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ATTRACTIVENESS OF ARTHROPODAL HEXAPOD ORDERS TO LIGHT-EMITTING DIODE AND INCANDESCENT BULB LIGHT COLOURS

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ABSTRACT

Dearth of information on response of hexapod orders to light sources and colours informed this study. The study was conducted in Federal University Wukari, Nigeria in the month of May, 2019 to evaluate the attractiveness of hexapod orders to Light-emitting Diode (LED) and Incandescent bulb light colours. Daily sampling using fabricated light traps with 5 different colours (white, yellow, red, green and blued) for each bulb type in 6 replicates was done. A trap with no lighting source was the control. Hexapods collected were sorted into their respective orders. Of the overall 13 insect orders collected, LED bulbs attracted 11 while incandescent, 10. Even though, certain hexapod orders exhibited higher affinity to specific colours, statistical analysis revealed that of the 11 orders from LED, differences in the mean number of insects attracted among the bulb colours was significant ($p<0.05$) only in Coleoptera and Lepidoptera while for incandescent bulb colours, the mean number of insects attracted was significant for Coleoptera, Lepidoptera, Hemiptera, Hymenoptera, Orthoptera, Mantodea, Odonata and Homoptera. Insect orders generally had higher affinity to white and blue colours. LED bulb colours significantly attracted higher number of insects than their corresponding incandescent colours, except for white on which incandescent was more attractive ($p>0.05$). Overall, attractiveness to hexapod orders increases with rinsing light intensity and LED bulbs were found to be more attractive to hexapods than do incandescent bulbs. Therefore, LED bulbs of higher light intensity with colours around the blue/white spectrum show potential for use in manipulating hexapods for man's benefit.

Contribution/Originality: This study discovers that hexapod orders are largely highly responsive positively to blue and white electric light of higher intensity. It also shows that, the LED bulbs were generally more attractive to the hexapod orders than the incandescent. This knowledge can be harnessed in manipulating the hexapods for man's benefit.

1. INTRODUCTION

Arthropodal hexapods belong to the taxonomic class 'Insecta'. The insects are made up of about thirty different orders. The hexapods are very important group of arthropods as aside being pestiferous, they provide various ecosystem services (Chukwu *et al.*, 2019). Researches had shown that about 60% of the hexapods are night-active and well attracted to artificial light during night time (Owens and Lewis, 2018). These among other factors influences, hexapod feeding behaviour, mate selection, oviposition and navigation (Ouyang *et al.*, 2018).

The attractiveness of arthropodal hexapods to artificial light at night has been reported to be preferential to light source, intensity and wavelength (Hickel *et al.*, 2018; Chukwu and Okrikata, 2019; Chukwu *et al.*, 2019). Red colour is credited with the longest wavelength and lowest frequency while violet, the shortest wavelength with highest frequency thereby eliciting different effects on different hexapod species (Nirmal *et al.*, 2017). Although the phototactic response of hexapods to artificially lit light at night has its negative impact in the ecosystem and insect biology by threatening the biodiversity of surrounding ecosystems and reducing a number of insects bio-processes among others (Botha *et al.*, 2017); manipulating artificial light has been used to sample insect pest population, forecast pest infestation, harvest insects for food (Chukwu and Okrikata, 2019) and, study population dynamics and diversity of insects (Antony and Sebastian, 2016).

Studies in some parts of the globe have shown that, different hexapod orders are differentially attracted to artificial light (Nirmal *et al.*, 2017; Shibuya *et al.*, 2018). However, such investigation had hardly been conducted in Nigeria, and more particularly, in the study area. Thus, the findings of this investigation is designed to fill this knowledge gap for the purpose of enhancing the management of noxious insect species for the benefit of man, harvesting hexapods for food and scientific research and pest forecasting.

2. MATERIALS AND METHODS

2.1. Study Area

This investigation was conducted in the Research Farm of Federal University Wukari, Taraba State, Nigeria. Wukari is within the Nigerian Southern Guinea Savannah with Latitude 7.8°N and Longitude 9.77°E. It has an elevation of 189m above sea level. Its average temperature is 26.8°C and its annual precipitation; 1,205mm (Okrikata and Yusuf, 2016).

2.2. Hexapod Sampling Technique

Twelve (12) fabricated light traps were constructed using transparent polyethylene sheetings attached to two wooden frames (served as the screen) in May, 2019. Each of five traps were attached with one of White, Blue, Green, Yellow and Red light-emitting diode (LED) bulbs (ECOMIN-QP05014/3W; AC220-240V/50-60Hz) at 1m above ground level. A trap without bulb served as the control set-up and all were arranged in a Completely Randomized Design (CRD). Same setting was made for incandescent bulbs (JUNGSRAM 25W; G45, 220V, E27, 1000h). Traps were spaced 3m apart and a bowl containing ¾ level of water with 2% liquid soap (collection medium) was placed beneath each trap as shown in Figure 1.

Light intensity of each bulb was measured in a dark room using a digital Lux meter (Serial no.: 20111100416). The bulbs were simultaneously powered with tiger generator (TG950) from 1800hr to 2400hr daily. Each trap was serviced the following morning and all trapped hexapods were sorted into their respective orders on the basis of bulb type and colour.

Figure-1. Arrangement of fabricated light traps used for hexapod collections.

Source: Field study, May 2019.

2.3. Data Analysis

To normalize the data collected, they were transformed using $\sqrt{x} + 0.5$ before variance analysis. Significantly different means were separated by Student Newman Keul's test (SNK) at 5 % level of probability. Student's t-test was used for comparing the attractiveness of LED and Incandescent bulb colours to the hexapod orders. Correlation and linear regression analyses were used to determine the relationship between light intensity of each bulb type and the density of the hexapod orders that were attracted. All analyses were done using IBM SPSS Statistics version 23.0

3. RESULTS

3.1. Hexapod Orders Attracted by LED and Incandescent Bulb Colours

Generally, the result of the study indicates that a total of 13 key hexapod orders; Coleoptera, Diptera, Lepidoptera, Hymenoptera, Hemiptera, Odonata, Isoptera, Mantodea, Homoptera, Blattodea, Orthoptera, Collembola and Thysanura were collected using the various lights traps of which LED bulbs attracted 11 hexapod orders without Odonata and Homoptera Table 1a while incandescent bulbs attracted 10 hexapod orders without Collembola, Blattodea and Thysanura Table 1b. Although preferential attractiveness of the hexapods to the respective light colours was observed, Table 1a indicated significant differences ($p < 0.001$) within the Coleopterans and Lepidopterans attracted to LED bulb colours. Table 1b showed significant difference within all hexapod orders attracted to incandescent bulb colours except for Diptera ($p = 0.122$) and Isoptera ($p = 0.327$).

3.2. Comparing the Attractiveness of Hexapods to LED and Incandescent Bulb Colours

Table 2 shows that with exception of the white coloured bulbs ($p = 0.692$), LED bulbs were consistently and significantly ($p < 0.05$) more attractive to hexapods than the Incandescent bulbs.

3.3. Relationship between Bulb Intensity and Density of Attracted Hexapod Orders

Table 3a shows that the density of all hexapod orders collected correlated positively and significantly ($P < 0.05$) with incandescent bulb intensities except for Isoptera ($p > 0.05$) and, R^2 values ranged from 0.122 for isoptera to 0.993 for hemiptera. Similar trend was also observed for LED bulb intensities. Table 3b shows that except for Blattodea, Hymenoptera and Thysanoptera which were positive but, not significant ($p > 0.05$); densities of all the other hexapod orders correlated positively and significantly ($p < 0.05$) with LED bulb light intensities and, coefficient of determination (R^2) ranged from 0.004 for Thysanura to 0.901 for Lepidoptera.

Table-1a. Attractiveness of LED bulb colours to major hexapod orders.

Bulb Colours	Mean Number of Hexapod Orders Retrieved										
	Coleoptera	Diptera	Lepidoptera	Isoptera	Hemiptera	Hymenoptera	Orthoptera	Mantodea	Collembola	Blattodea	Thysanura
White	$5.96\pm1.20a^{b}$	1.66 ± 0.66^{a}	4.28 ± 0.41^{ab}	1.78 ± 0.59^{a}	1.53 ± 0.31^{a}	6.96 ± 2.51^{a}	2.91 ± 0.90^{a}	1.55 ± 0.31^{a}	0.71 ± 0.02^{a}	1.07 ± 0.21^{a}	0.80 ± 0.01^{a}
Yellow	2.95 ± 0.77^{bc}	2.28 ± 0.40^{a}	2.28 ± 0.40^{bc}	1.41 ± 0.45^{a}	1.26 ± 0.13^{a}	5.20 ± 2.43^{a}	2.39 ± 0.75^{a}	1.24 ± 0.25^{a}	0.71 ± 0.05^{a}	0.71 ± 0.03^{a}	0.71 ± 0.06^{a}
Red	3.09 ± 0.66^{bc}	1.38 ± 0.22^{a}	2.42 ± 0.49^{bc}	0.80 ± 0.08^{a}	1.54 ± 0.48^{a}	4.16 ± 0.43^{a}	1.61 ± 0.43^{a}	1.08 ± 0.19^{a}	0.71 ± 0.04^{a}	1.00 ± 0.18^{a}	0.71 ± 0.04^{a}
Green	2.87 ± 0.29^{bc}	1.59 ± 0.33^{a}	4.27 ± 0.98^{ab}	2.41 ± 1.02^{a}	1.54 ± 0.31^{a}	5.39 ± 1.50^{a}	2.36 ± 0.59^{a}	1.52 ± 0.21^{a}	0.71 ± 0.01^{a}	0.80 ± 0.09^{a}	0.71 ± 0.01^{a}
Blue	6.89 ± 1.39^{a}	2.44 ± 0.62^{a}	6.19 ± 0.96^{a}	2.16 ± 0.97^{a}	1.81 ± 0.42^{a}	5.57 ± 1.88^{a}	2.75 ± 0.65^{a}	1.60 ± 0.35^{a}	0.86 ± 0.15^{a}	0.71 ± 0.10^{a}	0.71 ± 0.01^{a}
Control	0.71 ± 0.01^{c}	0.71 ± 0.10^{a}	0.71 ± 0.03^{c}	0.71 ± 0.02^{a}	0.71 ± 0.20^{a}	0.71 ± 0.05^{a}	0.71 ± 0.01^{a}	0.71 ± 0.08^{a}	0.71 ± 0.10^{a}	0.71 ± 0.05^{a}	0.71 ± 0.03^{a}
F-value	6.92	2.32	9.24	1.12	1.41	1.51	1.76	2.04	1.00	1.78	1.00
P-value	0.000	0.068	0.000	0.373	0.249	0.217	0.151	0.101	0.435	0.146	0.435

Note: Mean (±SE) followed by the same superscript letter(s) within a column are not significantly different using Student-Newman-Keul's (SNK) test (P≤0.05).

Table-1b. Attractiveness of Incandescent bulb colours to major hexapod orders.

Bulb Colours	Mean Number of Hexapod Order Retrieved									
	Coleoptera	Diptera	Lepidoptera	Isoptera	Hemiptera	Hymenoptera	Orthoptera	Mantodea	Odonata	Homoptera
White	5.98 ± 1.20^{a}	1.54 ± 0.54^{a}	5.76 ± 0.77^{a}	0.90 ± 0.19^{a}	2.03 ± 0.20^{a}	4.67 ± 0.77^{a}	1.81 ± 0.49^{a}	2.62 ± 0.55^{a}	1.62 ± 0.46^{a}	6.45 ± 1.26^{a}
Yellow	3.39 ± 0.70^{b}	0.71 ± 0.01^{a}	0.94 ± 0.15^{b}	1.28 ± 0.42^{a}	1.03 ± 0.15^{b}	2.08 ± 0.45^{b}	1.07 ± 0.19^{ab}	1.55 ± 0.23^{b}	0.80 ± 0.09^{a}	3.99 ± 0.70^{b}
Red	1.10 ± 0.24^{bc}	0.80 ± 0.09^{a}	0.90 ± 0.19^{b}	0.71 ± 0.07^{a}	0.71 ± 0.00^{b}	1.13 ± 0.21^{b}	1.17 ± 0.16^{ab}	1.17 ± 0.16^{b}	0.71 ± 0.30^{a}	2.15 ± 0.49^{bc}
Green	3.28 ± 0.33^{b}	1.05 ± 0.22^{a}	1.03 ± 0.15^{b}	0.80 ± 0.09^{a}	0.88 ± 0.11^{b}	2.48 ± 0.41^{b}	1.13 ± 0.21^{ab}	1.07 ± 0.19^{b}	0.71 ± 0.01^{a}	2.62 ± 0.91^{bc}
Blue	1.93 ± 0.30^{bc}	0.71 ± 0.06^{a}	0.88 ± 0.11^{b}	0.80 ± 0.09^{a}	0.71 ± 0.03^{a}	1.76 ± 0.42^{b}	0.80 ± 0.09^{b}	1.11 ± 0.14^{b}	0.71 ± 0.03^{a}	1.88 ± 0.77^{bc}
Control	0.71 ± 0.09^{c}	0.71 ± 0.03^{a}	0.71 ± 0.03^{b}	0.71 ± 0.06^{a}	0.71 ± 0.02^{a}	0.71 ± 0.02^{b}	0.71 ± 0.01^{b}	0.71 ± 0.02^{b}	0.71 ± 0.01^{a}	0.71 ± 0.02^{c}
F-value	10.23	1.91	34.47	1.21	21.40	9.81	2.55	6.22	3.78	6.48
P-value	0.000	0.122	0.000	0.327	0.000	0.000	0.049	0.000	0.009	0.000

Note: Mean (±SE) followed by the same superscript letter(s) within a column are not significantly different using Student-Newman-Keul's (SNK) test (P≤0.05).

Table-2. Comparison of Incandescent and LED bulb colors on their attractiveness to hexapods.

Bulb Colours	Mean hexapod count for Incandescent	Mean hexapod count for LED	Mean Difference	t-value	p-value
White	3.10±0.32	2.49±0.34	0.61±0.47	1.29	0.692^{ns}
Yellow	1.30±0.13	1.82±0.26	-0.52±0.29	-1.74	0.027^{*}
Red	1.02±0.07	1.60±0.15	-0.58±0.17	-3.28	0.000^{***}
Green	1.43±0.14	2.07±0.24	-0.64±0.28	-2.24	0.013^{*}
Blue	1.09±0.10	2.70±0.34	-1.61±0.35	-4.39	0.000^{***}

Note: * = Significantly difference (P≤0.05)
** = Significantly difference (P≤0.01)
*** = Significantly different (P≤0.001)
ns = not significantly difference (P>0.05).

4. DISCUSSION

That arthropodal hexapods are attracted to light was seen in this investigation as in the two light types, the various colours largely attracted more hexapods than the control. That hexapods also respond differently to various light sources and wavelengths which can be attributed to differences in light intensities and spectral distribution of the emitted light was indicated by Wakefield *et al.* (2017) and Chukwu *et al.* (2019). This phenomenon was apparently observed in the present study with respect to both the LED and Incandescent bulb colours.

Generally, among the LED bulbs, the present study showed higher attraction of hexapods to blue and white coloured bulbs while, the white colour was consistently the most attractive among the incandescent bulb colours. The overall high attractiveness of blue coloured LED bulb as observed in the present study corroborates the report of Owens and Lewis (2018) who opined that, blue colour is the zone of maximum response by hexapods. That blue LED bulbs attracted higher numbers of some hexapod orders also buttresses the findings of Barghini and Souza de Medeiros (2012). The very high attractiveness of white LED bulbs to hexapod orders could be due to its emission of light towards the blue spectra as reported by Chukwu *et al.* (2019). Hemipterous hexapods have been reported to be more attracted to white and blue lights (Pacheco-Tucuch *et al.*, 2012). A similar trend was also observed in this study.

In comparing the attractiveness of hexapods to bulb types, the present study showed that LED bulbs attracted more hexapod orders (11) than the incandescent bulbs which attracted 10. Though the difference was marginal, that LED bulbs attracts more hexapod diversity than incandescent bulbs had been reported by Pawson and Bader (2014) and Wakefield *et al.* (2017). However, contrary to the present finding in which consistently higher hexapod density were attracted to LED bulb colours except for white, Wakefield *et al.* (2017) reported higher hexapod density for incandescent bulbs than for LED bulbs. Even though the report of Pawson and Bader (2014) was at variance with that of Wakefield *et al.* (2017) with respect to density of hexapods attracted, both authors tied their findings to variations in light intensity. While Pawson and Bader (2014) reported higher light intensity for LED bulbs, Wakefield *et al.* (2017) reported a higher light intensity for incandescent bulbs. This variation may have influenced the differences in their findings.

Buttressing the findings of Pawson and Bader (2014) and Hickel *et al.* (2018) LED bulbs were reported by Chukwu and Okrikata (2019) to be more attractive to Red Pumpkin Beetle (*Aulacophora africana* Weise) due to preference to light colour and/or intensity. Also, corroborating the findings of Wakefield *et al.* (2017) the present study showed that white incandescent bulbs which had the highest mean light intensity attracted the highest mean number of hexapods thereby highlighting the influence of light intensity to hexapod attraction. However, in minimising the influence of light intensity, Wakefield *et al.* (2016) opined that heat emitted by light could act as a thermal attractant to insects.

5. CONCLUSION

Hexapods have limitless economic and ecological importance to man and the environment. Harvest of most arthropodal hexapod species for various purposes have largely been through rigorous strategies while control of many noxious species have also been basically through methods that are detrimental to man and the environment. The phototactic response of hexapods can hence be harnessed for proper management and manipulation of the species for the benefit of man. Thus from the present study, it is concluded that LED bulbs were more attractive to hexapods than do incandescent bulbs. Such was also observed with respect to colurs within the blue-white spectrum. Hence blue-rich white LED bulbs of higher intensity can be manipulated to manipulate hexapods for the benefit of man (eg., forecasting pest outbreaks and, harvesting insects for food and research) and the environment.

Table-3a. Correlation and regression analysis between major hexapod orders and incandescent bulb intensity

Variable	Correlation Coefficient (r)	Regression equation	Coefficient of determination (R^2)
Coleopteran density x Incandescent Intensity	0.93^{**}	Y = 1.516±0.004x	0.857
Dipteran density x Incandescent Intensity	0.89^{**}	Y = 0.718±0.001x	0.794
Lepidopteran density x Incandescent Intensity	0.97^{***}	Y = 0.395±0.005x	0.934
Hymenopteran density x Incandescent Intensity	0.94^{**}	Y = 1.249±0.003x	0.883
Hemipteran density x Incandescent Intensity	0.997^{***}	Y = 0.661±0.001x	0.993
Isopteran density x Incandescent Intensity	0.350^{ns}	Y = 0.814±0.000x	0.122
Orthopteran density x Incandescent Intensity	0.916^{**}	Y = 0.873±0.001x	0.839
Odonatan density x Incandescent Intensity	0.978^{***}	Y = 0.632±0.001x	0.957
Mantodea density x Incandescent Intensity	0.977^{***}	Y = 0.929±0.002x	0.956
Homopteran density x Incandescent Intensity	0.957^{***}	Y = 1.656±0.005x	0.917
Mean hexapod density x Incandescent Intensity	0.987^{***}	Y = 0.924±0.002x	0.974

Note: Mean (±SE) intensity in Lux of Incandescent bulbs; **Red** = 65.3±3.55, **Yellow** = 334.00±3.36, **Green** = 157.20±4.24, **Blue** = 45.40±1.57, **White** = 1094.20±38.51.

* = Significantly difference ($P \leq 0.05$)

** = Significantly difference ($P \leq 0.01$)

*** = Significantly different ($P \leq 0.001$)

^{ns} = not significantly difference ($P > 0.05$).

Table-3b. Correlation and regression analysis between major hexapod orders and LED bulb intensity

Var□able	Correlation coefficient (r)	Regression equation	Coefficient of determination (R^2)
Coleopteran density x LED intensity	0.76^{*}	Y = 1.770±0.006x	0.581
Dipteran density x LED intensity	0.73^{*}	Y = 0.312±0.001x	0.536
Lepidopteran density x LED intensity	0.95^{**}	Y = 1.262±0.007x	0.901
Isopteran density x LED intensity	0.92^{**}	Y = 0.806±0.002x	0.854
Hemipteran density x LED intensity	0.75^{*}	Y = 1.074±0.001x	0.564
Hymenopteran density x LED intensity	0.66^{ns}	Y = 3.071±0.005x	0.429
Orthopteran density x LED intensity	0.78^{*}	Y = 1.385±0.002x	0.612
Mantodea density x LED intensity	0.89^{**}	Y = 0.931±0.001x	0.785
Collembola density x LED intensity	0.74^{*}	Y = 0.684±0.000x	0.544
Blattodea density x LED intensity	0.20^{ns}	Y = 0.869±0.000x	0.042
Thysanopteran density x LED intensity	0.06^{ns}	Y = 0.722±0.000x	0.004
Mean hexapod density x LED intensity	0.86^{*}	Y = 1.204±.002x	0.735

Note: Mean (±) intensity in Lux of LED bulbs; **Red** = 60.18±5.97, **Yellow** = 243.20±16.47, **Green** = 513.80±27.00, **Blue** = 736.80±13.02, **White** = 351.20±4.31.

* = Significantly difference ($P \leq 0.05$)

** = Significantly difference ($P \leq 0.01$)

*** = Significantly different ($P \leq 0.001$)

^{ns} = not significantly difference ($P > 0.05$).

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