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Study of LED Radiation Effects on Insect Phototaxis Response for the Development of Light-Based Pest Trap

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Abstract: Commercial agriculture is a resource intensive industry that employs significant amounts of agrochemicals to maintain a high yield output. Excessive application of insecticides has detrimental impacts on human health, environment and long-term sustainability. One particular area of interest is in exploring how insects are attracted to specific bands of the visible light spectrum. This paper details the study of several light conditions using Light Emitting Diodes (LEDs) to determine its phototaxis response on the common grasshopper, garden moth and lava beetle. The results conclude that all three insects exhibit positive phototaxis response on wavelengths around 491nm and below, which encompasses ultraviolet, blue and green. The radiant intensity experiment revealed a threshold response of 2.8mW/m2, or 25m in reciprocal distance.

Keywords: Insect, phototaxic response, wavelength, radiant intensity, ultraviolet light, Light Emitting Diode, agriculture, Sarawak, Pulse Width Modulation, visible light, electromagnetic radiation

1. Introduction

Insecticides are a groups of synthetic organic chemical used to control insect population. In agriculture, these agrochemicals are typically applied to reduce crop loss from insect damage in order to maximize yield.

The major point of concern insecticides is their persistence in the environment. The accumulation of insecticides when metabolized can cause a plethora of ill effects to the human body development, wildlife, and vital agriculture pollinator health. In efforts to reduce reliance on these agrochemicals, several alternatives have been proposed and applied with varying levels of success, all part of a broader concept known as Integrated Pest Management [1-6]. However, these approaches have limitations in their ability to substitute insecticides role due to its broad spectrum effect. Some other hurdles include accessibility, farmer's knowledge and training and economics [7].

One promising technology of interest is a light trap system. In a nutshell, utilizing specific bands of the electromagnetic radiation to attract flying pest. At the moment, a majority of research on light-based trap systems are optimised for on-field insect capturing and monitoring functions. However, there is optimistic interest that these existing prototypes can be adapted to serve as insect elimination tools. Combined with other modes of pest control, the light trap technology could potentially be a major component in reducing pest infestation.

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2. Insect Phototaxis Response To Light

2.1 Insects See the Light

Light plays an essential role in the life cycle of insects. Insects have a strong affinity to specific bands of the electromagnetic spectrum, in part due to the unique photoreceptors in the insect's compound eyes. The spectral sensitivities of the insect's photoreceptors determine the wavelength of light visible, which often extends into the ultraviolet (UV) region of less than 400nm, which is invisible to humans [8]. The photo-receptors cells within the eyes contain various rhodopsins, visual pigments that react to light in specific wavelengths. Insects that are sensitive to 2 wavelength ranges, or biochromatic express two types of rhodopsins, one of which has a maximum absorption in the ultraviolet range (UV) and another with maximum absorption in the green range [9]. The same is true for trichromatic insects that express a third pigment whose absorption peaks at blue. Some insects, certain species of Lepidoptera, are tetrachromatic and carry another additional pigment that peaks at the red wavelength region [9].Files must be in MS Word only and should be formatted for direct printing, using the CRC MS Word provided. Figures and tables should be embedded and not supplied separately.

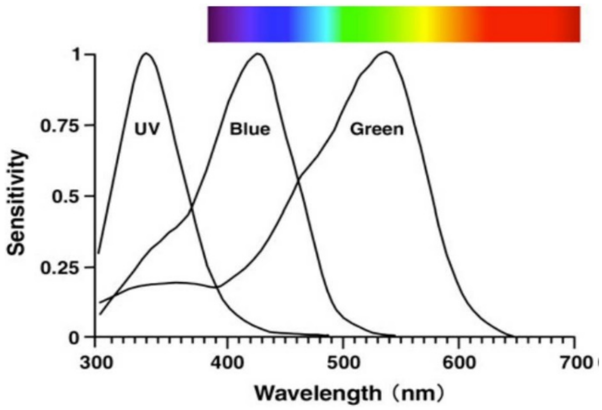

Fig. 1 - Spectral sensitive curves of photoreceptor cells (UV, Blue, Green) of honeybee Apis mellifera [3]

The advent of artificial lighting such as Compact Fluorescent Tubes (CFTs) and LED lamps has paramount impacts on insect light perception as these light sources radiate wavelengths that overlap with insect photoreceptor sensitivities. This is more apparent when insects fly towards and around domestic lighting at night as sources of also emit a significant amount of blue end radiation [9].

2.2 Light Intensity response on Insects

The effects on light intensity and insect behavior has been observed prior, such as by Reber [10] where a decrease in light levels effect the flight trajectory of free flying bumblebees Bombus terrestis. It would make logical sense to concur that the impairment of visibility would impact insect navigation activity. However, the degree of sensitivity on light intensity is the precursor to the understanding its effects. This is a big factor in designing suitable light traps that could target insects in a certain area of luminance, although the exact range of insect vision sensitivity is varied [11].

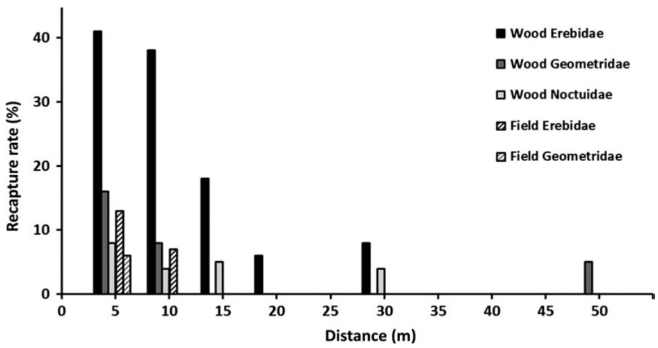

Fig. 2 - Percentage recaptured macro-moth species of three families against distance(m) from light source [6]

Merckx and Slade [11] found that weak light trap have remarkably local sampling ranges, which results in samples which are highly representative of the local habitat. Some benchmark the range as near as 10m [12] to as far as 40m [13].

3. Radiant Intensity

To conduct research on light intensity solely on distance as a variable in a lab would be unfeasible. It would be impractical to afford the space to construct the testing ground based on distance. An alternative solution is to apply the properties of Inverse Square Law of Light to quantify distance as a reciprocal of radiant intensity. The general equation is

$$\frac{\phi}{d^2} \tag{1}$$

Where E is the radiant intensity in milliwatt per meter squared (mW/m2), Φ is the radiant flux in milliwatts (mW) and d for distance from source, in meters (m).

4. Light Emitting Diodes

Light Emitting Diodes, or commonly referred as LEDs, are polar semiconductors that emit visible light when a forward current is applied [14,15].

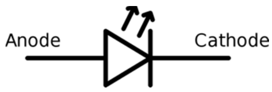

Fig. 3. LED Symbol

The spectral emission of LEDs are highly specific depending on the doping material used. The properties of the semiconductors' interaction with electric current enables the emission of specific wavelength radiation [16-21]. The wavelength radiation corresponds to the colour that the human eyes perceive.

Table 1 - LED colour, wavelength and associated doping material [22]

Colour	Peak Wavelength	Material
UV	372	InGaN
Royal Blue	440 – 450	InGaN
Blue	460 – 470	InGaN
Green	510 – 535	InGaN
Amber	590	InGaN/AlGaInP
Yellow	>590	GaAsP:N
Yellow -Green	>565	GaP:N
Red	636 – 650	AlInGaP /GaAlAs

An added benefit of LEDs compared to other bulb types is its instantaneous response time. This advantageous property permits meticulous control of the light output by using Pulse Width Modulation, since the instantaneous on-off by LEDs can follow the changes in step response. Also, unlike other forms of light source, LEDs can produce monochromatic light with a very narrow wavelength width. This allows the production of very specific spectral emission that is necessary in the study of wavelength response on insects.

5. Methodology

The framework of this methodology in this paper is based on several authors, namely Peter J.T White [23], Katsuki [24] and Stukenberg [25]. The basis of the methodology is to create a small, manageable environment in lab conditions to study the insect response. Furthermore, the use of quantifiable metrics to compare and generate data will provide a stronger case of advocating the implications of the result.

5.1 Calibration of LED

Since radiant output is a function of the current supplied, a resistor will be needed to control the current supply. However, resistors available come in discrete increments, to obtain the exact value to satisfy the current demand would be unfeasible. Therefore, Pulse Width Modulation will drive the LEDs.

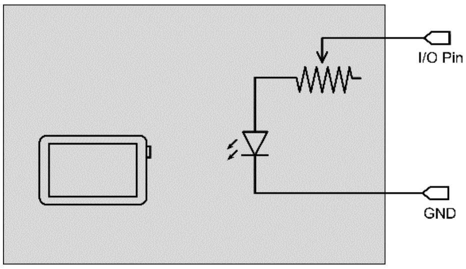

Fig. 4 - Top view diagram of LED calibration setup

The calibration was done in a standard shoe box, with all holes and corners sealed to minimize stray light entry. The LED is wired in series to a calibrating potentiometer, where the wiper terminal is connected to the Analog I/O Pin of the Arduino Uno microcontroller. The instrument chosen for the calibration is the LMS600 Portable Spectroradiometer. The spectroradiometer is placed 1cm away from the LED bulb, with the epoxy lens angled at direct line of sight to the instrument's sensor window. The final resistance across the potentiometer is used to find the nearest available resistance value.

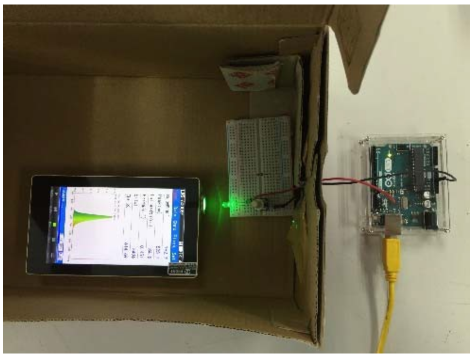

Fig. 5 - Example calibrating a 435nm LED

For the wavelength response, a total of 5 types of wavelength emissions were used as the variables of testing. The constant emission is fixed at 35mW/m2 where the magnitude is referred to the peak wavelength on the spectrum chart.

For the radiant intensity response, the spectral emission of choice is based on the results of the wavelength response prior. For this case, the wavelength that produced the greatest phototaxis response is the 379nm emission (UVA). From this, 4 sets of radiant emission is calibrated by adjusting the PWM output from the Arduino Uno.

5.2 Setup of Test Chamber

The insect specimens that exhibit positive phototaxis response will move towards the light source. The sensitivity towards the light source can be quantified by the number of specimens that are within the perimeter of light source, which in turn represents the proportion of specimens trapped around the preferred light source as a direct function of the sensitivity towards the wavelength.

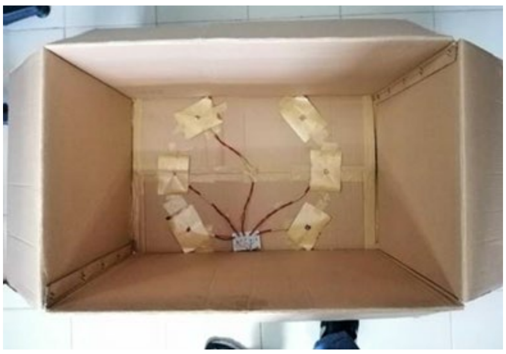

Fig. 6 - Wiring and LED installation for wavelength response in test chamber

A large cardboard box measuring 0.8m x 0.45m x 0.5m was used as the test with the edges, rims and any openings are inspected and sealed. At the bottom centre of the larger face of the box, a small perforation was made to allow the wiring of the LEDs to be driven by the Arduino Uno microcontroller placed outside. Since the SMD indicating-LEDs on the board emit visible light that could interfere with the existing wavelength emissions, the microcontroller was decided to be placed outside.

For the wavelength response, the 5 LEDs and its corresponding resistors are arranged and wired. Beneath each LED is placed a sticky fly paper measuring 13cm x 9cm which will adhere the specimen when it responds towards the light source. A 6th slot is included as a control. All the variables are arranged radially around a common center.

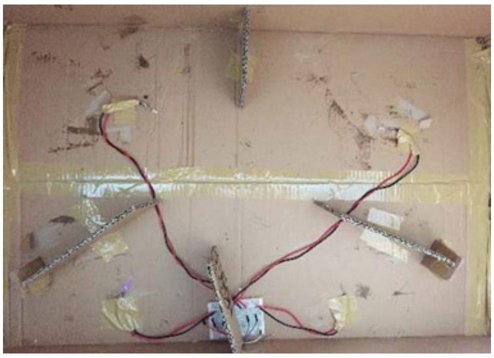

Fig. 7 - Test chamber configuration for radiant intensity response with 4 varying intensities of 375nm emission. Note vertical partitions between each source to isolate the emission

After determining the wavelength of the highest proportion of phototaxis response the test chamber was reconfigured to contain 4 of the selected wavelengths with varying radiant intensity. Cardboard partitions are included between adjacent light sources to confine the spectral emission to its respective areas.

5.3 Insect Specimen Collection

The 3 specimens of test selected are the common grasshopper Oxya yezoensis, garden moth Lepidoptera sp., the lava beetle Podontia affinis.

During specimen collection, much effort has been taken to ensure consistency, in particular the grasshoppers which undergo multiple molting stages of maturation during its lifecycle. As such, a minimum of 2.5cm specimen length will be accepted, with a light green flesh and undeveloped hind wings preferred. For the moth and beetle this is not a problem since they have consistent sizes and forms upon maturity. All specimens are required to have complete morphology without defects, injuries or missing parts.

Depending on the yield of catch, between 8 to 12 specimens were collected per container used. The lid should not be sealed tight but rather slightly unscrewed to permit gaseous exchange for insect respiration. Alternatively, small perforations on the lid is acceptable compromise. Once collected, the specimens are left in the lab for at least 2 hours to acclimatize to the indoor temperature and humidity.

5.4 Testing of Specimen

The LEDs are first powered up by the Arduino Uno and checked if all the light sources are functioning. The container is the placed in the center of the test chamber, with the lid slowly removed and the box lid covered. The setup is then left for at least 6 hours, after which the box content is reexamined.

A successful count is considered when the insect specimen is adhered within the fly paper of the LED. Should less than half of the total tested specimens have responded, the box is closed again and left to incubate for another least 6 hours. If after 3 consecutive runs the results is inconclusive, a fresh batch of testing should be done.

6. Results

6.1 Wavelength Response

Table 2 - Wavelength response on lava beetle

	Wavelength (nm)					
	379	**435**	**521**	**589**	**629**	**Ctrl**
Trial 1	**5**	**1**	**8**	**0**	**0**	**1**
Trial 2	**3**	**1**	**5**	**0**	**0**	**0**

Trial 3	**3**	**0**	**5**	**0**	**0**	**5**
Average	**3.7**	**0.6**	**5.3**	**0**	**0**	**2**

Table 3 - Wavelength response on grasshopper

	Wavelength (nm)					
	379	**435**	**521**	**589**	**629**	**Ctrl**
Trial 1	**3**	**3**	**2**	**1**	**0**	**1**
Trial 2	**3**	**1**	**4**	**0**	**0**	**1**
Trial 3	**2**	**3**	**1**	**3**	**0**	**0**
Average	**2.7**	**2.3**	**2.3**	**1.3**	**0**	**0.6**

Table 4 - Wavelength response on moth

	Wavelength (nm)					
	379	**435**	**521**	**589**	**629**	**Ctrl**
Trial 1	**4**	**1**	**2**	**0**	**0**	**1**
Trial 2	**2**	**1**	**2**	**0**	**2**	**0**
Trial 3	**4**	**1**	**2**	**0**	**0**	**0**
Average	**3.3**	**1.0**	**2.0**	**0**	**0.6**	**0.3**

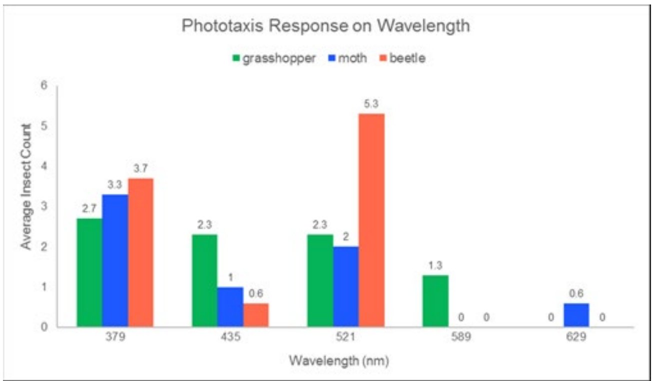

Fig. 8 - Combined chart of average insect count against wavelength emission

The wavelength results indicated that all three insect species display the strong positive phototaxis response ($n \geq 1$) to the 375nm emission, with varying levels for the 435nm and 521nm emission. This trend coincides with the colour of the light output, with UVA (275nm), Blue (435nm) and Green (521nm) being the major three sensitive colours in the rhodopsin photoreceptors of the insect eyes [13]. This would imply that these insects are in fact trichromatic. There is no significant phototaxis response at the around the 629nm emission, and minimal response at the 589nm. This confirms that the photoreceptors of these insects lack the adaptation to detect longer wavelength near infrared red. In other words, red and above are invisible to these insects.

6.2 Radiant Intensity Response

Table 4 - Radiant intensity response on grasshopper

	Radiant Intensity (mW/m^2)			
	280	**11.2**	**2.8**	**0.7**
Trial 1	**1**	**2**	**2**	**0**
Trial 2	**0**	**2**	**1**	**0**
Trial 3	**2**	**1**	**1**	**0**
Average	**1.0**	**1.7**	**1.3**	**0**

Table 5 - Radiant intensity response on moth

	Radiant Intensity (mW/m^2)			
	280	**11.2**	**2.8**	**0.7**
Trial 1	2	2	0	0
Trial 2	1	2	1	0
Trial 3	3	1	2	0
Average	2.0	1.7	1.0	0

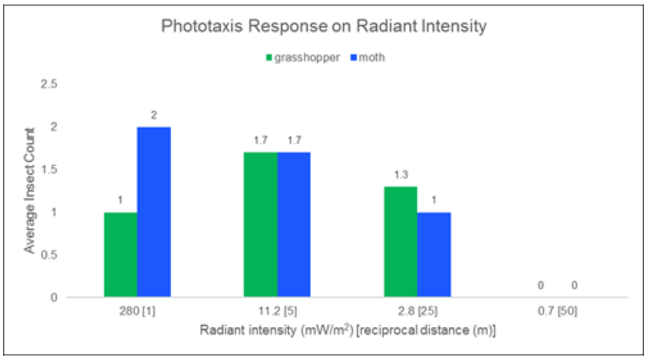

Fig. 9 - Combined average insect count against radiant intensity

The results of the radiant intensity response show that a radiation of 2.8mW/m2, or 25m in reciprocal distance, is the threshold of the insect's sensitivity towards the light source. The data tallies with other findings, especially with their stated range of 35-40m [13]. Unfortunately, the beetles could not be tested due to the shortage of available supply of specimens. However, based on the similar responses from both the grasshopper and moth, it could be estimated that the beetle would also follow a similar response.

Although the findings of this research paper yield substantial evidence on LED's efficacy towards insects, there were instances throughout the literature review process that claim otherwise. Again, the efficacy of LED light traps is subjective and highly dependent on various factors, such as insect taxa being diurnal [27], photophobia or light adaptation [28]. Others suggest that even thermal emission may result in skewed attraction from LEDs in part radiating little heat [29]. In retrospect, the LED sources in this methodology, although attempted with greatest effort, could not guarantee adequate discretization of light emission. Ideally, future improvements should include a better design of the test chamber, to confine light radiation which would help dispel much ambiguity on the extent of an individual light source effect.

In this paper, the methodology was designed specifically to exclude external lighting from test. It would raise interest to further deepen the scope research by factoring in the presence of external sources of light, natural or artificial on phototaxis response. This is particularly significant by considering original pathways of insect visual navigation, nocturnal or diurnal, since these invertebrates were adapted to receive visual information by light emanating from celestial sources. In particular, nocturnal insects such as moths rely on moonlight and its physical luminance properties for spatial orientation [30]. More concerning would be the phenomena of light pollution, where excessive artificial lighting has been well documented prior to interfere with insect behavior and could potentially threaten its ecology [27]. On this thought, herein presents opportunities of research into further develop a wholesome understanding of insect's attraction to light in the context of real-world environment, enhanced with an engineering approach built upon quantitative metrics of comparison.

7. Methodology

This paper has demonstrated an engineering's approach to quantify the phototaxis response of insects in a lab setting. The results from the experiment is consistent with prior studies conducted outdoor, which opens the possibilities of other variables to be tested that will mimic outdoor conditions. The feasibility of this approach would be the precursor to further design a suitable LED-Based light trap that is optimized for specific targets.

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