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ROLE OF LED LIGHTS IN THE DESIGN OF ULTRA-VIOLET LIGHT TRAPS FOR HOUSE FLY MONITORING AND CONTROL

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Abstract The light emitting diode (LED) lamp market is predicted to experience massive growth over the next decade. Outside the domestic lighting sector there are a number of specialist uses for LED technology that have warranted research into specific frequencies of light emission. Ultra-violet (UV-A waveband) LEDs are becoming powerful enough to offer a credible alternative light source to the fluorescent lamps currently used in ultra-violet light traps for the monitoring or control of flying insects in urban environments. Whilst there are significant energy savings to be made in employing this technology, other differences between LEDs and fluorescent lamps can be exploited to maximise their characteristics of light emission to catch flying insects. The hypothesis that an insect light trap using a UV-A LED luminaire can be as efficient at removing a known number flies from an environment as a light trap using fluorescent lamps is tested using common chasses with spectroscopy and replicated bioassays.

Key words House fly, *Musca domestica*, spectral sensitivity, visual response

INTRODUCTION

In 2015, the global price of LED bulbs was estimated to have fallen by 30-40% and by 2016 the global LED lighting market exceeded $30.5 billion US dollars (Anon, 2016). With the rise in domestic use of LED lighting manufacturers have sought to expand market share by leveraging technology into related niche markets including ultra violet (UV) and infrared (IR) applications. The largest market for UV LEDs is in ink curing, a rapid polymerisation process that fixes inks to surfaces that requires neither water nor solvents. The ink curing market is curiously fortuitous for the future of insect light traps in that the frequencies of UV light commonly used to fix ink (365nm wavelength) is close to a peak in spectral sensitivity in the visual apparatus of the house fly, *Musca domestica* (Goldsmith and Hernandez, 1968)

UV-A mercury phosphor lamps have been used in commercial insect light traps for over 40 years (Roberts, 1990) and such units are commonplace in commercial and industrial setting, particularly those handling foodstuffs. Mercury phosphor lamps have a non-negligible environmental impact, even in relatively niches uses as insect light traps and are subject to increasing regulation such as the European Union's recent Restriction on Hazardous Substances II (RoHS II) regulation, the implementation of which saw a shift from lamps emitting peak UV-A wavelength at 350 nm to those emitting at a peak of 365 nm due to the quantities of lead used to attenuate the output. There are important waste considerations for Pest Management Companies too; each lamp has a functional life of approximately one year, after which it degrades to a point where the peak wavelength has shifted and the intensity declined to a level that no longer draws flies to the trap having been saturated by ambient light.

House flies are an important urban disease vector (Davies, 2016) that are controlled or monitored with insect light traps by pest management companies that will respond to changes in change number or species by proofing to restrict the insects' access to the area in question or remove them from the environment where ingress is inevitable. Quantifiable measurements from these traps that purport to effect catch rate are often quoted as de facto figures for their efficacy, including total lamp power, UV-A output and lethal surface area. Whilst there is certainly some evidence to support the maximisation of these measurements (Pickens and Thimijan, 1986) previous studies and suggest that various design factors that may negate any advantages gained through such efforts (Hanley et al., 2009; Green, 2011; Jones et al., 2017).

Light emission spectrographic variation between the LED and fluorescent luminaires from previous (unpublished) studies shows that under known ambient light levels (400LUX) the shape of UV-A light cone produced by an LED luminaire differs from that of that of three 15 W UV-A fluorescent lamps mounted in an identical chassis. The 'forward facing' directional nature of LEDs throws light further away from the trap.

The aim of this work was to derive a relative efficacy rank from a consistent series of tests that enables direct comparison between LED and fluorescent luminaires operating on the same trap chasses. Removing flies from the environment as fast as possible is seen as the most important factor for the end user (Sargent, 2010) to reduce the risk to human health. This is the role of light traps when used to monitor areas where risk is low and hazard is high (usually traps with adhesive surfaces to aid identification for origin and cause/point of ingress); and when they are used as a control device in areas where risk is high and hazard is low (areas with direct access to the external environment where high voltage grids are employed in light traps). Catch rate in this study was quantified by estimating the best possible time to catch 50% of flies within a room.

A significant amount of prior investigation into catch rates for *Mucsa domestica* has centred on UV light wavelength attraction (Smallegange, 2003; Roberts et al., 1992; Syms, 1988). Black light bulbs sold for the fly killer market radiate light in the 330-385 nm ultra-violet range, within which there does not seem to be a consensus for the wavelength that is most attractive *M. domestica* in practice, despite electrophysiological studies (Smallegange, 2003).

MATERIALS AND METHODS

Two light trap chasses (Figures 1-4) were tested with two luminaires in identical controlled environment rooms (4 m^2 with a volume of 9 m^3), maintained at 25° C ± 2° C and 50% ± 10% RH, illuminated daily on a 12- hour cycle. The rooms were subject to 10 air changes per hour and sealed to prevent flies escaping.

Figure 1. Chassis A with fluorescent lamp (left) and LED (right) luminaires.

Figure 2. Chassis B with fluorescent lamp (left) and LED (right) luminaires. Role Of LED Lights In The Design Of Ultra-Violet Light Traps

UV lamps used in the traps were on for a minimum of 100 hours prior to testing. LED luminaires were on for 2 hours to ensure the light output was stable (assessed with a handheld UV spectrometer). Traps tested were mounted 1.8 m from the floor.

Bioassay protocol followed Green (2001): 100 unsexed adult *Musca domestica* were released at floor level from the centre of the room. The number of flies captured in the unit was counted at intervals of: 15, 30, 60, 90, 120, 240 minutes, 5 hours, 7 hours and 24 hours. After 24 hours all live flies in the room, dead flies on the floor or within the unit (not on the glue) and observed escapees were accounted for. Six replicates of each test were conducted with fresh glue surfaces for each test and luminaires emitting the same level of UV-A light.

RESULTS

An average time for half the number of available flies to be caught (C_{50}) was calculated by averaging the counts from six days of testing. The C_{50} score is the minimum possible time that it would take each unit to catch 50% of the available flies (given maximal performance of the unit based on the average recorded catch for each of the eight time intervals), using the following equation:

$$C_{50} = \frac{t}{\log_2 (N_0/N_t)}$$

where C_{50} is the fastest average catch time, t is the time elapsed, N_0 is the initial percentage of flies (100) and N_t is the percentage remaining after t.

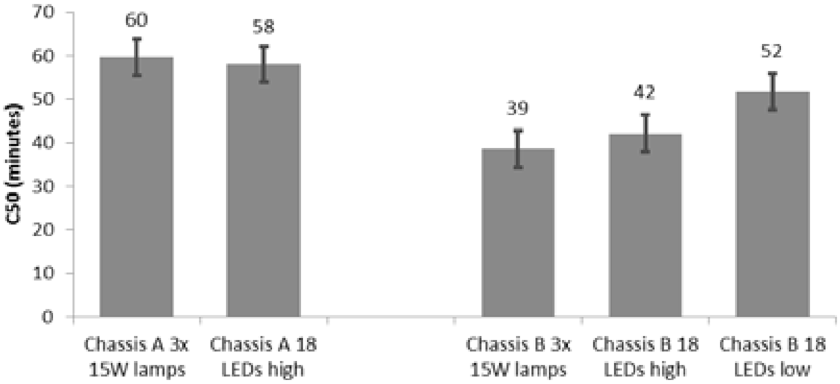

Figure 3. Catch rate variation with luminaire and power.

The results show chassis B to be more efficient than chassis A (although there is some notable cover colour and therefore contrast variation). At a high power setting the units with LED luminaires consume approximately 60% of the power of the units with fluorescent lamps, falling to below 50% at the low power setting over the test period. No significant difference ($p=0.05$) was found between luminaires for either chassis or power level.

DISCUSSION

Directional LED luminaires offer a number of interesting design choices for UV-A insect light traps. The use pattern and power dimming capabilities of LEDs make them a particularly good fit for use in insect light traps, the limiting factor currently being power output that will gradually be overcome as technological hurdles of cooling and reliability are addressed. Variable power supply to LEDs would initially seem to be of nominal use for light traps given some test methods currently used for assessing light trap effect, this work has shown that under single choice bioassay conditions UV-A LEDs offer comparable risk protection against fly-borne disease in low light settings to fluorescent lamps with a fraction of the power consumption required to maintain an arc in a mercury phosphor lamps emitting light at the same peak frequency.

The use of a single light trap chassis allowed us to investigate the effect of changing the luminaire without affecting any other variable that would influence the catch rate of a trap in a room with a known number of house flies. Single choice bioassays should be the norm for insect light trap testing as LED luminaires become more common in the market. The alternative two choice testing will inevitably result in a bias towards high power units (regardless of luminaire type) being deployed in situations where a comparable level of disease risk reduction from house flies could be achieved using potentially lower UV-A light output more attuned to ambient light levels (Jones et al., 2017).

Further work will seek to define and optimise the relationship between an LED luminaire and the trap chassis to accentuate the directionality adaptive power modes unique to this technology. The results are also is in line with observations by Syms (1988) that sub-sets of flies within the released population are for unclear reasons do not display the same level of flight and attraction to UV-A than others. The behaviour of released sets house flies and identification and quantification of any sub-set therein that is more or less attracted to light traps shall be documented to improve the operational understanding and limitations of these units.

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