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SHORT COMMUNICATION

Photo-Response of Tobacco Whitefly, *Bemisia tabaci* Gennadius (Hemiptera: Aleyrodidae), to Light-emitting Diodes

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Abstract The photo-response of the tobacco whitefly to light-emitting diodes of four different wavelengths and various intensities was tested in an LED-equipped Y-maze chamber and compared with the response to black light (BL), which is typically used in commercial traps. The BL showed the highest attraction rate (90.3%) to *Bemisia tabaci*, followed by a similarly strong attraction to the blue LED (89.0%), the yellow LED (87.7%), the green LED (85.3%), and the red LED (84.3%). These results suggest that energy-efficient LEDs could be used for more environmentally friendly insect control.

Keywords: attraction · *Bemisia tabaci* · light-emitting diodes · photo-response · power consumption

The tobacco whitefly, *Bemisia tabaci* Gennadius (Hemiptera: Aleyrodidae), is one of the most damaging and intractable insect pests of agricultural production systems (Erdogan et al., 2008). It damages plants via increased mold growth as a result of honey dew production, leaf sucking, and plant virus transmission, and affects most horticultural crops, including cucumber, paprika, pepper, tomato, and sweet melon (Lisha et al., 2003). In recent years, the damage caused by *B. tabaci* has increased significantly, particularly in tomato greenhouses where whiteflies mediate the spread of tomato yellow leaf curl virus (TYLCV) (Matsuura and Hoshino, 2009).

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B. tabaci are primarily controlled by biological and chemical agents. Chemical pesticides are often required when biological agents do not maintain adequate control (Moreau and Isman, 2010). Chemical pest control has been the preferred method of control in agriculture for a long time, but this approach is associated with well-documented negative effects including pesticide resistance, environmental toxicity, and destruction of biological control agents (Antignus, 2000; Yang et al., 2002; Kim et al., 2004). The development of new safe and efficient control systems is therefore needed (Toyama et al., 2011).

Sustainable, ecologically-friendly management systems represent a key goal for agricultural research. The advantages of light-emitting diodes (LEDs) are adjustable light intensity and quality, compact size, low thermal output, wavelength specificity, as well as high photoelectric conversion efficiency (Yeh and Chung, 2009). These advantages suggest the possibility of using LEDs to control insects in managed environments such as greenhouses. Herein, the photo-responses of *B. tabaci* to LEDs under laboratory conditions are reported.

The cultures of tobacco whitefly, *B. tabaci*, were obtained from the National Academy of Agricultural Science, Rural Development Administration (Korea). The whiteflies were reared on eggplants in plastic rearing cages (45 cm × 45 cm × 45 cm) at 27±1^{o}C, 60±5% RH and a photoperiod of 16L/8D. Only adult flies were used in these experiments.

Light sources were purchased from Ciel Light (Korea) and Photron (Korea). The visual colors, wavelengths, part numbers, and luminous flux (lm) of the lights chosen for testing were as follows: blue (470 nm, CL-1W-UBB, 15.0±3.1 lm), green (520 nm, CL-1W-UPGB, 45.0±3.5 lm), yellow (590 nm, PP592-8L61-AOBI, 40.0±10.0 lm), and red (625 nm, CL-1W-URB, 35.0±1.2 lm). The effects of the LEDs to whiteflies were compared with that of black light (BL) (F8T5 BLB: Sankyo-Denki Co. Ltd., Japan), which served as a control. The test chambers for analyzing the phototactic responses of whiteflies were constructed using a modified Y-maze phototactic chamber designed by Oh et al. (2011) and Jeon et al. (2012). The Y-maze chamber was comprised of an opaque acrylic body (W40 cm × D40 cm × L20 cm) and two transparent acrylic walls situated at both ends of the interface on the light side to allow the passage of light. The insect entrance hole was placed between the light and dark sides, and covered with nylon netting cloth to prevent the insects from escaping. The light source was installed on the outside of the light side of the Y-maze chamber at a distance of 25 cm. The Y-maze chamber was maintained at 27.5°C, 60±5% RH, and kept dark.

The phototactic response of the tobacco whiteflies to LEDs was investigated in the Y-maze chamber under different light conditions, including wavelength, luminance intensity, and duration. The intensity of luminance (lx) at 60 cm from the light source (LEDs and BL) was measured using an illuminometer (LM-332; AS ONE Co. Ltd., Japan), and the optimal luminance intensity was determined for use in the experiments. Thirty tobacco whitefly adults were collected using a vacuum cleaner and released through the insect entrance hole of the Y-maze. To determine the attractive effects of the light, the numbers of tobacco whiteflies in the light and dark sides of the modified Y-maze were counted. The attractive effects of different wavelengths at various luminance intensities (20, 40, 60, 80, and 100 lx) was investigated. In the second experiment, the resultant optimal luminance intensity was used to examine the attraction rate of tobacco whiteflies at different light durations (30, 60, 90, 120, 150, and 180 min). Finally, to determine which LEDs were most attractive to the tobacco whiteflies, responses to different wavelengths of light were repeatedly measured under optimal conditions. All experiments were repeated at least six times.

One-way ANOVA (analyses of variance) was used to compare the numbers of tobacco whiteflies in the attraction test, and data were analyzed with SPSS statistical software (version 18.0, SPSS Inc., USA). Ducan's multiple-range test was performed to compare differences among the mean values. Data were expressed as means and standard error of the mean (SEM).

Insect behavior is influenced by three characteristics of light: quality or wavelength, intensity, and duration (Callahan, 1957; Sambaraju and Phillips, 2008). Therefore the attractive effects of visible (blue, green, yellow and red) LEDs at various luminance and durations were investigated. The attraction response of *B. tabaci* adults to different LEDs under various luminance intensities (20, 40, 60, 80, and 100 lx) over 30 min are shown in Table 1. Blue (470 nm) and green (520 nm) LEDs showed higher attraction to flies at a luminance of 40 lx (74.0 and 73.3%, respectively), whereas yellow (590 nm) and red (625 nm) LEDs resulted in the highest attractive response at 20 lx (76.7 and 60.0%, respectively). Based on these results, the optimal luminance was determined for each wavelength (blue and green; 40 lx, yellow and red; 20 lx). Next, the attraction rate of *B. tabaci* for the LEDs using the optimal luminance at varying durations of light-exposure (30, 60, 90, 120, 150, and 180 min) was determined. The optimal duration of light exposure for all lights tested was 90 min, with no significant differences in the percentage of attracted *B. tabaci* adults as light exposure duration increased above 90 min (Table 2). The attractive effect and power consumption of LEDs were evaluated under optimal light conditions and compared with the commonly used BL in a light trap, which served as a positive

Table 1 Attraction of *B. tabaci* to light emitting diodes under various illumination intensities[1)]

Color (wavelength)	Attraction rate (means ± SEM, %)[2)]				
	Luminance intensity (lx)				
	20	40	60	80	100
Blue (470 nm)	66.7±1.2	74.0±1.4	70.0±0.8	66.7±0.9	50.0±1.1
Green (520 nm)	68.1±1.4	73.3±0.6	70.0±0.5	73.3±1.3	70.0±1.2
Yellow (590 nm)	76.7±0.6	70.0±1.5	76.7±0.7	73.3±0.9	66.7±2.0
Red (625 nm)	60.0±0.8	46.7±1.8	43.3±2.3	40.0±3.1	56.7±2.5

[1)]Each value is the average of six determinations after 30 min, with 30 adult insects per replication.
[2)]Attraction rate (%) is the average percentage of the 30 adults that were attracted to various luminance intensities.

Table 2 Attraction of *B. tabaci* to light-emitting diodes at different light exposure times[1)]

Color (nm)	Luminance intensity (lx)	Attraction rate (means ± SEM, %)[2)]					
		Time (min)					
		30	60	90	120	150	180
Blue (470)	40	73.3±1.3	79.0±2.4	89.0±0.9	89.0±1.3	89.0±1.6	89.0±1.1
Green (520)	40	74.3±2.1	78.3±1.8	85.3±2.2	84.3±3.3	85.3±2.5	84.3±3.3
Yellow (590)	20	71.0±1.9	79.0±2.3	87.7±1.3	87.7±1.7	88.7±2.8	87.0±2.4
Red (625)	20	51.0±3.0	80.0±1.4	84.3±2.2	84.3±1.8	85.7±1.5	84.3±2.1

[1)]Each value is the average of six determinations per each light-exposure time at optimal luminance intensity of each wavelength, using 30 adult insects per replication
[2)]Attraction rate (%) is the average percentage of the 30 adults that were attracted to various levels of luminance.

Table 3 Attraction of *B. tabaci* to light-emitting diodes under optimal light conditions[1)]

Color (nm)	Luminance intensity (lx)	Insect population (means ± SEM)		Attraction rate (%)[2)]	Power Consumption (W)	Relative Power Consumption[3)]
		Attraction	No choice			
Blue (470)	40	26.7±1.5[a]	3.3±0.9	89.0[a]	2.40	3.33
Green (520)	40	25.6±0.3[a]	4.4±0.3	85.3[a]	4.20	1.90
Yellow (590)	20	26.3±0.7[a]	3.7±0.7	87.7[a]	3.60	2.22
Red (625)	20	25.3±2.0[a]	4.7±2.0	84.3[a]	1.28	6.25
BL	-	27.1±0.6[a]	2.9±0.2	90.3[a]	8.00	1.0

[1)]Each value is the average of six determinations using the optimal luminance intensity at 90 min, with 30 adult insects per replication.
[2)]Attraction rate (%) is the average percentage of the 30 *B. tabaci* adults attracted toward the light side.
[3)]Relative power consumption = power consumption of BL/power consumption of each light wavelength.

control (Table 3). Under optimal light conditions, the BL showed the highest attraction rate (90.3%) to *B. tabaci*, followed by the blue LED (89.0%), the yellow LED (87.7%), the green LED (85.3%), and the red LED (84.3%). There was no significant difference in the attraction rate of *B. tabaci* adults between the BL and the LEDs. On the other hand, relative power consumption by the red LED (1.28 W) was approximately 6.25 times higher than the BL (8.00 W), followed by the blue LED at 3.33 times (2.40 W), the yellow LED at 2.22 times (3.60 W), and the green LED at 1.90 times (4.20 W).

Visual (color, shape, size) and olfactory (host odor) cues are the primary means used by insects to orient to their plant hosts, either singly or synergistically (Prokopy and Owens, 1983; Terry, 1997; Antignus, 2000). Furthermore, Mound (1962) suggested that the whitefly *B. tabaci* did not react to the odor of the host plant but did react to two ranges of wavelengths of light, blue/ultraviolet, which induces migratory behavior, and yellow, which guides host plant selection. Plastic cup traps equipped with lime-green LEDs have shown to be efficient at attracting and trapping *B. tabaci* (Chu et al., 2003). As demonstrated, LEDs with low power consumption could be used for environmentally friendly insect control. Further research should be conducted on the photo-response of white flies to attraction traps under field conditions.

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