

Original Research Article

Light-emitting diodes (LED) as luminous lure for adult *Spodoptera frugiperda* (J. E. Smith, 1797) (Lepidoptera: Noctuidae)

ABSTRACT

The capture of insects through luminous sources can represent another control option of pest integrated-handling programs. The purpose hereof was to verify the attractiveness of different-colored Light-Emitting Diodes on adult *Spodoptera frugiperda*. The research was conducted at the Plant Breeding and Environmental Sciences Department's Entomology Laboratory of the Federal University of Paraíba's Agricultural Sciences Center – CCA/UFPB, Areia-PB. We assembled an environment composed of two plastic containers connected by a PVC pipe. Adult subjects of *S. frugiperda* were inserted into one of these containers, and the opposite container was used to house the lamp. Ultra LED lamps were used as light source in the colors: yellow, green, white, red, and blue, each one of them with specific wavelengths, illuminance, and exposure period. The LED lamp colors of greater attractiveness rate for adult subjects of *S. frugiperda* were: the green-colored lamp (31.22 and 49.91% at the times of 24 and 48 hours, respectively), followed by the white- and yellow-colored lamps, while the red (25.75%) and blue (7.4%) colors, at the time of 48 hours, were the ones of lower rates. The attractiveness of *S. frugiperda* gradually increased over the exposure period for the treatments with the green, yellow, white, and red LED. The green LED lamp, followed by the yellow and white LED, is the most attractive ones for adults of this species.

Keywords: luminous trap; ethological control; fall armyworm

1. INTRODUCTION

The species of the genus *Spodoptera* are widely distributed in the world. Among the most important ones, the *Spodoptera frugiperda* (J. E. Smith, 1797) stands out due to its nutritional habits: it feeds on more than 180 species of plants, including the cotton tree, corn, and soy [1]. On top of that, it takes advantage of alternative hosts to remain in several agroecosystems [2]. The species belongs to the Lepidoptera order, Noctuidae family, and is considered as the most important pest of the corn culture [3], whose cost to control this caterpillar in the culture are superior to 600 million dollars per year for the producing countries [4].

The experts recommend several control tactics to handle the pest, including cultural, chemical, and biological methods. Farmers usually employ synthetic insecticides that, in addition to their elevated cost, also represent environmental and animal contamination risks [5]; they also might end up selecting populations of resistant insects [6].

To offer alternatives of efficient handling linked to agrochemical reduction, we need to adopt planned measures in the sustainable agriculture model to control the pest-insects to increase the benefit-cost ratio and achieve a production free from toxic waste [7]. In the specific case of *S. frugiperda*, the search for alternatives to the use of synthetic insecticides is permanent. Besides the use of resistant varieties, biological control, insecticide plants, resistance induction, and others, there is a tendency of searching for researches that prioritize the capture of adult insects. With that in mind, the use of luminous traps to capture pest-insects is a promising alternative to reduce the production cost of some cultures, given that they basically work through the principle of attraction and interception, attracting adult insects, avoiding their oviposition, and therefore reducing their population increase.

In recent researches, we notice a considerable interest in the pest control technology that uses the insects' response to light as a sustainable pest control method, especially by drastically reducing the use of synthetic products in agriculture [8, 9, 10].

Most insects have two kinds of photoreceptor organs: compound eyes and ocelli. Compound eyes are composed of several light-sensitive units called ommatidia. Ommatidia have long photoreceptor-cell beams, each one of them with specific spectral sensitivities [11]. These responses to light are essentially influenced by several factors, including light intensity, wavelengths, wavelength combinations, exposure time, light source direction, and light source and ambient light intensity contrast [9, 10].

The capture of Noctuidae subjects of great economic importance, such as *Helicoverpa zea*, *S. frugiperda* and *Spodoptera eridania*, using luminous traps, like black light, was reported by several authors [14, 15, 16, 17]. Researches report the attractiveness of other species, such as *Spodoptera exigua* and *Plutella xylostella*, to Light-Emitting Diodes (LED) [18, 19], besides other species and light sources that are being studied to clarify the light's spectral composition and the level of positive phototaxis for insects.

Light-Emitting Diodes have several advantages, such as adjustable illuminance intensity, are small, have a prolonged lifespan, wavelength specificity, high efficiency, shock resistance, and low thermal energy production [20, 21]. Additionally, Light-Emitting Diodes (LED) were reported as potential pest controllers due to their attractive and repellent effects against hygienic pests, such as species of the Culicoides genus and agricultural pests [22, 23, 24, 25]. With that in mind, the purpose hereof was to evaluate the attractiveness of adult subjects of *S. frugiperda* to Light-Emitting Diodes (LED) of different spectral bands.

2. MATERIAL AND METHODS

The research was conducted at the Plant Breeding and Environmental Sciences Department's Entomology Laboratory of the Federal University of Paraíba's Agricultural Sciences Center (CCA/UFPB). The attractiveness experiments were performed in a temperature-controlled environment under the following conditions: temperature of $25 \pm 2^\circ\text{C}$, relative humidity of $70 \pm 10\%$, and a 12-hour photophase.

2.1. Raising of *Spodoptera frugiperda*

The insects used in the experiment originated from the previously established raising performed at the entomology laboratory of the CCA/UFPB. The insects were raised in B.O.D.-type temperature-controlled chambers under the following conditions: temperature of $25 \pm 1^\circ\text{C}$, relative humidity of $70 \pm 10\%$, and a 12-hour photophase. The larvae were individually inserted into flat-bottom glass tubes of 2.5 cm in diameter x 8.5 cm in length, which were clogged with cotton and kept in a temperature-controlled chamber under the aforementioned conditions until the pupal stage. The standard diet established by Nalim [24], composed of pinto bean, wheat germ, brewer's yeast, Nipagin, agar, and ascorbic and sorbic acids, was adopted. The content of this artificial diet was used to fill the aforementioned tubes up to 1/4 of their height. After the pupae's sexing, *S. frugiperda*, couples were made and placed in PVC (polyvinyl chloride) cages—each one of them receiving 10 couples—of 20 cm in diameter by 20 cm in height, internally covered with sulphite paper, and whose top was covered with "voile" fabric and the bottom with plastic material.

2.2. Attractiveness test

For the attractiveness evaluation, we used 3W bulb-type Ultra LED lamps (7.9 cm in height x 4.5 cm in diameter) as our light source. Their colors were: yellow, green, white, yellow, and blue (Figure 1A), totalizing five treatments with ten repetitions each, without choice. The information provided by the manufacturer of each lamp regarding light frequency and wavelength is presented in Table 1. Besides these features, we also evaluated the illuminance, that is, the luminous flux that shines on a given area or the amount of light that arrives to given spot. The resulting data were gathered from a distance of 1.2 m, with the assistance of a Digital Light Meter (SKLD-400).

Table 1. Classification of the colors according to wavelength, light frequency, and illuminance.

Color	$\Delta \lambda$ (nm)	Δf (THz)	E (lux)
Yellow	$\approx 565-590$	$\approx 530-510$	48,8
Green	$\approx 500-565$	$\approx 600-530$	55,5
White	-----*	-----*	223,5
Red	$\approx 625-740$	$\approx 480-405$	0,8,8
Blue	$\approx 440-485$	$\approx 680-620$	31,6

$\Delta \lambda$: Wavelength interval; Δf : Frequency interval; E: Illuminance
 ----- Absence of values for this parameter

Each experimental unit was composed of two blacked-colored plastic containers (9 cm in height x 14 cm in diameter) connected by a PVC pipe (120.0 cm in length x 4.0 cm in diameter) (Figure 1 B). In this container, in one side of the pipe, two- or three-day-old adult subjects of *S. frugiperda* were inserted and kept without food for 24 hours. In the other side of the container, used to house the lamp, an adhesive layer was applied to capture the insects that were lured. The assessment of the number of captured adults was made at 1, 12, 24, 48, and 72 hours after the release of the insects in the environment.

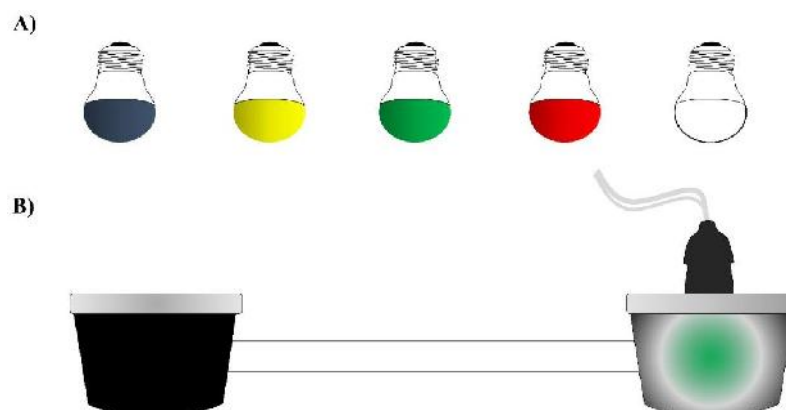


Figure 1. Bulb-type ultra LED lamps (A), complete scheme of the environment (B).

To evaluate the attractiveness of the moths to the Light-Emitting Diodes, we adopted a completely randomized design in a 5x2 factorial scheme (five LED lamp colors and two genders) with ten repetitions. The capture data were submitted for a Beta distribution analysis, processed through the SAS [25], and the treatments' averages were compared by Tukey's test at probability level of 5%. To evaluate the attractiveness over exposure periods, the data were submitted for a regression analysis.

3. RESULTS AND DISCUSSION

The attractiveness of different spectral bands of LED lamps presented significant statistical differences regarding the ratio lamp color and insect capture after 48 hours of exposure to the light. From the evaluated LEDs, the lamp colors of greater capture rate of adult subjects of *S. frugiperda* were: the green-colored lamp (with an attractiveness rate of 49.91%), followed by the yellow- and white-colored lamps, while the red- (28.75%) and blue-colored (7.40%) lamps had the lower attractiveness rates, indicating a possible repelling effect on adult subjects of *S. frugiperda* (Table 2).

Table 2. Percentage of adult subjects of *S. frugiperda* attracted by the LED lamps (T: $25 \pm 2^\circ\text{C}$; RH: $70 \pm 10\%$ and a 12-hour photophase).

Colors of the LED lamps	Captured insects (%) ($\pm$ EP)
	48 h
Yellow	45,36 $\pm$ 5,53 A
Green	49,91 $\pm$ 6,73 A
White	38,88 $\pm$ 7,53 A
Red	28,75 $\pm$ 9,12 B
Blue	7,40 $\pm$ 3,74 B

Means followed by the same uppercase letter in the column are not statistically different according to Tukey's test ($p = 0.05$).

The relation between the colors and the increased attractiveness rates found herein were also reported at the evaluation of the attractiveness potential of Light-Emitting Diodes of adult subjects of *Spodoptera exigua* [26], proving that the green-, white-, and yellow-colored LED lamps were more appealing (88.9%, 91.1%, and 63.3%, respectively) in comparison with the red-colored LED, which had the lowest attractiveness rate (55%) for the studied species. Still regarding the relation between colors and attractiveness, we noticed that the trap that employed the green-colored LED was the most effective one in the capture of *Euscepes postfasciatus* and *Bemisia tabaci* [27], and of adult subjects of *Plutella xylostella* [28]. Except for the blue color, which presented a high attractiveness rate for *S. exigua* and herein, it resulted in low activity for *S. frugiperda*. Some of the possible reasons for the insects' response differences to LED lights may be the difference of species and of the experimental conditions [29].

The relation between colors and the insects' attractiveness or repellency has been the subject of study of several investigations by researchers of the whole world, especially regarding the development of traps, whether adhesive or luminous. We know that the eyes of insects have several photoreceptors that accept specific wavelengths and therefore use vision (color) to feel the surrounding dangers [30]. Some of the types of receptors of some species of butterflies, dragon-flies, and insects that belong to the Hymenoptera order cover visual bands that are classified as the wider ones described in animals (from 300 to 700 nm) [31, 32, 33, 34, 35]. Therefore, insects are apparently attracted or repelled by different electromagnetic wavelength bands.

When we evaluated the relation between the light incidence period and attractiveness, we notice that the treatments' attractiveness rate gradually increased over the light exposure period from 1 to 72 hours, except for the blue-colored LED lamp (Figure 2). These results prove that the attractiveness rate is affected not only by the wavelength and illuminance, but also by the exposure period. Therefore, this behavior agrees with the attractiveness tendency over time, which was reported at the evaluation of the attractiveness of several light sources for adult subjects of *S. exigua*, in which a direct and gradual relation between the greatest exposure time and the greatest percentage of captured insects was reported [26]. On top of that, the green-colored LED had the greatest attractiveness rate (63.8%) in the greatest period of exposure to light, followed by the white- and yellow-colored LED (60% and 43%, respectively). On the other hand, the lowest attractiveness percentages were registered at the maximum period of exposure to the red- and blue-colored LED (38.7% and 7.4%, respectively).

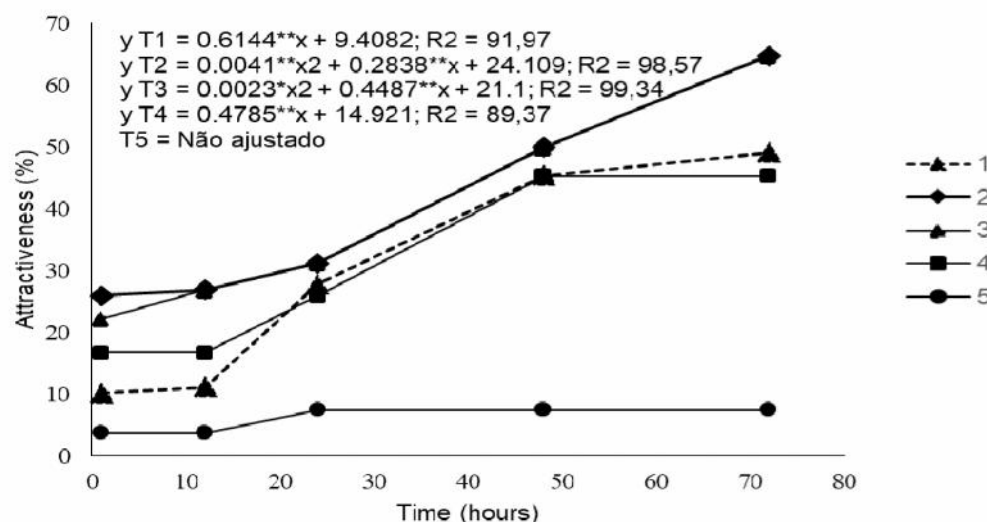


Figure 2. Attractiveness of different-colored LED lamps for adult subjects of *Spodoptera frugiperda* over several exposure periods (1, 12, 24, 48, and 72 hours).

1= yellow LED; 2= green LED; 3= white LED; 4= red LED; 5= blue LED.

The attractiveness for the different spectral bands of LED lamps according to the gender of *S. frugiperda* did not present significant statistical differences regarding the color of the lamp and the capture of the insects after 48 hours of exposure to the treatments.

Table 3. Attractiveness of adult subjects (males and females) of *Spodoptera frugiperda* under the effect of different spectral bands (Temperature of $25 \pm 2^\circ\text{C}$, Relative Humidity of $70 \pm 10\%$, and Photophase of 12 hours).

Colors of the LED lamps	Insects captured after 48 h	
	Female ($\pm\text{EP}$)	Male ($\pm\text{EP}$)
Yellow	$48,16 \pm 5,53 \text{ a}$	$47,85 \pm 5,53 \text{ a}$
Green	$50,01 \pm 6,73 \text{ a}$	$52,15 \pm 6,73 \text{ a}$
White	$38,88 \pm 7,53 \text{ a}$	$38,88 \pm 7,53 \text{ a}$
Red	$27,85 \pm 9,12 \text{ a}$	$26,75 \pm 9,12 \text{ a}$
Blue	$7,82 \pm 3,74 \text{ a}$	$7,35 \pm 3,74 \text{ a}$

Means followed by the same uppercase letter in the column and lowercase letter in the line are not statistically different according to Tukey's test ($p = 0.05$).

4. CONCLUSION

The different spectral bands have different levels of attractiveness for adult subjects of *Spodoptera frugiperda*, as the green-, yellow-, and white-colored LED lamps were proven as the most attractive for the species.

The attractiveness of *S. frugiperda* gradually increases over the exposure period for the green-, yellow-, white-, and red-colored LED.

REFERENCES

- 179 1. Casmuz A, Juárez ML, Socías MG, Murúa MG, Prieto S, Medina S, Willink, et al. Revisión de los
180 hospederos del gusano cogollero del maíz, *Spodoptera frugiperda* (Lepidoptera: Noctuidae). Revista
181 de la Sociedad Entomológica Argentina. 2010; 69:209-231.
- 182 2. Barros EM, Torres JB, Ruberson JR & Oliveira MD. Development of *Spodoptera frugiperda* on
183 different hosts and damage to reproductive structures in cotton. Entomologia Experimentalis et
184 Applicata. 2010; 137: 237-245.
- 185 3. Nagoshi RN, Silvie P, Meagher LR, Lopez J & Machado V. Identification and Comparison of fall
186 armyworm (Lepidoptera: Noctuidae) host strains in Brazil, Texas, and Florida. Annals of the
187 Entomological Society of America. 2007; 100: 394-402.
- 188 4. Ferreira Filho JBS, Alves LRA, Gottardo LCB & Georgino M. Dimensionamento do custo
189 econômico representado por *Spodoptera frugiperda* na cultura do milho no Brasil. In: 48º Congresso
190 da sociedade brasileira de economia, administração e sociologia rural, Campo Grande, Anais, Online.
191 2010; Acessado em 18 de fevereiro de 2014. Disponível em: [http://www.sober.org.br/](http://www.sober.org.br/palestra/15/1168.pdf)
192 [palestra/15/1168.pdf](http://www.sober.org.br/palestra/15/1168.pdf).
- 193 5. Vianna UR, Pratisoli D, Zanuncio JC, Lima ER, Brunner J, Pereira FF & Serrão JE. Insecticide
194 toxicity to *Trichogramma pretiosum* (Hymenoptera: Trichogrammatidae) females and effect on
195 descendant generation. Ecotoxicology. 2009; 18:180-186.
- 196 6. Lima JFM, Grützmaier DA, Cunha US, Porto PM, Martins SJF & Dalmaso OG. Ação de
197 inseticidas naturais no controle de *Spodoptera frugiperda* (J.E. Smith, 1797) (Lepidoptera: Noctuidae)
198 em milho cultivado em agroecossistema de várzea. Ciência Rural. 2008; 38: 607- 613.
- 199 7. Oliveira ACR, Veloso VRS, Barros RG, Fernandes PM & Souza ERB. Captura de *Tuta absoluta*
200 (meyrick) (Lepidoptera: Gelechiidae) com armadilha luminosa na cultura do tomateiro tutorado.
201 Pesquisa Agropecuária Tropical. 2008; 38:153-157.
- 202 8. Ben-Yakir D, Antignus Y, Offir Y, Shahak Y. Optical manipulations: an advance approach for
203 reducing sucking insect pests. Adv Technol Manag Insect Pests. 2013; 1:249–267.
- 204 9. Honda K. Reactions to light in insects and practical applications. J Soc Biomech. 2011; 35:233–236
205 (Japanese)
- 206 10. Johansen NS, Vänninen I, Pinto DM, Nissinen AI, Shipp L. In the light of new greenhouse
207 technologies: 2. Direct effects of artificial lighting on arthropods and integrated pest management in
208 greenhouse crops. Ann Appl Biol. 2011; 159:1–27.
- 209 11. Shimoda M & Honda K. Insect reactions to light and its applications to pest management.
210 Appl Entomol Zool. 2013; 48: 413-421.
- 211 12. Campbell SD, Walgenbach JF & Kennedy GG. Comparison of black light and pheromone traps for
212 monitoring *Helicoverpa zea* (Boddie) (Lepidoptera: Noctuidae) in tomato. Journal of Agricultural
213 Entomology. 1992; 9: 17-24.
- 214 13. Silvain JF & Ti-a-hing J. Prediction of larval infestation in pasture grasses by *Spodoptera*
215 *frugiperda* (Lepidoptera: Noctuidae) from estimates of adult abundance. The Florida Entomologist.
216 1985; 68:686-691.
- 217 14. Zenker MM, Botton M, Teston JA & Specht A. Noctuidae moths occurring in grape orchards in
218 Serra Gaúcha, Brazil and their relation to fruit-piercing. Revista Brasileira de Entomologia. 2010;
219 54:288-297.
- 220 15. Carvalho JR, Quadros IPS, Fornazier DL, Pratisoli D & Zago HB. Captura de *Spodoptera*
221 *eridania* usando como atrativo luz fluorescente. Nucleus. 2012; 9:75-82.

- 222 16. Oh MS, Lee CH, Lee SG & Lee HS. Evaluation of high power light emitting diodes (HPLEDs) as
223 potential attractants for adult *Spodoptera exigua* (Hübner) (Lepidoptera: Noctuidae). Journal of the
224 Korean Society for Applied Biological Chemistry. 2011; 54:416-422.
- 225 17. Park JH, Lee SM, Lee SG & Lee HS. Attractive effects efficiency of LED trap on controlling
226 *Plutella xylostella* adults in greenhouse. Journal of Applied Biological Chemistry. 2014; 57:255-257.
- 227 18. Tamulaitis G, Duchovskis P, Bliznikas Z, Breivė K, Ulinskaitė R, Brazaitytė A, Novičkovas A &
228 Žukauskas A. High-power light-emitting diode based facility for plantcultivation. J Phys D-appl Phys.
229 2005; 38:3182-3187.
- 230 19. Wu, M. C, Hou, CY, Jiang CM, Wang YT, Wang CY, Chen HH & Chang HM. A novel approach of
231 LED lightradiation improves the antioxidant activity of pea seedlings. Food Chem. 2007; 101:1753-
232 1758.
- 233 20. Bishop AL, Worrall RJ, Spohr LJ, Mckenzie HJ & Barchia IM. Improving light-trap efficiency for
234 *Culicoides* spp. with light-emitting diodes. Vet Ital. 2004; 40:266-269.
- 235 21. Burkett DA & Butler JR. Laboratory evaluation of colored light as an attractant for female *Aedes*
236 *aegypti*, *Aedes albopictus*, *Anopheles quadrimaculatus*, and *Culex nigripalpus*. Fla Entomol. 2005;
237 88:383-389.
- 238 22. Bentley MT, Kaufman PE, Kline DL & Hogsette JA. Response of adult mosquitoes to light-emitting
239 diodes placed in resting boxes and in the field. Journal of the American Mosquito Control Association.
240 2009; 25:285-291.
- 241 23. Jung MP, Bang HS, Kim MH, Han MS, Na, YE, Kang KK & Lee DB. Response of ussur brown
242 katy did, *Paratlanticus ussuriensis* to light-emitting diodes (LED). Journal of the Korean Society for
243 Applied Biological Chemistry. 2009; 28:468-471.
- 244 24. Nalim DM. Biologia, nutrição quantitativa e controle de qualidade de populações de *Spodoptera*
245 *frugiperda* (J.E. Smith, 1797) (Lepidoptera: Noctuidae) em duas dietas artificiais. 1991; 150. Tese de
246 Doutorado-Escola Superior de Agricultura "Luiz de Queiroz", Universidade de São Paulo, Piracicaba.
- 247 25. Cody R. An introduction to SAS University Edition. Cary, NC. Statistical Analysis System Institute.
248 2015; 366p.
- 249 26. Oh MS, Lee CH, Lee SG & Lee HS. Evaluation of high power light emitting diodes (HPLEDs) as
250 potential attractants for adult *Spodoptera exigua* (Hübner) (Lepidoptera: Noctuidae). Journal of the
251 Korean Society for Applied Biological Chemistry. 2011; 54:416-422.
- 252 27. Kishan RS & Thoma TW. Responses of adult *Plodia interpunctella* (Hübner) (Lepidoptera:
253 Pyralidae) to light and combinations of attractants and light. Journal of Insect Behavior. 2008; 21:422-
254 439.
- 255 28. Chu CC, Jackson CG, Alexander PJ, Karut K & Henneberry TJ Plastic cup traps equipped with
256 light-emitting diodes for monitoring adult *Bemisia tabaci* (Homoptera: Aleyrodidae). Journal of
257 Economic Entomology. 2003; 96:543-546.
- 258 29. Park JH, Lee SM, Lee SG & Lee HS. Attractive effects efficiency of LED trap on controlling
259 *Plutella xylostella* adults in greenhouse. Journal of Applied Biological Chemistry. 2014; 57:255-257.
- 260 30. Briscoe AD & Chittka L. The evolution of color vision in insects. Annu. Rev. Entomol. 2001;
261 46:471-510.
- 262 31. Arikawa K, Inokuma K, Eguchi E. Pentachromatic visual system in a butterfly.
263 Naturwissenschaften. 1987; 74:297-298.

- 264 32. Briscoe AD. Six opsins from the butterfly *Papilio glaucus*: molecular phylogenetic evidence for
265 paralogous origins of red-sensitive visual pigments in insects. *J. Mol. Evol.* 2000; 51:110–121.
- 266 33. Meinertzhagen IA, Menzel R, Kahle G. The identification of spectral receptor types in the retina
267 and lamina of the dragonfly *Sympetrum rubicundulum*. *J. Comp. Physiol.* 1983; 151:295–310.
- 268 34. Paul R, Steiner A, Gemperlein R. Spectral sensitivity of *Calliphora erythrocephala* and other insect
269 species studied with Fourier interferometric stimulation (FIS). *J. Comp. Physiol.* 1986; 158:669–680.
- 270 35. Yang E-C, Osorio D. Spectral sensitivities of photoreceptors and lamina monopolar cells in the
271 dragonfly, *Hemicordulia tau*. *J. Comp. Physiol.* 1991; 169:663–669.