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Attractiveness of light-emitting diodes (LEDs) of different wavelengths to the South American rice water weevil

Atratividade de diodos emissores de luz (LEDs) de diferentes comprimentos de onda aos adultos da bicheira-da-raiz

Eduardo Rodrigues Hickel[1]*, Gustavo Carlos Knabben[2], Débora Dal Zotto[3], Maicon William Machado Carvalho[2], Bruno Bertoldi[2], Yales Rômulo Novaes[2]

ABSTRACT: The South American rice water weevil *Oryzophagus oryzae* (Costa Lima) (Coleoptera: Curculionidae) is a key pest of irrigated rice in Brazil. Light traps could be used as an integrated pest management (IPM) strategy since these weevils have strong phototropism. Thus, the aim of this study was to search the attractiveness of LEDs of different wavelengths to *O. oryzae* to define the best light-emitting diodes (LED) arrangement to build the lamp of photovoltaic light traps. LEDs of different wavelengths were tested in a dark room with a hexagonal arena with exits to light sources. Groups of 200 insects were released in the center of the arena and captured at the end of exposure time in plastic bags placed in the exits. The LEDs in the short-wave band of the light spectrum (365 and 460 nm) and white LEDs, as well as the light mix of 365 with 460 nm or white LEDs, were attractive to *O. oryzae*. Beyond the LEDs with ultraviolet (UV) spectrum, the LEDs above 380 nm were the most attractive and, this way, might be used to build LED lamps of photovoltaic light traps.

KEYWORDS: Coleoptera; Curculionidae; light trap; semiconductors; *Oryza sativa*.

RESUMO: Uma das pragas-chave do arroz irrigado é a bicheira-da-raiz, denominação comum atribuída às larvas do gorgulho aquático *Oryzophagus oryzae* (Costa Lima) (Coleoptera: Curculionidae). A utilização de armadilhas luminosas poderia ser uma alternativa viável no manejo integrado, pois esse gorgulho apresenta elevado fototropismo positivo. Assim, objetivou-se determinar a atratividade de diodos emissores de luz (LEDs) de diferentes comprimentos de onda ao *O. oryzae* e definir o seu melhor arranjo para compor a lâmpada de armadilhas luminosas fotovoltaicas. LEDs de diferentes comprimentos de onda foram testados em sala escura, em uma arena hexagonal com saídas para as fontes de luz. Grupos de 200 indivíduos foram liberados no centro da arena e capturados em sacos plásticos nas saídas ao fim do tempo de exposição. Os LEDs da faixa do espectro luminoso de ondas curtas (365 e 460 nm) e LEDs brancos, bem como as misturas de luzes de LEDs 365 com 460 nm ou branco, foram atrativos ao *O. oryzae*. Entre os LEDs com espectro ultravioleta, os mais atrativos foram aqueles acima de 380 nm, devendo estes compor, prioritariamente, lâmpadas de LED para uso nas armadilhas luminosas fotovoltaicas.

PALAVRAS-CHAVE: Coleoptera; Curculionidae; armadilha luminosa; semicondutores; *Oryza sativa*.

[1]Empresa de Pesquisa Agropecuária e Extensão Rural de Santa Catarina – Itajaí (SC), Brazil
[2]Universidade do Estado de Santa Catarina – Joinville (SC), Brazil
[3]Universidade Federal de Santa Catarina – Florianópolis (SC), Brazil
*Corresponding author: hickel@epagri.sc.gov.br
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INTRODUCTION

One of the key pests of irrigated rice in Brazil is the South American rice water weevil, *Oryzophagus oryzae* (Costa Lima) (Coleoptera: Curculionidae), which prunes the root system of plants. This pest widely occurs in irrigated rice fields and is one of the main phytosanitary constraints of the crop (CAMARGO et al., 1990; MARTINS; PRANDO, 2004; HICKEL et al., 2013). In Santa Catarina state, Brazil, the control of this insect is directed to the larval stage and mainly done by insecticide application in the irrigation water, which increases the risks of environmental contamination (MARTINS; PRANDO 2004; HICKEL et al., 2013). Adult insects are not always subject to control (MARTINS; CUNHA 2007), because there are no practical methods to know the time and the number of individuals that are infesting the crops.

Several taxonomic groups of insects are attracted by light, especially for bright spots (lamps) at night. Coleoptera, Lepidoptera, Hemiptera, and Hymenoptera are among those with the highest positive phototropism (MUIRHEAD-THOMSON, 1991). The color of light also interferes with the attractiveness, so the capture of a particular group in a light trap can be improved by the choice of lamp type (ASHFAQ et al., 2005; PAWSON et al., 2009; RAMAMURTHY et al., 2010, JEON et al., 2012).

The use of light traps for monitoring or even controlling the water weevil might be a viable alternative in the integrated pest management, since these weevils have a high positive phototropism. The BL (black light) fluorescent lamp has been adopted as the standard light source to attract the water weevils (CAMARGO et al., 1990, SHANG et al., 2004; HICKEL; MILANEZ, 2013).

A major impediment in the use of light traps for monitoring or even controlling irrigated rice pests is the lack of electric distribution network permeating the cropping areas. In order to overcome this impediment, KNABBEN et al. (2015) have developed a prototype of an autonomous light trap (Sonne), which uses photovoltaic solar energy to power the electronic system. Sonne was derived from the light trap model Luiz de Queiroz, disseminated in the 1970s by the Escola Superior de Agricultura "Luiz de Queiroz" (ESALQ) of the São Paulo University (Universidade de São Paulo — USP) (MATIOLI, SILVEIRA NETO, 1988). Among the most significant innovations, Sonne was equipped with light-emitting diodes (LEDs) as a light source with low energy consumption. Until then, the planned and produced autonomous light traps remained using the BL fluorescent lamp, requiring a bulky and heavy battery bank to supply energy (ZANUNCIO et al., 1991) (see also https://www.ufrb.edu.br/agencia/pesquisa-academica/3493-professor-da-ufrb-desenvolve-armadilha-solar-autonoma-para- controle-da-helicoverpa; and http://www.feagri.unicamp.br/energia/agrener2002/ jdownloads/ pdf/0133.pdf).

The use of LEDs in the light traps, besides allowing the reduction of the volume of the battery bank, would also allow to compact and to improve the whole electronic system, making portable the designed model (COHNSTAEDT et al., 2008; KNABBEN, 2014). Another advantage is the possibility of maximizing the energy extracted from the solar irradiation, improving the autonomy of the system.

LEDs are present in high performance lamps and manufactured to emit lights at specific wavelengths (color). The wavelength band of the LED light is narrower than that one of conventional lamps, which results in increased color saturation (SCHUBERT, 2006). Therefore, it is necessary to search the equivalence of LED lamps in insect attraction. The objective of this work was to search the attractiveness of LEDs of different wavelengths to *O. oryzae* and, thus, to define the best arrangement of these to compose the LED lamp of photovoltaic light traps.

MATERIAL AND METHODS

The research was conducted at the Experimental Station of Empresa de Pesquisa Agropecuária e Extensão Rural de Santa Catarina (Epagri) in Itajaí, Santa Catarina, Brazil, in a dark room, from 4 p.m. to 8 a.m. (exposure period), through two experiments performed as multiple-choice tests. In the first experiment, conducted from January 14 to February 8, 2014, under room temperature of 32±3ºC, LEDs with wavelengths of 365 (ultraviolet — UV), 460 (blue) and 520 nm (green), and white LED were tested in three sessions of five nights each. The white LED used was a broad-spectrum, emitting light at all wavelengths between 400 and 850 nm, with peaks of intensity at 460 and 570 nm. In the second experiment, from October 1st to October 27, 2015, under room temperature of 22±1ºC, only UV LEDs were tested at 370, 380, 390, 400 and 410 nm wavelengths in four sessions of four nights each.

Printed circuit boards were produced to accommodate eight LEDs, powered by a 12V direct current (DC) source delivering the same voltage across each LED connector. The LEDs were plugged into these boards, either pure or in combination, and tested in hexagonal metal arena, specially designed for this purpose (Fig. 1). A tube (100 mm diameter×600 mm length) was connected on each side of the arena, with the output to a light source. A transparent plastic bag was attached at the end of each tube to collect the insects. A small ball of paper towel soaked in water was placed inside each plastic bag to avoid any moisture gradient inside the arena. In order to eliminate interference between lights (HICKEL; MILANEZ, 2013), it was decided to connect only three LED boards at a time, leaving dark in the other three opposite outputs.

The adults of *O. oryzae* used were caught by two light traps, model "Luiz de Queiroz", with black light (T8 20W BL), installed on wooden tripods in the levee of a rice field. These traps were turned on once a week, from 4 p.m. to 9 a.m., and the insects collected, after screening, were kept in the laboratory in gerbox boxes lined with moistened paper towel to avoid drying. Insects in these conditions were active for two weeks, without the need to feed.

At each test session, 200 individuals were released in the center of the arena, without repeating the same group on consecutive dates. After the release, individuals headed freely into the supposedly more attractive light in a multiple-choice test. At the end of each exposure period, the insects were removed from the collector bags and from the interior of the arena (non-responsive individuals), and the LED boards were switched from rotating position. After each test session, the entire arena was detached and the refugee insects (those ones hiding in inaccessible corners) were removed. The number of insects attracted was transformed to $(x+0.5)^{0.5}$ and submitted to analysis of variance, in a completely randomized design, with five replications in 2014 and four replications in 2015. The means of the treatments were compared by the Tukey test, at the 5% probability level.

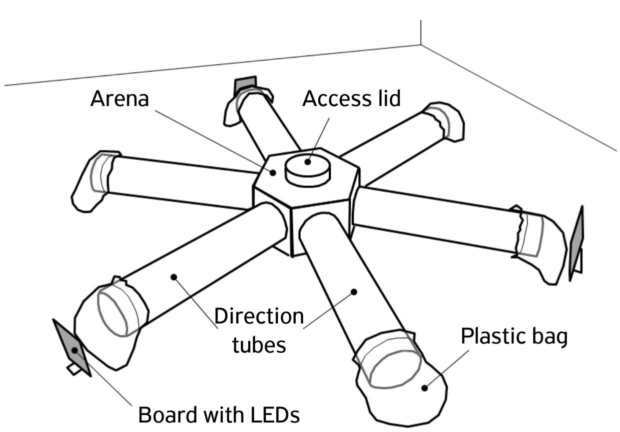
RESULTS AND DISCUSSION

In the test session carried out from January 14 to January 18, 2014, the attractiveness of the LEDs of 365 (UV) and 460 nm (blue) was higher than 520 nm (green) (Table 1), in part corroborating the results obtained by HICKEL; MILANEZ (2013) with fluorescent lamps. These authors found out that light in the UV spectrum was more attractive to adults of *O. oryzae*, but they also obtained some attractiveness for blue and green fluorescent lamps. In the session between January 28 to February 1st, among these individuals which chose to move, there was no preference for the color of light, whether it was 365 nm (UV), 460 nm (blue) or white (Table 1). The number of individuals that went to the dark exits was low in both sessions, revealing that those insects that chose to move rather preferred to do so toward a light source.

The UV light spectrum is assumed more attractive to *O. oryzae* (HICKEL; MILANEZ, 2013), but coleopterans may exhibit certain specificities. JEON et al. (2012) determined that the rice weevil *Sitophilus oryzae* L. (Coleoptera: Curculionidae) is more attracted by blue (450 nm) and green light (520 nm) — about 1.5 time more than UV light (365 nm). On the other hand, *Tribolium castaneum* (Herbst) (Coleoptera: Tenebrionidae) is more attracted by 390 nm UV light (DUEHL et al., 2011). *Leptinotarsa decemlineata* (Say) (Coleoptera: Chrysomelidae) moved towards yellow (585 nm), white and UV light (351 nm) (OTÁLORA-LUNA; DICKENS, 2011), whereas *Phyllotreta striolata* F. (also Chrysomelidae) is attracted by the UV/blue range between 350 and 430 nm (YANG et al., 2003). Among Lepidoptera, there is also variation in the response to light color, with *Plutella xylostella* L. (Lepidoptera: Plutellidae) and *Spodoptera litura* (F.) (Lepidoptera: Noctuidae) responding preferentially to the green light (520 nm) (CHO; LEE, 2012; YANG et al., 2012). The noctuid *Spodoptera exigua* (Hübner), as another point of view, is attracted by white LEDs (OH et al., 2011).

The attractiveness of white LEDs to *O. oryzae*, and eventually to other insects, may result from their own engineering, since they usually are UV or blue LEDs whose light excites the electrons of a layer of phosphorus, resulting in the perception of white light (SCHUBERT, 2006).

The test result of UV, blue and white LEDs led to conjecture about the possibility of mixing different LEDs on printed circuit boards. Thus, a new test session was conducted (Table 2). The mixtures involving UV LEDs provided the best results and this was hopeful, because it will reduce the cost of



LEDs: light-emitting diodes.

Figure 1. Schematic drawing of the multiple-choice arena of light spectrum

Table 1. Mean number of *Oryzophagus oryzae* attracted by light-emitting diodes (LEDs) of different wavelengths or that remained visible in the arena of free choice (non-responsive insects). Itajaí, Santa Catarina, Brazil, January/February 2014.

Treatment	Test session[1]	
	January 14 to January 18	January 28 to February 1st
LED 365 nm (UV)	53.4±24.2 a	31.8±15.2 a
LED 460 nm (blue)	36.4±16.5 ab	31.4±13.8 a
LED 520 nm (green)	7.6±6.3 cd	-
LED broad spectrum (white)	-	23.2±13.1 ab
Dark	2.7±3.1 d	6.6±3.6 b
Non-responsive insects	19.0±7.2 bc	33.0±16.2 a
CV (%)	28.5	26.6

[1]means followed by the same letter in columns do not differ by the Tukey test ($p \leq 0.05$); UV: ultraviolet; CV: coefficient of variation.

a possible LED lamp for photovoltaic light trap. UV LEDs are more expensive than the other ones, and, if they make up the lamp in fewer numbers, the cost will be reduced. This result also opens the possibility of new studies, aiming to obtain the best mixing ratio of LEDs, without losing attractive efficiency.

The test sessions to search the attractiveness of LEDs in the UV spectrum conducted in October 2015 revealed that longer wavelength LEDs attracted more individuals (Table 3). These wavelengths are closer to the violet/blue light spectrum, reinforcing the idea of composing the LED lamp with blends of UV LEDs and blue or even white LEDs. CASTERON; ROJAS (2010) observed that the caterpillars of *Estigmene acrea* (Drury) (Lepidoptera: Arctiidae) responded preferentially to wavelengths from the UV/green spectrum (380, 400 and 520 nm), while adult females to the range of UV/blue spectrum (340, 350, 370, 380, 420 and 460 nm). COWAN; GRIES (2009) found out that moths of *Plodia interpunctella* (Hübner) (Lepidoptera: Pyralidae) were more attracted by LEDs of 350 and 405 nm than by LEDs of 435, 450 or 470 nm.

Table 2. Mean number of *Oryzophagus oryzae* attracted by combination of light-emitting diodes (LEDs) of different colors[1] or that remained visible in the arena of free choice (non-responsive insects). Itajaí, Santa Catarina, Brazil, February 2014.

Treatment	Test session[2] February 4 to February 8
LEDs 365 nm (UV) + 460 nm (blue)	51.6 ± 18.2 a
LEDs 365 nm (UV) + white	51.0 ± 24.2 a
LEDs 460 nm (blue) + white	19.2 ± 6.8 bc
Dark	7.6 ± 1.7 c
Non-responsive insects	27.8 ± 6.4 ab
CV (%)	20.4

[1] 1:1 LED combinations on printed circuit boards; [2]: means followed by the same letter in columns do not differ by the Tukey test (p≤0.05); UV: ultraviolet; CV: coefficient of variation.

COWAN (2009) also reported that the blend of UV LEDs (350 with 405 nm) is equally attractive to *P. interpunctella* and should be used in traps to obtain greater light intensity and to reduce costs and the risk of retinal damage to human eye.

The position in which the LED boards were settled in the arena had no influence on the attractiveness of the individuals:

- F=0.15, p=0.86, for the session from January 14 to January 18;
- F=1.15, p=0.35, for the session from January 28 to February 1st;
- F=3.39, p=0.07, for the session from February 4 to February 8;
- F=0.21, p=0.81, for the session of October 1st to October 7;
- F=0.54, p=0.60, for the session from October 8 to October 14;
- F=2.16, p=0.17, for the session from October 15 to October 20;
- F=0.45, p=0.65, for the session from October 22 to October 27.

Likewise, HICKEL; MILANEZ (2013) did not verify the effect of the position of the lamp in the arena, which excludes the possibility of geomagnetic orientation of the adults of *O. oryzae*.

As also noted by HICKEL; MILANEZ (2013), at each release of insects, 30 to 60% of individuals took refuge in some corner of the arena and did not respond to the light stimulus. However, these individuals remained cumulatively in the arena, able to respond to the light stimulus during the following exposure periods. The accumulated refugee insects were only withdrawn at the end of each test session. DUEHL et al. (2011) obtained a response of only 20% of the individuals released in the capture tests of *T. castaneum* with light trap in closed environment. The number of non-responsive insects, those that were visible in the arena, without directing to a light source, was generally low, with the exception of the sessions from January 28 to February 1st and from February 4 to February 8, 2014 (Tables 1 and 2). It probably

Table 3. Mean number of *Oryzophagus oryzae* attracted by ultraviolet (UV) light-emitting diodes (LEDs) of different wavelengths or that remained visible in the arena of free choice (non-responsive insects). Itajaí, Santa Catarina, Brazil, October 2015.

Treatment	Test session[1]			
	October 1st to October 7	October 8 to October 14	October 15 to October 20	October 22 to October 27
LED 370 nm	5.7±3.6 b	-	8.5±6.9 b	-
LED 380 nm	-	27.0±14.3 ab	49.7±4.7 a	-
LED 390 nm	29.5±13.2 a	-	77.0±44.8 a	54.2±13.8 a
LED 400 nm	-	58.0±14.8 a	-	55.7±13.2 a
LED 410 nm	45.5±11.2 a	45.0±20.0 a	-	43.7±5.7 a
Dark	0.5±1.0 b	9.0±8.0 b	8.3±5.9 b	2.3±1.5 c
Non-responsive insects	9.0±10.1 b	12.0±0.8 b	16.0±12.1 b	12.8±6.4 b
CV (%)	27.1	11.6	15.8	6.2

[1]means followed by the same letter in columns do not differ by the Tukey test (p≤0.05); CV: coefficient of variation.

resulted from the pre-hibernal state of the individuals used in these sessions, since they were, when captured in the field between January and February, seeking shelters for hibernation (HICKEL et al., 2013).

HICKEL; MILANEZ (2013) proposed that the lack of response of some individuals of *O. oryzae* to the light stimulus may be due to the interference of atmospheric pressure, since temperature, humidity and illumination were under control in the experimental environment. These authors argued that the perception of barometric fluctuations would benefit aquatic weevils, because it would allow them to fly shortly before or during periods of rain and, thus, to ensure the encounter of flooded land for reproduction.

Due to the results of the attractiveness tests, the proposed LED lamp for photovoltaic light traps involves its construction with 390 (UV), 460 nm (blue) and white LEDs, in the preliminary ratio of 3:2:1, respectively. It should be noted, however, that field assessments are necessary for the adequacy of the tool.

CONCLUSION

- LEDs of 365 (UV) and 460 nm (blue) and white (wide spectrum), and the LED blends of 365 nm (UV) with 460 nm (blue) or white are attractive for *O. oryzae* adults.
- Among the UV spectrum LEDs, those ones with wavelengths of 380, 390, 400 and 410 nm are more attractive to *O. oryzae* adults.

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