004). Therefore, there is an urgent need to develop safe and effective control systems, such as electric, food attractant, and pheromone traps for management of stored grain insect pests (Park et al., 2000; Papadopoulou and Buchelos, 2002; Michaelraj and Sharma, 2006).

Electric traps have long been used for various stored grain insect pests including *Lasioderma serricorne* and *Plodia interpunctella* (Papadopoulou and Buchelos, 2002; Sambaraju and Phillips, 2008). In recent years, commercial electric traps have been replaced with light-emitting diodes (LEDs) that have several advantages compared to the commercial electric traps. The advantages of LEDs include adjustable light intensity and quality, high luminous efficiency, low thermal output, selective wavelength, and small size (Tamulaitis et al., 2005; Yeh and Chung, 2009). These advantages make LEDs suitable for supporting plant growth in plant growth chambers and plant tissue culture rooms. LEDs are also used for the mass trapping and monitoring of phototactic insects. Visual cues, such as architecture, color, color contrast, shape, and size are used by insects to distinguish between plants and surrounding environment (Antignus, 2000). Therefore, specific LED wavelengths have been observed to elicit a variety of behavioral responses from various insect species, such as *Culex*

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erraticus, *Euscepes postfasciatus*, *Lygus hesperus*, and *Plodia interpunctella* (Nakamoto and Kuba, 2004; Blackmer and Canas, 2005; Sambaraju and Phillips, 2008; Bentley et al., 2009). For example, a red light trap was more effective than a blue, green, or incandescent light trap in attracting *Phlebotomus papatasi* (Hoel et al., 2007). Mutwiwa and Tantau (2005) reported that *Trialeurodes vaporariorum* adults were attracted by UV rays. The response of insects to light may be influenced by the wavelength of the light, the light intensity, and the duration of the light (Sambaraju and Phillips, 2008). Although several studies have investigated the effectiveness of various light sources as components of insect traps, the specific characteristics of the light (wavelength, light intensity, and light duration) have not been studied in detail. Therefore, in the present study, the phototactic response of *S. oryzae* to LEDs under laboratory conditions was investigated. In addition, the phototactic responses of rice weevils to LEDs and luring lamp, which are used in commercial electric traps, were compared.

Materials and Methods

Rearing of insects. The cultures of the rice weevil, *S. oryzae*, were obtained from the National Academy of Agricultural Science, RDA (Suwon, Korea). The insects were mass reared in the laboratory without exposure to insecticides on rice grains, in plastic rearing containers (30 cm × 30 cm × 25 cm) at 27±0.5°C, 60±5% RH, and a 16-h light/8-h dark photoperiod. Only adults were used for the behavioral tests.

Light sources. The light sources were purchased from Kodenshi Auk Co. Ltd (Iksan, Korea). The LED (Table 1) types used were as follows: near-infrared (IR) (730 nm, K=0.2707, V=1.693), red (660 nm, K=128.6115, V=2.152), green (520 nm, K=53.1483, V=3.142), blue (450 nm, K=33.2563, V=2.916), and ultraviolet (UV) (365 nm, V=3.609) as measured with a spectrometer (OPT-100, Optel Precision Co. Ltd, Jeon-Ju, Korea). Each of the LED circuit boards (70 mm × 140 mm) consisted of 400 LEDs. The LED circuit boards were attached to a control circuit board (300 mm × 150 mm) in a phototactic chamber. The wavelength and intensity of light were controlled by a controller connected to the control circuit board. Only the light intensity of visible rays was controlled, because non-visible rays could not be measured by the spectrometer. A switched-mode power supply (S-100-36, MEAN WELL Technology Co. Ltd., Suzhou, Taiwan) was used as the electric power source for the LEDs. The effect of LEDs to weevils were compared with the effect of luring lamp (F8T5 BLB: Sankyo-Denki Co. Ltd., Hiratsuka, Japan), which served as a control.

Test chamber. The phototactic responses of the weevils were investigated using a modified Y-maze phototactic chamber designed by Oh and Lee (2010). The Y-maze was composed of an opaque acrylic body (W400 × D400 × L200 mm) and two transparent acrylic boards that were situated at both ends of the boundary surface on a light arm to allow the passage of light (Fig. 1). The outside of the light arm on the Y-maze was equipped with the light source (LEDs or BL) at a distance of 250 mm. The insect entrance was situated at a point between the light arm and the dark arm. The Y-maze was maintained in darkness, at 27±0.5°C, 60±5% RH, and the insect entrance (100 mm in diameter) was covered with nylon netting cloth.

Experimental design. The phototactic responses of the rice weevils were investigated in the Y-maze according to different wavelengths, intensities, and durations of light. The intensity of illumination (lux) of the LEDs at the starting point (600 mm from the light source) was measured using an illuminometer (LM-332; AS ONE Co. Ltd., Tokyo, Japan), and a specific light intensity was selected for this experiment. After collection of 30 rice weevils using a tiny brush, they were released into the Y-maze through the insect entrance hole. To determine the attraction effects of the light, the numbers of weevils in the light zone and dark zone of the modified Y-maze were recorded. First, the attractive effects of different wavelengths were investigated at various light intensities (25, 50 and 100 lux) and light durations (6, 12, 24, 36, and 48 h), followed by investigation of the attractiveness of different wavelengths of light under the optimal lighting conditions determined in step 1 to elucidate the wavelength(s) of light most attractive to the rice weevils. All experiments were repeated at least six times.

Statistical analysis. The software used for data analysis was SPSS version 18.0 (SPSS Inc., Chicago, IL). Determination of

Table 1 Technical specifications of the LEDs

Color	P.W. (nm)[1]	Color Coordinates		K (cd/mW) @If=20 mA	Vf [V]
		x	y		
Infrared ray (IR)	730	0.543	0.282	0.2707	1.683
Red	660	0.699	0.297	128.6115	2.152
Green	520	0.150	0.720	53.1483	3.142
Blue	450	0.136	0.058	33.2563	2.916
Ultraviolet (UV)	365	ND[2]	ND	ND	3.609

The technical specifications of the LEDs were measured with an OPT-100, a color coordination system recognized by the International Commission on Illumination

[1]Peak wavelength

[2]No data

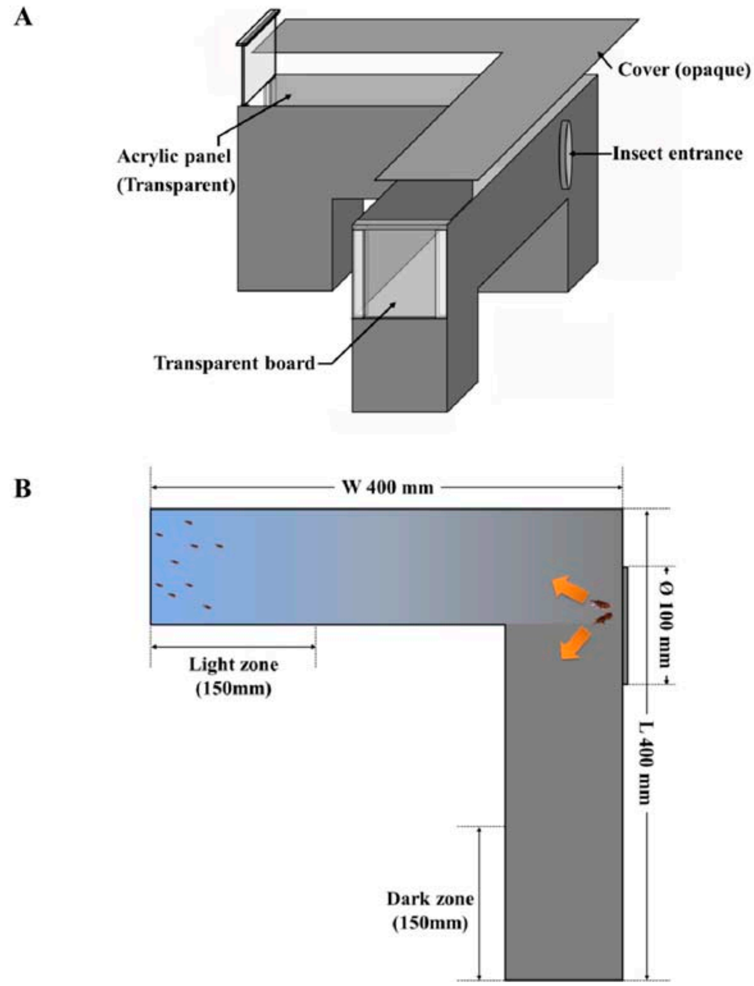

Fig. 1 Model of Three dimension (A) and cross section (B) in modified Y-maze. Modified Y-maze for preference response of rice weevil to LEDs.

optimal lighting conditions was performed using two-way ANOVA. Comparisons between wavelengths were made using one-way ANOVA. Significant differences between group means were assessed by post hoc analysis using Tukey's HSD at $p < 0.05$. Data are expressed as means and standard error of the means (SEM).

Results and Discussion

The phototactic responses of *S. oryzae* to visible (red, green, and blue) LEDs are shown in Table 2. Red (660 nm) LEDs at a light intensity of 25 lux attracted rice weevils, and this attraction increased over time - 40.0, 43.3, 50.0, 61.0, and 62.0% of the weevils were attracted to the light at 6, 12, 24, 36, and 48 h, respectively. Moreover, similar results were observed with IR (730 nm), green (510 nm), blue (440 nm), and UV (365 nm) LEDs. On the basis of the 48 h attractive effects of visible LEDs, red and blue LEDs at 25 lux attracted significantly more weevils than red and blue LEDs at 50 and 100 lux (18.6±1.4, $F_{4,\,25r}$= 10.389, $p < 0.001$; 25.0±0.8, $F_{4,\,25}$=71.587, $p < 0.001$). For the green LEDs, 50 lux resulted in the highest attractive response (22.7±1.7, $F_{4,\,25}$=26.006, $p < 0.001$). The attractive effect of red LEDs decreased as the light intensity increased from 25 to 50 to 100 lx (F_2=42.830, $p < 0.001$), but increased with increasing light intensity duration (6 to 48 h) (F_4=38.040, $p < 0.001$). Significant differences in the attractive effects of green and blue LEDs were observed according to light intensity (F_2=16.158, $p < 0.001$; F_2= 21.347, $p < 0.001$) and light duration (F_4=37.075, $p < 0.001$; F_4= 121.342, $p < 0.001$). Phototactic responses are well known to be highly dependent on both the wavelength and the intensity of the light (Mutwiwa and Tantau, 2005). In a previous study, Sambaraju and Phillips (2008) demonstrated that high-intensity UV light was significantly more attractive to *Trialeurodes vaporariorum* than low-intensity UV light. Gjullin et al. (1973) found that a low-intensity red light trap was more attractive to *Culex tarsalis* than a high-intensity red light.

The attractive effect of LEDs was evaluated under optimal lighting conditions and compared with that of the commonly used luring lamp, which served as a positive control (Table 3). Under optimal lighting conditions, blue LED (84.3%) was the most attractive to *S. oryzae*, followed by green (74.3%), red (64.3%),

Table 2 Attraction of *S. oryzae* to visible wavelengths under various lighting conditions

Color (nm)	Insect population (means ± SEM)					p-value[1)]
	Time (h)					
	6	12	24	36	48	
Red (660)						
25 lx	12.0±0.9	13.0±0.9	15.0±0.7	18.3±0.5	18.6±1.4	10.389 ***
50 lx	11.3±0.4	14.3±0.6	13.3±0.2	17.0±0.9	18.3±0.2	27.423***
100 lx	8.3±0.4	10.0±1.2	9.0±0.6	12.0±0.9	16.0±1.1	12.173***
Green (510)						
25 lx	8.3±0.4	11.0±0.9	14.3±0.8	17.0±0.6	18.6±1.0	30.644***
50 lx	12.3±0.7	13.7±0.3	17.0±0.6	21.0±0.5	22.7±1.7	26.006***
100 lx	13.3±1.1	13.3±0.8	14.0±2.1	16.3±0.4	17.3±1.2	2.145 NS[2)]
Blue (440)						
25 lx	11.3±0.9	10.0±1.0	16.3±1.0	24.3±0.3	25.0±0.8	71.587***
50 lx	7.3±0.8	9.3±0.4	14.3±1.2	18.3±0.5	20.3±1.4	34.354***
100 lx	10.7±0.6	13.0±0.8	17.3±0.7	18.3±0.9	19.0±0.5	26.206***

Values represent means ± SEM. Two-way ANOVA was performed to compare light intensity and light duration.
[1)]Means ± SEM differ significantly at p <0.05 (*), p <0.01 (**) and p <0.001 (***)
[2)]NS, not significant at the 5% level (ANOVA)

Table 3 Attraction of *S. oryzae* to various wavelengths of light under optimal lighting conditions

Wavelength (nm)	N[1)]	Insect population (means ± SEM)			Attraction rate
		Light zone	No choice	Dark zone	
LED					
IR (730)	30	14.6±0.5a	8.7±0.3a	6.7±0.7a	48.7%
Red (660)	30	19.3±1.1ab	6.2±0.7ab	4.5±0.7ab	64.3%
Green (510)	30	22.3±1.7bc	4.3±0.9bc	3.3±0.9bc	74.3%
Blue (440)	30	25.3±0.7c	2.8±0.5c	1.8±0.4c	84.3%
UV (365)	30	19.0±1.1ab	6.7±0.7ab	4.3±0.6ab	63.3%
Control					
BL (352)	30	17.0±0.9ab	7.2±0.6ab	5.8±0.4ab	56.7%

Values represent means ± SEM. Different letters next to the values in the column indicate significant differences at p <0.05 (Tukey's HSD test).
[1)]Sample size, 15 males and 15 females per test

UV (63.3%), and IR (48.7%) LEDs. Moreover, blue and green LEDs were approximately 1.5 and 1.3 times more attractive than luring lamp to *S. oryzae*, respectively. These results are consistent with a previous study that found that the sweet potato weevil preferred green LEDs to yellow and red LEDs (Nakamoto and Kuba, 2004). Hausmann et al. (2004) reported that green and blue LEDs are more attractive to the blossom weevil, *Anthonomus pomorum*, than UV light and dark conditions. Together, these results suggest that weevils are sensitive to shorter wavelengths of visible light such as blue and green.

Traditional insecticide-based insect traps have recently started to be replaced with newer and safer materials due to the environmental damage, resistance, and toxicity caused by synthetic insecticides. For example, plastic cup traps equipped with lime-green LEDs, green LED traps, and UV lamps have shown to be efficient at attracting and trapping various agricultural and stored-grain insects, such as *Bemisia tabaci*, *Cylas formicarius*, and *Plodia interpunctella* (Chu et al., 2003; Nakamoto and Kuba, 2004; Sambaraju and Phillips, 2008). Insects use visual and olfactory stimuli to locate host plants, and sometimes these two sources of stimuli are complementary (Antignus, 2000; Mutwiwa and Tantau, 2005). Taken together, the results of previous studies and the present study suggest that electric traps equipped with blue and green LEDs could be a new pest control strategy. Further studies should be conducted to determine the visual ecology of *S. oryzae* and to investigate if synergistic effects can be obtained using olfactory stimulants, such as aggregation pheromones or plant-derived volatiles.

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