Appl Biol Chem (2017) 60(2):137–144
DOI 10.1007/s13765-017-0263-2

Online ISSN 2468-0842
Print ISSN 2468-0834

REVIEW

Phototactic behavioral response of agricultural insects and stored-product insects to light-emitting diodes (LEDs)

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

Received: 9 February 2017 / Accepted: 22 February 2017 / Published online: 6 March 2017

Abstract Agricultural insects and stored-product insects are influenced by luminance intensities, exposure times, and wavelengths of light-emitting diodes (LEDs). Based on the phototactic behaviors of the agricultural insects, green or blue LEDs are most attractive for *Bemisia tabaci*, *Trialeurodes vaporariorum*, *Myzus persicae*, *Liriomyza trifolii*, *Spodoptera exigua*, and *Spodoptera litura*. Green LED attracts *Plutella xylostella* and *Frankliniella occidentalis*. Similarly, green or blue LEDs are more attractive to agricultural insects, such as *Liriomyza sativae*, *Sogatella furcifera*, and *Nilaparvata lugens*, than other wavelength LEDs. Concerning the phototactic behaviors of the stored-product insects, red LED is attractive for, in descending order *Tribolium castaneum*, *Sitophilus zeamais*, *Lasioderma serricorne*, and *Tyrophagus putrescentiae*. Blue LED captures most *Sitophilus oryzae* and *Sitotroga cerealella*. Red and blue LEDs are more attractive for stored-product insect pests rate than ultraviolet LED and green, yellow, white, and infrared LEDs. Based on the attraction rate of the stored-product insects on granary, red LED is most attractive for *S. cerealella* and *Plodia interpunctella*. These light sources are effective in controlling agricultural and stored-product insects. Applying LED technology for greenhouses and granaries along with conventional traps reduces crop loss due to moths, beetles, aphids, and weevils. LEDs have potential value in integrated pest management.

✉ Hoi-Seon Lee
hoiseon@jbnu.ac.kr

[1] Department of Bioenvironmental Chemistry, Chonbuk National University, Jeonju 54896, Korea

Keywords Agricultural insect · Behavior response · Light-emitting diodes · Light perception · Phototaxis · Stored-product insects

Introduction

Many countries are using synthetic insecticides as the primary means of controlling insect pests [1, 2]. However, repeated use of synthetic insecticides can increase the development of resistance in the insect pests and has negative effects on the environment and nontarget insects [2, 3]. Efforts are ongoing to develop sustainable alternative and eco-friendly methods, such as the use of electric traps, food traps, and natural insecticides [1–4].

Phototaxis is the behavior of insect species in response to light sources. This movement is influenced by the light wavelength, and the quality and intensity of the light source [5]. In general, insect pests can perceive light ranging in wavelength from 350 to 700 nm and respond in diverse ways [6]. The alternative techniques being developed include phototaxis; electric traps equipped with black and incandescent light bulbs are used for surveillance, for example. The incandescent bulb as the standard light commonly used in light traps ranges in wavelength from 350 to 700 nm with a maximum output wavelength at 700 nm [7]. Insect species can be attracted or repelled to special light sources, such as artificial lights [8]. Certain insect species exhibit a directional response to light-emitting sources including high- or low-intensity light [9]. The use of artificial light sources in integrated pest management (IPM) has increased globally [10]. Light-emitting diodes (LEDs) have emerged as an important technology in the development of agricultural systems [11, 12]. The many advantages of LEDs include the eco-friendly technology, functional improvement, plant

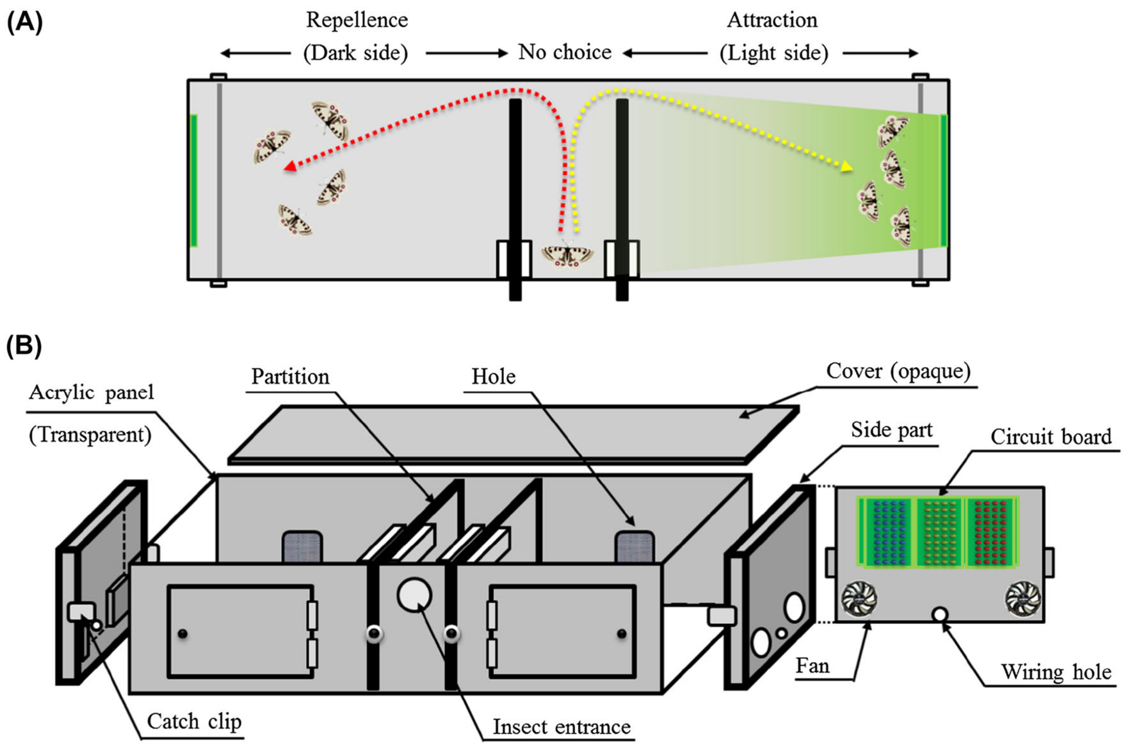

Fig. 1 Experimental layout for effective examination of HPLEDs in the laboratory [11]: (**A**) *Top view* of the test chamber. (**B**) *Side view* of three-dimensional of the test chamber

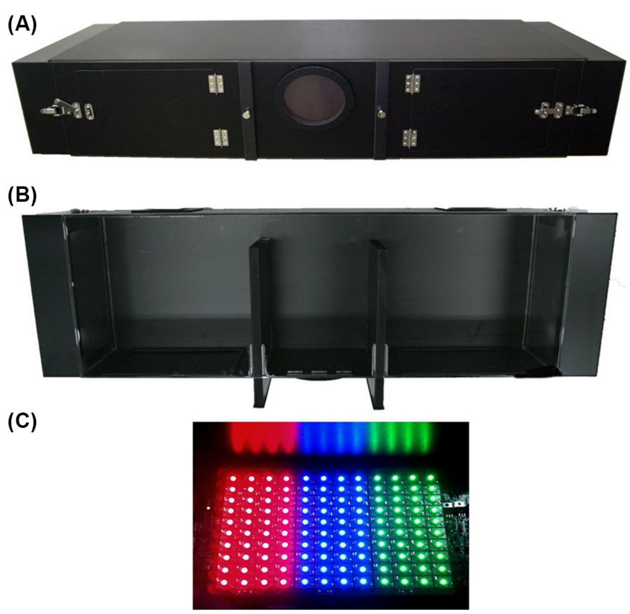

Fig. 2 Photograph of test chamber used for the laboratory using by HPLEDs [11]: (**A**) *Facade view*, (**B**) *top view*, and (**C**) HPLEDs circuit board of the test chamber

growth, high luminous efficiency, selectivity of specific wavelength and light intensity, low weight, low electronic consumption, small size, prolonged lifetime, and environmental affinity [13, 14].

LED traps may be a potential alternative to commercial traps for mass trapping and phototactic monitoring of insect pests. Specific wavelength LED sources are being used for monitoring as well as trapping [7, 15]. Pest insects will move toward light lamps or other illuminations in outdoor settings [16]. This phototactic behavior of pest insects is the basis of the design of electronic insect traps [16]. The light traps are equipped with LED sources; they effectively attract agricultural and stored grain insect pests including aphids, beetles, moths, and weevils and prevent the entry of these insects into greenhouses and granaries [17, 18]. Interest is growing in control technology that exploits insect behaviors to light sources as an alternative to synthetic insecticides [16, 19]. Here, we review the advanced control technologies of insect species that employ new light sources including LEDs.

Classification of phototactic behavioral responses to light sources of various insects

Insect behavior to light is varied and can be categorized [20]. The typical behavior is phototaxis. Insects display several phototactic responses including attraction (movement toward the light source: positive phototaxis) and repulsion (movement away from the light source: negative phototaxis). Optimal conditions, which include effective

Table 1 Phototactic behavior of agricultural insects to LED sources

Pests	Wavelength (color)	Luminous intensity (lx)	Time (min)	Number of adults (mean ± SEM)		Attraction rate (%)[a]	References
				Light side	No choice		
Bemisia tabaci	520 ± 5 nm (green)	40	90	25.6 ± 0.3	4.4 ± 0.3	85.3	[34]
	470 ± 10 nm (blue)	40	90	26.7 ± 1.5	3.3 ± 0.9	89.0	
	BLB (control)	–	90	26.9 ± 0.6	3.1 ± 0.3	89.6	
Trialeurodes vaporariorum	520 ± 5 nm (green)	40	90	28.9 ± 0.7	1.1 ± 0.8	96.6	[36]
	470 ± 10 nm (blue)	40	90	29.2 ± 1.3	0.8 ± 0.5	97.4	
	BLB (control)	–	90	25.3 ± 1.7	4.7 ± 2.1	84.3	
Myzus persicae	520 ± 5 nm (green)	40	120	25.6 ± 0.9	4.4 ± 1.2	85.3	[37]
	470 ± 10 nm (blue)	60	120	22.5 ± 1.5	7.5 ± 2.9	75.0	
	BLB (control)	–	120	18.5 ± 1.5	11.5 ± 2.2	61.7	
Liriomyza trifolii	520 ± 5 nm (green)	60	120	29.9 ± 0.3	0.1 ± 0.1	99.7	[17]
	470 ± 10 nm (blue)	80	120	27.3 ± 2.0	2.7 ± 2.0	91.2	
	BLB (control)	–	120	21.3 ± 1.7	8.7 ± 2.1	71.1	
Spodoptera exigua	520 ± 5 nm green)	40	100	27.1 ± 0.9	2.0 ± 0.6	90.3	[11]
	470 ± 10 nm (blue)	40	100	24.3 ± 0.3	2.0 ± 0.6	81.1	
	BLB (control)	–	100	24.0 ± 0.6	2.3 ± 0.6	80.0	
Spodoptera litura	520 ± 5 nm green)	40	60	19.3 ± 0.7	6.3 ± 0.3	64.3	[33]
	470 ± 10 nm (blue)	40	60	17.3 ± 0.8	7.0 ± 0.6	57.7	
	BLB (control)	–	60	15.0 ± 1.2	7.3 ± 1.5	50.0	
Plutella xylostella	520 ± 5 nm green)	60	15	29.5 ± 0.2	0.5 ± 0.3	98.3	[32]
	BLB (control)	–	15	26.0 ± 0.6	0.0 ± 0.0	86.7	
Frankliniella occidentalis	520 ± 5 nm (green)	40	90	13.3 ± 0.8	15.1 ± 0.9	44.3	[38]
	BLB (control)	–	90	11.7 ± 1.1	18.3 ± 0.7	39.0	

[a] Attraction rate (%) is the average percentage of pests attracted under optimal conditions

wavelengths, exposure time, and intensities to light source, are diverse among insect species [21, 22]. Negative phototaxis could be useful to prevent entrance of pest insects to greenhouses and granaries [23, 24]. Behavioral responses to light by insect species also include light adaptation, circadian periodicity, photoperiodism, and light toxicity [20]. Nocturnal insects can adapt to light sources; typical adaptive behaviors are diminished migration, settling near the light source, and mating [20]. Circadian periodicity is daily behavioral response that encompasses courtship, feeding, flight, and locomotion [25]. Artificial light at night can change the diurnal or nocturnal responses and timing of insect species [26], which represents a phase shift in chronobiology [27]. Photoperiodism is the physiological behavior of insect species to light, such as day light. The start of resting can be prevented by repeatedly exposing insects to light sources for some days [28]. Insects that do not enter diapause cannot overwinter. Continuous light irradiation is structurally damaging and causes light toxicity [29]. Photo-irradiation is also useful for treatment of crops before the post-harvest in the greenhouse and granary settings. Insect behaviors to light sources are significantly influenced by various factors of the light, such as intensity, single or combined wavelengths, exposure time, and

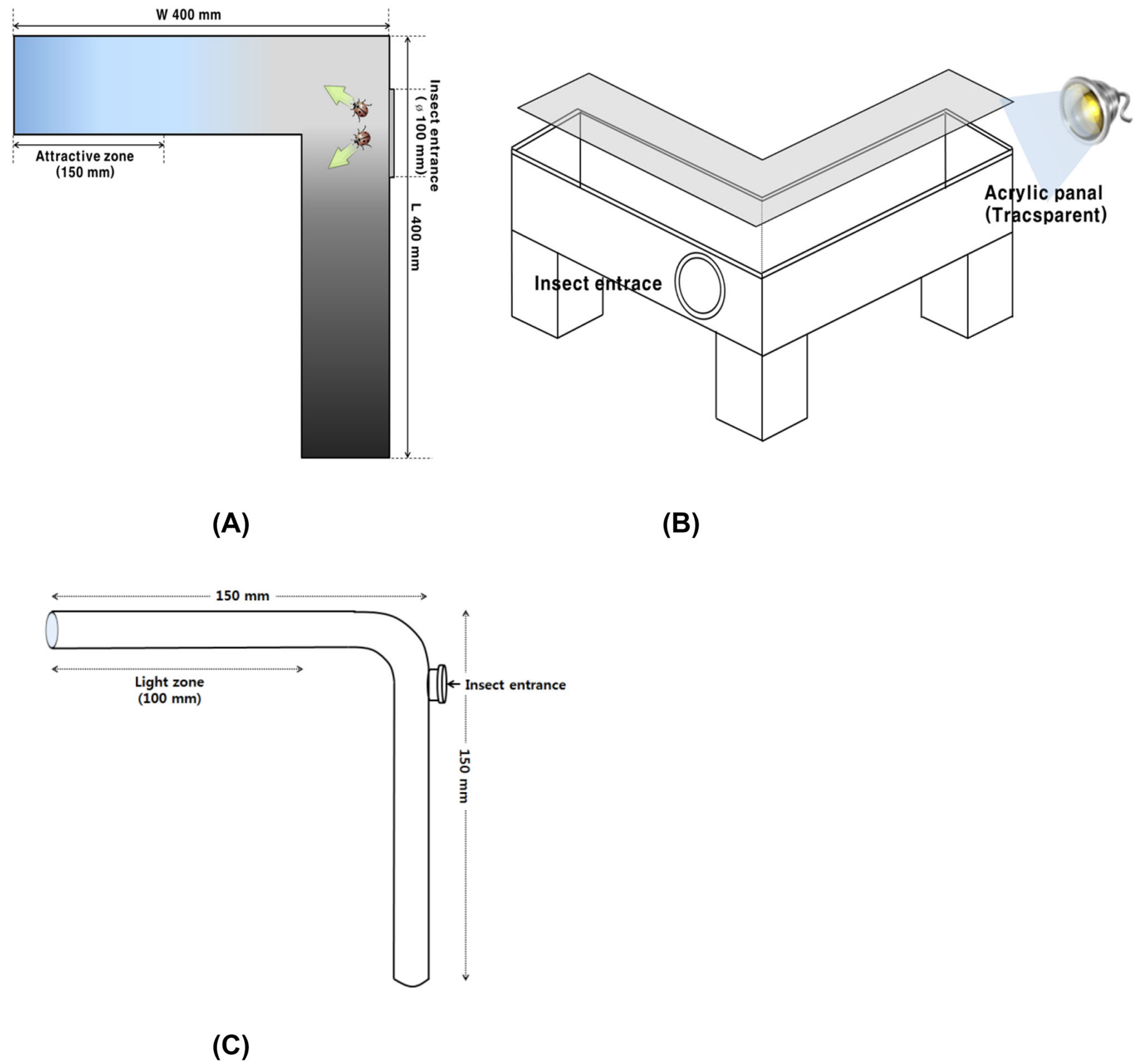

Fig. 3 Model of cross section (**A**), three dimention (**B**), and insert tube (**C**) in modified Y-maze [47]

differences of light intensity and color to those of ambient lighting [19, 30]. In the remainder of this minireview, we discuss the technologies being currently being used to control many insect species.

Phototactic behavior to LED source for agricultural insect pests

Agricultural insect species include aphids, leaf miners, moths, and whiteflies. Their reactions are influenced by various characteristics of light, such as luminance intensity, light exposure time, and light wavelength [31]. Evaluation of the phototactic responses of insect species to these aforementioned aspects typically uses a chamber capable of dark and illuminated settings (Figs. 1, 2). Phototactic behavior of agricultural insect species has been amply correlated with characteristics of light [11, 32–38]. *Bemisia tabaci* and *Trialeurodes vaporariorum* showed a significantly more favorable response to the green (520 nm) and blue (470 nm) LEDs at a luminance intensity of 40 lx and exposure time of 90 min than to red (625 nm) and yellow (590 nm) LEDs [34, 36]. Under optimal light exposure times and luminance intensities, LED light sources that emit relatively short wavelengths attract agricultural insect species [11, 32–38] (Table 1). Based on the phototactic

Table 2 Phototactic behavior of stored-product insects to LED sources

Pests	Wavelength (color)	Luminous intensity (lx)	Time (h)	Number of adults (mean ± SEM)			Attraction rate (%)[a]	References
				Light side	No choice	Dark side		
Lasioderma serricorne	625 ± 10 nm (red)	100	1.5	9.3 ± 3.4	11.9 ± 4.0	8.8 ± 0.9	31.0	[24]
	BLB (control)	–	1.5	8.7 ± 1.3	7.6 ± 2.2	13.7 ± 0.9	29.0	
Sitophilus oryzae	470 ± 10 nm (blue)	25	48	25.3 ± 0.7	2.8 ± 0.5	1.9 ± 0.4	84.3	[44]
	BLB (control)	–	48	17.0 ± 0.9	7.2 ± 0.6	5.8 ± 0.4	56.7	
Sitophilus zeamais	625 ± 10 nm (red)	25	48	18.0 ± 1.0	7.3 ± 1.3	4.7 ± 1.3	59.8	[45]
	BLB (control)	–	48	8.2 ± 2.0	12.3 ± 2.8	9.5 ± 0.9	27.3	
Sitotroga cerealella	470 ± 10 nm (blue)	60	0.6	18.3 ± 0.6	8.1 ± 1.5	3.6 ± 0.6	61.0	[17]
	BLB (control)	–	0.6	17.4 ± 2.1	2.2 ± 1.7	10.4 ± 0.6	58.0	
Plodia interpunctella	520 ± 5 nm (green)	60	0.5	22.0 ± 0.5	2.1 ± 1.1	5.86 ± 1.4	52.2	[12]
	BLB (control)	–	0.5	8.7 ± 2.1	6.0 ± 1.5	15.32 ± 1.8	28.9	
Tribolium castaneum	625 ± 10 nm (red)	30	48	29.4 ± 1.6	0.6 ± 0.5	0.0 ± 0.1	97.8	[49]
	BLB (control)	–	48	8.4 ± 1.5	0.2 ± 0.1	21.8 ± 2.6	28.0	
Tyrophagus putrescentiae	625 ± 10 nm (red)	40	2	5.4 ± 2.7	41.7 ± 1.7	2.9 ± 1.6	18.0	[47]
	BLB (control)	–	2	2.2 ± 1.3	44.5 ± 1.7	3.3 ± 2.0	7.3	

[a] Attraction rate (%) is the average percentage of pests attracted under optimal conditions

Table 3 Phototactic behavior of stored-product insects to LED sources in granary settings[a]

Pests	Wavelength (color)	Luminous intensity (lx)	Time (days)	Number of adults (mean ± SEM)	Attraction rate (%)[a]	References
Plodia interpunctella	520 ± 5 nm (green)	60	4	199.1 ± 2.5	66.3	[48]
	BLB (control)	–	4	94.1 ± 1.6	31.4	
Sitotroga cerealella	470 ± 10 nm (blue)	60	4	248.4 ± 1.9	82.7	[48]
	BLB (control)	–	4	105.5 ± 2.1	35.2	
Sitophilus zeamais	625 ± 10 nm (red)	60	4	201.4 ± 2.9	67.1	[49]
	BLB (control)	–	4	92.4 ± 2.0	30.8	
Tribolium castaneum	625 ± 10 nm (red)	60	4	244.5 ± 2.6	81.5	[49]
	BLB (control)	–	4	90.4 ± 0.8	30.1	

[a] Attraction rate (%) is the average percentage of pests attracted under optimal conditions

behaviors, green and/or blue LEDs show the highest attraction rate against *Bemisia tabaci* (85.3 and 89.0%), *Trialeurodes vaporariorum* (96.6 and 97.4%), *Myzus persicae* (85.3 and 75.0%), *Liriomyza trifolii* (99.7 and 91.2%), *Spodoptera exigua* (90.3 and 81.1%), *Spodoptera litura* (64.3 and 57.7%), *Plutella xylostella* (green LED, 98.3%), and *Frankliniella occidentalis* (green LED, 44.3%) [11, 32–38]. In contrast, the relatively long wavelengths of red light (625 nm) and infrared light (IR, 730 nm) are repellent for the leaf miner (*L. trifolii*), moths (*S. litura* and *P. xylostella*), and whitefly (*T. vaporariorum*) [32, 33, 35, 36]. Green and/or blue LEDs are attractive for several agricultural insect pests including *T. vaporariorum*, *Liriomyza sativae*, *Sogatella furcifera*, and *Nilaparvata lugens* [39, 40]. Matteson and Terry [41] reported that *F. occidentalis* exhibited strong attractiveness to the blue LED traps. Vaishampayan et al. [42] evaluated the ultraviolet (UV, <400 nm), yellow-green region (520–610 nm), and red (610 to ca. 700 nm) light in attracting *T. vaporariorum* and found that the yellow-green region attracted

Fig. 4 LED trap to stored-product insects on granary [48, 49]

the most individuals compared with ultraviolet and red light. The collective data indicate that light traps with green and blue LEDs have the potential to control the agricultural insects in IPM.

Phototactic behavior on stored-product insects to LED sources

Similar to the behaviors of agricultural insect species, the behavior of various stored-product insect pests, such as weevil and moth, are influenced by light sources [12, 15, 17, 43–46] (Fig. 3). Under optimal light exposure times and luminance intensities of each wavelength, red, green, and blue LEDs have proven to be most attractive for stored-product insect species [12, 17, 44–46]. Based on the phototactic behavior under laboratory conditions, red LED (625 nm) is more efficient in attracting *Sitophilus zeamais* (59.8%) and *Tribolium castaneum* (97.8%), but less efficient in attracting *Lasioderma serricorne* (31.0%) and *Tyrophagus putrescentiae* (18.0%) [24, 47] (Table 2). Blue LED is significantly more effective in attracting *S. oryzae* and *Sitotroga cerealella* than UV (365 nm), green (510–520 nm), red (625–660 nm), and IR (730 nm) LEDs [17, 44]. Green LED best attracted *Plodia interpunctella* (52.2%) [12]. Based on the attraction rate under optimal conditions (luminous intensity of 60 lx and exposure time of 4 days), red LED showed the highest attraction rate against *S. cerealella* (67.1%) and *P. interpunctella* (81.5%) [48, 49] in a granary setting (Table 3). In the same setting, *P. interpunctella* (66.3%) and *S. cerealella* (82.7%) exhibited strong attractiveness to the green and blue LEDs, respectively [48] (Fig. 4). The effectiveness of LEDs has also been chronicled for blossom weevil (*Anthonomus pomorum*) and sweet potato weevil (*Euscepes postfasciatus*) [15, 50]. Nakamoto and Kubo [15] reported that light trapping of *E. postfasciatus* was more efficient using green (536 nm) LED. Hausmann et al. [50] found that the green and blue LEDs were more efficient in attracting and trapping *A. pomorum* than UV light. These optimal conditions of LED sources are an advantage to control insect pest behaviors. In future, the development of LED devices containing practical application is expected.

Study on physical control of insect pests by using light sources

The influence of LEDs on insect color and light perception with different wavelengths and on behavior, and the development of control technology involving new light sources has been described [19]. Physiological systems have been comprehensively utilized to measure the influence on many insect species in a wide range of wavelengths [51]. Phototactic responses of many insect species to LED sources have been investigated to clarify the relationship between insect behaviors and light wavelengths, with the goal of determining the effective attractant and repellent wavelengths for target insect pests [51]. The development of LED sources that are able to be used instead of incandescent light traps is an ongoing research interest. In addition, wavelengths of light that effectively attract parasitoids, which are natural enemies of insect pests, are being investigated [19].

In conclusion, LED equipment with various wavelengths can now be manufactured due to current technological advances, and new agricultural technology using light is starting to attract attention. Advances are also expected in the use of light for insect control as the results of these technological developments in lighting. Based on the new research being conducted by National Agricultural Research Organisation, we hope to ensure the further development of agricultural technology founded on a good balance of input from basic study in universities and independent administrative institutions and applied technology from private companies and public research institutes to establish the next generation of pest control technology.

Acknowledgments This work was carried out with the support of "Cooperative Research Program for Agriculture Science & Technology Development (Project title: Development of integrated pest management techniques using natural products and LEDs in the grain storage, Project No. PJ01004501)" Rural Development Administration, Korea.

References

1. Lee HK, Lee HS (2016) Toxicities of active constituent isolated from *Thymus vulgaris* flowers and its structural derivatives

against *Tribolium castaneum* (Herbst). Appl Biol Chem 59:821–826
2. Kim MG, Lee HS (2016) Insecticidal toxicities of naphthoquinone and its structural derivatives. Appl Biol Chem 59:3–8
3. Lee HW, Lee HS (2015) Acaricidal potency of active constituent isolated from *Mentha piperita* and its structural analogs against pyroglyphid mites. J Korean Soc Appl Biol Chem 58:597–602
4. Yun JH, Kim YJ, Koh KH (2016) Investigation into factors influencing antioxidant capacity of vinegars. Appl Biol Chem 59:495–509
5. Cloyd RA (2007) Phototaxis of fungus gnat, *Bradysia* sp. nr *coprophila* (Lintner) (Diptera: Sciaridae), adults of different light intensities. HortScience 42:1217–1220
6. Land MF (1997) Visual acuity in insects. Annu Rev Entomol 42:147–177
7. Bishop AL, Worrall R, Spohr LJ, McKenzie HJ, Barchi IM (2004) Response of *Culicoides* spp. (Diptera: Ceratopogonidae) to light-emitting diodes. Aust J Entomol 43:184–188
8. Vanninen I, Johansen NS (2005) Artificial lighting (AL) and IPM in greenhouse. IOBC/WPRS Bull 28:295–304
9. Turlings TCJ, Davison AC, Tamo C (2004) A six-arm olfactometer permitting simultaneous observation of insect attraction and odour trapping. Physiol Entonol 29:45–55
10. Garstang RH (2004) Mount Wilson observatory: the sad story of light pollution. Observatory 124:14–21
11. Oh MS, Lee CH, Lee SG, Lee HS (2011) Evaluation of high power light emitting diodes (HPLEDs) as potential attractants for adults *Spodoptera exigua* (Hubner) (Lepidoptera: Noctuidae). J Korean Soc Appl Biol Chem 54:416–422
12. Park JH, Lee HS (2016) Phototactic behavior 10: phototactic behavioral effects of *Plodia interpunctella* (Hűbner) (Lepidoptera: Pyralidae) adults to different light-emitting diodes of seven wavelengths. J Appl Biol Chem 59:95–98
13. Zheng LX, Zheng Y, Wu WJ, Fu YG (2014) Field evaluation of different wavelengths light-emitting diodes as attractants for adult *Aleurodicus dispersus* Russell (Hemiptera: Aleyrodidae). Neotrop Entomol 43:409–414
14. Yeh N, Chung JP (2009) High-brightness LEDs-energy efficient lighting sources and their potential in indoor plant cultivation. Renew Sustain Energy Rev 13:2175–2180
15. Nakamoto Y, Kuba H (2004) The effectiveness of a green light emitting diode (LED) trap at capturing the West Indian sweet potato weevil, *Euscepes postfasciatus* (Fairmaire) (Coleoptera: Curculionidae) in a sweet potato field. Appl Entomol Zool 39:419–495
16. Antignus Y (2000) Manipulation of wavelength-dependent behavior of insects: an IPM tool to impede insects and restrict epidemics of insect-borne viruses. Virus Res 71:213–220
17. Kim MG, Lee HS (2014) Phototactic behavior 5: attractive effects of the Angoumois grain moth, *Sitotroga cerealella*, to light-emitting diodes. J Korean Soc Appl Biol Chem 57:259–262
18. Park JH, Lee SM, Lee SG, Lee HS (2014) Attractive effects efficiency of LED trap on controlling *Plutella xylostella* adults in greenhouse. J Appl Biol Chem 57:255–257
19. Honda K (2011) Reactions to light in insects and practical applications. J Soc Biochem 35:233–236
20. Shimoda M, Honda K (2013) Insect reactions to light and its applications to pest management. Appl Entomol Zool 48:413–421
21. Kinoshita M, Arikawa K (2000) Colour constancy in the swallowtail butterfly *Papilio xuthus*. J Exp Biol 203:3521–3530
22. Yang EC, Lee DW, Wu WY (2003) Action spectra of phototactic responses of the flea beetle, *Phyllotreta striolata*. Physiol Entomol 28:362–368
23. Reisenman CE, Lazzari CR, Giurfa M (1998) Circadian control of photonegative sensitivity in the haematophagous bug *Triatoma infestans*. J Com Physiol A 183:533–541
24. Kim MG, Yang JY, Lee HS (2013) Phototactic behavior: repellent effects of cigarette beetle, *Lasioderma serricorne* (Coleoptera: Anobiidae), to light-emitting diodes. J Appl Biol Chem 56:331–333
25. Shimoda M, Kiguchi K (1995) The sweet potato hornworm, *Agrius convolvuli*, as a new experimental insect: behavior of adult moths in a rearing cage. Jpn J Appl Entomol Zool 39:321–328
26. Okada Y, Tomioka K, Chiba Y (1991) Circadian phase-response curves for light in nymphal and adult crickets, *Gryllus bimaculatus*. J Insect Physiol 37:583–590
27. Pittendrigh CS (1993) Temporal organization: reflections of a Darwinian clock-watcher. Annu Rev Physiol 55:17–54
28. Saunders D (2012) Insect photoperiodism: seeing the light. Physiol Entomol 37:207–218
29. Ghanem I, Shamma M (2007) Effect of non-ionizing radiation (UVC) on the development of *Trogoderma granarium* Everts. J Stored Prod Res 43:362–366
30. Nissinen A, Kristoffersen L, Anderbrant O (2008) Physiological state of female and light intensity affect the host-plant selection of carrot phyllid, *Trioza apicalis* (Hemiptera: Triozidae). Eur J Entomol 105:227–232
31. Sambaraju KR, Phillips TW (2008) Responses of adult *Plodia interpunctella* (Hübner) (Lepidoptera: Pyralidae) to light and combinations of attractants and light. J Insect Behav 21:422–439
32. Cho KS, Lee HS (2012) Visual preference of diamondback moth, *Plutella xylostella*, to light-emitting diodes. J Korean Soc Appl Biol Chem 55:681–684
33. Yang JY, Kim MG, Hs Lee (2012) Phototactic behavior: attractive effects of *Spodoptera litura* (Lepidoptera: Noctuidae), tobacco cutworm, to high-power light-emitting diodes. J Korean Soc Appl Biol Chem 55:809–811
34. Kim MG, Yang JY, Chung NH, Lee HS (2012) Photo-response of tobacco whitefly, *Bemisia tabaci* Gennadius (Hemiptera: Aleyrodidae), to light-emitting diodes. J Korean Soc Appl Biol Chem 55:567–569
35. Kim MG, Lee HS (2014) Attractive effects of American serpentine leafminer, *Liriomyza trifolii* (Burgess), to light-emitting diodes. J Insect Behav 27:127–132
36. Jeon JH, Kim MG, Lee HS (2014) Phototactic behavior 4: attractive effects of *Trialeurodes vaporariorum* adults to light-emitting diodes under laboratory conditions. J Korean Soc Appl Biol Chem 57:197–200
37. Yang JY, Lee SM, Lee HS (2015) Phototactic behavior 6: behavioral responses of *Myzus persicae* (Hemiptera: Aphididae) to light-emitting diodes. J Korean Soc Appl Biol Chem 58: 9–12
38. Yang JY, Sung BK, Lee HS (2015) Phototactic behavior 8: phototactic behavioral responses of western flower thrips, *Frankliniella occidentalis* Pergande (Thysanoptera: Thripidae), to light-emitting diodes. J Korean Soc Appl Biol Chem 58:359–363
39. Yang HB, Hu G, Zhang G, Chen X, Zhu ZR, Liu S, Liang ZL, Zhang XX, Cheng XN, Zhai BP (2013) Effect of light colours and weather conditions on captures of *Sogatella furcifera* (Horváth) and *Nilaparvata Lugens* (Stål). J Appl Entomol 138:743–753
40. Affeldt HA, Thimijan RW, Smith FF, Webb RE (1983) Response of the greenhouse whitefly (Homoptera: Aleyrodidae) and the vegetable leafminer (Diptera: Agromyzidae) to photospectra. J Econ Entomol 76:1405–1409
41. Matteson NA, Terry LI (1992) Response to color by male and female *Frankliniella occidentalis* during swarming and non-swarming behavior. Entomol Exp Appl 63:187–201
42. Vaishampayan M, Kogan M, Waldbauer GP, Woolley JT (1975) Spectral specific responses in the visual behavior of the greenhouse whitefly, *Trialeurodes vaporariorum* (Homoptera: Aleyrodidae). Entomol Exp Appl 18:344–356

43. Thomas C, Gries G (2009) Ultraviolet and violet light: attractive orientation cues for the Indian meal moth, *Plodia interpunctella*. Entomol Exp Appl 131:148–158
44. Jeon JH, Oh MS, Cho KS, Lee HS (2012) Phototactic responses of the rice weevil, *Sitophilus oryzae* Linnaeus (Coleoptera: Curculionidae), to light-emitting diodes. J Korean Soc Appl Biol Chem 55:35–39
45. Park JH, Sung BK, Lee HS (2015) Phototactic behavior 7: phototactic response of the maize weevil, *Sitotroga zeamais* motsch (Coleopter: Curculionidae), to light-emitting diodes. J Korean Soc Appl Biol Chem 58:373–376
46. Song J, Jeong EY, Lee HS (2016) Phototactic behavior 9: phototactic behavioral response of *Tribolium castaneum* (Herbst) to light-emitting diodes of seven different wavelengths. J Appl Biol Chem 59:99–102
47. Lee SM, Lee JB, Lee HS (2015) Controlling *Tyrophagus putrescentiae* Adults in LED-equipped Y-maze chamber. J Appl Biol Chem 58:101–104
48. Jeon YJ, Lee HS (2016) Control effects of LED trap to *Sitotroga cerealella* and *Plodia interpunctella* in the granary. J Appl Biol Chem 59:203–206
49. Song J, Jeong EY, Lee HS (2016) Effect of LED trap on controlling *Sitophilus zeamais* and *Tribolium castaneum* in granary. J Appl Biol Chem 59:129–132
50. Hausmann C, Samietz J, Dorn S (2004) Visual orientation of overwintered *Anthonomus pomorum* (Coleoptera: Curculionidae). Environ Entomol 33:1410–1415
51. Hironaka M, Hariyama T (2009) Insect orientation to natural and artificial light. Jpn J Appl Entomol Zool 53:135–145