I. Evaluation of the impact of alternative light technology on male broiler chicken growth, feed conversion, and allometric characteristics[1]

Allison G. Rogers, Elizabeth M. Pritchett, Robert L. Alphin, Erin M. Brannick, and Eric R. Benson[2]

Department of Animal and Food Sciences, University of Delaware, Newark, DE

ABSTRACT This study evaluates the impact of light-emitting diode (LED), cold cathode fluorescent (CCFL), and incandescent lamps on broiler performance. Male Ross 708 broilers (n = 672) were raised to 6 wk age in 8 black-out modified large colony houses, under identical intermittent lighting conditions using 4 unique types of lamps, which were gradually dimmed throughout the study. Incandescent lamps served as the control; experimental technologies tested included CCFL and 2 different LED lamps. Each technology was tested in duplicate for each of 4 trials (8 replications total per technology) conducted across the course of one year to account for seasonal variance. Live performance for each technology was evaluated using live broiler body weight (BW), weight gain, feed conversion, and mortality. Birds were removed from each house at 7, 14, 35, and 42 d to be humanely euthanized, weighed, and necropsied for allometric tissue sample analysis. Relative to the technologies tested, results indicate that birds raised under incandescent lamps had significantly higher BW by 42 d, compared to birds raised under CCFL lamps, which had poorer BW performance ($P = 0.03$). Birds raised under both LED technologies grew to final BWs similar to those raised under incandescent light, with significant differences in neither feed conversion nor mortality.

Key words: broiler, LED, light, growth, performance

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INTRODUCTION

Changes in photoperiod and light intensity have brought about improvements in broiler chicken production; however, limited research is available to evaluate the impact of the type of light source birds are exposed to as they grow. In a study conducted by Mendes et al. (2013), utilizing 12 groups of 30 broiler chickens exposed to light-emitting diode (LED) and compact fluorescent lamps (CFL) in light-controlled pens, results indicated that birds grown under LED lighting generally exhibited improved production performance compared to those grown under CFL lamps during development. By day 40, however, there were significant differences in neither feed intake, live body weight (BW), nor feed conversion in both males and females. raised under either LED or CFL (Mendes et al., 2013). This is an incentive to evaluate the effect of a variety of alternative lighting technologies on broiler growth and performance throughout the birds' development, with a focus on the final live BW and feed conversion ratio obtained by the broilers, as this is of economic concern to broiler producers and growers.

Recently, light technology has been of interest to the agriculture industry given the advancement of alternative, high-efficiency lamps. Standard incandescent lamps, which consist of a heated filament within a bulb, have a short working life, and convert only 5% of the energy they draw into usable light, wasting the remaining energy as heat (Matsumoto and Tomita, 2010). Alternative technologies that have been utilized in the field, including LEDs and fluorescent lamps. LED lamps are compound semiconductor devices that release electrical energy as photons, producing different colors based on the energy state of the photons (Jacob, 2009). Cold cathode fluorescent lamps (CCFLs) apply a high voltage to an electrode, which causes mercury within the bulb to become excited and emit ultraviolet light. The ultraviolet light is then converted to visible light by a phosphor coating on the inside of the bulb (Alberts et al., 2010). Of the various technologies, LED lamps have the advantage of requiring neither preheating nor startup time, and are favored as a more sustainable light source because they do not contain mercury (Rea, 2010). Each of these technologies contrasts sharply with the natural light under which the broilers' ancestors would have lived in that they emit narrow, distinct ranges of the visible light spectrum (Prescott and Wathes, 1999; E.R. Benson, unpublished research). Natural light, on the other hand, displays a very broad,

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[2]Corresponding author: ebenson@udel.edu

uniform distribution of power over the visible light spectrum, as well as into the ultraviolet and infrared range (Prescott and Wathes, 1999). The uneven distribution of wavelength in artificial lighting undoubtedly has an effect on avian behavior and physiology; however, little is known about how chickens perceive and respond to these different light sources.

Domestic chickens have highly sensitive, complex eyes and photoreception systems. Light enters the avian eye and activates the retinal sensory tissue at the back of the eye. The light is absorbed by photopigments, such as rhodopsin and iodopsin, in the retina where it is then converted and transmitted to the optic lobes of the brain as electrical signals by the optic nerve (Lewis and Morris, 2006). Chickens are capable of seeing a wide range of the light spectrum, including ultraviolet light, with the use of several visual receptors including rods, cones, and oil droplets which are thought to enhance vision (Meyer, 1986). These mechanisms allow the birds to have a high spectral sensitivity in comparison to humans. Poultry, like humans, are most sensitive to green light (520 to 580 nm) wavelengths; however, birds are more sensitive to blue light (460 to 500 nm) and yellow-orange-red light (620 to 680 nm) than humans. Increased light sensitivity results in poultry perceiving light from some sources more intensely than humans and may result in behavioral and physiological responses to varied lighting conditions (Meyer, 1986; Saunders et al., 2008).

The objective of this study was to examine the performance effects of LED and CCFL light technologies on commercial broiler chickens as compared to standard incandescent lighting. Live performance parameters were used to quantify differences between each technology.

MATERIALS AND METHODS

Male Ross 708 broiler chickens (n = 672) were obtained and raised from day zero to market age (42 d) in 8 large colony houses, following standard husbandry procedures outlined by the Agricultural Animal Care and Use Committee (AACUC) on the University of Delaware Farm [(33) 04-17-12R]. Each large colony house was blackout modified, and one of the 4 light technologies was installed throughout each house to serve as an experimental treatment, as described below. Birds (n = 84) were placed into each colony house under intermittent lighting programs (2 h light/4 h dark). Conditions in each large colony house differed only by lighting technology during the trial. This procedure was replicated 4 times over the course of one year to account for seasonal variance.

Technologies Implemented

Four lighting technologies were tested in this experiment: one brand of standard incandescent bulb (75 W Sylvania, Danvers, MA), 2 brands of LED lamps referred to as LED A and LED B for this study (LED A-10 W Next Gen, Fayetteville, AR; LED B -12 W ONCE AgriShift PLWB, Plymouth, MN), and one brand of CCFL (8 W Litetronics Microbrite, Alsip, IL). As the current industry standard, the incandescent bulb served as the control technology, while CCFL and LED lamps served as the experimental technologies. Each of the 4 light technologies was placed throughout 2 houses for a total of 8 houses/trial. Between seasonal trials, the light technologies were rotated through the large colony houses prior to the start of a new trial to account for house effects.

Light Intensity and Duration

The lamps were integrated with electronic controller (Chore-Time, Model 8, Milford, IN) and dimmer (Precision Lighting System 7200 MR3, Hot Springs, AR) systems to control the photoperiod, light intensity, and temperature in each house. An intermittent lighting program was used to allow the birds to fully feed during the light period, and for the birds' crops to empty completely during the dark period (Barott and Pringle, 1951). The lighting program was standardized across houses, with a program of 24 h light to 0 h dark (24L:0D) for the first 2 days, changing to 23L:1D at day 3. At day 7, bird acclimation to an intermittent lighting schedule began with a change to a cycling of 5.45 h light and 15 min dark. Between days 7 and 22, photoperiod was reduced by 15 min each day until a schedule of 2L:4D was achieved; this setting was then maintained to completion of the trial. Luminance in each house began at 43 lux (LX), equivalent to 4 foot candles (FCs), and was reduced to 11.1 LX (1 FC) at day 7. Luminance was further reduced to 8.9 LX (0.8 FC) at day 15, and was gradually lowered to 6.7 LX (0.6 FC) at day 16, 4.4 LX (0.4 FC) at day 17, and 2.2 LX (0.2 FC) at day 20. A final luminance of 1.1 LX (0.1 FC) was maintained from days 21 to 42. The luminance was adjusted and measured using a light meter (Sper Scientific, Model 840020, Scottsdale, AZ). Air temperature, relative humidity, and illumination were monitored at 15 min intervals using Hobo U12 data loggers (Onset Computer Corporation, Bourne, MA). This data was downloaded weekly and exported to Excel to track house conditions.

Broiler Care and Feed Monitoring

The broilers were raised in 2.29 × 3.35 m (7.5 × 11 ft) pens within each large colony house to reach the industry standard stocking density of 0.07 m^2/broiler (0.75 ft^2/broiler) at 42 days. and feed and water were provided ad libitum. Birds were fed commercial broiler starter feed [Crude protein (CP), 22%; crude fat, 3.5%] for days 1 to 21, and then commercial broiler finisher feed (CP, 18%; crude fat, 4%) for days 22 to 42

(Southern States Cooperative, Richmond, VA). Mortality was recorded daily, as was the weight of each deceased bird, to increase the accuracy of the feed conversion ratios. Feed consumption was measured (in kilograms) using a hanging scale (Rubbermaid Pelouze 7750, Winchester, VA) to weigh both the feed remaining each day and the amount of new feed added.

Randomly selected broilers (n = 6) were weighed each week to monitor growth and obtain representative weights to estimate weekly feed conversion. The remaining 480 birds were kept throughout the trial to collect additional live performance data. Cumulative feed conversion (CFC) from each house was calculated using Equation (1)

$$CFC = \frac{total\, feed\, wt.}{(total\, wt.\, birds\, remaining + mortality\, wt. + necropsy\, wt. - initial\, wt.\, of\, placed\, chicks)} \tag{1}$$

Live Performance and Allometric Characteristics

Randomly selected birds (n = 6) were removed and humanely euthanized by cervical dislocation from each house at days 7, 14, 35, and 42, to evaluate live performance and allometric growth characteristics. Live performance was measured by recording the live weight of the birds. The weight of the entire left breast muscle (pectoralis major and minor), heart, liver, and duodenal loop, along with the length of the duodenal loop were collected to compare allometric growth.

Statistical Analysis

Tests conducted include ANOVA, Fit Model, and Student's t-test using the statistical software JMP Pro (Version 10.0, Cary, NC). All statistical analysis was conducted at the 5% significance level ($\alpha = 0.05$).

RESULTS

Effect of Light Technology on Undressed Market-Age Weight

BW mean values for the experimental technologies were compared to the control mean under incandescent lamps (Figure 1). Day 42 BW did not differ significantly between incandescent, LED A, and LED B. However, BW under CCFL lamps were significantly lower than body weights under incandescent ($P = 0.03$).

Effect of Light Technology on Average Weekly BW Gain

Average weekly BW gain was calculated for each technology for 3 trials and averaged to observe growth trends. No significant difference was observed among technologies at each week (Figure 2).

Effect of Light Technology on CFC Ratio

No significant difference was detected in CFC across light technologies (Figure 3). LED B showed a lower CFC, and CCFL showed a higher average CFC. However, the difference between CCFL and incandescent is insignificant ($P = 0.3$), as is the difference between LED A and incandescent ($P = 0.18$). Likewise, there was no significant difference between LED B and CCFL ($P = 0.24$) or between LED technologies ($P = 0.14$).

Impact of Season on Market Age BW and CFC Ratio

Due to differences in BW performance observed during each trial, a statistical analysis of mean market age (42 d). BW and CFC ratios was performed by trial (season) and technology (Table 1). Mean broiler BW under CCFL were significantly lower during trial 2 (fall) than under all other trials ($P \leq 0.0002$). Mean BW under LED A were significantly lower as well during Trial 2 (fall) as compared with trial 3 (spring) ($P = 0.04$). No other significant differences were detected in feed conversion ratios among the remaining trials under all technologies.

Effect of Light Technology on Whole Breast Muscle Weight

No significant difference was observed between light technologies with respect to whole breast muscle weight; however, it was noted that the breast muscle weights proportionately paralleled mean BW. Breasts from birds raised under incandescent lamps were the heaviest on average, and those from CCFL-raised birds were the lightest.

Effect of Light Technology on Broiler Mortality

No significant difference in mortality was found across technologies (Figure 4). Mortality was calculated by flock by dividing the number of dead and culled broilers by the total number of birds raised under the technology in both houses, and converted to a percentage for ease of comparison. No difference in mortality was observed between CCFL and incandescent

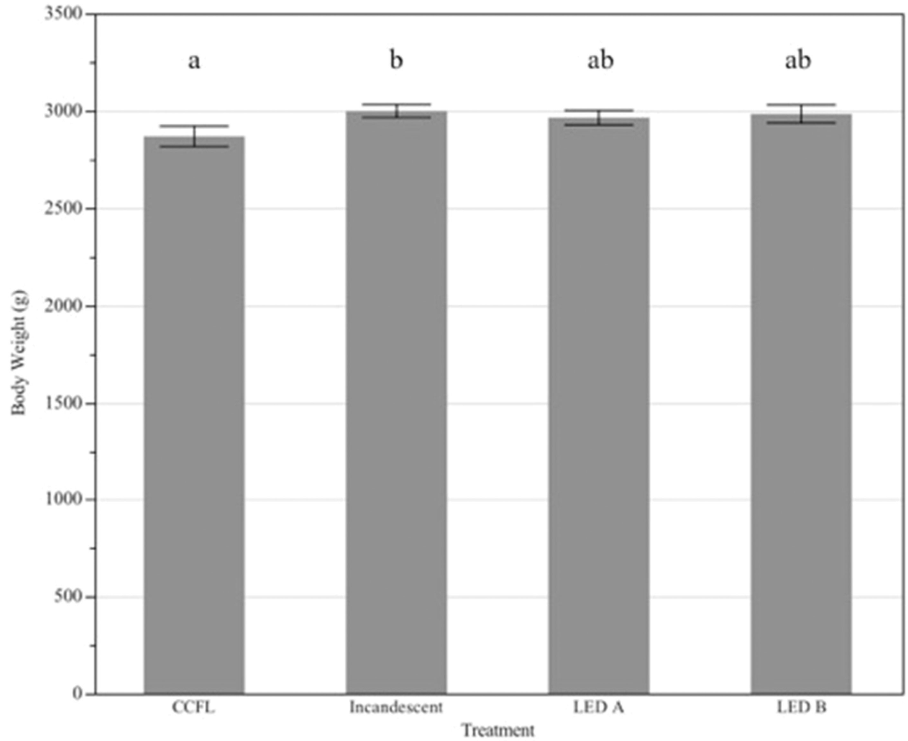

Figure 1. Mean BW in grams of adult male Ross 708 broilers, 42-days-old, arranged by lighting technology. Error bars represent SEM (CCFL, n = 49; incandescent, n = 48; LED A, n = 47; and LED B, n = 48). Letters denote statistical significance between treatments.

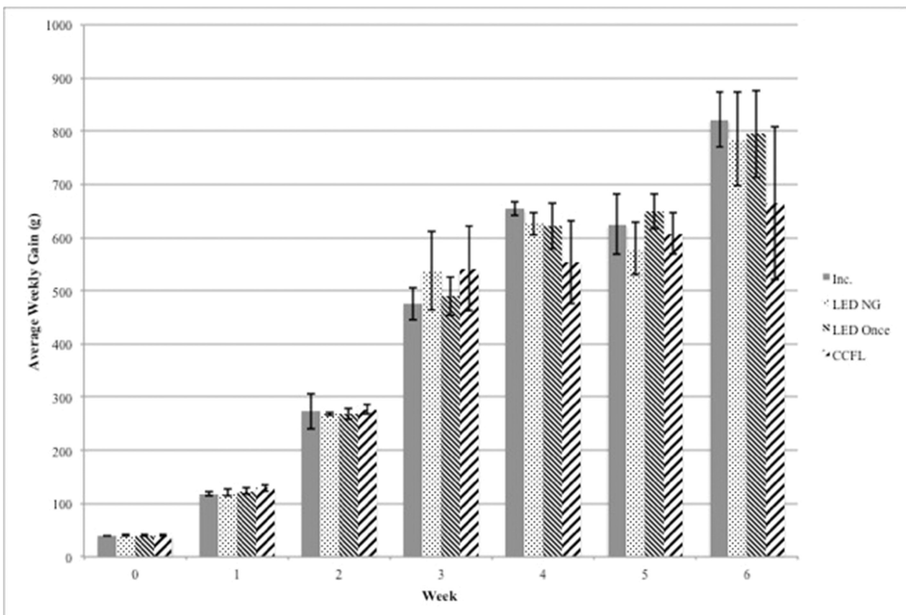

Figure 2. Average weekly BW gain in grams of male Ross 708 broilers under each technology arranged by trail. Error bars represent SEM (CCFL, n = 49; incandescent, n = 48; LED A, n = 47; and LED B, n = 48).

lamps ($P = 0.50$). The greatest disparity in technology, although still not significant, is between CCFL and LED B ($P = 0.33$) with birds raised under CCFL experiencing less mortality on average than those raised under LED B.

Additional Allometric Analysis

Additional allometric analysis was conducted on tissues collected from the euthanized broilers in this study for further insight into organ development. No

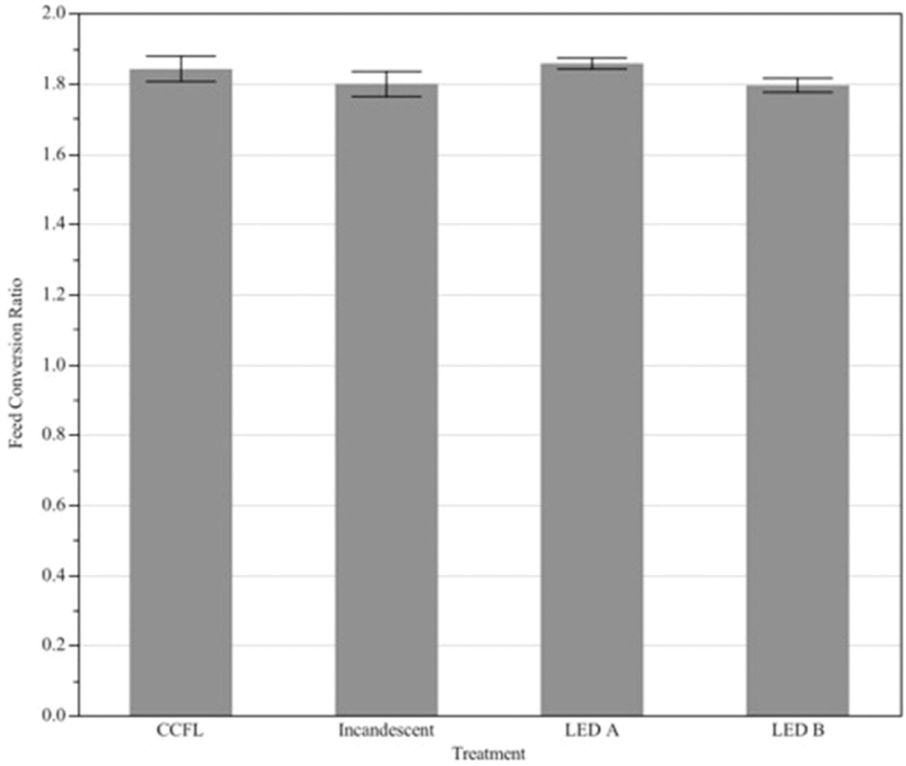

Figure 3. Mean CFC ratio of adult male Ross 708 broilers (kilograms feed per kilograms birds). Error bars represent SEM (CCFL, n = 8, incandescent, n = 7; LED A, n = 7; and LED B, n = 8).

significant differences were witnessed in the duodenal length, or mass of the birds' hearts, livers, and duodenums under any technology tested. Organ characteristics were additionally normalized to individual bird BW and were not found to be significantly different between treatments.

Table 1. Mean BW and CFC ratio of male Ross 708 broiler chickens, 42-days-old, for the light treatments incandescent, LED A, LED B, and CCFL during trials 1 to 4. Data presented as mean ± SEM. Trial 1, summer; trial 2, fall; trial 3, winter; and trial 4, spring.

Treatment	Trial	Mean BW (g)	Feed conversion ratio (kg)
Incandescent	1	3,031 ± 64[1]	1.75 ± 0.0
	2	2,915 ± 93[1]	1.81 ± 0.09
	3	3,097 ± 51[1]	1.87 ± 0.05
	4	2,958 ± 41[1]	1.75 ± 0.09
	Mean	3,000 ± 33	1.80 ± 0.04
LED A	1	3,007 ± 68[1, 2]	1.90 ± 0.0
	2	2,877 ± 62[1, 2]	1.81 ± 0.004
	3	3,091 ± 69[2]	1.87 ± 0.03
	4	2,901 ± 85[1, 2]	1.88 ± 0.004
	Mean	2,966 ± 37	1.86 ± 0.02
LED B	1	2,986 ± 64[1]	1.82 ± 0.04
	2	2,953 ± 92[1]	1.77 ± 0.006
	3	3,062 ± 73[1]	1.82 ± 0.002
	4	2,941 ± 134[1]	1.78 ± 0.09
	Mean	2,986 ± 46	1.80 ± 0.02
CCFL	1	3,038 ± 76[1]	1.83 ± 0.004
	2	2,487 ± 58[2]	1.89 ± 0.08
	3	2,971 ± 123[1]	1.89 ± 0.02
	4	2,979 ± 64[1]	1.76 ± 0.14
	Mean	2,871 ± 53	1.84 ± 0.04

[1, 2]Means within the same column without a common superscript differ ($P < 0.05$).

Analysis of Environmental Variables

A summary of fit was conducted at $\alpha = 0.05$ and $\alpha = 0.1$ to determine the impact of each trial (season), house, and experimental technology on the market age weight of the birds using JMP Pro 10. An R^2 value of 0.18 was obtained, indicating that the majority of the variability seen in our data is due to random error, which can most likely be tied back to individual differences between each bird; in conducting an effect test, trial number (or season) was found to be significant at $\alpha = 0.05$ ($P > 0.0001$), and experimental technology was found to be significant at the $\alpha = 0.1$ level ($P > 0.09$). Effect of house was insignificant at both $\alpha = 0.05$ and $\alpha = 0.1$.

DISCUSSION

The objective of this study was to examine the effect of incandescent, LED, and CCFL technologies on broiler performance. Converse to the hypothesis that no differences would be observed in performance across technologies (incandescent, LED A, LED B, and CCFL), lighting technology significantly impacted the 42 day BW of the broilers in this study, with CCFL lamps resulting in lower average BW. CCFL lamps, however, resulted in significantly lower BW on

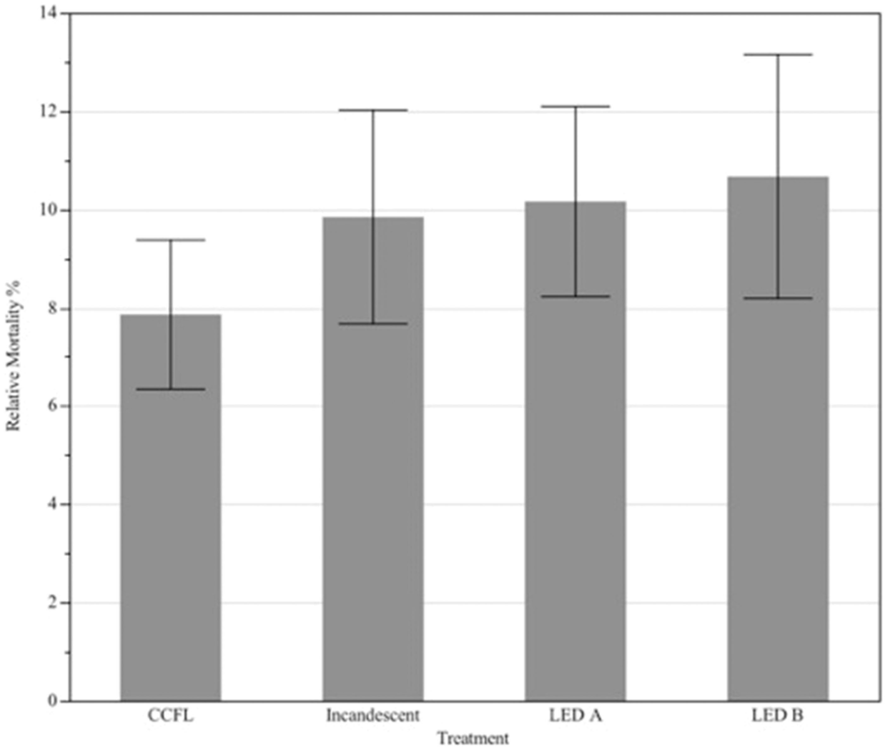

Figure 4. Mean experimental percentage of mortality of male Ross 708 broilers by technology. Error bars represent SEM (CCFL, n = 8; Incandescent, n = 7; LED A, n = 7; and LED B, n = 8).

average than the control, with a difference of about 130 g observed on average between incandescent and CCFL lamps. On the other hand, the 2 LED technologies performed similarly to the control incandescent lamps, which could support implementation of LED lighting in broiler houses in the future.

As compared to male Ross 708 performance standards normalized for live BW, deboned breast muscle weights obtained during this study were found to be lower on average (Aviagen, 2012). This disparity between the Ross standards and the average weights from the experimental subjects is likely due to human inaccuracy (during removal of the pectoralis major and minor from the keel bone), as trained volunteers rather than professional production workers collected specimens. More importantly, however, the mass of the breast muscle under each technology correlated with the mass of the birds in this study at market age. Thus, birds raised under CCFL lamps had lower breast muscle weights on average than birds raised under the control or either of the 2 LED technologies.

In this study, it was determined that season had a significant impact on performance, but house placement did not. A seasonal difference in performance of broilers throughout the year is well-supported both in the literature and anecdotally (Sinclair et al., 1990). In this study, it was not possible to control for all variables, such as potential differences in breeder flocks. Thus, variance in BW might have been due to breeder flock differences between trials; however, these differences were likely amplified by the technology under which the birds were raised during each trial.

It is unclear at this time what lamp attributes could be causing the differences in BW, and to a lesser degree in breast weight, between the CCFL lamps and the control incandescent lamps. One possibility is that the differences in the light output spectrum for CCFL versus the incandescent and LED lamps used in this study may affect the broilers' growth, even after light intensity is decreased with age, as is the normal for broiler management. For instance, Prayitno et al. (1997) found that broilers raised under red light early in growth showed increased BW compared with those raised under blue light during the same time period, suggesting that the wavelength of light plays a critical role in growth. In contrast, studies carried out by Rozenboim et al. (2004) and Cao et al. (2012) indicated that a significantly higher final BW in broilers was achieved with monochromatic green LED light early in growth followed by a switch to monochromatic blue light, as opposed to a conventional white light program. An additional study conducted by Baxter et al. (2014) found that Smoky Joe Leghorn laying hens raised under monochromatic green LED lighting, as compared to monochromatic red or white LED lighting, showed increased growth from 23 to 52 wk age. A significant difference between Baxter et al. (2014) and this study is that the other study worked with laying hens, and these birds experienced different physiological stressors including egg production, leading the authors to conclude that this increase in BW may have been due to a correlating decrease in egg production. Further studies utilizing a spectrophotometer to characterize the spectral power distribution of different lighting technologies used in this study are underway. Additional research on the effect of light wavelength on broiler growth, health, genetics, and behavior is needed to further understand poultry's interaction with their environmental light source. The impact of lighting technology on bird stress was considered in a parallel investigation to production parameters, and is provided in part 2 of this study.

This study provides evidence that not all lamp technologies may be suitable for implementation in commercial broiler chicken houses. Although there was little difference observed in production parameters between the 2 LED technologies and standard incandescent lamps, the CCFL lamp used in this study may have contributed to lower final BW2 in the birds raised under this technology. Thus, LED technology may be installed as a high-efficiency alternative to incandescent lighting, whereas CCFL may not, when considering cost savings in energy consumption for broiler growers while maintaining bird profit.

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REFERENCES

Alberts, I. L., D. S. Barratt, and A. K. Ray. 2010. Hollow cathode effect in cold cathode fluorescent lamps: A review. J. Display Technol. 6:52–59.

Aviagen. 2012. Ross 708 Broiler Performance Objectives. Aviagen Group, Huntsville, AL. 2–22.

Barott, H. G., and E. M. Pringle. 1951. Effect of environment on growth and feed and water consumption of chickens: IV. The effect of light on early growth. J. Nutr. 45:265–274.

Baxter, M., N. Joseph, V. R. Osborne, and G. Y. Bédécarrats. 2014. Red light is necessary to activate the reproductive axis in chickens independently of the retina of the eye. Poult. Sci. 93:1289–1297.

Cao, J., Z. Wang, Y. Dong, Z. Zhang, J. Li, F. Li, and Y. Chen. 2012. Effect of combinations of monochromatic lights on growth and productive performance of broilers. Poult. Sci. 91: 3013–3018.

Jacob, B. 2009. Lamps for improving the energy efficiency of domestic lighting. Light. Res. Technol. 41:219–228.

Lewis, P., and T. Morris. 2006. Poultry Lighting: The Theory and Practice. Northcote House Publishers, Andover, Hampshire, U.K.

Matsumoto, T., and M. Tomita. 2010. Modified blackbody radiation spectrum of a selective emitter with application to incandescent source design. Opt. Express 18:192–200.

Mendes, A. S., S. J. Paixao, R. Restellato, G. M. Morello, D. J. de Moura, and J. C. Possenti. 2013. Performance and preference of broiler chickens exposed to different lighting sources. J. Appl. Poult. Res. 22:62–70.

Meyer, D. B. 1986. The Avian Eye and Vision. Pages 40–44 in Avian Physiology. 4th ed. P. D. Sturkie, ed. Springer–Verlag, New York, NY.

Prayitno, D., C. Phillips, and D. Stokes. 1997. The effects of color and intensity of light on behavior and leg disorders in broiler chickens. Poult Sci. 76:1674–1681.

Prescott, N. B., and C. M. Wathes. 1999. Reflective properties of domestic fowl (*Gallus g. domesticus*), the fabric of their housing and the characteristics of the light environment in environmentally controlled poultry houses. Br. J. Poult. Sci. 40: 185–193.

Rea, M. S. 2010. Opinion: The future of LED lighting: Greater benefit or just lower cost. Light. Res. Technol. 42:370.

Rozenboim, I., I. Biran, Y. Chaiseha, S. Yahav, A. Rosenstrauch, D. Sklan, and O. Halevy. 2004. The effect of a green and blue monochromatic light combination on broiler growth and development. Poult. Sci. 83:842–845.

Saunders, J., J. Jarvis, and C. Wathes. 2008. Calculating luminous flux and lighting levels for domesticated mammals and birds. Animal 2:921–32.

Sinclair, R. W., F. E. Robinson, and R. T. Hardin. 1990. The effects of parent age and posthatch treatment on broiler performance. Poult Sci. 69:526–534.