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Comparison of Incandescent, CFL, LED and Bird Level LED Lighting: Growth, Fear and Stress

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Abstract: The eventual removal of incandescent lights from the market has left poultry producers with the need to find alternative lighting sources. Light-emitting diode (LED) and compact fluorescent lamp (CFL) bulbs have arisen as the likely replacements for incandescent lights. However, there is little knowledge how these bulbs compare with each other in how they affect bird production, behavior and stress. To investigate this broilers (n = 120 per treatment) were raised under incandescent (INCAN), CFL, or LED lighting or an alternative of using LED lights at bird level (LED bird). All lighting was 23L:1D at 20 lx for 14 d and then was changed to 20L:4D at 5 lx for the remaining 31 d. Fearfulness was determined using several fear tests and stress susceptibility was assessed using a composite asymmetry score determined by middle toe length and metatarsal length and width. All alternative lighting to INCAN improved weight gain at 45 d ($p<0.05$). Both LED treatments exhibited less fear and less stress susceptibility than those raised under CFL or INCAN ($p<0.05$). Using CFL and LED bulbs can increase the size of the birds while not changing FCR and LED bulbs appear to reduce fear and stress in older birds compared with CFL or Incan bulbs. The results also indicate that LED bird not only increases growth and feed conversion but results in birds that are less fearful and less stress susceptible. This method of illuminating birds might save energy and improve production and bird welfare.

Key words: Broiler, light, fear, stress, growth

INTRODUCTION

All poultry need light to live and modern farming practices usually require artificial lighting to meet this need. Light itself is a complex and varied phenomenon, made up of an entire spectrum of wavelengths and intensities. As such, light affects many aspects of growth and behavior in all manner of living organisms and must be taken into account when attempting to provide the most efficient controlled environment for poultry production. Poultry have evolved highly specialized visual systems to aid in their survival and much of poultry behavior is mediated by their vision (Mendes *et al.*, 2013). If an ideal poultry production environment is to be created, one must understand how the birds will react to different light spectrums and intensities.

For many years the industry has relied on incandescent light bulbs to provide illumination in poultry houses. These bulbs come in a variety of colors and intensities, but are currently being phased out due to their relatively high power consumption. Fluorescent lights, especially the newer compact fluorescent lights (CFLs), offer a significantly lower level of power consumption for a similar light output and are currently favored by the industry (Burrow, 2008). However, CFLs do not all work well on the dimmers needed to set an adequate light level in the house and those that do, have not standardized their function. They also contain small levels of toxic heavy metals that may cause problems if the bulb is broken. More recently light emitting diodes (LEDs) have been moving into the market and are becoming more affordable. They offer much longer life spans than the other types of bulbs, decrease power consumption and provide a different spectrum output which has been described as more realistic by various reviewers (Morrison, 2013). By selecting the optimum light source for a particular flock, one should be able to maximize growth and efficiency while reducing unneeded stress and fostering ideal behavior.

A lighting program for raising broiler chickens contains numerous factors, namely light period, light spectrum and light intensity. While light period and light intensity are well documented and can affect behavior and health (Alvino *et al.*, 2009a,b; Blatchford *et al.*, 2009, 2012) very little research has been conducted investigating the spectrum of light. Light spectrum refers to the combination of different wavelengths of electromagnetic radiation emitted from a light source. Poultry perceive light differently than humans including the ability to see into the ultraviolet (UV) range due to the addition of a fourth type of single-cone photoreceptor (Osorio *et al.*, 1999; Prescott and Wathes, 1999). Furthermore, spectral sensitivity is not even across the spectrum and birds have been shown to have maximum visual sensitivity at 415, 455, 508 and 571 nm (Prescott *et al.*, 2003). Different light spectrums have been shown to affect bird behavior (Sultana *et al.*, 2013) and even growth (Cao *et al.*, 2008; Riber, 2015), so a proper understanding of the effects of different types of light on poultry is essential to the industry. Certain behaviors have been shown to be frequency dependent. Birds have been shown to spend more time sitting or standing under short wavelengths (blue/green) and exhibited more locomotion under longer (red/yellow) wavelengths (Sultana *et al.*, 2013). Furthermore, birds raised under red/yellow light exhibit tonic immobility for longer periods of time, indicating that they are more fearful than the short-wavelength exposed birds. Green light has been shown to cause the greatest feeding duration (Sultana *et al.*, 2013), but also has been shown to reduce time spent feeding (Huber-Eicher *et al.*, 2013). Skeletal muscle growth can also be affected by light spectrum, with higher muscle weights being found in birds exposed to green or blue lights (Halevy *et al.*, 1998). When exposed to ultraviolet light at a young age, birds were seen to have significantly reduced development of rickets and tibial dyschondroplasia (Edwards, 2003).

The spectra emitted by various commercial bulbs varies quite a bit by type; incandescent bulbs have an almost linear increase in intensity with very low UV output up to high infrared output, CFLs have a spectrum composed of many highly focused peaks throughout the visual spectrum and LEDs produce a fairly smooth spectrum with a small peak in the blue range and a larger peak in the red range (Morrison, 2013). Of the incandescent, CFL and LED, the LED bulbs produce the spectrum that most closely matches the spectral sensitivity of birds as outlined in Prescott and Wathes (1999).

Growth and feed conversion in poultry can be affected by light spectra and bulb type. Seven day old birds have been observed to have a better feed conversion under white LEDs than under CFLs but there was no difference in older birds (Mendes *et al.*, 2013). According to Mendes *et al.* (2013), birds raised under LEDs performed better overall than birds raised under CFLs, with males reacting more favorably than females. Using halogen lighting has resulted in greater live weight than incandescent controls without any reduction in welfare (Bayraktar *et al.*, 2012). Rozenboim *et al.* (1999) found that raising broilers under green and blue light enhanced weight gain over birds raised under white and red light. Rozenboim *et al.* (2004) demonstrated that green light best stimulates growth before 10 days of age while blue stimulates growth from 10 to 46 days and thus green can be switched out for blue at 10 days to further increase growth. LED lighting has also been shown to improve feed conversion over CFL lighting in broiler chickens (Huth and Archer, 2015).

Stress parameters such as Heterophil/Lymphocyte ratios (Onbasilar *et al.*, 2007), immune function (Xie *et al.*, 2008) and physical asymmetry (Campo *et al.*, 2000) are affected by changes in lighting programs. Physical asymmetry is simply a comparison of bilateral structures on a bird; structures on the left and right side of the bird are measured and a larger difference indicates greater asymmetry (Campo *et al.*, 2008). Physical asymmetry has been strongly correlated to stress in many studies, with greater asymmetry indicating a stronger perception of stress (Graham *et al.*, 1993; Knierim *et al.*, 2007; Archer *et al.*, 2009; Archer and Mench, 2013, 2014). Asymmetry also allows the assessment of longer term stress via a non-invasive measure. It has been demonstrated that LED can lead to lowered stress and fear when compared to CFL bulbs (Huth and Archer, 2015).

Fear response has also been shown to be affected by different spectra impact fear responses differently (Sultana *et al.*, 2013). As poultry are prey animals, fear of predation and predator avoidance are major components of a bird's fear response. It has been demonstrated that anti-predator fear responses are the most reliable fear measures. Ratner (1967) defines the anti-predator fear response in 4 categories progressing from freezing, to fleeing, to fighting and finally tonic immobility.

Since there has been limited research on the effects of alternative lighting technologies on the behavior, stress and growth of broiler chickens, an experiment was conducted to elucidate any differences between 4 types of light source. The objective of this study was to evaluate how incandescent (INCAN), compact fluorescent (CFL), light emitting diodes (LED) at traditional ceiling level or LEDs at bird level (LED bird), each which produces as different spectral output, affect production and welfare of broiler chickens. It is hypothesized that the use of LEDs in place of INCAN and CFLs will improve growth and welfare of broiler chickens.

MATERIALS AND METHODS

Animals and husbandry: This experiment involved 4 treatments: Overdrive (LED; 8 watt 5000K, Clifton, NJ, USA) LEDs and TCP (CFL; TruDim 5012350K, Aurora, OH) Dimmable CFLs, Sylvania 60 watt Incandescent (INCAN; 60 watt DL, Danvers, MA, USA) and Superbrightled strip LEDs (LED bird; WFLS-X3, Saint Louis, MO, USA). A comparison of spectra between these bulbs can be seen in Fig. 1. Each treatment consisted of 6 pens containing 20 Cobb broiler chicks each in a light tight room outfitted with one of the 4 light sources. Each of the 4 rooms utilized was set up in an identical pattern, with the only difference being the light bulbs. The room measured 8.1 x 5.8 m and was sealed to prevent any outside light from entering. Each of the pens measured 1 m wide, 2 m long and 0.6 m high (stocking density 1.47 kg/m^2). The pens were constructed of solid black plastic on all but the front side, which was made of mesh wire. The birds were managed according to the guidelines set forth in the Guide for the Care and Use of Agricultural Animals in Research and Teaching (FASS, 2010) and methods

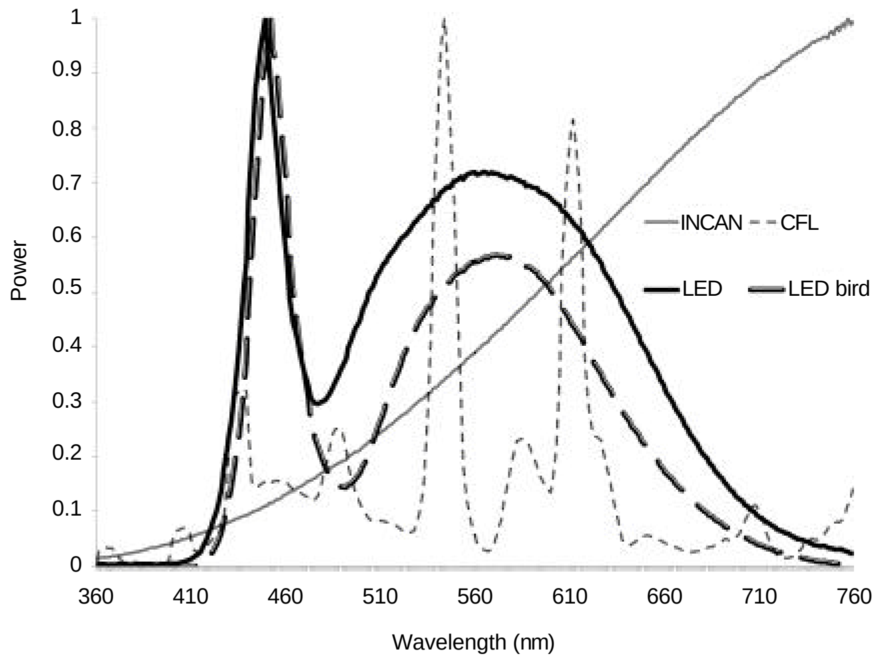

Fig. 1: Comparison of spectrum readings of the 4 different lighting sources incandescent (INCAN), compact fluorescent (CFL), light emitting diode (LED) and light emitting diode at bird level (LED bird). Horizontal axis is light spectrum in nM and vertical axis is relative power

were approved by the Texas A and M institutional animal care and use committee. The pens were lined with several inches of pine shavings. One feeder and a single row of 6 nipple drinkers were provided per pen and adjusted for height as the birds grew. There were 6 light fixtures in each room with overhead lighting and 4 of them were directly over the pens 3 m above the floor. All lights were connected to a single dimmer and timer per room. The LED bird room had lighting attached along the water line and around the feeder. These strip lights were also connected to a dimmer. For the first week, the birds were given 23L:1D at 20 lux of light as measured at bird head height using a light meter (Extech 401027, Extech Instruments, Nashua, NH). For the rest of the trial the lights were dimmed down to 5 lux and 20L:4D which are commonly used by commercial poultry producers in the United States. For the first three weeks, heat was provided by a single ceramic heat lamp hung in each pen which produces no visible light. Upon conclusion of the study, all birds were euthanized with a mixture of air and CO_2.

Growth and feed conversion: The birds in each pen were weighed at day 0 and day 45 and body weight gain was calculated by subtracting day 0 weight from day 45 weights. All pens had the same initial starting weight. Feed was weighed before it was added to the feeder in each pen and residual feed was weighed back on bird weigh days so that feed intake could be calculated. Feed conversion ratio (FCR) was calculated by dividing the total feed intake per pen by the total body weight gain per pen and was corrected for mortality.

Fear tests: When fear testing began at 3 weeks of age, 10 birds were selected from each pen and marked with a different colored livestock paint on each wing so individual birds could be identified. The same set of patterns was used in every pen in every treatment to insure that no effect of marking the birds would affect the results. Several fear tests were conducted as according to Ratner (1967) animals will exhibit differing fear responses.

Emergence: The emergence test was conducted at 3 weeks of age, modified from methods found in Archer and Mench (2014). In brief, 10 marked birds were taken to a separate room and kept in a large holding container. A lidded 19-liter bucket was modified to have a sliding door in the side and the person performing the test was seated at an angle to be able to view the door but not be easily seen by an emerging bird. The birds were individually placed in the bucket with the door and lid closed. After 20 sec, the door was slid open and a timer was started. The timer was stopped when the bird first stepped out of the container, or at a maximum of 3 min. This continued until all sets of birds were tested. Longer latency to emerge was considered to indicate more fearfulness (Archer and Mench, 2014).

Isolation: The isolation tests were performed 2 days after the emergence tests and was modified from methods outlined in (Archer and Mench, 2014). The 10 marked birds per pen birds were individually placed in an unlidded 19-liter bucket. A timer was set for 3 min and the number of vocalizations produced by the bird during this time was counted. More vocalizations was considered to indicate more fearfulness (Forkman *et al.*, 2007).

Tonic immobility: Tonic Immobility (TI) was conducted at 5 weeks of age on the 10 marked birds per pen. Methods were modified from previous research by Jones (1986) and Archer and Mench (2014). Each bird was individually taken and placed on its back in a wooded cradle which was covered with a black cloth. The head of the bird was covered with one hand while the breast was held with the other for approximately 15 sec to induce tonic immobility, after which time contact was removed and a timer was started. If the bird righted itself in under 15 sec, the timer was reset and the above procedure was performed again for up to 3 attempts. If the bird was not able to be induced into tonic immobility after three tries it was recorded as a time of 0. Otherwise the time of righting (or attempting to right) was recorded, with a maximum of 10 min. Longer times to first head movement and righting were considered to indicate more fearfulness (Jones, 1986).

Any tests that took multiple days were performed at the same time each day, with equal numbers of birds from each treatment. The lighting and temperature remained constant in the separate room where the emergence, isolation and TI tests were performed and care was taken to transport all the birds to the room in the same low stress manner.

Stress measures: Physical asymmetry of each marked bird was measured at 45 days, immediately after each was euthanized using a CO_2/air mixture and before rigor mortis began to set in, following the protocol outlined in Archer and Mench (2013). Using a calibrated Craftsman IP54 Digital Caliper (Sears Holdings, Hoffman Estates, IL), the middle toe length, metatarsal length and metatarsal width were measured for both the right and left legs. The composite asymmetry score was calculated by taking the sum of the absolute value of left minus right of each trait, then dividing by the total number of traits. Thus the formula for this trial would be $(|L-R|_{MTL}+|L-R|_{ML}+|L-R|_{MW})/3$ = composite asymmetry score.

Statistical methods: To investigate treatment effects on composite asymmetry, isolation, emergence, tonic immobility, weight gain and feed conversion using the GLM procedure was used with treatment and pen nested within treatment as factors. Pen nested within treatment was the error term used to test for treatment effects. The least significant difference test was used to test all planned comparisons. All of the assumptions were tested (Shapiro-Wilk test for normality, Levene's test for homogeneity of variance). No transformations were needed to meet assumptions. All analyses were performed using SAS 9.4 for Windows (SAS Institute Inc.). Significant differences were at $p<0.05$.

RESULTS

Growth and feed conversion: There was an effect of lighting treatment on 45 d weight gain and 45 d feed conversion (Table 1). The INCAN broilers (2.73±0.08 kg) weighed less after 45 d than the CFL (2.97±0.06 kg, p = 0.01), LED (2.95±0.06 kg, p = 0.02) and LED bird (3.02±0.05 kg, p = 0.004) broilers. The INCAN broilers (1.71±0.03) had a higher 45 d feed conversion than the LED bird (1.61±0.02, p = 0.03) broilers. All other treatments did not differ from each other in feed conversion (p>0.05).

Fear response: The latency to emerge during the emergence test was affected by treatments (Table 2). The INCAN (160.68±6.73 sec) and CFL (152.67±7.53 sec) broilers took longer to emerge than and LED bird (128.62±9.15 sec; p = 0.004 and p = 0.03, respectively) broilers. The LED broiler did not differ in latency to emerge (p>0.05) from all other treatments. The number of vocalizations in response to isolation at 10 days of age was affected by treatments (Table 2). The LED bird broilers vocalized less (13.32±2.10 vocalizations/3min) than all the other treatments (INCAN, 27.70±3.72 vocalizations/3min, p = 0.003; CFL, 31.14±3.99 vocalizations/3min, p<0.001; LED, 23.20±3.65 vocalizations/3min, p = 0.04). The latency to right during the tonic immobility test was affected by treatments (Table 2). The INCAN broilers had longer latencies to right (312.3±26.6 sec) than both the LED (225.3±25.9 sec, p = 0.02) and the LED bird (230.5±27.6 sec, p = 0.03) broilers. The CFL broilers were intermediate of all other treatments (242.6±26.9 sec).

Stress response: The composite asymmetry scores were affected by treatments (Table 1). The CFL (2.46±0.18 mm) and INCAN (2.82±0.19 sec) broilers did not differ (p>0.05) from each other; however both differed from the LED (1.68±0.15 mm; p = 0.002 and p<0.001, respectively) and LED bird (1.83±0.15 mm; p = 0.01 and p<0.001, respectively) broilers.

DISCUSSION

The results of this study sought to further our overall understanding of the effects of different light sources that are available for use in the production of broiler chickens. This study looked at a traditional light source the incandescent light bulb, two energy efficient

Table 1: 45 d weight gain (kg) and feed conversion (FCR) and composite asymmetry score (mm)±SE of broilers raised under incandescent (INCAN), compact fluorescent (CFL), light emitting diodes (LED), or LEDs at bird level (LED bird)

Treatment	45 d weight gain	45 d FCR	Asymmetry
INCAN	2.73±0.08[A]	1.71±0.03[A]	2.82±0.19[A]
CFL	2.97±0.06[B]	1.69±0.05[AB]	2.46±0.18[A]
LED	2.95±0.06[B]	1.67±0.01[AB]	1.68±0.15[B]
LED bird	3.02±0.05[B]	1.61±0.02[B]	1.83±0.15[B]

[A, B]Different letter within column significantly different ($p<0.05$)

Table 2: Fear responses of broilers raised under incandescent (INCAN), compact fluorescent (CFL), light emitting diodes (LED), or LEDs at bird level (LED bird). Latency to emerge (s) during emergence test, number of vocalizations during isolation test (vocalizations/3 min) and latency to right during tonic immobility test (s)±SE

Treatment	Latency to emerge	Number of vocalizations	Latency to right
INCAN	160.68±6.73[A]	27.70±3.72[A]	312.32±26.64[A]
CFL	152.67±7.53[A]	31.14±3.95[A]	262.60±27.46[AB]
LED	148.93±7.43[AB]	23.20±3.65[A]	225.27±25.93[B]
LED bird	128.62±9.15[B]	13.31±2.10[B]	230.50±27.62[B]

[A, B]Different letter within column significantly different ($p<0.05$)

alternatives CFL and LED, as well as a novel approach to using LED strip lighting to light birds at bird level instead of from the ceiling. A comparison of spectra between these bulbs can be seen in Fig. 1. Overall the results of this study indicate that INCAN bulbs resulted in reduced growth and feed conversion and increased fear and stress when compared to alternative lighting sources.

The INCAN birds weighed less after 45 d than all other treatments. There was no difference observed in growth or feed conversion between the either LED treatment or the CFL treatment which agrees with Mendes *et al.* (2013). This does not agree with what Huth and Archer (2015) previously observed. Huth and Archer (2015) observed an increase in feed conversion in two different LED bulbs over CFL bulbs. This difference could be explained by the fact that the LED used in this study was not one of the bulbs used in Huth and Archer (2015); furthermore, it was demonstrated in Huth and Archer (2015) that not all LED bulbs produce the same light and that effects birds differently as a consequence. Rogers *et al.* (2015) also observed an increase in growth in broilers raised under LED or CFL when compared to INCAN. Though again this is not always constant observation with LED bulbs as Olanrewaju *et al.* (2015) observed increased weight gain in one type of LED bulb over INCAN bulbs but did not see the same effect in another LED bulb. The LED bird treatment had better feed conversion than the INCAN birds as well and as this was a novel approach to lighting broilers it is an interesting finding. The increased feed conversion could be due to birds being attracted to the feed and water sources to more efficiently eat and also could be related to the decreased fear and stress response observed in these birds as well. The LED bird light is a "cool" LED light so it has more blue/green light in it than incandescent bulbs and Sultana *et al.* (2013) found that blue/green light caused birds to rest more than more yellow/red light. This extra resting could have resulted in the improved feed conversion as well though it needs future research to confirm. Furthermore, birds have been observed to feed more efficiently under blue/green light (Huber-Eicher *et al.*, 2013; Sultana *et al.*, 2013)

The fear responses observed in this study demonstrated that raising birds under LED light can reduce tonic immobility response but does not always reduce fear responses in other fear tests. Similar results were observed in Huth and Archer (2015) in which LED lights only reduced fear response in the tonic immobility test. However, in this experiment the LED bird treatment actually observed less fear response in the tonic immobility, emergence and isolation fear tests. This indicates that lighting birds in this manner may improve their welfare by reducing their fear response across the more types of fear. This is possibly attributed to the wide difference in spectrum between INCAN, CFL (many small peaks) and LEDs (two large gradual peaks) (Morrison, 2013). The LED light likely results in a more natural, or at least favorable, lighting environment and lighting at bird level may reduce fear as only the immediate environment is lit and not the area above the animals. Fear tests look at different areas of the birds natural fear response. As an example, TI tests for a fear response related to being caught by a predator (Ratner, 1967), while the isolation test targets fear related to anxiety of separation from flock members (Forkman *et al.*, 2007).

Physical asymmetry has been well documented (Graham *et al.*, 1993; Moller and Swaddle, 1997) as a measure of stress in poultry. The physical asymmetry measures in this study showed that birds raised under INCAN and CFL were significantly more asymmetrical than the 2 LED treatments. The fact that LED and LED bird treatments grew less asymmetrically indicates that they perceived less stress or handled stressors better than both the INCAN and CFL birds. This agrees with the TI scores discussed previously and with previous research comparing CFL to LEDs (Huth and Archer, 2015); furthermore, increase in physical asymmetry has been related to an increase TI duration (Campo *et al.*, 2008).

Overall it appears that alternatives to incandescent lighting in broiler chickens such as CFL and LED offer advantages in both growth and welfare. All alternatives increased bird growth while LEDs improved bird welfare by decreasing fear and stress. Reduction in fear and stress is becoming more of a public concern and can lead to increased growth and feed efficiency. This was demonstrated by the LED bird treatment which had the least amount of fear and stress susceptibility and also had the best feed conversion. Finding new management methods to improve welfare and production is very important to the poultry industry. While overhead LED lighting did not differ from CFL lighting as previous research had indicated this could be due to variation in LED bulbs available. The novel approach of lighting birds only at their level through production appears to have the benefit of improve production and welfare simultaneously and merits further investigation as an alternative means to grow broiler chickens. The appropriate spectrum of light and feasibility in a commercial broiler house need to be investigated but this technology offers an innovative approach to meet the needs of producers and the desires of the public for improve animal welfare.

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