Türk. entomol. derg., 2020, 44 (4): 477-486
DOI: http://dx.doi.org/10.16970/entoted.774867

ISSN 1010-6960
E-ISSN 2536-491X

Original article (Orijinal araştırma)

The effect of illumination with different light wavelengths on the orientation of Turkestan cockroach, *Blatta lateralis* (Walker, 1868) (Blattodea: Blattidae)[1]

Farklı dalga boyuna sahip ışınların Türkistan hamamböceği, *Blatta lateralis* (Walker, 1868) (Blattodea: Blattidae)'in yönelimi üzerine etkisi

Abdullah BURHAN[2] **Nimet Sema GENÇER[2*]**

Abstract

In this study, the effect of illumination with different light wavelengths (red, green, yellow, blue, white and a dark control) on the orientation of the Turkestan cockroach, *Blatta lateralis* (Walker,1868) (Blattodea: Blattidae) was investigated. The study was conducted under laboratory conditions in 2019 at Bursa Uludağ University. In orientation trials, adult cockroaches were exposed to three different light illuminances (25, 250 and 2500 lux). The trials were conducted in six- and two-arm choice arenas. In each trial, three replicates and 100 individuals were used. The data obtained show that the sensitivity to the illumination with different wavelengths may increase depending on light intensity. In particular, in the six-arm and two-arm trial, in the experiment where blue light of 2500 lux intensity was applied, the cockroach orientation was the lowest at 0.9% and 1.8%, respectively. In general, the highest orientation was against the dark (control) chamber in all trials. In addition, under all lux values, the orientation to red light was higher than with green, yellow, blue and white light. As a result of this study, it has been determined that blue light may have a repellent effect on cockroaches, and red light may be more attractive than other wavelengths. These studies can be useful in the development of an alternative method of control to replace chemicals used against cockroaches that would be harmless to human health and the environment.

Keywords: *Blatta lateralis*, LED light, light wavelength, Turkestan cockroach

Öz

Bu çalışmada, farklı dalga boylarına (kırmızı, yeşil, sarı, mavi, beyaz ve karanlık) sahip ışınların Türkistan hamamböceği, *Blatta lateralis* (Walker,1868) (Blattodea: Blattidae)'in yönelimi üzerindeki etkisi araştırılmıştır. Çalışma, 2019 yılında Bursa Uludağ Üniversitesi'nde laboratuvar koşullarında yürütülmüştür. Yönelim denemelerinde, ergin hamamböcekleri üç farklı ışık şiddetine (25, 250 ve 2500 lüks) maruz bırakılmıştır. Denemeler 6-kollu ve 2-kollu seçimli olarak yürütülmüştür. Tüm denemelerde 3 tekerrür ve her tekerrürde 100 birey kullanılmıştır. Elde edilen veriler, ışık şiddetine bağlı olarak farklı dalga boyuna sahip ışınlara yönelim hassasiyetinin artabileceğini göstermektedir. Özellikle, altı -kollu ve iki -kollu denemede, 2500 lüks şiddetinde mavi ışık uygulandığında, hamamböceğinin yönelimi en düşük seviyede olup, sırasıyla, %0.9 ve %1.8 oranında olmuştur. Genel olarak en yüksek yönelim, tüm denemelerde karanlık (kontrol) odacığa olmuştur. Ayrıca tüm lüks değerleri altında kırmızı ışığa yönelim, yeşil, sarı, mavi ve beyaz ışığa göre daha fazla olmuştur. Bu çalışma sonucunda, mavi ışığın hamamböcekleri üzerinde kaçırıcı bir etki gösterebileceği, kırmızı ışığın ise diğer dalga boylarına göre daha çekici olabileceği tespit edilmiştir. Yapılan bu çalışmalar, hamamböceklerine karşı kullanılan kimyasalların yerini alabilecek insan sağlığına ve çevreye zararsız olan alternatif bir mücadele metodunun geliştirilmesinde faydalı olabilir.

Anahtar sözcükler: *Blatta lateralis*, LED ışık, ışık dalga boyu, Türkistan hamamböceği

---

[1] This article is a part of Master Science Thesis of the first author, accepted at 09.07.2020 in Uludağ University, Graduate School of Natural and Applied Sciences.

[2] Bursa Uludağ University, Faculty of Agriculture, Department of Plant Protection, 16059, Nilüfer, Bursa, Turkey
* Corresponding author (Sorumlu yazar) e-mail: nsgencer@uludag.edu.tr

Received (Alınış): 28.07.2020 Accepted (Kabul ediliş): 20.10.2020 Published Online (Çevrimiçi Yayın Tarihi): 21.10.2020

Introduction

Cockroaches (Blattellidae) have out-survived dinosaurs, ice ages and they first appeared early in Upper Carboniferous period (Vishniakova, 1982; Vršanský, 2005, 2008). They are pests in homes, restaurants, hospitals, warehouses, offices and food processing areas. Their spread takes place mostly by movement of people and trade (Rehn, 1945). It is known that cockroaches have an allergic effect in humans and can carry various pathogenic organisms (Rosenstrich et al., 1997; Ahmad et al., 2011). They can transmit almost 150 bacterial species, 60 species of fungus, 45 species of parasitic worms and 90 species of protozoa to human either biologically or mechanically (Collins et al., 1995; Tatfeng et al., 2005; Etim et al., 2013). Cosmopolitan species such as American cockroach, *Periplaneta americana* (Linnaeus, 1758) (Blattodea: Blattidae) and German cockroach, *Blattella germanica* (Linnaeus, 1767) (Blattodea: Blattellidae) are common insects worldwide. In addition, the Turkestan cockroach, *Blatta lateralis* (Walker,1868) (Blattodea: Blattidae) are found in Afghanistan, Libya, Pakistan, southern Russia, Uzbekistan (Alesho, 1997), some urban areas of Punjub State of India (Sandhu & Sohi, 1981) and in southwestern United States (Kim & Rust, 2013). Turkestan cockroach live occasionally indoors, but it is found especially animal manure piles and around structures in gardens (Alesho, 1997; Artyukhina, 1972). Also, Turkestan cockroach and oriental cockroach, *Blatta orientalis* Linnaeus, 1758 (Blattodea: Blattidae) have been identified in Turkey (Demirsoy, 2014).

Given the insecticidal effects of synthetic chemicals such, as sulfluramid, fipronil and imidacloprid, that are often used to control cockroaches (Rust et al., 1995). However, cockroaches develop resistance to these chemicals (Ko et al., 2015). In addition, these chemicals have negative effects on human health and the environment. Therefore, new methods need to be developed in the control of cockroaches. To manage these pests, some insect repellents (plant essential oils) (Prakash et al., 1990, Paranagama & Ekanayake, 2004; Yilmaz & Tunaz, 2013), diatomaceous earth application (Özcan et al., 2018; Alkan et al., 2019) and biocontrol methods are used (Fox & Bressan-Nascimento, 2006; Hernández-Ramírez et al., 2007; Maketon et al., 2010; Tee et al., 2011; Hubner-Campos et al., 2013; Gutierrez et al., 2016; Baggio-Deibler et al., 2018). Also, insecticidal paints can provide useful control of *P. americana* populations for up to 3 months (Bueno-Marí et al., 2013).

Under normal conditions, cockroaches are active overnight, undertaking exploration, feeding and mating (Lipton & Sutherland, 1970a, b; Seelinger, 1984) avoiding illuminated areas (Kelly & Mote, 1990). One of the most well-known behavioral features of cockroaches are escape reactions in response to sudden illumination, they hide immediately in the nearest dark shelter. The cockroach visual system consists of two simple eyes, ocelli, and two large compound eyes, so such reactions to light depend on their intensity and wavelength (Kelly & Mote, 1990) and are mainly based on light input through the compound eyes (Okada & Toh, 1998). The ocelli of the cockroach can be recognized as two large white spots, located between the compound eyes at the base of the antennae (Cooter, 1975; Weber & Renner, 1976) and each ocellus contains about 10,000 photoreceptors that converge to only four larges second-order lamina cells (Toh & Sagara, 1984).

Artificial lights can be useful in the control of pests in the context of integrated control or in greenhouses (Johansen et al., 2011). It is generally known that some insect species that are active at night are attracted to an UV light source. Therefore, various UV light traps have been developed for population tracking or mass capture (Shimoda & Honda, 2013). Light sources of different colors have different effects (mortality, attractive and behavioral) on various insect species. Blue light has lethal effects on *Drosophila melanogaster* Meigen, 1830 (Diptera: Drosophilidae) (Hori et al., 2014). The UV (black) source was determined and for all light sources, the most common insect sets of traps were Diptera, Coleoptera and Lepidoptera, respectively (Ashfaq et al., 2005). Furthermore, lighting has been shown to affect the activities of agriculturally beneficial organisms, such as predators. This was found in studies of *Orius sauteri* (Poppius, 1909) (Heteroptera: Anthocoridae), an agriculturally beneficial insect (Wang et al., 2013).

Recently, especially with the production of LED bulbs, the use of lights in the control of harmful insects has increased (Shimoda & Honda, 2013). It has been found that illumination with different wavelengths may have lethal, adductive or attractive effects on insects (Pate & Curtis, 2001; Ashfaq et al., 2005; Van Langevelde et al., 2011; Shimoda & Honda, 2013; Hori et al., 2014). In Turkey, there have been no reports on the orientation of cockroaches to light. However, Uluca & Karaca (2016) conducted studies on the effect of ultrasonic pest repellents on Turkestan cockroaches. Therefore, the aim of this study is to develop a control method that could replace the chemicals in the control of cockroaches that is harmless to human health and environment. For this purpose, the effect of illumination having different wavelengths and intensity on Turkestan cockroaches was investigated.

Materials and Methods

The trials were conducted in 2019 in the laboratory of the Department of Entomology, Bursa Uludağ University, Faculty of Agriculture, Department of Plant Protection.

Insects

A commercial supply of *B. lateralis* female and male adults used in the experiment and purchased from insect breeder, Antalya Çekirge (Mira Canlı Hayvan Böcek Tur. İnş. Tarım Tic. Ltd. Şti., Antalya, Turkey), a package containing 1500 individuals (Anonymous, 2019).

Light and sticky trap

LED light sources with different wavelengths were used in this research (Figure 1a). The power of the LEDs used is 1.5 W. The wavelengths used were red (678 nm), green (620 nm), yellow (580 nm), blue (478 nm) and white (all colors). In the experiment, yellow sticky traps were placed in the base area of each chamber (except the release point) in order to accurately determine the number of adult insects (Figure 1b).

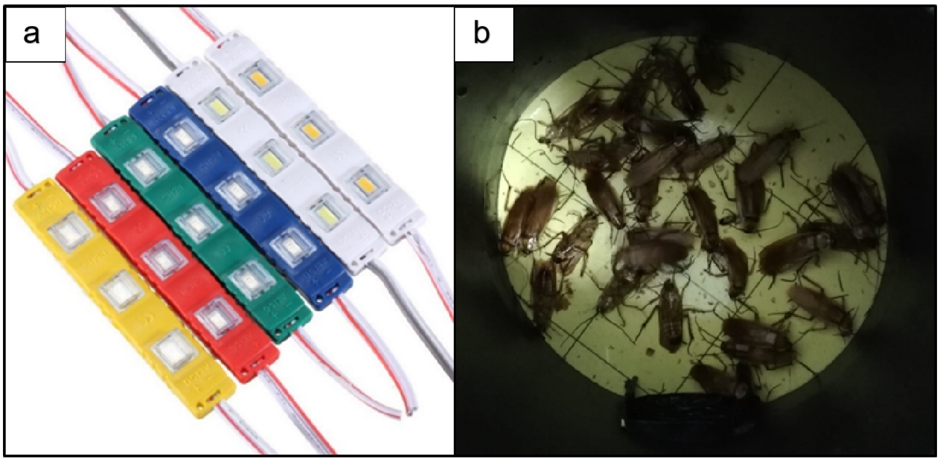

Figure 1. a) LED lights and b) sticky trap.

Plastic black flower pots (9 × 10 cm) were used as hiding places for cockroaches. The pots (chambers) illuminated by LED light sources with different wavelengths were connected by a plastic tube (5 × 10 cm) at the center in a single combination.

Six and two-arm choice test

The light wavelength preference of adult male Turkestan cockroaches was tested in a six-arm arena, similar to that previously used for *Orius* bugs and a parasitoid fly (Ogino et al., 2015; Tokushima et al., 2016). This setup enables the cockroaches to be presented with six LED light sources simultaneously.

The six equal chambers used in this study were connected to the starting point in the middle by means of insect passage (Figure 2). Adult insects were placed in the middle starting point (Figure 2). Five of the chambers were illuminated by LEDs of different wavelength. One of them had light source (dark control). The floor area of each chamber was covered with a sticky trap in order to determine the number of insects entering. All light sources in the chambers were adjusted to an intensity of 25 lux. Light intensities were measured with a light meter.

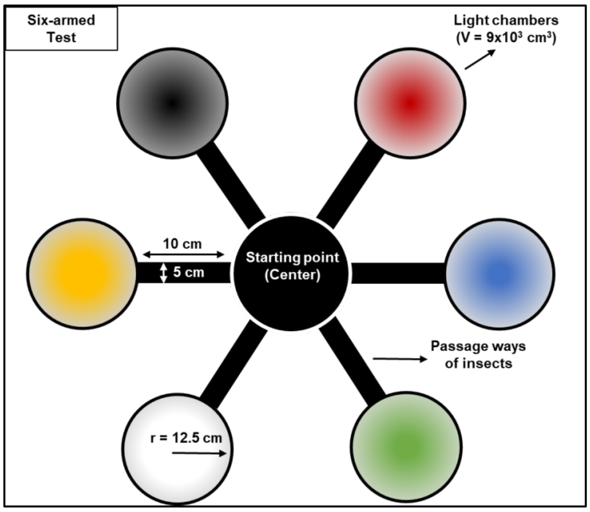

Figure 2. Schematic view of the six-arm choice arena.

In two-arm choice test, the orientation to the chambers illuminated only with 2500 lux LED light sources was observed in binary combinations with five light colors.

Experimental procedure

First, the chambers illuminated by LED light sources with different wavelengths were connected by tubes to the center in a single combination. The orientation of the cockroach adults to the chambers with three different light intensities (25, 250 and 2500 lux) were observed. In the next step, the orientation towards the chambers illuminated by LED light sources of only 2500 lux intensity was observed in binary combinations (dark-light). In this experiment, five combinations (control-red light, control-blue light, control-green light, control-white light and control-yellow light with dark as the control) were tested. One hundred adult male cockroaches were released at the same time in the center point and the orientation of the insects to light was determined after 15 min. Each application was replicated three times.

Statistical analysis

Statistical differences in the ratio of cockroaches to chambers with different wavelengths and different light intensities were analyzed by two-way analysis of variance. LSD test ($P < 0.05$) was used to determine the difference between means. Differences in the proportions of *B. lateralis* adult attraction by moving toward one of the light sources or toward the dark (control) and different lux intensity were analyzed using the Pearson chi-squared test. Insects that did not make a choice were excluded from the statistical analysis.

Results

Orientation of Turkestan cockroach to different wavelength in six-arm combinations

The orientation of cockroach adults place in the center of chambers with different wavelengths was observed at three different light intensities and the results are given in Table 1.

Table 1. Average proportion (%) of adult orientation of Turkestan cockroaches to different wavelength light sources at different light intensities (25, 250 and 2500 lux)

	Proportion of adults (%)					
	25 lux		250 lux		2500 lux	
Control (dark)	20.7	d	27.8	b	34.1	a
Red	17.4	e	21.5	cd	22.9	c
Blue	9.5	ij	2.5	l	0.9	m
Green	14.1	f	9.5	ij	5.3	k
White	10.5	hi	12.0	gh	12.8	fg
Yellow	13.6	f	8.0	j	4.9	k

The orientation of Turkestan cockroach was highest to the dark control at light intensities of 250 and 2500 lux (27.8 and 34.1%, respectively) and then to red-light (21.5 and 22.9%, respectively). Also, the orientation to the control at 25 lux was 20.7%. The lowest orientation was to blue color (0.9% at 2500 lux), and then yellow and green color (4.9 and 5.3%, respectively). Generally, as light intensity decreased, the differences between orientation to different wavelengths likewise decreased (Figure 3).

Considering only light with different wavelengths, the highest Turkestan cockroach orientation was towards the dark control (82.6%). After the control, the statistically highest trend was 61.7% to chambers with red and white light (35.2%), respectively. The orientation to chambers with green and yellow light was no statistically different, a mean of 27.7%. Statistically, the lowest orientation was towards chambers with blue light with 12.9% (Table 1). Considering only the different lux light intensities, 25 lux give no statistical significance (*P*>0.05). However, 250 and 2500 lux were statistically significant (*P* < 0.01).

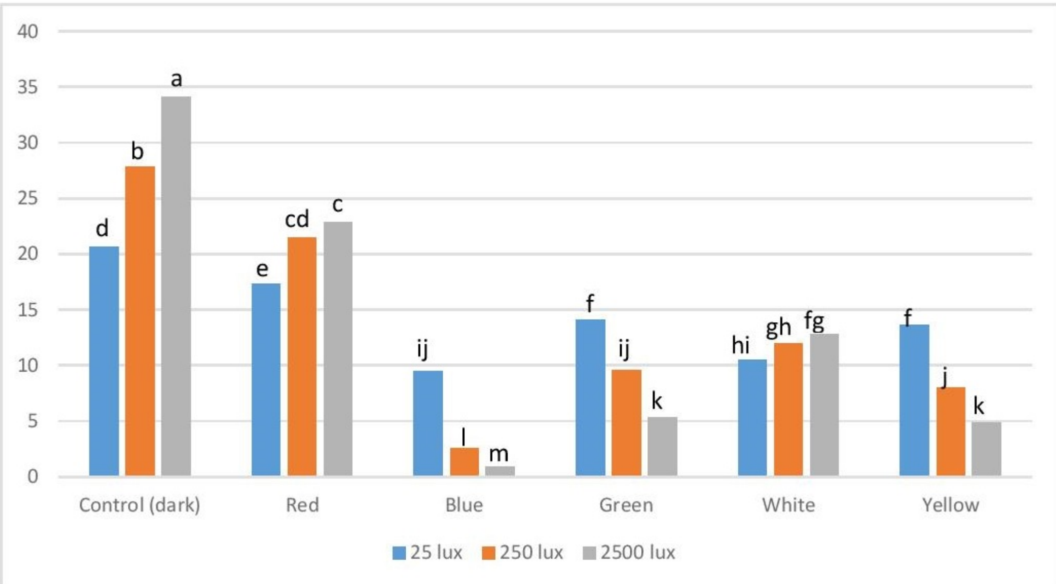

Figure 3. Orientation of Turkestan cockroach adults to the three light intensities (25, 250 and 2500 lux) for six treatments (F=184; df=20; P>0.0001).

Orientation of the Turkestan cockroach to the two-arm combinations at the highest light intensity (2500 Lux)

The orientation of Turkestan cockroaches in binary light combinations under 2500 lux light intensity is given in Table 2. In this binary combination study, the orientation towards the dark control was the highest and varied between 44.3 and 62.3%. In the center (dim) values were 25.0 to 35.9%. In addition, in application with LED lights, the highest orientation was 30.7% for red light, the lowest orientation for blue light (1.8%), followed by yellow (8.7%), green (9.1%) and white (20.1%) light. These results were similar to the six-arm combinations and so support each other. The results of two-arm choice test between light colors show statistically significant with blue light (df=1, x^2=90.34, $P < 0.01$).

Table 2. Average proportion (%) of adult orientation of Turkestan cockroaches in binary light combinations of different wavelengths at 2500 lux (%)

Combination	Orientation	Proportion of adults (%)	
Dark-Red	Control (dark)	44.3	a
	Center (dim)	25.0	c
	Red	30.7	b
Dark-Blue	Control (dark)	62.3	a
	Center (dim)	35.9	b
	Blue	1.8	c
Dark-Green	Control (dark)	58.9	a
	Center (dim)	31.9	b
	Green	9.1	c
Dark-White	Control (dark)	51.7	a
	Center (dim)	28.2	b
	White	20.1	c
Dark-Yellow	Control (dark)	58.6	a
	Center (dim)	32.8	b
	Yellow	8.6	c

Discussion

In this study, the highest orientation of the Turkestan cockroach (*B. lateralis*) was to non-illuminated chamber (i.e. dark control) and the lowest orientation was to blue light. However, the orientation towards red light was found to be second highest following dark (control) in all trial conditions. The orientation to green and yellow light was not statistically different under at three light intensities (25, 250 and 2500 lux). Unlike our studies, in an experiment with light sources having a wavelength of 350 to 700 nm, Koehler et al. (1987) suggested that green or UV light changed the behavior of German cockroaches by 30%, while yellow and red light did not show any effect. Furthermore, in our study, some of the cockroaches were found in the dim light at the release point. Similar to our results, Zhukovskaya et al. (2017) state that green light promotes mobility in *P. americana* adults and dim UV light source causes adults to remain inactive.

In the study by Okada & Toh (1998), *P. americana* escape in a shadow-dependent pause (shadow response) was observed even at less than 0.01 lux (very low light levels). Similarly, as a result of the observations made in this study, it was observed that *B. lateralis* adults were statistically more oriented towards the dark chamber. The average number of adult insects under dim light was statistically less than the number of adults in the chamber illuminated by red LED light. Overall, red light is more attractive than dim light and less attractive than darkness. In contrast to our study, Dean (2017) found that red light repels a greater number of Dublin cockroaches than yellow, blue, white, green, black and no light control (dark).

In our study, blue light was found to be the least attractive. In contrast to our study, Dean (2017) reported that blue light was the most attractive to Dublin cockroaches. Yellow and green light showed the least attraction after blue. Similar to our study, the same researcher emphasizes that green light is the second least attractive color. Contrast to our study, in different insect groups, green LEDs are attractive for adults of *Plutella xylostella* (Linnaeus, 1758) (Lepidoptera: Plutellidae) and *Frankliniella occidentalis* (Pergande, 1895) (Thysanoptera: Thripidae) (Park et al., 2014; Yang et al., 2015). In this study, yellow light was found to be the second least attractive after blue, but Dean (2017) emphasizes that yellow light attracts cockroaches.

Various results have been obtained in studies with other insect species on this subject. In addition, Shibuya et al. (2018) reported that blue light has lethal effects on different stages of vinegar fly, (*D. melanogaster*). Also, Hori et al. (2014) examined the lethal effects of visible light with short wavelength on insects. They found that short wavelength visible (blue) light had lethal effects on the vinegar fly eggs, larvae, pupae and adults. In the same study, they found that blue light had a lethal effect for mosquitoes and flour beetles, but that the effective wavelength at which death occurs differed between insect species. The findings in the same study also show that high toxic wavelengths of visible light are species-specific in insects and that shorter wavelengths are not always more lethal. For some organisms, such as insects, blue light appears to be more harmful than UV light. Our study confirms the results of, Hori et al. (2014). Orientation of adult cockroaches tends to vary with light wavelength. In our study, especially blue light showed the least attraction. In this regard, light sources with storage insects were studied. Similar to our study, Kim et al. (2013) found repellent effect of the blue light to *Lasioderma serricorne* (Fabricius, 1792) (Coleoptera: Anobiidae). In contrast to our study, Jeon & Lee (2016) reported that blue light is the most attractive to *Sitotroga cerealella* (Olivier, 1789) (Lepidoptera: Gelechiidae). Also, in contrast to our study, Jeon et al. (2012) reported blue light attraction in *Sitophilus oryzae* (Linnaeus, 1763) (Coleoptera: Curculionidae). Similar to our study, Wang et al. (2013), determined that red light was attractive to *O. sauteri* and the research found the blue and red light had a negative impact on the development of this predator species. Lee et al. (2015) also found the repellent effect of the blue light on *Tyrophagus putrescentiae* (Schrank, 1781) (Acari: Acaridae).

In conclusion, the orientation of cockroaches under light intensity of 250 and 2500 lux was low with blue light. In this case, it is understood that the blue light has a negative effect. However, as light intensity decreases (25 lux), the orientation to blue light increases becoming equivalent to white light. In this study it was determined that light sources can be used as an alternative to chemical methods in the control of cockroaches. In the future, it is thought that red light could be used as an attractant and blue light as a repellent for Turkestan cockroaches. In addition, it was understood that LED sources with different levels of light intensity would exhibit significantly variable activity on cockroaches.

Acknowledgement

The authors thank the anonymous referees for their invaluable comments and suggestions which helped improve this manuscript.

References

Ahmad, A., A. Ghosh, C. Schal & L. Zurek, 2011. Insects in confined swine operations carry a large antibiotic resistant and potentially virulence enterococcal community. BMC Microbiology, 11 (23): 1471-2180.

Alesho, N. A., 1997. Synathropic cockroaches of Russia. Proceedings of the International Colloquia on Social Insects, 3-4: 45-50.

Alkan, M., T. Atay, S. Ertürk & İ. Kepenekçi. 2019. Comparison of bioactivities of native diatomaceous earth against Turkestan cockroach [*Blatta lateralis* Walker (Blattodea: Blattidae)] nymphs. Applied Ecology and Environment Research, 17 (3): 5897-5994.

Anonymous, 2019. Antalya çekirge. (Web page: www.antalyacekirge.net) (Date accessed: 2 October 2020).

Artyukhina, I., 1972. Ecology of Turkestan cockroaches (*Shelfordella tartara*) in some villages of the Uzber-SSR. Medicinskaya Parazitologiya i Parazitarnye Bolezina, 41 (1): 49-53.

Ashfaq, M., R. A. Khan, M. A. Khan, F. Rasheed & S. Hafeez, 2005. Insect orientation to various color lights in the agricultural biomes of Faisalabad. Pakistan Entomologist, 27 (1): 49-52.

Baggio-Deibler, M. V., M. da Costa Ferreira, A. C. Monteiro, A. de Souza Pollo & M. V. Franco Lemos, 2018. Management of the American cockroach's oothecae: The potential of entomopathogenic fungi control. Journal of Invertebrate Pathology, 153 (March): 30-34.

Bueno-Marí, R., A. Bernués-Bañeres, F. J. Peris-Felipo, J. Moreno-Marí & R. Jiménez-Peydró, 2013. American cockroach control assays in the municipal sewerage system of Valencia (Spain). Polish Journal of Entomology, 82 (3): 143-150.

Collins, C. H., P. M. Lyne & J. M., Grange, 1995. Collins and Lyne's Microbiological Methods. 7th Ed. Butterworth and Heinmann, London, 493 pp.

Cooter, R., 1975. Ocellus and ocellar nerves of *Periplaneta americana* L. (Orthoptera: Dictyoptera). International Journal of Insect Morphology and Embryology, 4 (3): 273-288.

Dean, K. A., 2017. Step into the light: How choosy are cockroaches about light? California State Science Fair 2017. Project Summary. Ap2/17, 1 p. (Web page: http://csef.usc.edu/History/2017/Projects/J2306.pdf) (Date accessed: 16 October 2020).

Demirsoy, A., 2014. Yaşamın Temel Kuralları Omurgasızlar/Böcekler Entomoloji. Hacettepe Yayınları, Ankara, 940s.

Etim, S. E., O. E. Okon, P. A. Akpan, G. I. Ukpong & E. E. Oku, 2013. Prevalence of cockroaches (*Periplanata americana*) in households in Calabar: Public health implications. Journal of Public Health and Epidemiology, 5 (3): 149-152.

Fox, E. G. P. & S. Bressan-Nascimento, 2006. Biological characteristics of *Evania appendigaster* (L.) (Hymenoptera: Evaniidae) in different densities of *Periplaneta americana* (L.) oothecae (Blattodea: Blattidae). Biological Control, 36 (2): 183-188.

Gutierrez, A. C., J. A. Machado, R. Hubner-Campos, M. A. Pennisi, J. Rodrigues, C. C. López Lástra, J. J. García, É. K. Fernandes & C. Luz, 2016. New insights into the infection of the American cockroach *Periplaneta americana* nymphs with *Metarhizium anisopliae* s.l. (Ascomycota: Hypocreales). Journal of Applied Microbiology, 121 (5): 1373-1383.

Hernández-Ramírez, G., F. Hernández-Rosas, H. Sánchez-Arroyo & R. Alatorre-Rosas, 2007. Infectivity, age and relative humidity related with susceptibility on nymphs and adults of *Periplaneta americana* to *Metarhizium anisopliae* and *Beauveria bassiana* (Ascomycota: Hypocreales). Entomotropica, 22 (1): 27-36.

Hori, M., K. Shibuya, M. Sato & Y. Saito, 2014. Lethal effects of short-wavelength visible light on insects. Scientific Reports, 4 (7383): 1-6.

Hubner-Campos, R. F., R. N. Leles, J. Rodrigues & C. Luz, 2013. Efficacy of entomopathogenic hypocrealean fungi against *Periplaneta americana*. Parasitology International, 62 (6): 517-521.

Jeon, Y. J. & H. S. Lee, 2016. Control effects of LED trap to *Sitotroga cerealella* and *Plodia interpunctella* in the granary. Journal of Applied Biological Chemistry, 59 (3): 203-206.

Jeon, J. H., M. S. Oh, K. S. Cho, & H. S. Lee, 2012. Phototactic responses of the rice weevil, *Sitophilus oryzae* Linnaeus (Coleoptera: Curculionidae), to light-emitting diodes. Journal of Korean Society for Applied Biological Chemistry, 55 (1): 35-39.

Johansen, N. S., I. Vänninen, D. M. Pinto, A. I. Nissinen & L. Shipp, 2011. In the light of new greenhouse technologies: 2. Direct effects of artificial lighting on arthropods and integrated pest management in greenhouse crops. Annals of Applied Biology, 159 (1): 1-27.

Kelly, K. M. & M. I. Mote, 1990. Electrophysiology and anatomy of medulla interneurons in the optic lobe of the cockroach, *Periplaneta americana*. Journal of Comparative Physiology A, 167 (6): 745-756.

Kim, T. & M. K. Rust, 2013. Life history and biology of the invasive Turkestan cockroach (Dictyoptera: Blattidae). Journal of Economic Entomology, 106 (6): 2428-2432.

Kim, M. G., J. Y. Yang & H. S. Lee, 2013. Phototactic behavior: repellent effects of cigarette beetle, *Lasioderma serricorne* (Coleoptera: Anobiidae), to light-emitting diodes. Journal of Applied Biological Chemistry, 56: 331-333.

Ko, A. E., D. N. Bierman, C. Schal & J. Silverman, 2015. Insecticide resistance and diminished secondary kill performance of bait formulations against German cockroaches (Dictyoptera: Blattellidae). Pest Management Science, 72 (9): 1778-1784.

Koehler, P. G., H. R. Agee, N. C. Leppla & R. S. Patterson, 1987. Spectral sensitivity and behavioral response to light quality in the German cockroach (Dictyoptera: Blattellidae). Annals of the Entomological Society of America, 80 (6): 820-822.

Lee, S. M., J. B. Lee & H. S. Lee, 2015. Controlling *Tyrophagus putrescentiae* adults in LED-equipped Y-maze chamber. Journal of Applied Biological Chemistry, 58 (2): 101-104.

Lipton, G. R. & D. J. Sutherland, 1970a. Activity rhythms in the American cockroach, *Periplaneta americana*. Journal of Insect Physiology, 16 (8): 1555-1566.

Lipton, G. R. & D. J. Sutherland, 1970b. Feeding rhythms in the American cockroach, *Periplaneta americana*. Journal of Insect Physiology, 16 (9): 1757-1767.

Maketon, M., A. Hominchan & D. Hotaka, 2010. Control of American cockroach (*Periplaneta americana*) and German cockroach (*Blattella germanica*) by entomopathogenic nematodes. Revista Colombiana de Entomología, 36 (2): 249-253.

Ogino, T., T. Uehara, T. Yamaguchi, T. Maeda, N. C. Yoshida & M. Shimoda, 2015. Spectral preference of the predatory bug *Orius sauteri* (Heteroptera: Anthocoridae). Japanese Jornal of Applied Entomology and Zoology, 59 (1): 10-13.

Okada, J. & Y. Toh, 1998. Shade response in the escape behaviour of the cockroach, *Periplaneta americana*. Zoological Science, 15 (6): 831-835.

Özcan, K., H. Tunaz, A. A. Işıkber & M. K. Er, 2018. Lethal effect of Turkish diatomaceous earth (Bgn-1) against adults of German cockroaches (*Blattella germanica* L.). Julius-Kühn-Archiv, 463 (2): 743-746.

Paranagama, P. A. & E. M. D. S. Ekanayake, 2004. Repellant proporties from essential oil of *Alpinia calcarata* Rosc. against the American cockroach, *Periplanata americana*. Journal of the National Science Foundation of Sri Lanka, 32 (1&2): 1-12.

Park, J. H., S. M. Lee, S. G. Lee & H. S. Lee, 2014. Attractive effects efficiency of LED trap on controlling *Plutella xylostella* adults in greenhouse. Journal of Applied Biological Chemistry, 57 (3): 255-257.

Pate, J. & A. Curtis, 2001. Insects response to different wavelengths of light in New River State Park, Ash County, North Carolina. Field Biology and Ecology, 12 (2): 4-8.

Prakash, S., C. P. Srivastava, S. Kumar, K. S. Pandey, M. P. Kaushik & K. M. Rao, 1990. N, N-diethylphenyl acetamide-a new repellent for *Periplaneta americana* (Dictyoptera: Blattidae), *Blattella germanica* and *Supella longipalpa* (Dictyoptera: Blattellidae). Journal of Medical Entomology, 27 (6): 962-967.

Rehn, J. A. G., 1945. Man's uninvited fellow traveler: the cockroach. Science Monthly, 61: 265-276.

Rosenstrich, D. L., P. Eggleston, M. Kattan, D. Baker, R.G. Slavin, P. Gergen & F. Malveaux, 1997. The role of cockroach allergy and exposure to cockroach allergen in causing morbidity among inner-city children with asthma. The New England Journal of Medicine, 336 (19): 1356-1363.

Rust, M. K., J. M. Owens & D. A. Reierson, 1995. Understanding and Controlling the German cockroach. New York, NY: Oxford University Press, 419 pp.

Sandhu, G. S. & A. S. Sohi, 1981. Occurrence of different species of cockroaches at Ludhiana Punjab India. The Journal of Bombay Natural History Society, 78 (1): 179-181.

Seelinger, G., 1984. Sex-specifc activity patterns in *Periplaneta americana* and their relation to mate-fnding. Zeitschrift für Tierpsychologie, 65 (5): 309-326.

Shibuya, K., S. Onodera & M. Hori, 2018. Toxic wavelength of blue light changes as insects grow. PloS one, 13 (6): 199-266.

Shimoda, M. & K. I. Honda, 2013. Insect reactions to light and its applications to pest management. Applied Entomology and Zoology, 48 (4): 413-421.

Tatfeng, Y. M., M. U. Usuanlele, A. Orukpe, A. K. Digban, M. Okodua, F. Oviasogie & A. A. Turay, 2005. Mechanical transmission of pathogenic organisms: role of cockroaches. Journal of Vectore Borne Diseases, 42 (4): 129-134.

Tee, H. S., A. R. Saad & C. Y. Lee, 2011. Evaluation of *Aprostocetus hagenowii* (Hymenoptera: Eulophidae) for the control of American cockroaches (Dictyoptera: Blattidae) in sewers and crevices around buildings. Journal of Economic Entomology, 104 (6): 2031-2038.

Toh, Y. & H. Sagara, 1984. Dorsal ocellar system of the American cockroach: I. Structure of the ocellus and ocellar nerve. Journal of Ultrastructure Research, 86 (2): 119-134.

Tokushima, Y., T. Uehara, T. Yamaguchi, K. Arikawa, Y. Kainoh & M. Shimoda, 2016. Broadband photoreceptors are involved in violet light preference in the parasitoid fly *Exorista japonica*. PLOS ONE, 11 (8): 1-16.

Uluca, M. & İ. Karaca, 2016. *Blatta lateralis* Walker (Blattodea: Blattidae) üzerine ultrasonik zararlı kovucuların performansının ölçülmesi. Süleyman Demirel Üniversitesi Fen Bilimleri Enstitüsü Dergisi, 20 (3): 558-565.

Van Langevelde, F., J. A. Ettema, M. Donners, M. F. Wallis DeVries & D. Groenendijk, 2011. Effect of spectral composition of artificial light on the attraction of moths. Biological Conservation, 144 (9): 2274-2281.

Vishniakova, V. N., 1982. Yurskie tarakanovye semyeistva Blattulidae fam. nov. (Insecta: Blattida) [Jurassic cockroaches of the family Blattulidae fam. nov. (Insecta: Blattida)]. Paleontological Journal, (2): 69-79.

Vršanský, P., 2005. Insect in a drilling core-cockroach Kridla stastia sp.nov. from the Verkhne-Bureinskaya depression in Eastern Russia. Entomological Problems, 35 (2): 115-116.

Vršanský, P., 2008. A complete larva of a Mesozoic (Early Cenomanian) cockroach from the Sisteron amber. Geologica Carpathica, 59 (3): 269-272.

Wang, S., X. L. Tan, J. P. Michaud, F. Zhang & X. Guo, 2013. Light intensity and wavelength influence development, reproduction and locomotor activity in the predatory flower bug *Orius sauteri* (Poppius) (Hemiptera: Anthocoridae). BioControl, 58 (5): 667-674.

Weber, G. & M., Renner, 1976. The ocellus of the cockroach, *Periplaneta americana* (Blattariae). Cell and Tissue Research, 168 (2): 209-222.

Yang, J. Y., B. K. Sung & H. S. Lee, 2015. Phototactic behavior 8: phototactic behavioral responses of western flower thrips, *Frankliniella occidentalis* Pergande (Thysanoptera: Thripidae), to light-emitting diodes. Journal of Korean Society for Applied Biological Chemistry, 58 (3): 359-363.

Yilmaz, Y. B. & H. Tunaz, 2013. Fumigant toxicity of some plant essential oils and their selected monoterpenoid components against adult American cockroach, *Periplaneta americana* (Dictyoptera: Blattidae). Turkish Journal of Entomology, 37 (3): 319-328.

Zhukovskaya, M., E. Novikova, P. Saari & R. V. Frolov, 2017. Behavioral responses to visual overstimulation in the cockroach *Periplaneta americana* L. Journal of Comparative Physiology A, 203 (12): 1007-1015.