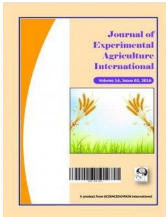

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Light-emitting Diodes (LED) as Luminous Lure for Adult *Spodoptera frugiperda* (J. E. Smith, 1797) (Lepidoptera: Noctuidae)

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Authors' contributions

This work was carried out in collaboration between all authors. Authors INN and HMA designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors GMO and MSS managed the analyses of the study. Author GSN, ACLA and JLB managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

The capture of insects through luminous sources can represent another option for integrated pest management (IPM). The purpose of this study was to verify the attractiveness of different-colored Light-Emitting Diodes (LED) on adult *Spodoptera frugiperda*. The research was conducted at the Entomology Laboratory of Plant Breeding and Environmental Sciences Department, Federal

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University of Paraíba's Agricultural Sciences Center – CCA/UFPB, Areia-PB. An environment composed of two plastic containers connected by a PVC pipe was assembled for this study. 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. Different colors of light viz., yellow, green, white, red, and blue, each one of them with specific wavelengths, illuminance, and exposure period were used. The study revealed that the attractiveness rate for adult subjects of *S. frugiperda* varied by the LED lamp colors and the exposure period. The green-colored lamp showed a greater attractiveness rate (31.22 and 49.91% at the times of 24 and 48 hours, respectively), which was followed by the white- and yellow-colored lamps. The red (25.75%) and blue (7.4%) colors, with an exposure period of 48 hours, showed the lower rates. The attractiveness of *S. frugiperda* gradually increased over the exposure period for the treatments with the green, yellow, white, and red colored LEDs. The green LED lamp, followed by the yellow and white LED, was proved to be the most attractive ones for adults of this species.

Keywords: Luminous trap; ethological control; fall armyworm; Spodoptera frugiperda.

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) (Lepidoptera: Noctuidae) 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 the advantage of alternative hosts to remain in several agro-ecosystems [2]. The species belongs to the *Lepidoptera* order, *Noctuidae* family, and is considered as the most important pest of the corn crop [3]. The cost to control this caterpillar in the culture is nearly 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 pollution 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 thereby reducing their population increase.

In recent researches, a considerable interest in the pest control technology that uses the insects' response to light as a sustainable pest control method has been observed, 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]. The 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 [12,13].

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]. Researchers reported 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.

LED have several advantages, such as adjustable illuminance intensity, small size, prolonged lifespan, wavelength specificity, high efficiency, shock resistance, and low thermal energy production [20,21]. Additionally, LEDs 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 these facts in mind, the this study was conducted to evaluate the attractiveness of adult subjects of *S. frugiperda* to LED of different spectral bands.

2. MATERIALS AND METHODS

The research was conducted at the Entomology Laboratory, Plant Breeding and Environmental Sciences Department, Federal University of Paraíba's Agricultural Sciences Center (CCA/UFPB). The experiments were performed in a temperature-controlled environment under the following conditions: temperature of 25 ± 2°C, relative humidity of 70 ± 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 ± 1°C, relative humidity of 70 ± 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 (165 g), wheat germ (79, 2 g), brewer's yeast (50,5 g), Nipagin (3,15 g), agar (20,5 g), and ascorbic (1,65 g) and sorbic acids (5,10 g), 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 sex identification, *S. frugiperda,* couples were selected and placed in PVC (polyvinyl chloride) cages-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. Each cage contained 10 couples of *S. frugiperda.*

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 the light source. The studied colors were: yellow, green, white, red, and blue (Fig. 1A), totalizing five treatments with ten replications 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, the illuminance, that is, the luminous flux that shines on a given area or the amount of light that arrives to given spot was also evaluated. The resulting data were gathered from a distance of 1.2 m, with the assistance of a Digital Light Meter (SKLD-400).

Each experimental unit was composed of two black-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, at one side of the pipe, two- or three-days-old adult subjects of *S. frugiperda* were inserted and kept without food for 24 hours. In the other side of the container, which was 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 interval after the release of the insects in the environment.

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

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

Color	Δ λ (nm)	Δ *f* (THz)	E (lux)
Yellow	≈ 565-590	≈ 530-510	48,8
Green	≈ 500-565	≈ 600-530	55,5
White	-------*	-------*	223,5
Red	≈ 625-740	≈ 480-405	0,8,8
Blue	≈ 440-485	≈ 680-620	31,6

Δ λ: Wavelength interval; Δ f: Frequency interval; E: Illuminance -------- Absence of values for this parameter

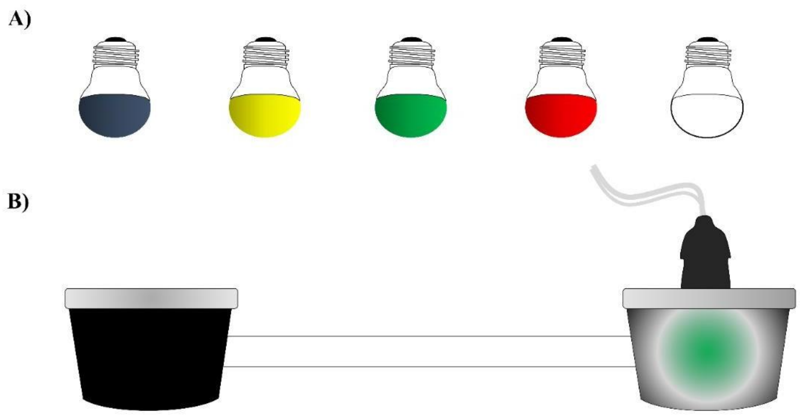

Fig. 1. Bulb-type ultra LED lamps (A), complete scheme of the environment (B)

3. RESULTS AND DISCUSSION

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

Table 2. Percentage of adult subjects of *S. frugiperda* attracted by the LED lamps (T: 25 ± 2°C; RH: 70 ± 10% and a 12-hour photophase)

Colors of the LED lamps	Captured insects (%) (±EP)
	48 h
Yellow	45,36 ± 5,53 A
Green	49,91 ± 6,73 A
White	38,88 ± 7,53 A
Red	28,75 ± 9,12 B
Blue	7,40 ± 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 were also reported at the evaluation of the attractiveness potential of LEDs of adult subjects of *Spodoptera exigua* [26]. It was observed 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. Regarding the relation between colors and attractiveness, it was reported that the trap with 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 all over the 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 they 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 the relation between the light incidence period and attractiveness was evaluated in the present study, it was noticed that the treatments' attractiveness rate gradually increased from 1 to 72 hours, except for the blue-colored LED lamp (Fig. 2). These results proved that the

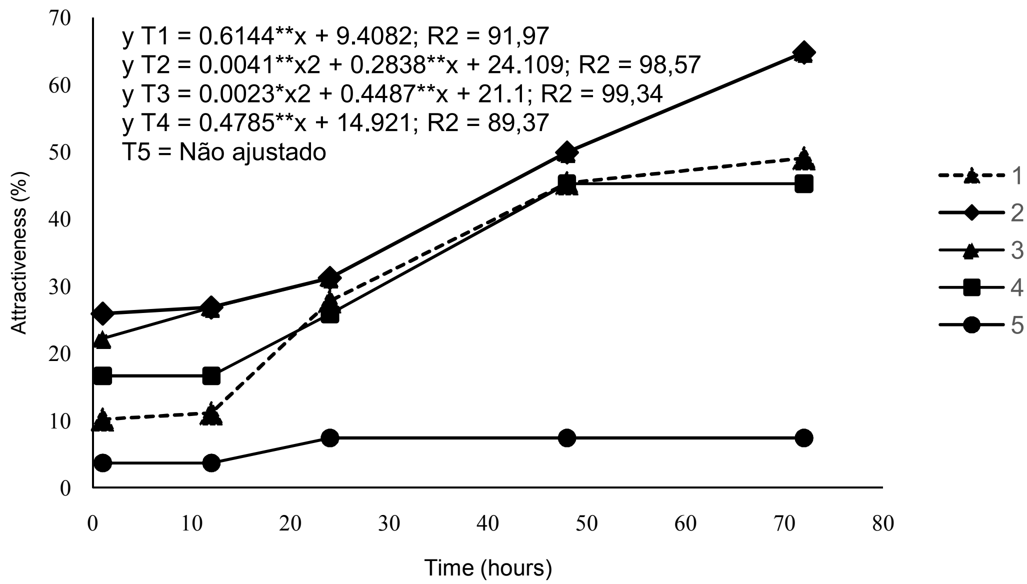

Fig. 2. Attractiveness of different-colored LED lamps for adult subjects of *Spodoptera frugiperda* over several exposure periods (1, 12, 24, 48, and 72 hours)
1= yellow LED; 2= green LED; 3= white LED; 4= red LED; 5= blue LED

Table 3. Attractiveness of adult subjects (males and females) of *Spodoptera frugiperda* under the effect of different spectral bands (Temperature of 25 ± 2°C, relative humidity of 70 ± 10%, and photo phase of 12 hours)

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

attractiveness rate was 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]. The green-colored LED had the greatest attractiveness rate (63.8%) in the greatest period of light exposure, 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).

The attractiveness for the different spectral bands of LED lamps according to the gender of *S. frugiperda* did not show a 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).

4. CONCLUSION

It can be concluded from the present study that different spectral bands showed different levels of attractiveness for adult subjects of *Spodoptera frugiperda*, as the green-, yellow-, and white-colored LED lamps were proved to be the most attractive for the species. The attractiveness of *S. frugiperda* gradually increased over the exposure period from 1 to 72 hours for the green, yellow-, white-, and red-colored LED. No significant statistical differences were detected regarding the colors of the lamps and the genders of the captured insects after 48 hours of exposure to the treatments.

Therefore, it can be said that luminous attractive LED type can be a promising alternative from the perspective of integrated pest management for the control of *Spodoptera frugiperda*.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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