

**EVALUATION OF ALTERNATIVE LIGHTING TECHNOLOGIES ON  
BROILER PERFORMANCE AND STRESS**

by

Allison Grace Rogers

A thesis submitted to the Faculty of the University of Delaware in partial fulfillment of the requirements for the degree of Master of Science in Animal Science

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## TABLE OF CONTENTS

LIST OF TABLES .....	vi
LIST OF FIGURES .....	vii
ABSTRACT.....	ix
Chapter	
1 INTRODUCTION .....	1
2 MATERIALS AND METHODS.....	10
Technologies Implemented.....	10
Light Intensity and Duration.....	12
Broiler Care and Feed Monitoring.....	14
Live Performance and Allometric Characteristics.....	15
Heterophil-to-Lymphocyte Ratios .....	15
Statistical Analysis.....	17
3 RESULTS .....	18
Effect of Light Technology on Undressed Market Weight .....	18
Effect of Light Technology on Cumulative Feed Conversion.....	20
Impact of Season on Market Age Body Weight and Feed Conversion Ratio .....	22
Effect of Light Technology on Whole Breast Muscle Weight .....	24
Effect of Light Technology on Broiler Mortality .....	26
Effect of Light Technology on Heterophil:Lymphocyte Ratio.....	28
Additional Allometric Analysis .....	36
Environmental Data .....	37
4 DISCUSSION.....	42
5 CONCLUSIONS .....	55
REFERENCES .....	58

Appendix

A	LUMINOUS EMISSION OF ONCE AGRISHIFT PL LED LAMP .....	63
B	AACUC APPROVAL LETTER .....	65

## LIST OF TABLES

Table 1	Rotation of light technology by trial in large colony houses .....	11
Table 2	Luminance and photoperiod applied during experiment to all houses by trial day .....	13
Table 3	Mean body weight and cumulative feed conversion ratio of male Ross 708 broiler chickens at 42 days of age for the treatments incandescent (Inc.), LED A, LED B, and CCFL during trials 1-4. Data presented as mean $\pm$ standard error of the mean ( $X \pm S.E.M.$ ) .....	23
Table 4	Mean heterophil to lymphocyte ratio of male Ross 708 broiler chickens from all trials for the treatments incandescent (Inc.), LED A, LED B, and CCFL at 7, 14, 35, and 42 days of age. Data presented as mean $\pm$ standard error of the mean ( $X \pm S.E.M.$ ) .....	31
Table 5	Mean heterophil to lymphocyte ratio of male Ross 708 broiler chickens for the experimental trials 1-4 at 7, 14, 35, and 42 days of age. Data presented as mean $\pm$ standard error of the mean ( $X \pm S.E.M.$ ).....	33
Table 6	Mean weight of heart, duodenum and liver, and mean length of duodenum, of male Ross 708 broiler chickens at 42 days of age. Data presented as mean $\pm$ standard error of the mean ( $X \pm S.E.M.$ ).....	37

## LIST OF FIGURES

Figure 1	Representative arrangement of light technologies in eight large colony houses (Trial 1: Summer).....	12
Figure 2	Representative example of a heterophil (A) and lymphocyte (B) stained using the Wright-Giemsa staining method. ....	16
Figure 3	Mean body weight in grams of adult male Ross 708 broilers at 42 days of age arranged by lighting technology. Error bars represent standard error of the mean (S.E.M.) (CCFL: n=49, Incandescent: n=48, LED A: n=47, LED B: n=48). Letters denote statistical significance between treatments ( $\alpha=0.05$ ). ....	19
Figure 4	Mean cumulative feed conversion of adult male Ross 708 broilers (kg feed/kg birds). Error bars represent S.E.M. (CCFL: n=8, Incandescent: n=7, LED A: n=7, LED B: n=8). ....	21
Figure 5	Mean adult male Ross 708 broiler breast muscle weight at 42 days of age in grams. Error bars represent S.E.M. (CCFL: n=49, Incandescent: n=48, LED A: n=46, LED B: n=48). ....	25
Figure 6	Mean experimental percentage of mortality of male Ross 708 broilers by technology. Error bars represent S.E.M. (CCFL: n=8, Incandescent: n=7, LED A: n=7, LED B: n=8). ....	27
Figure 7	Mean avian heterophil to lymphocyte ratio of all male Ross 708 broiler chickens for all trials and treatments by age (7, 14, 35, and 42 days). (Day 7: n=137, Day 14: n=187, Day 35: n=188, Day 42: n=187). Error bars represent S.E.M. Letters denote statistical significance between ages (days) ( $\alpha=0.05$ ). ....	29
Figure 8	Mean avian heterophil to lymphocyte ratio of all male Ross 708 broiler chickens for all trials arranged by technology at 7, 14, 35, and 42 days of age. (Incandescent: n=48, LED A: n=45, LED B: n=44, CCFL: n=45). Error bars represent S.E.M.....	30

Figure 9	Mean avian heterophil to lymphocyte ratio of male Ross 708 broiler chickens by trial at 7, 14, 35, and 42 days of age. (Trial 1: n=136, Trial 2: n=190, Trial 3: n=186, Trial 4: 187). Error bars represent S.E.M. ....	32
Figure 10	Mean avian heterophil to lymphocyte ratio of male Ross 708 broiler chickens by condition at 42 days of age (experimental), and 45 and 47 days of age (stress) (CCFL: n=45, Incandescent: n=48, LED A: n=45, LED B: n=44, Stress: n=22). Error bars represent S.E.M. Letters denote statistical significance between treatments ( $\alpha=0.05$ ). ....	35
Figure 11	Trial 1 (Summer) mean daily environmental temperature arranged by technology in large colony houses 1-8.....	38
Figure 12	Trial 2 (Fall) mean daily environmental temperature arranged by technology in large colony houses 1-8.....	39
Figure 13	Trial 3 (Winter) mean daily environmental temperature arranged by technology in large colony houses 1-8.....	40
Figure 14	Trial 4 (Spring) mean daily environmental temperature arranged by technology in large colony houses 1-8.....	41
Figure 15	Spectral emission of Once AgriShift PLW at full luminance (Once Innovations Inc., 2010, 1-6).....	63
Figure 16	Spectral emission of Once AgriShift PLW at 40% luminance (Once Innovations Inc., 2010, 1-6).....	64

## **ABSTRACT**

Broiler production and management has become highly specialized over the years to optimize bird performance. Recent research has focused on the effect of light on bird growth and health, specifically regarding the intensity, duration, and wavelength of light provided to the birds. This project evaluated the impact of light emitting diode (LED), cold cathode fluorescent (CCFL), and incandescent lamps on broiler performance and welfare. Six hundred and seventy-two (672) male Ross 708 broilers were raised to six weeks of age in 8 light-tight modified large colony houses under identical intermittent lighting conditions using 4 unique types of lamps. Incandescent lamps served as the control; experimental technologies tested were a CCFL bulb produced by Precision Lighting Systems, an LED produced by Once Innovations, Inc., and an LED produced by Next Gen Lights. Each technology was tested in duplicate for each of the 4 trials (8 replications total per technology) conducted across the course of a single year to account for seasonal variance. Live performance for each technology was evaluated using live broiler body weight, feed conversion, and mortality. Birds were removed from each house at days 7, 14, 35, and 42 to be humanely euthanized, weighed, and harvested for allometric tissue sample analysis. Blood collection via cardiac puncture was performed to obtain heterophil:lymphocyte (H:L) ratios for evaluation of environmental stress. Relative to the technologies tested, results indicate that incandescent and LED lamps

result in heavier birds with lower feed conversion ratios, while CCFL lamps yield poorer body weight performance and higher feed conversion ratios. An evaluation of heterophil to lymphocyte ratios shows strong correlations between age, seasonality, and technology.

## **Chapter 1**

### **INTRODUCTION**

Improving broiler chicken performance through artificial lighting has been extensively studied over the past fifty years as producers have sought to increase broilers' muscle gain, while maintaining an efficient feed conversion ratio and bird health. Changes in photoperiod and light intensity have brought about improvements in each of these areas; however, limited research is available evaluating the impact of the type of light source that the birds are exposed to as they grow. As the United States has begun to shift towards use of energy-efficient light lamps within homes and offices, as well as in industrial and agricultural settings, interest has grown in investigating the effect of these technologies on our agricultural products (EISA, 2007, 82-105). This study was designed to determine the impact that high-efficiency lamps may have on broiler chickens' productivity and stress if a similar transition occurs in the poultry production industry.

Light technology has been of interest to the agriculture industry recently with the advancement of alternative, high efficiency light 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, 192-200). Several companies are now producing high-efficiency “Ag-specific” lamps, which can be further specified for application with swine, cattle, and poultry, in the hopes that farmers will replace their low-efficiency incandescent lamps to minimize energy costs. Alternative technologies used in the field include LED 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, 225). Cold cathode fluorescent lamps (CCFL) apply a high voltage to an electrode, which causes mercury within the bulb to become excited and emit UV light. The UV light is then converted to visible light by phosphor coated on the inside of the bulb (Alberts et al., 2010, 52). Producers of LED lamps, such as Greengage Lighting Ltd. (2011, 1-30), state that in addition to an energy reduction of up to 90%, growers may expect to see a more stable environmental temperature, with no discernable flickering. LED lamps have the advantage of not requiring pre-heating or start up time, and are favored as a more sustainable light source because they do not contain mercury (Bedecarrats, 2011, 1-6; Rea, 2010, 370). In contrast, CCFL lamps require a start-up time, taking up to five minutes to reach full luminance, and require the use of mercury for light emission (Alberts et al., 2010, 52).

Preliminary research conducted by Benson et al. (2013, 103-111) placed non-agriculture specific incandescent, light-emitting diode (LED), and cold cathode fluorescent (CCFL) lamps in three large-scale broiler production houses in southern

Delaware. Data on lamp energy efficiency, lamp performance, and broiler performance were collected for each lamp type through 3 flocks. Results of the study indicated that broilers raised under incandescent lamps had the highest body weight at market age (53 days) despite energy inefficiency and high operating expense for incandescent lighting. Both the CCFL and LED light lamps proved to have high efficiency with a low operating cost, resulting in an 88% energy savings for CCFL and 95% savings for LED; however, both technologies resulted in lighter birds and economic loss to the grower (4% for CCFL and 7% for LED cumulative across 3 flocks) (Benson et al., 2013, 103-111).

A study conducted by Watkins installed three different LED lamps in commercial broiler houses and calculated an 80% energy savings compared to standard incandescent lamps with no compromise in bird performance (Sullivan and Watkins, 2011, 1-2). This same study installed 8 watt CCFL lamps resulting in a 66% energy savings; however, it also found that the CCFL showed both a short life span compared to LED lamps and a loss of light output due to lamp lumen depreciation and dust accumulation. Though CCFL technology can have a lifespan of 25,000 hours, it typically experiences degradation of light output due to lamp phosphor degradation (Kahl, 1998, 1-5). There has been additional concern associated with the frequency with which fluorescent lamps emit light. The domestic chicken has been shown to be visually sensitive to a frequency around 105 Hz, almost twice the sensitivity of humans, who are sensitive up to 60 Hz (Widowski, 2010, 295-296). With most

fluorescent lamps flickering at twice line frequency, or 120 Hz, humans are able to see the light emitted as continuous, whereas there is concern that the heightened sensitivity of the chicken may cause them to perceive the emitted light as flickering, especially as the lights are dimmed during grow-out (Nuboer et al., 1992, 123-133).

Domestic chickens have highly sensitive, complex eyes and photoreception systems that may be differentially impacted by light technologies installed in houses. Light enters the avian eye and hits the sensory retinal tissue at the back of the eye. The light is absorbed by photopigments, such as rhodopsin and iodopsin, in the retinal tissue 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, 7-9). Chickens are capable of seeing a wide range of the light spectrum, including into the ultraviolet range, with the use of several visual receptors including rods, cones, and oil droplets thought to enhance vision (Meyer, D.B., 1986, 40-44). These mechanisms allow the birds to have a high spectral sensitivity in comparison to humans, with peaks that occur between 400-480 nm (blue-green light), 560-570 nm (yellow), and 580-650 nm (orange-red) (Lewis and Morris, 2006, 2). This increased sensitivity results in poultry perceiving light from some sources more intensely than humans and can result in behavioral and physiological responses in the birds (Meyer, D.B., 1986, 40-44; Saunders et al., 2008, 921-932).

Retinal tissue also plays a role in the regulation of melatonin production in the pineal gland, a small endocrine gland located at the surface of the brain in a triangular

region centered between the cerebral hemispheres and the cerebellum. This gland is crucial both as a regulator of circadian rhythm and photoreception that is closely tied to sensory information relayed by the retina and hypothalamus through a signal path referred to as the retinohypothalamic tract which is the major drive for behavioral and physiological response to light (Brandstatter et al., 2000, 12324-12328; Gwinner and Hau, 2000, 557-565). The pineal gland is the main source of melatonin production; melatonin is a “dark-regulated” hormone that is rhythmically produced by a lack of light being received by the pineal gland or retinal tissue (Kumar, 2002, 93-112). In the chicken, the pineal gland is dependent either on light intensity strong enough to penetrate the skull and cranial tissues, or on negative feedback from retinal tissue, to inhibit melatonin production (Meyer, D.C., 1986, 501-504). In low light conditions, the retinal tissue can still respond by releasing dopamine, which suppresses the production of serotonin-N-acetyltransferase, an enzyme necessary for melatonin production (Lewis and Morris, 2006, 9). This allows the bird to suppress melatonin production even in very low light levels (less than 4 lux) when it is not possible for light to penetrate the avian skull to stimulate the pineal gland directly. The pineal gland is directly stimulated primarily by longer wavelengths of light (red, orange), which make up a large proportion of full-spectrum white light and which are able to penetrate the skull more easily (Prayitno et al., 1997, 452-457). Studies conducted by Brandstatter et al. (2000, 12324-12328) on house sparrows indicate that the pineal gland may also be capable of storing and retaining information on the length of the

photoperiod, which could allow birds to anticipate day length, consequently affecting feeding, preening, and other natural behaviors.

A variety of lighting schedules are currently implemented in the broiler industry to optimize bird growth and health by augmenting activity through the retinohypothalamic tract. A commonly used program is an intermittent lighting schedule in which the birds are exposed to 1-2 hours of light, followed by 3-4 hours of darkness. The reasoning behind this scheduling is that long periods of darkness will enhance growth more than continuous (23 hours) light (Rozenboim et al., 1999, 452-457). Barott and Pringle (1951, 265-274) found that heavier body weights were obtained by one hour of light followed by 3-4 hours of dark and it was concluded that the light period should be sufficiently long enough to allow the chickens to fully feed, and the dark period should be long enough for the birds' crops to completely empty prior to the next photoperiod. Improvements in immune function and skeletal health have also been observed under intermittent lighting programs due to the reduction of bird activity (Lewis and Morris, 2006, 146). Abbas et al. (2008, 665-671) found that an intermittent lighting regimen of 2 hours of light and 2 hours of (2L:2D) dark induced activation of both peripheral B and T lymphocyte proliferation and energized antibody production in broilers when compared with broilers raised under continuous and non-intermittent restricted light (12L:12D). Furthermore, intermittent lighting was found to result in improved feed conversion, smaller abdominal fat pads, and increased

nitrogen retention in broilers during growth when compared with a constant (23L:1D) lighting schedule (Buyse et al., 1996, 589-594).

Thus, adverse lighting conditions within a production facility could potentially impact the activity and physiological stress response of the broilers being raised in the facility (Campo et al., 2007, 37-45). Stress response in poultry may be measured by a variety of methods depending on the degree and duration of the stress being applied. Two such methods include testing of blood samples for relative levels of plasma corticosterone, a short-lived adrenal hormone associated with a “fight or flight” response in the bird, and comparing ratios of white blood cells, specifically heterophils to lymphocytes (H:L), in the blood. Corticosterone levels have been shown to dramatically increase as a direct response to acute (i.e. seconds to minutes of exposure) stress with levels returning to pre-stress ranges shortly after the stressor has been removed. Corticosterone has also been shown to return to, and to remain at, low concentrations if the birds are repeatedly aggravated (Muller et al., 2011, 566-576). In contrast, leukocyte response is slow, taking hours to days to respond to an applied stressor and is, thus, a better indicator of chronic stress (Carlson et al., 1969, 817-833; McFarlane et al., 1989, 522-527; Muller et al., 2001, 566-576; Vleck, 2002, 401-411). A ratio of peripheral blood circulating heterophils to circulating lymphocytes has been shown to be a method of chronic stress evaluation (Gross and Siegel, 1983, 972-979). Heterophils, equivalent to the mammalian neutrophil, are the most abundant granulated leukocyte in avian species, and are associated with the inflammatory

response in gallinaceous birds. Lymphocytes are the primary circulating non-granulated leukocyte and are typically involved in cellular immunity and viral infection (Harmon, 1998, 972-977; Vleck, 2002, 401-411). In the event of a stress response, circulating heterophils increase and circulating lymphocytes decrease (Davis et al., 2008, 762; Gross and Siegel, 1983, 972). Lymphocyte numbers decrease due to recruitment from the bloodstream into body tissues such as the spleen, lymph nodes, and skin to prepare for potential pathogen exposure, while heterophils are stimulated to migrate from the bone marrow to the circulatory system thereby elevating the H:L ratio (Bishop et al., 1968, 249-260; Davis et al., 2008, 763; Dhabar, 2002, 556-564; Fauci, 1975, 669-680).

The time needed to stimulate migration of peripheral blood leukocytes necessitates that the H:L ratio be a measure of chronic, rather than acute, stress. Davis et al. (2008, 760-772) found that H:L ratios did not increase significantly within 1 hour of capture in house finches. McFarlane et al. (1989, 522-527) conducted a study measuring the leukocyte (H:L) ratio and adrenal hormone responses in chickens that were chronically stressed, and found that in chronic stress scenarios, changes in leukocyte numbers in response to environmental stress were more reliable and enduring as an indicator of stress than the corticosterone response. Gross and Siegel (1983, 972-979) similarly concluded that a rise in the H:L ratio is a reliable measure of long-term physiological change and chronic sub-optimal conditions. A challenge associated with employing the leukocyte profile as a stress response is determining if

changes are associated with the applied stressor, or due to concurrent inflammation or disease in the birds. This distinction proves difficult due to the leukocytes' primary duty as a first line of immune defense in vertebrate systems, with the effect of disease on the leukocyte profile closely mimicking that of stress (Branton et al., 1997, 540-547; Davis et al., 2008, 760-772).

Given the substantial effects that lighting can have on broiler chicken performance and stress, it is important to examine all aspects of light supplied to the birds as they grow. The purpose of this study was to examine the performance and stress effects of LED, CCFL, and incandescent light technologies on commercial broiler chickens. Live performance parameters and H:L ratios were used to quantify differences between each technology.

## **Chapter 2**

### **MATERIALS AND METHODS**

Six hundred and seventy-two (672) male Ross 708 broiler chickens were obtained from Mountaire Farms' hatchery in Millsboro, DE and were raised from day zero to market age (42 days) in eight large colony houses following standard husbandry procedures on the University of Delaware Farm (AACUC, (33) 04-17-12R). Each large colony house was modified to be light tight, with a selected light technology installed to serve as the variable. Eighty-four (84) birds were placed in each of eight large colony houses, and intermittent lighting programs (2 hr. light/4 hr. dark) differing only by lighting technology during the trial were used. This procedure was replicated four 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 (75w Sylvania, Danvers, MA), two brands of light emitting diode (LED) lamps referred to as LED A and B for this experiment (10w Next Gen, Fayetteville, AR; 12w ONCE AgriShift PLWB, Plymouth, MN respectively), and one brand of cold-cathode fluorescent lamp (CCFL) (8w Litetronics Microbrite, Alsip, IL). As the current industry standard, the incandescent bulb served as the control

technology in each trial. The experimental technologies were the CCFL and two LED lamps. Each of the four light technologies was placed in two houses for a total of 8 houses utilized per trial. The light technologies were rotated through the large colony houses prior to the start of each trial to account for house effects; this rotation is shown in Table 1. A representative layout of the light technologies is diagrammed in Figure 1.

Table 1 Rotation of light technology by trial in large colony houses

Trial	House 1	House 2	House 3	House 4	House 5	House 6	House 7	House 8
1 Summer	Incand.	LED A	LED B	CCFL	Incand.	LED A	LED B	CCFL
2 Fall	CCFL	Incand.	LED A	LED B	CCFL	Incand.	LED A	LED B
3 Winter	LED B	LED A	CCFL	Incand.	LED B	LED A	CCFL	Incand.
4 Spring	LED A	CCFL	Incand.	LED B	LED A	CCFL	Incand.	LED B

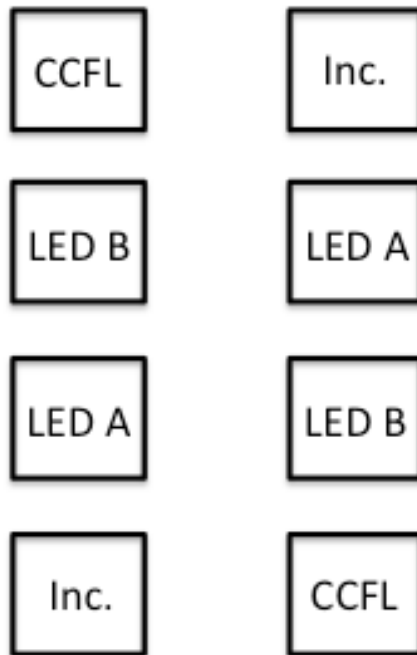


Figure 1 Representative arrangement of light technologies in eight large colony houses (Trial 1: Summer)

### **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 both the photoperiod and light intensity in each house. The light level in each house began at 4 foot candles (fc) (43 lux), with a program of 24 hr. light: 0 hr. dark for days 1-2. Luminance and photoperiod were decreased days 3-22 until grow out (days 23-42), during which the light program remained at 2 hr. light: 4

hr. dark, at 0.1 fc (1 lux). Table 2 shows the full light schedule applied to each house. 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-minute intervals using Hobo U12 data loggers (Onset Computer Corporation, Bourne, MA). This data was downloaded weekly and exported to Excel to track house conditions.

Table 2 Luminance and photoperiod applied during experiment to all houses by trial day

Day	Illumination		Photo Period
	Foot Candles (fc)	Lux	Hours of Light:Dark
0	4	54	24:0
1	4	54	24:0
2-6	4	54	23:1
7	1	11	5.45:0.15 (x 4)
8	1	11	5.30:0.30
9	1	11	5.15:0.45
10	1	11	5.00:1.00
11	1	11	4.45:1.15
12	1	11	4.30:1.30
13	1	11	4.15:1.45
14	1	11	4.00:2.00
15	0.8	8.5	3.75:2.15
16	0.6	6.5	3.30:2.30
17	0.4	4	3.15:2.45
18	0.4	4	3.00:3.00
19	0.4	4	2.45:3.15
20	0.2	2	2.30:3.30
21	0.1	1	2.15:3.45
22-42	0.1	1	2.00:4.00

## Broiler Care and Feed Monitoring

The broilers were raised in 2.28 m by 3.35 m (7.5 ft. by 11 ft.) pens within each large colony house at the industry standard stocking density of 0.07 sq. m/broiler (0.75 sq. ft./broiler) at 42 days, and provided feed and water *ad libitum*. Birds were fed commercial broiler starter feed (crude protein: 22%, crude fat: 3.5%) for days 1-21 and commercial broiler finisher feed (crude protein: 18%, crude fat: 4%) for days 22-42 (Southern States Cooperative, Richmond, VA). Mortality was recorded daily, with the weight of each deceased bird also recorded. Feed consumption was recorded (in kg) using a hanging scale (Rubbermaid Pelouze 7750, Winchester, VA) to measure the weight of the feed remaining each day and the amount of new feed added. Six randomly selected broilers were weighed each week to monitor growth and obtain representative weights to estimate weekly feed conversion. Deceased birds during each trial were weighed and recorded for increased accuracy of feed conversion ratios. The remaining 480 birds were kept throughout the trial to collect additional live performance data including weekly live body weights and feed conversion ratios. Cumulative feed conversion (CFC) from each house was calculated using Equation 1.

Equation 1:

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

### **Live Performance and Allometric Characteristics**

Six, randomly-selected birds were removed and humanely euthanized by cervical dislocation from each house at days 7, 14, 35, and 42 to evaluate live performance, allometric growth characteristics, and to collect blood for obtaining a heterophil to lymphocyte (H:L) ratio. Live performance was measured by recording the live weight of the birds. The weight of the left breast muscle (pectoralis major and minor), heart, liver, and duodenal loop, along with the length of the duodenal loop were collected for allometric growth characteristics.

### **Heterophil-to-Lymphocyte Ratios**

Blood was collected post-mortem during necropsies by cardiac puncture. One drop of each blood sample was immediately transferred to slides and prepared as a smear of one cell layer (Gross and Siegel, 1983, 972-979). Each slide was fixed in histological-grade methanol, and submitted to the University of Delaware Comparative Pathology Laboratory for staining using the Wright-Giemsa (Polysciences, Inc., Warrington, PA) method shown in Figure 2.

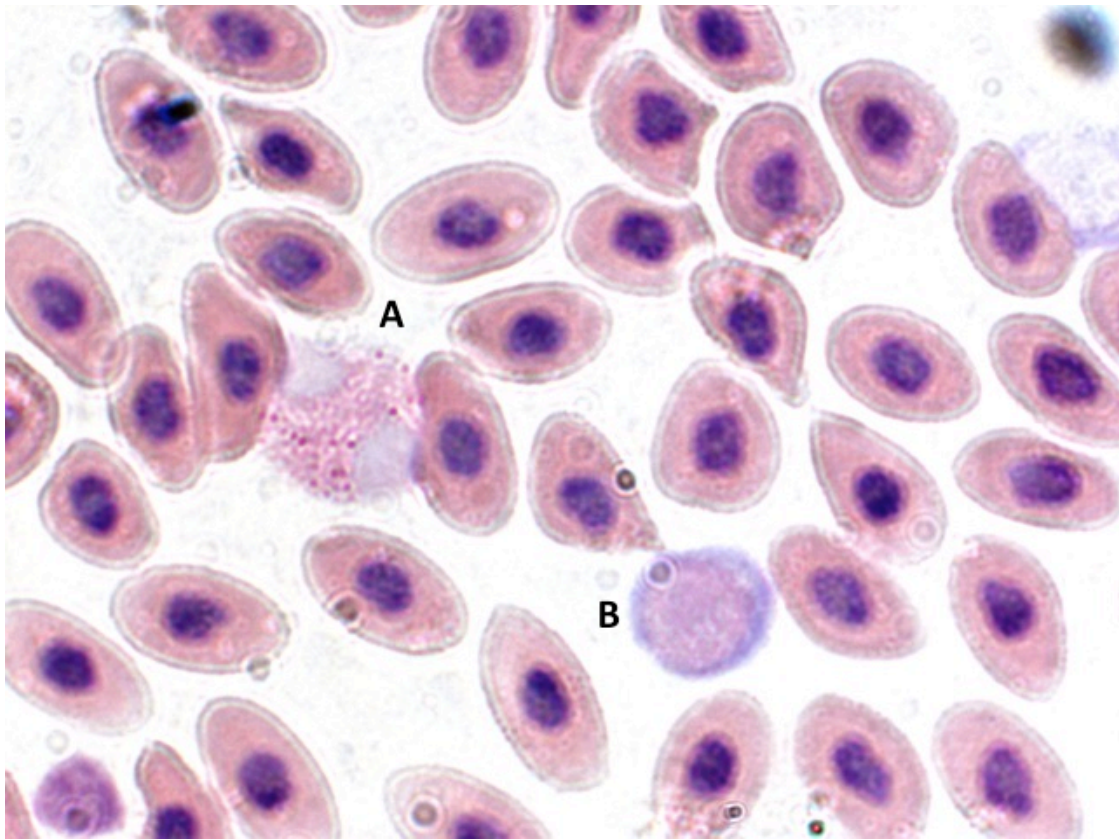


Figure 2 Representative example of a heterophil (A) and lymphocyte (B) stained using the Wright-Giemsa staining method.

The H:L ratio was obtained following methods outlined by Gross and Siegel (1983, 972-979). A combination of heterophils and lymphocytes were tallied to the first fifty cells encountered and the counts were recorded for each slide by a single observer; the ratio was calculated by dividing the number of observed heterophils by the number of observed lymphocytes. Any errors in the fixing or staining of a slide

that resulted in it being un-readable excluded that sample from statistical analysis.

The mean H:L ratios were calculated both by technology and by season.

At the conclusion of Trial 4, birds remaining in one control house (incandescent) were feed restricted by  $\frac{1}{2}$  the daily food consumed for three days to elicit both feed and social stress as a positive control measure. Twelve birds were then euthanized, weighed, and blood was drawn via cardiac puncture for H:L ratio comparison. Remaining birds were again subjected to feed restriction by  $\frac{1}{2}$  daily food consumption for two additional days, and an additional twelve birds were euthanized for blood collection. Results from this test were used as a positive control indicating success of our use of H:L ratios to evaluate stress in the chickens.

### **Statistical Analysis**

Tests conducted included 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 ( $\alpha=0.05$ ).

## **Chapter 3**

### **RESULTS**

#### **Effect of Light Technology on Undressed Market Weight**

Body weight means under different lighting technologies were compared to the control mean under incandescent lamps as illustrated in Figure 3. Day 42 body weight did not differ significantly between incandescent, LED A, and LED B. Body weights under CCFL lamps ( $2871 \text{ g} \pm 53$ ) were significantly lower than body weights under incandescent ( $3000 \text{ g} \pm 33$ ) ( $p= 0.03$ ). Birds grown under CCFL lamps showed poor performance against those raised under LED A ( $2966 \text{ g} \pm 37$ ) and LED B ( $2986 \text{ g} \pm 46$ ) lamps ( $p= 0.12$ ,  $p= 0.06$  respectively). LED A and LED B appear to produce similar growth results, and are not significantly different from one another ( $p= 0.75$ ) or from incandescent lamps ( $p= 0.58$ ,  $p= 0.81$  respectively).

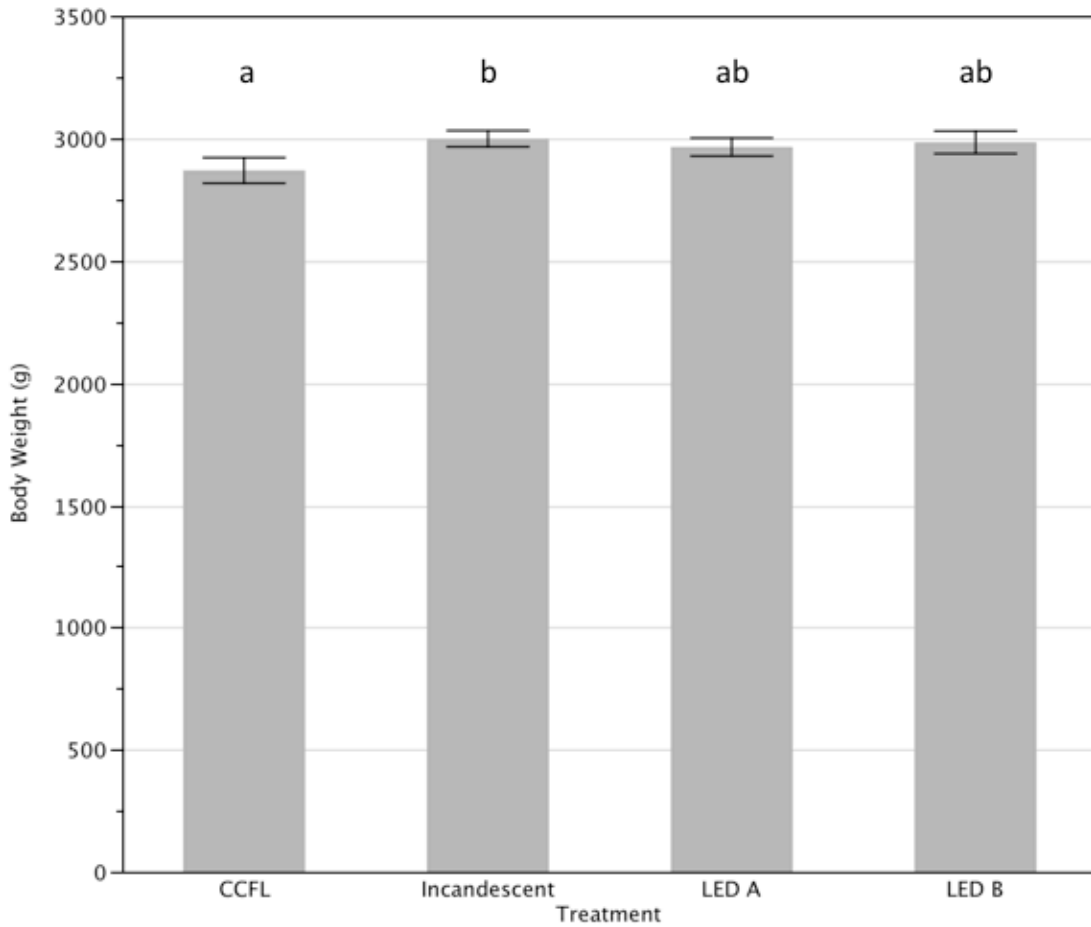


Figure 3 Mean body weight in grams of adult male Ross 708 broilers at 42 days of age arranged by lighting technology. Error bars represent standard error of the mean (S.E.M.) (CCFL: n=49, Incandescent: n=48, LED A: n=47, LED B: n=48). Letters denote statistical significance between treatments ( $\alpha=0.05$ ).

### **Effect of Light Technology on Cumulative Feed Conversion**

No significant difference was detected in feed conversion ratios (FCR) between light technologies (Figure 4). Incandescent and LED B appear to perform similarly, as do LED A and CCFL. LED B showed a lower FCR ( $1.80 \pm 0.02$ ), and CCFL showed a higher average FCR ( $1.84 \pm 0.04$ ). The difference between CCFL and incandescent ( $1.80 \pm 0.04$ ) is insignificant ( $p= 0.3$ ), as is the difference between LED A ( $1.86 \pm 0.02$ ) and incandescent ( $p= 0.18$ ). The difference between LED B and CCFL is insignificant ( $p= 0.24$ ), as is the difference in performance between LED technologies ( $p= 0.14$ ).

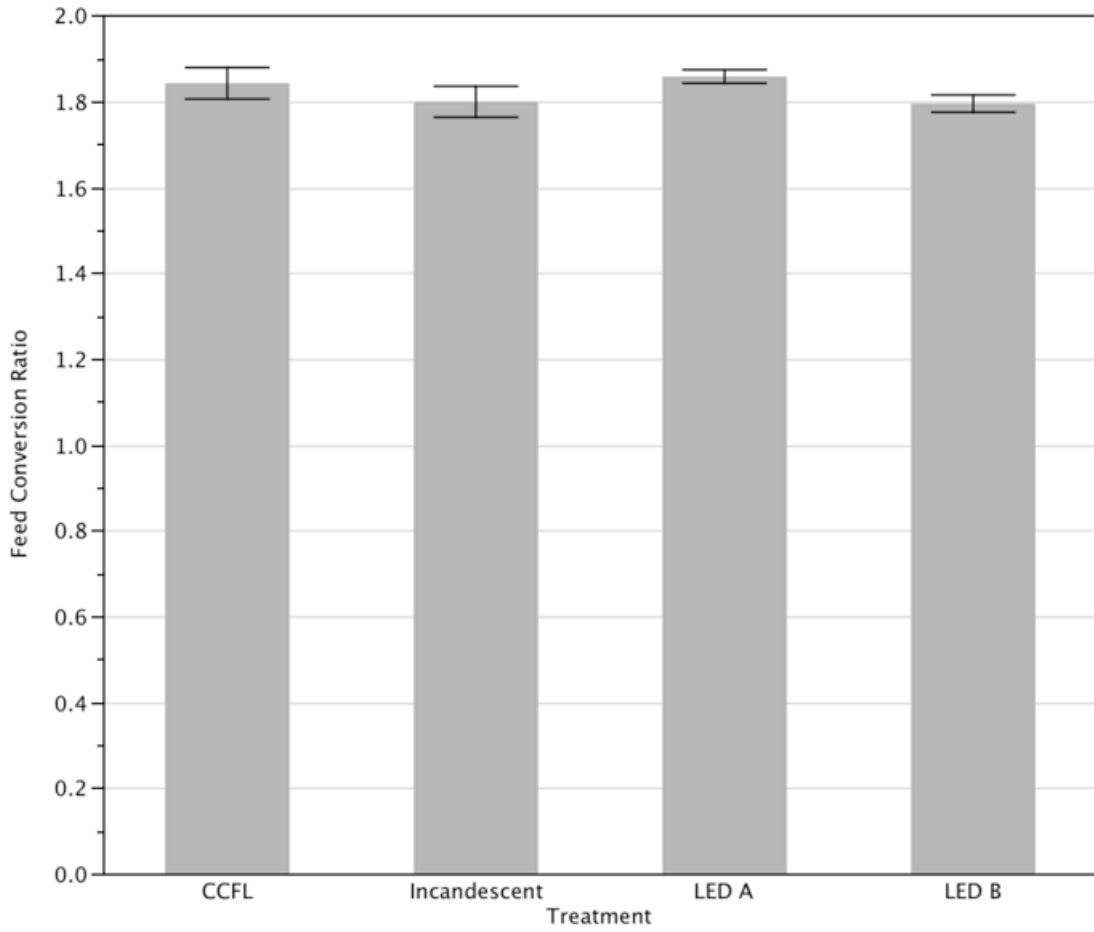


Figure 4 Mean cumulative feed conversion of adult male Ross 708 broilers (kg feed/kg birds). Error bars represent S.E.M. (CCFL: n=8, Incandescent: n=7, LED A: n=7, LED B: n=8).

### **Impact of Season on Market Age Body Weight and Feed Conversion Ratio**

Due to differences in body weight performance observed during each trial, a statistical analysis of mean market age (42 days) body weights and cumulative feed conversion ratios by trial and technology was performed. Table 3 shows that mean broiler body weights under CCFL were significantly lower during Trial 2 than under all other trials ( $p \leq 0.0002$ ). Mean body weights under LED A were significantly lower as well during Trial 2 as compared with Trial 3 ( $p= 0.04$ ). No significant differences were seen in feed conversion ratios between all trials under all technologies.

Table 3 Mean body weight and cumulative feed conversion ratio of male Ross 708 broiler chickens at 42 days of age for the treatments incandescent (Inc.), LED A, LED B, and CCFL during trials 1-4. Data presented as mean  $\pm$  standard error of the mean ( $X \pm S.E.M.$ ).

Treatment	Trial	Mean Body Weight (g)	Feed Conversion Ratio (kg)
Incandescent	1	3031 $\pm$ 64 <sup>a</sup>	1.75 $\pm$ 0.0
	2	2915 $\pm$ 93 <sup>a</sup>	1.81 $\pm$ 0.09
	3	3097 $\pm$ 51 <sup>a</sup>	1.87 $\pm$ 0.05
	4	2958 $\pm$ 41 <sup>a</sup>	1.75 $\pm$ 0.09
	Mean	3000 $\pm$ 33	1.80 $\pm$ 0.04
LED A	1	3007 $\pm$ 68 <sup>ab</sup>	1.90 $\pm$ 0.0
	2	2877 $\pm$ 62 <sup>a</sup>	1.81 $\pm$ 0.004
	3	3091 $\pm$ 69 <sup>b</sup>	1.87 $\pm$ 0.03
	4	2901 $\pm$ 85 <sup>ab</sup>	1.88 $\pm$ 0.004
	Mean	2966 $\pm$ 37	1.86 $\pm$ 0.02
LED B	1	2986 $\pm$ 64 <sup>a</sup>	1.82 $\pm$ 0.04
	2	2953 $\pm$ 92 <sup>a</sup>	1.77 $\pm$ 0.006
	3	3062 $\pm$ 73 <sup>a</sup>	1.82 $\pm$ 0.002
	4	2941 $\pm$ 134 <sup>a</sup>	1.78 $\pm$ 0.09
	Mean	2986 $\pm$ 46	1.80 $\pm$ 0.02
CCFL	1	3038 $\pm$ 76 <sup>a</sup>	1.83 $\pm$ 0.004
	2	2487 $\pm$ 58 <sup>b</sup>	1.89 $\pm$ 0.08
	3	2971 $\pm$ 123 <sup>a</sup>	1.89 $\pm$ 0.02
	4	2979 $\pm$ 64 <sup>a</sup>	1.76 $\pm$ 0.14
	Mean	2871 $\pm$ 53	1.84 $\pm$ 0.04

<sup>a-b</sup> Means within the same column with no common superscript differ ( $p < 0.05$ )

### **Effect of Light Technology on Whole Breast Muscle Weight**

No significant difference was observed between light technologies with respect to whole breast muscle weight, as seen in Figure 5. The greatest difference is observed between incandescent ( $633 \text{ g} \pm 11$ ) and CCFL ( $595 \text{ g} \pm 17$ ), and shows a trend towards significance ( $p= 0.058$ ) at  $\alpha=0.05$ . LED A ( $611 \text{ g} \pm 12$ ) and LED B ( $615 \text{ g} \pm 17$ ) show little difference from the control ( $p= 0.27$  and  $p= 0.36$  respectively), or from each other ( $p= 0.83$ ).

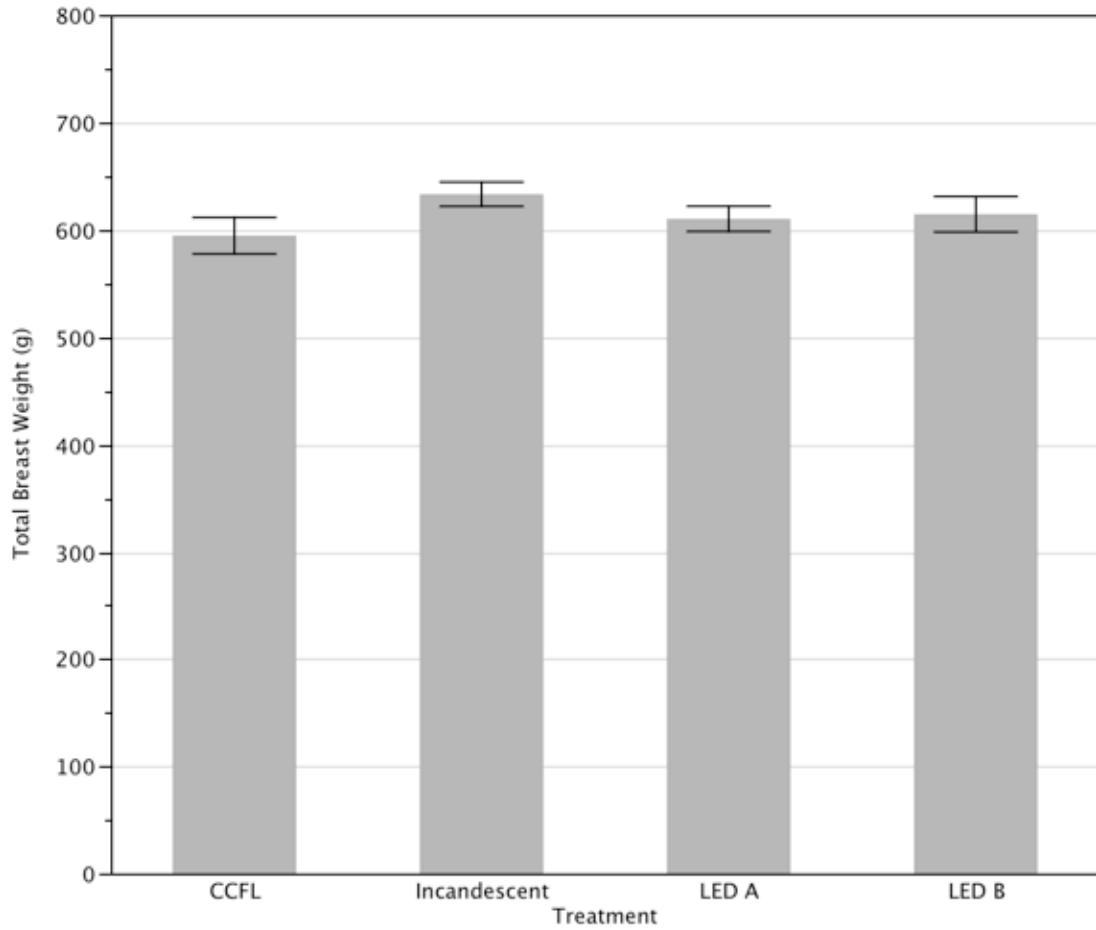


Figure 5 Mean adult male Ross 708 broiler breast muscle weight at 42 days of age in grams. Error bars represent S.E.M. (CCFL: n=49, Incandescent: n=48, LED A: n=46, LED B: n=48).

### **Effect of Light Technology on Broiler Mortality**

No significant difference was found in mortality between the technologies. Mortality was calculated by flock; the number of dead and culled broilers was divided by the total number of birds raised under each technology. This value was converted to a percentage for comparison, and is displayed in Figure 6. There is little difference between CCFL ( $7.9\% \pm 1.5$ ) and incandescent lamps ( $9.8\% \pm 2.2$ ) ( $p= 0.5$ ). The greatest disparity in technology, though still not significant, is between CCFL and LED B ( $10.7\% \pm 2.5$ ) ( $p= 0.33$ ). Both LED technologies yielded slightly higher average mortality than both incandescent and CCFL.

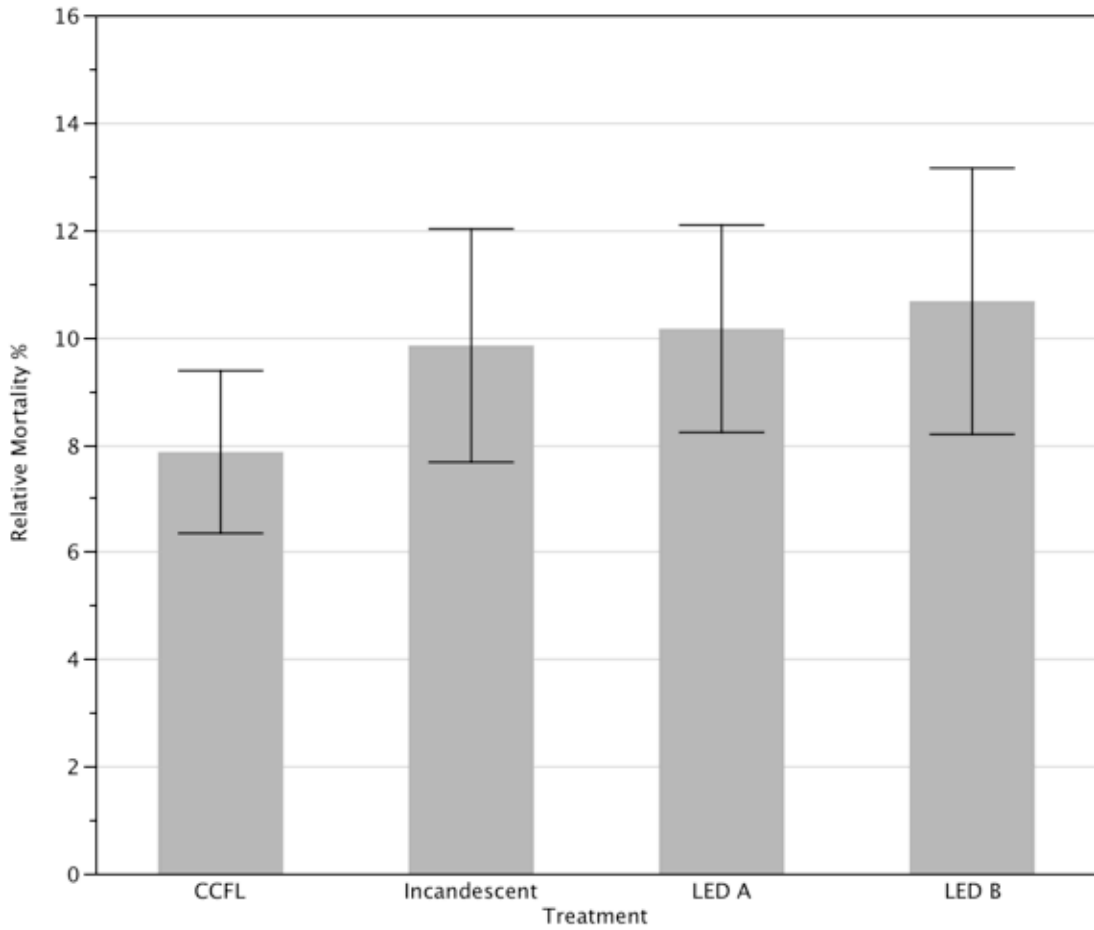


Figure 6 Mean experimental percentage of mortality of male Ross 708 broilers by technology. Error bars represent S.E.M. (CCFL: n=8, Incandescent: n=7, LED A: n=7, LED B: n=8).

## **Effect of Light Technology on Heterophil:Lymphocyte Ratio**

A significant age correlation was seen between the H:L ratio and the age of the broiler, with the ratios uniformly increasing over time (Figure 7). There are significant differences in the ratios between birds raised under CCFL and LED A, and those raised under incandescent lamps by day 42 (Figure 8). A typical H:L ratio for a broiler chicken is between 0.40 to 0.45 (Gross and Siegel, 1983, 972-979). This study shows that birds raised under CCFL and LED A technologies exhibited significantly higher ratios than incandescent, and reported averages ( $p = 0.03$  and  $p = 0.03$  as compared to incandescent, respectively). Table 4 lists average H:L ratios of the broilers arranged by age and technology; there was no significant difference between birds raised under LED B when compared to incandescent at day 42. Though birds raised under incandescent and LED B are also showing slightly elevated ratios by day 42, they are not as high as those under CCFL and LED A, and they also appear to be more stable between days 35 and 42.

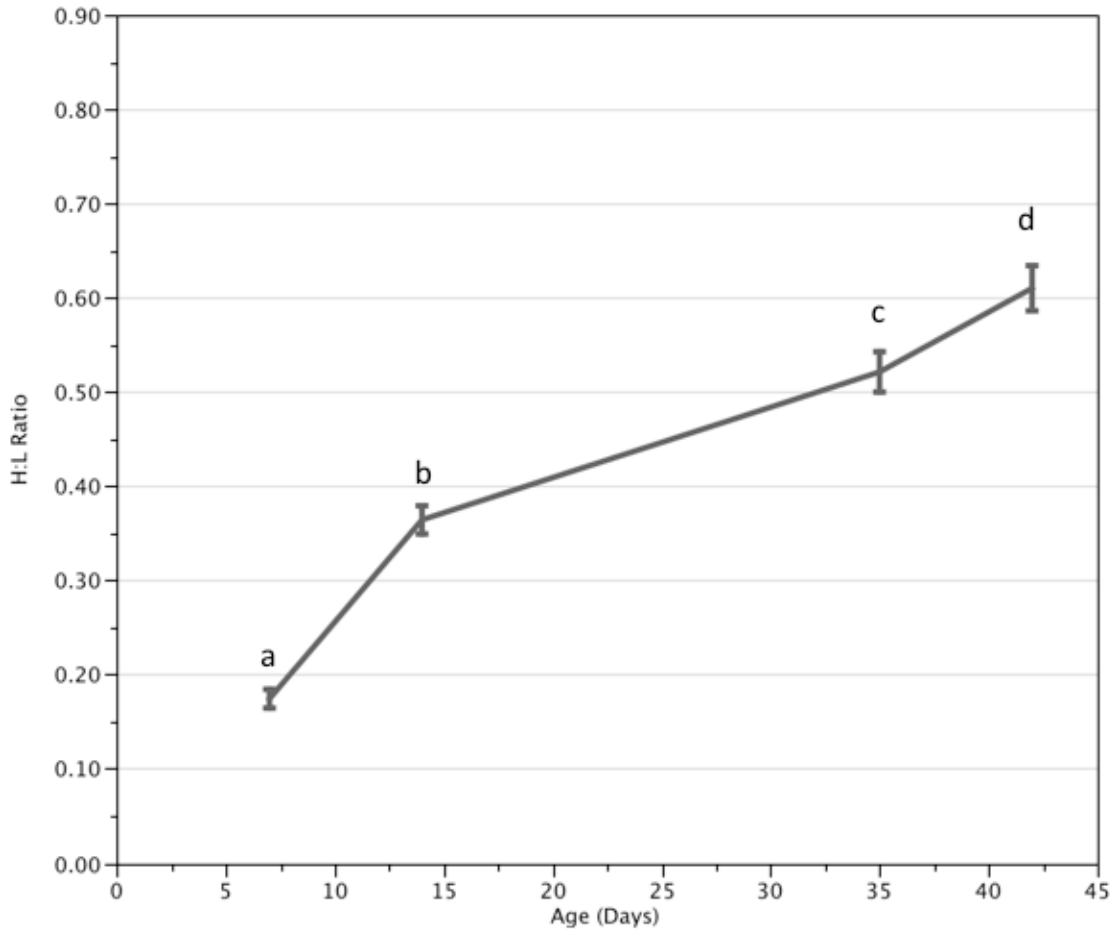


Figure 7 Mean avian heterophil to lymphocyte ratio of all male Ross 708 broiler chickens for all trials and treatments by age (7, 14, 35, and 42 days). (Day 7: n=137, Day 14: n=187, Day 35: n=188, Day 42: n=187). Error bars represent S.E.M. Letters denote statistical significance between ages (days) ( $\alpha=0.05$ ).

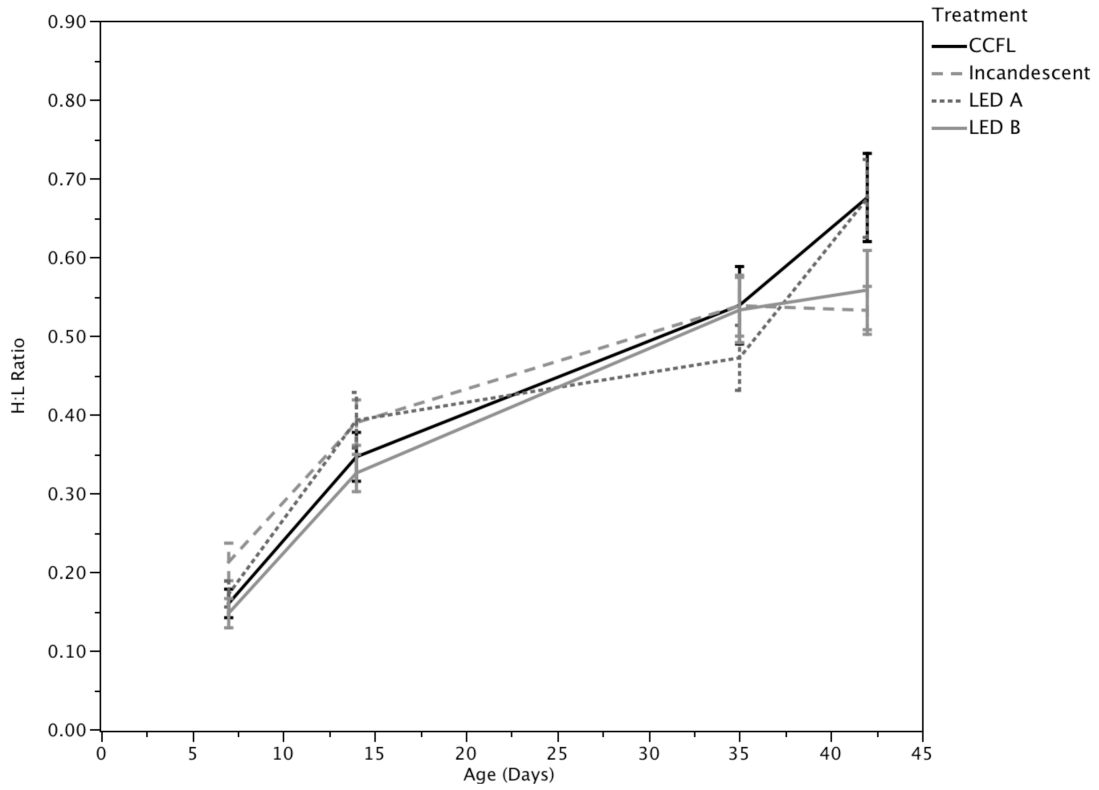


Figure 8 Mean avian heterophil to lymphocyte ratio of all male Ross 708 broiler chickens for all trials arranged by technology at 7, 14, 35, and 42 days of age. (Incandescent: n=48, LED A: n=45, LED B: n=44, CCFL: n=45). Error bars represent S.E.M.

Table 4 Mean heterophil to lymphocyte ratio of male Ross 708 broiler chickens from all trials for the treatments incandescent (Inc.), LED A, LED B, and CCFL at 7, 14, 35, and 42 days of age. Data presented as mean  $\pm$  standard error of the mean ( $X \pm S.E.M.$ ).

Age (Days)	N	Treatment			
		Inc.	LED A	LED B	CCFL
7	137	0.21 $\pm$ 0.02 <sup>aw</sup>	0.17 $\pm$ 0.02 <sup>abw</sup>	0.15 $\pm$ 0.02 <sup>bw</sup>	0.16 $\pm$ 0.02 <sup>abw</sup>
14	187	0.39 $\pm$ 0.03 <sup>ax</sup>	0.39 $\pm$ 0.04 <sup>ax</sup>	0.33 $\pm$ 0.02 <sup>ax</sup>	0.35 $\pm$ 0.03 <sup>ax</sup>
35	188	0.54 $\pm$ 0.04 <sup>ay</sup>	0.47 $\pm$ 0.04 <sup>ax</sup>	0.53 $\pm$ 0.04 <sup>ay</sup>	0.54 $\pm$ 0.05 <sup>ay</sup>
42	187	0.53 $\pm$ 0.03 <sup>ay</sup>	0.67 $\pm$ 0.05 <sup>by</sup>	0.56 $\pm$ 0.05 <sup>aby</sup>	0.68 $\pm$ 0.06 <sup>bz</sup>

<sup>a-b</sup> Means within the same row with no common superscript differ ( $p < 0.05$ )

<sup>w-z</sup> Means within the same column with no common superscript differ ( $p < 0.05$ )

Due to the difference in body weight performance of broilers between each trial, H:L ratios were evaluated each season. Figure 9 shows that ratios were significantly elevated in Trial 2 (Fall). Trial 2 was significantly higher than Trials 1 (Summer), 3 (Winter), and 4 (Spring) ( $p = < 0.001$ ,  $p = 0.006$ , and  $p = 0.002$  respectively), as shown in Table 5. Trials 3 and 4 were also significantly higher than Trial 1 ( $p = 0.004$  and  $p = 0.05$  respectively).

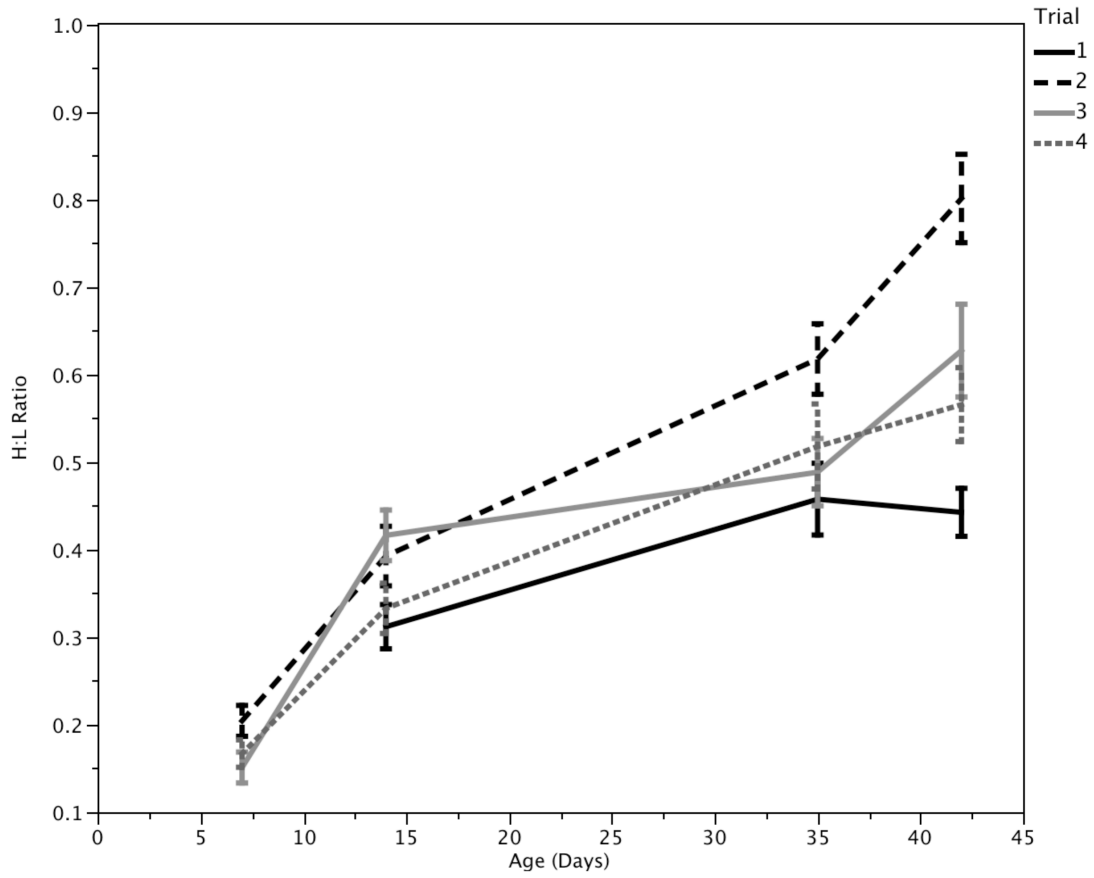


Figure 9 Mean avian heterophil to lymphocyte ratio of male Ross 708 broiler chickens by trial at 7, 14, 35, and 42 days of age. (Trial 1: n=136, Trial 2: n=190, Trial 3: n=186, Trial 4: 187). Error bars represent S.E.M.

Table 5 Mean heterophil to lymphocyte ratio of male Ross 708 broiler chickens for the experimental trials 1-4 at 7, 14, 35, and 42 days of age. Data presented as mean  $\pm$  standard error of the mean ( $X \pm S.E.M.$ ).

Age (Days)	N	Trial			
		1-Summer	2-Fall	3-Winter	4-Spring
7	137	No data*	0.20 $\pm$ 0.02 <sup>aw</sup>	0.15 $\pm$ 0.02 <sup>bw</sup>	0.17 $\pm$ 0.02 <sup>abw</sup>
14	187	0.31 $\pm$ 0.03 <sup>aw</sup>	0.39 $\pm$ 0.03 <sup>abx</sup>	0.42 $\pm$ 0.03 <sup>bx</sup>	0.33 $\pm$ 0.03 <sup>ax</sup>
35	188	0.46 $\pm$ 0.04 <sup>ax</sup>	0.62 $\pm$ 0.04 <sup>by</sup>	0.49 $\pm$ 0.04 <sup>ax</sup>	0.52 $\pm$ 0.05 <sup>aby</sup>
42	187	0.44 $\pm$ 0.03 <sup>ax</sup>	0.80 $\pm$ 0.05 <sup>cz</sup>	0.63 $\pm$ 0.05 <sup>by</sup>	0.57 $\pm$ 0.04 <sup>aby</sup>

<sup>a-b</sup> Means within the same row with no common superscript differ ( $p < 0.05$ )

<sup>w-z</sup> Means within the same column with no common superscript differ ( $p < 0.05$ )

\* Samples at this time point were unreadable due to staining error

At the conclusion of Trial 4, birds remaining in one control house (incandescent) were feed restricted as outlined in the Materials and Methods to elicit both feed and social stress as a positive control measure. Heterophil: lymphocyte ratios were calculated for these subjects, and compared to average H:L ratios of 42 d broilers by technology. An ANOVA and Student's T-test were conducted at the  $\alpha = 0.05$  level, and no significant difference was found between the age of the bird and the H:L ratio during the feed stress period (days 45 and 47). Consequently, blood samples collected from stressed birds on days 45 and 47 were combined for analysis. Results showed a significant increase when compared to each technology

(incandescent:  $p < 0.0001$ , LED B:  $p < 0.0001$ , LED A:  $p = 0.005$ , CCFL:  $p = 0.005$ ), as well as when compared to all birds ( $p < 0.0001$ ), seen in Figure 10.

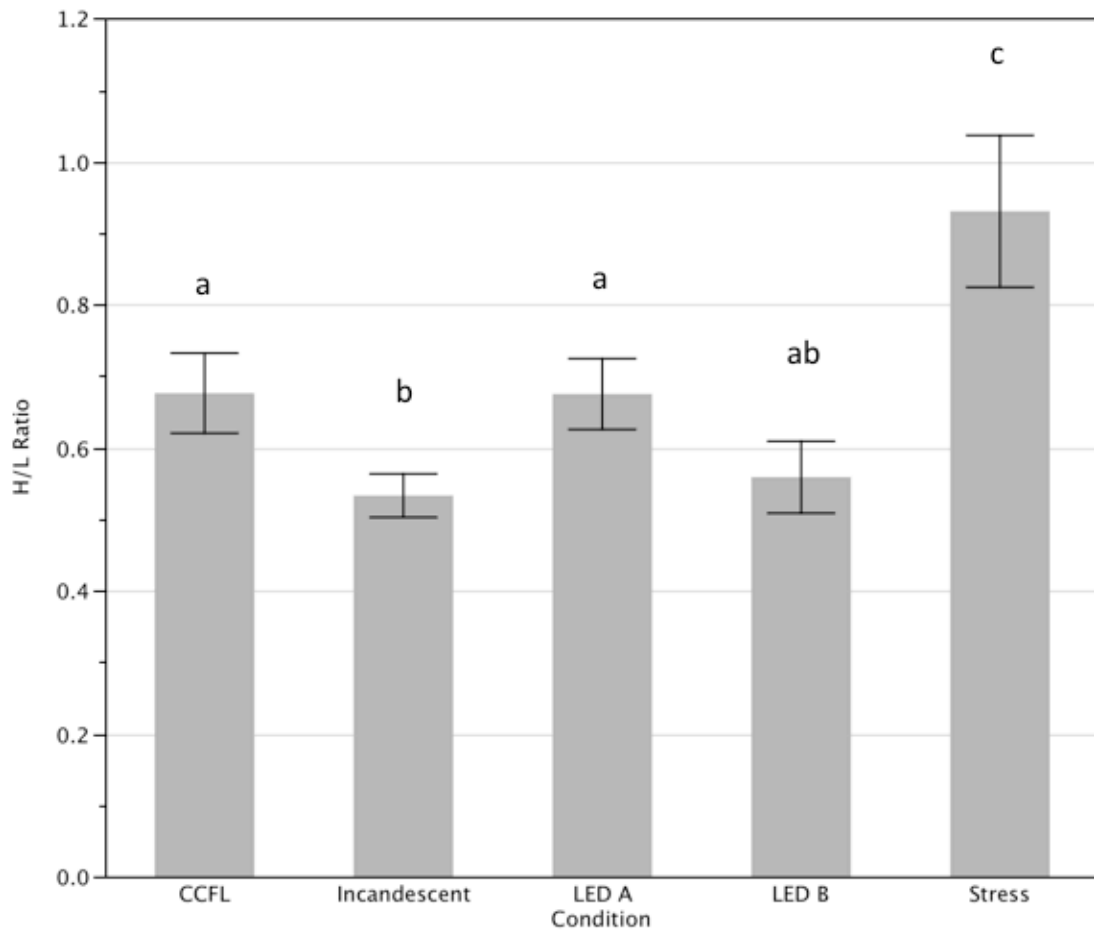


Figure 10 Mean avian heterophil to lymphocyte ratio of male Ross 708 broiler chickens by condition at 42 days of age (experimental), and 45 and 47 days of age (stress) (CCFL: n=45, Incandescent: n=48, LED A: n=45, LED B: n=44, Stress: n=22). Error bars represent S.E.M. Letters denote statistical significance between treatments ( $\alpha=0.05$ ).

### **Additional Allometric Analysis**

Additional allometric analysis was conducted on tissues collected from the euthanized broilers in this study for further insight into the birds' health; this data is displayed in Table 6. No significant differences were witnessed in the heart, liver, or duodenal mass of birds under any technology tested. At market age, hearts weighed 16 grams on average under each technology, livers weighed between 65-67 grams, and duodenums weighed approximately 15 grams. Duodenum lengths showed high variation, but were on average 30 cm in all birds under each technology, and not significantly different between experimental groups.

Table 6 Mean weight of heart, duodenum and liver, and mean length of duodenum, of male Ross 708 broiler chickens at 42 days of age. Data presented as mean  $\pm$  standard error of the mean ( $X \pm S.E.M.$ ).

Treatment	Heart Weight (g)	Duodenum Weight (g)	Liver Weight (g)	Duodenum Length (cm)
Incandescent	16.28 $\pm$ 0.33	15.18 $\pm$ 0.40	66.70 $\pm$ 2.1	30.90 $\pm$ 0.74
LED A	16.17 $\pm$ 0.35	15.34 $\pm$ 0.44	67.35 $\pm$ 1.8	30.49 $\pm$ 0.66
LED B	16.05 $\pm$ 0.36	15.97 $\pm$ 0.48	67.39 $\pm$ 1.6	29.92 $\pm$ 0.83
CCFL	16.07 $\pm$ 0.35	15.68 $\pm$ 0.53	64.68 $\pm$ 1.4	31.50 $\pm$ 0.63

### Environmental Data

Environmental temperature data collected throughout each trial was averaged per house and graphed to observe trends and possible reasons for disparity in performance. The results were not significant when applied to fit tests for house effects on bird weight or H:L ratio ( $p > 0.05$ ), and are displayed below in Figures 11-14.

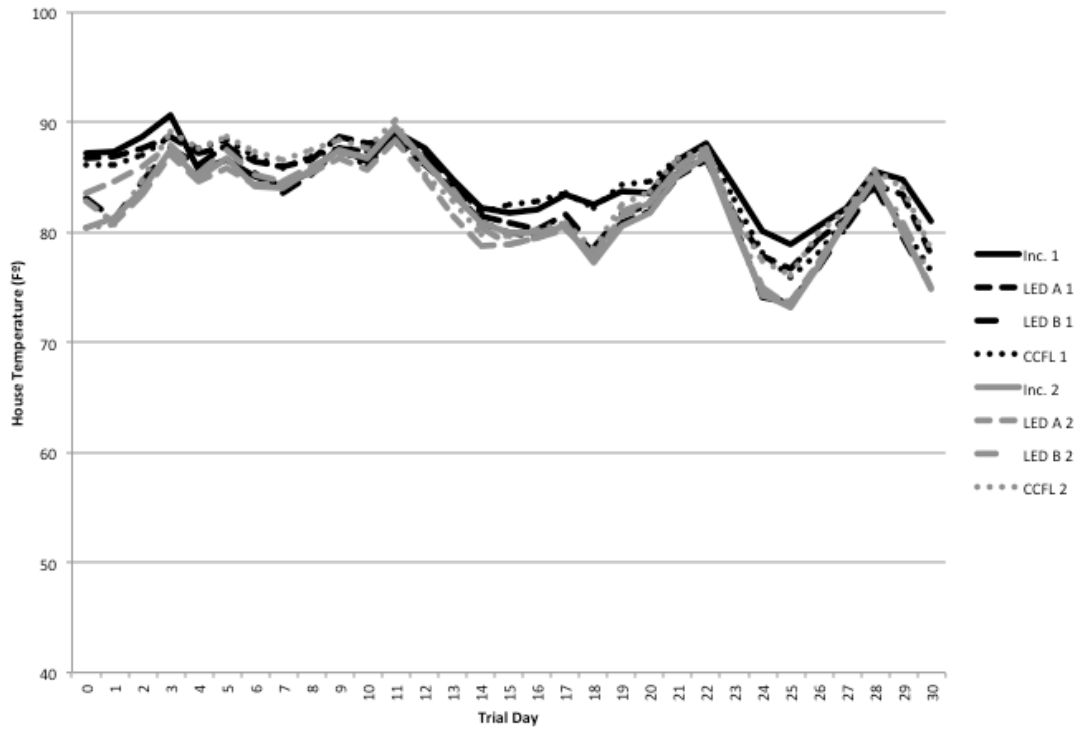


Figure 11 Trial 1 (Summer) mean daily environmental temperature arranged by technology in large colony houses 1-8.

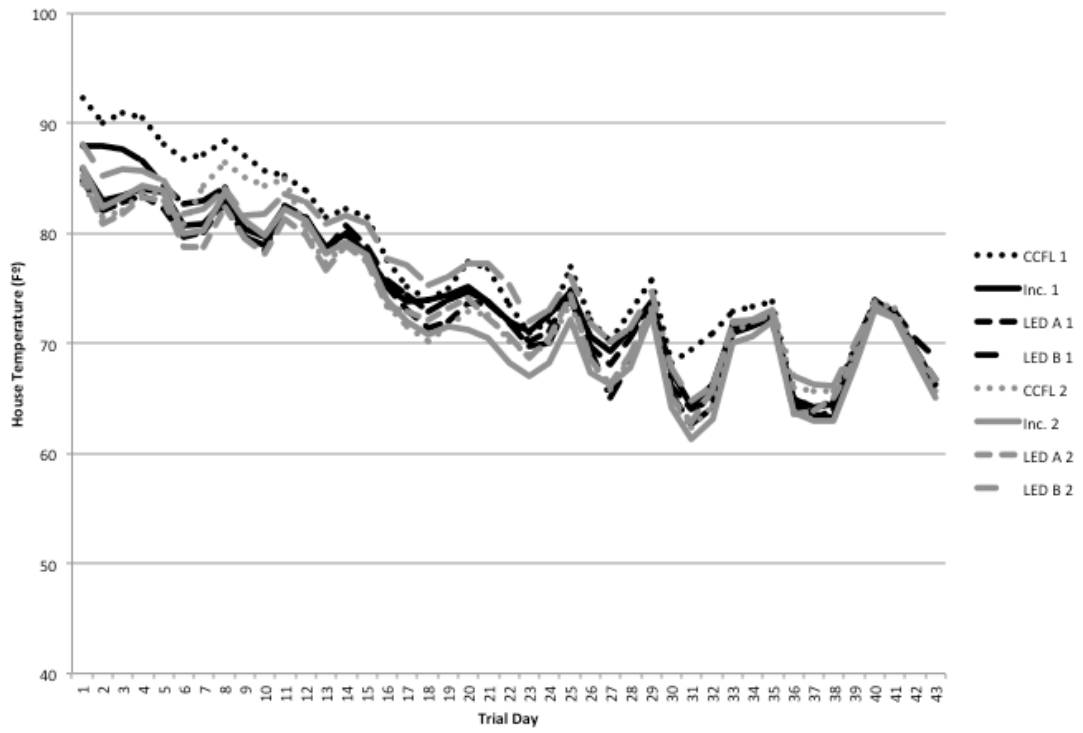


Figure 12 Trial 2 (Fall) mean daily environmental temperature arranged by technology in large colony houses 1-8.

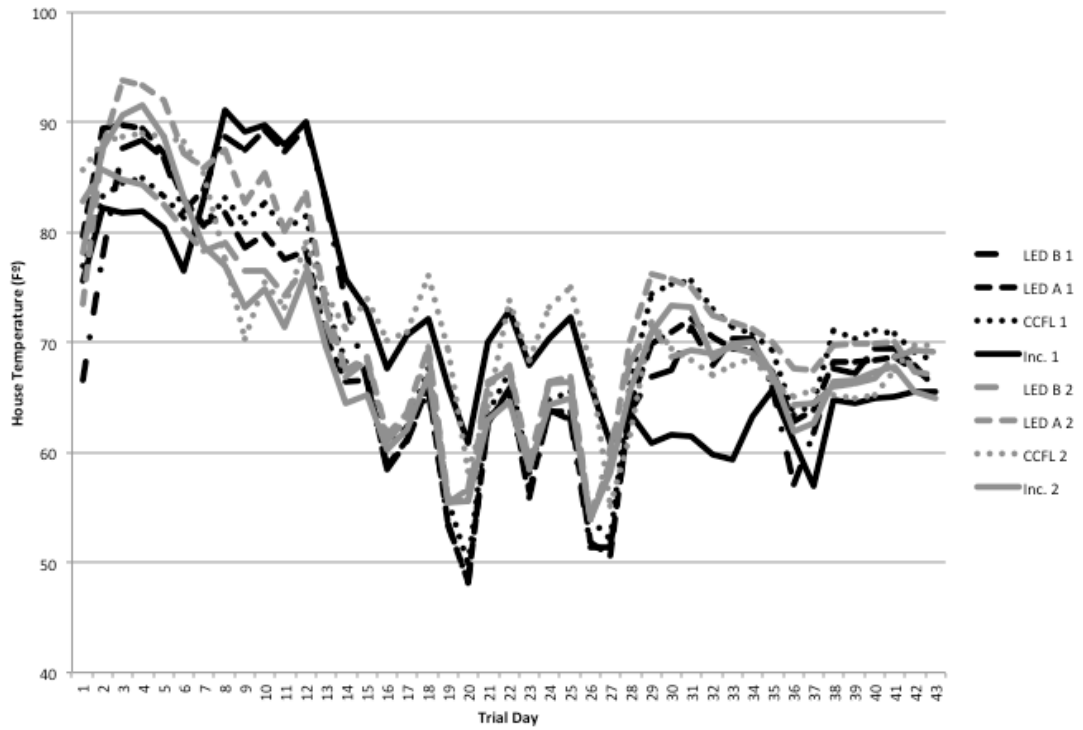


Figure 13 Trial 3 (Winter) mean daily environmental temperature arranged by technology in large colony houses 1-8.

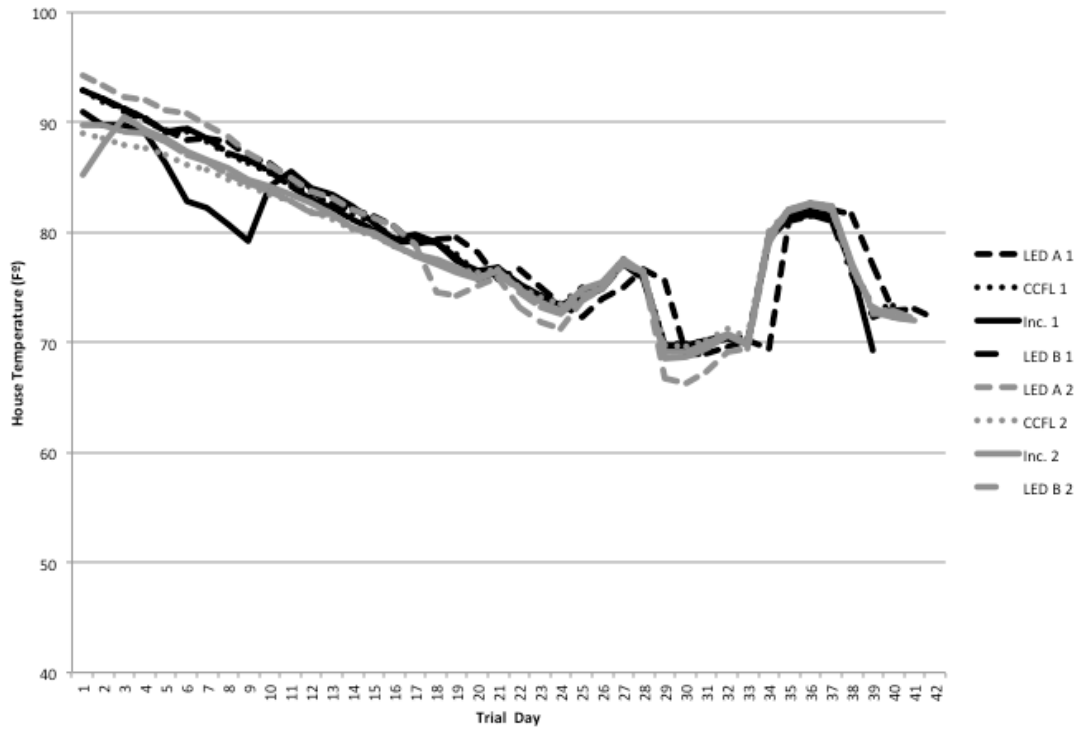


Figure 14 Trial 4 (Spring) mean daily environmental temperature arranged by technology in large colony houses 1-8.

## **Chapter 4**

### **DISCUSSION**

The objective of this study was to examine the effect of incandescent, light emitting diode, and cold cathode fluorescent lighting technologies on the growth, feed conversion, and physiological stress of commercial broiler chickens. A general trend towards greater growth under incandescent and one type of LED (LED B) lamps, along with lower feed conversion and heterophil to lymphocyte ratios, can be observed. In contrast, CCFL and LED A lamp technologies indicate a trend towards higher feed conversion and stress (H:L) ratios, with birds raised under CCFL lamps also showing significantly lower weights.

Most important of these results to industry is the difference observed between live body weights, and breast muscle weights, of the broilers at market age (42 days). The two LED technologies performed very similarly to the control incandescent lamps. This could be promising data supporting the implementation of LED lamps in broiler houses in the future. Incandescent, LED A, LED B, and CCFL all yielded broilers of a higher body weight on average (3000, 2966, 2985, and 2870 g respectively) than the standards for male Ross 708 broilers by day 42 (2842 g) (Aviagen, 2012, 2-22). CCFL lamps, on the other hand, resulted in significantly lower

body weights on average than the control, with a difference of about 130 grams observed on average between incandescent and CCFL lamps.

De-boned breast muscle weights obtained during this study were compared against male Ross 708 performance standards normalized for live body weight, and were found to be lower on average. Ross standards (2012, 2-22) calculate the de-boned breast weight as a percentage of total live body weight; for birds weighing 3.0 kg, breast muscle should be 23.58% of the total live body weight, or approximately 707 g. The average weight of the birds raised under incandescent, LED A, and LED B technologies fell at or within 40 g of 3.0 kg, and so their breast weights were compared against this percentage. The average breast weights were found to be 634 g under incandescent, 611 g under LED A, and 615 g under LED B. Birds raised under CCFL lamps had a mean live body weight of 2,870 g, which roughly aligns them in the category of 2.8 kg birds in performance standards; though their projected approximate breast muscle weight should be 653.8 g, we found these birds to have an average weight of 595 g. Reasons for disparity between the Ross standards and the average weights from the subjects may be largely attributed to human inaccuracy during de-boning of the pectoralis major and minor from the keel bone. Workers in processing plants are highly skilled and practiced in separating the breast muscle from the bone, whereas during our research we relied on trained graduate and undergraduate students. There is high potential for loss of breast tissue during de-boning when

performed by an inexperienced individual, and this could account for the difference in weights.

The lack of a significant difference in the technologies' cumulative feed conversion ratios is likely indicative of the broilers' capability to metabolically process feed similarly regardless of ambient lighting. We should note, however, that the CCFL and LED A lamps yield a higher, and therefore less efficient, feed conversion ratio on average than the other technologies tested. In contrast, birds raised under incandescent and LED B lamps had lower average feed conversion ratios. This may be indicative of improved performance when also taking into consideration that these technologies showed lower H:L ratios and good body and breast weight performance.

Relative flock mortality under each technology appears fairly similar, and there were no significant differences between treatments. Interestingly, CCFL lamps tend to yield the lowest mortality on average. This may be tied into the performance of the lamps in the areas of market age weight and feed conversion. One could argue that there is lower mortality on average due to the birds growing to a smaller size, and perhaps growing less quickly on average, than broilers raised under the incandescent or LED lamps. Broilers are prone to heart disease, heart failure, and injury due to their rapid body and muscle growth (Wideman et al., 2013, 64-83). It is possible that broilers raised under CCFL lamps may have experienced less heart and skeletal defects due to a decreased rate of growth and final body size. This theory was supported anecdotally during culling and necropsies of experimental birds, however,

analysis of significant differences of heart, liver, and duodenum weights did not indicate differential organ development as shown in Table 5.

Significant poor performance of the birds during Trial 2 (Fall) prompted statistical fit testing and analysis of the environmental temperatures of the houses to determine house, trial, and seasonal effects. This concern arose primarily from significantly decreased body weights of birds raised under CCFL technologies during this trial, which subsequently affected the total mean body weight of birds under this technology. There was also cause for concern during Trial 1 (Summer) when temperatures were frequently in excess of 21° C (70° F), as well as during Trial 3 (Winter) when we experienced difficulty regulating the temperature of the houses, resulting in temperatures at or below 10-16° C between days 14-28 (weeks 2-4). Significant research has been devoted to the impact of environmental temperature on broiler body weight and feed conversion. Broilers show optimum performance when brooded at approximately 32° C (90° F) at day of placement, followed by a linear lowering of house temperature by approximately 5.5° C (10° F) throughout the first two weeks (Fairchild, 2012, 1-4). Temperatures should then ideally be lowered gradually to approximately 20° C (68° F) for the final two weeks of the grow-out period. Research conducted by Deaton et al. (1978, 1070-1074) has shown that broilers show significant reductions in body weight when raised at temperatures in excess of 21° C (70° F), despite good feed conversion. This study also demonstrated poor performance and increased feed conversion ratios in cooler temperatures between

10-15.6° C (50-60° F). Surprisingly, when analyzed in comparison to body weights, feed conversion, and mortality of the birds during the trial, the temperature effects were found to be negligible. In fact, body weights of the broilers were higher during Trial 1 (Summer) and Trial 3 (Winter), and significantly lower during Trial 2 (Fall) when temperature control within the house was within preferable limits. Additionally, no significant differences were observed between the cumulative feed conversion ratios of each trial when organized by technology. Based on these results, it was concluded that factors affecting the body weight and feed conversion of the broilers were external to the environmental temperatures within the houses during each trial.

A summary of fit was conducted at  $\alpha=0.05$  to determine the impact of each trial, house, and experimental technology on the market age weight of the birds using JMP Pro 10. An R-square 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 linked to individual differences between each bird; however, an ANOVA resulted in a p-value of 0.0004, giving strong evidence that at least one of the effects in our study was significant. 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  $\alpha=0.1$ .

From these results it can be hypothesized that the season during which the trial took place has the most significant effect on the final market age body weight of the

birds, with contributing effects from the technology implemented in the house. A difference in performance of broilers throughout the year is well supported both in literature and anecdotally (Sinclair et al., 1990, 526-534). Following a review of the above fit test, it was concluded that a great deal of the difference we saw in body weight may have been due to the season of the trial, possibly due to decreased initial quality of the chicks obtained; however, these differences were likely aggravated and amplified by the technology that the birds were raised under during each trial.

Based on the results of our live performance values, there was great interest in the H:L ratios, and potential relative stress levels, of the birds in this study. Previous research defines a normal H:L ratio of an adult chicken to be between 0.4-0.45 (Gross and Siegel, 1983, 972-979; Lien et al., 2007, 1287-1293). Gross and Siegel (1983) used 8-week (56 day) old male and female white leghorn chickens when taking control H:L ratios, and Lien et al. (2007) used 40 day old male and female Ross 708 broiler chickens. In general, our birds exhibited elevated ratios at market age relative to the values obtained by Gross and Siegel and Lien et al. This effect can most likely be attributed to a variety of factors including the breed, sex, age, and health of our birds, which were 42 day-old male Ross 708 broilers (Campo and Davila, 2002, 1448-1453).

Age contributed significantly to the H:L ratios in this experiment and was observed as strong positive relationship (Figure 7). This may be indicative of maturation of the immune systems of the birds, with a natural increase in circulating heterophils occurring due to decreasing maternal antibody protection. This natural

decrease in maternal antibody, specifically the predominant maternal antibody IgY (the avian equivalent of IgG present in mammalian colostrum), has been documented, with initial high serum concentrations seen in the first week of life followed by a decrease before endogenous production of the antibody by the chick by day 21 post-hatch (Hamal et al., 2006, 1364-1372). A reasonable hypothesis is that, in response to decreasing maternal antibody, the innate immune system may become more active to defend against environmental antigens as the acquired immune system begins to produce antibodies independently. Consequently, we expected to see a “leveling” of heterophil production with age in the absence of infection as endogenous circulating IgY, and other antibodies, appear in the chicken. The age correlation to H:L ratios should be considered when designing future experiments for several reasons. First, it is important to note that the average ratios taken at the beginning of each trial did not necessarily correlate to poor performance or high ratios later in life. Additionally, the ratios appear to stabilize between weeks 5 and 6 of age; this should be taken into consideration when planning to monitor H:L ratios as an indicator of stress. Ratios will likely serve most useful when compared across as similar an age as possible to minimize this effect on results.

Broilers raised under CCFL and LED A lamp technologies showed significantly elevated H:L ratios by day 42 in comparison to incandescent technology (Figure 8). These results prompt the question of whether the birds raised under CCFL or LED A lamps are more environmentally or physiologically stressed than those

raised under incandescent or LED B lamps. The birds in this study were kept under standard grow-out conditions with feed and water provided *ad libitum* and intermittent lighting. Intermittent lighting has been shown to improve immune function, and increase peripheral blood lymphocyte proliferation in 6 week old broiler chickens (Abbas et. al, 2008, 665-671; Kliger, 2000, 18-25; Lewis and Morris, 2006, 146). A study conducted by Lien et al. (2007, 1287-1293) treated male and female broiler chickens to several photoperiod schedules (23L:1D and 18L:6D) and light intensities (1 or 0.1 FC). Blood was collected at 40 days of age for H:L ratios, and it was found that none of the treatments, alone or combined, affected the ratios, with a calculated average of 0.45. According to published literature, the broilers in this study could be expected to have good growth and health with normal H:L ratios; however, we do see a significant elevation under CCFL and LED A lamps, indicating that the technologies could be contributing to chronic stress in the birds (Abbas et. al, 2008, 665-671; Gross and Siegel, 1983, 972-979; Kliger, 2000, 18-25; Lewis and Morris, 2006, 146; Lien et al., 2007, 1287-1293). Given that CCFL also showed poorer body weight performance, and both technologies showed higher feed conversion ratios, it can be further speculated that the wavelengths of light being emitted by these lamps may be impacting the growth and stress of the chickens.

Heterophil:lymphocyte ratios were also analyzed by season due to disparities in performance seen during each trial. Significantly elevated ratios during Trial 2 (Fall) relative to Trials 1 (Summer), 3 (Winter), and 4 (Spring) were seen in

coordination with poor body weight performance. Trials 3 and 4 also had significantly elevated ratios relative to Trial 1, with Trial 3 having a slightly higher average ratio than Trial 4. Results from this analysis again suggest that the birds were adversely affected by environmental factors during Trial 2, however, no significant effect could be found aside from technology or the season of the trial. It is particularly surprising that the H:L ratios are so significantly lower during Trial 1, given that this trial took place during the hottest time of the year when it was difficult to keep the houses at ideal temperatures. As seen in Figure 11, house temperatures were regularly between 24-29° C (75- 85° F), if not higher on occasion. Within the broiler grower industry, it is believed that birds are not heat stressed unless environmental temperatures exceed 35° C (95° F) (Aviagen, 2009, 56). According to Zulkifli et al. (2003, 217-222), prolonged heat stress results in significantly elevated H:L ratios in male broiler chickens; however, heat stress defined during their study was greater than or equal to 39° C (102° F). Based on the definitions above, it is difficult to determine that our subjects were heat stressed sufficiently to elevate H:L ratios; however, the birds were not observed panting excessively or displaying other outward signs of distress during this trial. Given these observations, it was assumed that our birds were likely not experiencing heat stress. A possible alternative explanation for differences in both body weight and H:L ratios may be that the initial fitness or phenotypic profile for the birds differed during each season. Though broilers are bred for high performance consistency, there is potential for variation due to age and profile of the parent stock.

Sinclair et al. (1989, 526-534) found that breeder age significantly affect broiler body weight, with chicks from older flocks growing to be heavier, and at a faster rate, than those from young flocks. It is possible that birds from older breeding flocks may also have lower H:L ratios, with birds from younger flocks conversely exhibiting higher ratios. This correlation has not been confirmed, but may require consideration along with age and sex of the broiler when analyzing this stress parameter.

The elevation of the average H:L ratios of the birds in this study relative to the average according to published literature prompted verification of our test for environmental stress. Additional samples were taken at the end of Trial 4 to validate the H:L method to evaluate stress. The remaining birds in one control, incandescent house were allowed to live for 5 additional days under restricted feed conditions to induce feed and social stress. H:L ratios were significantly elevated in the birds that had been feed restricted, leading us to believe that our test of environmental stress in the broilers was valid. All other environmental test conditions (i.e. photoperiod, light intensity, and temperature) remained the same in the feed restricted house. Given that birds raised under incandescent lamps had shown the lowest average ratio, it could be determined that the feed restriction and resultant social stress were impacting the birds physiologically, thereby confirming our methods, as well as published studies referencing this effect (Gross and Seigel, 1983, 972-979; Zulkifli et al., 2003, 217-222). It can be argued that the age (45 and 47 days) of the chickens being feed stressed may have impacted the H:L ratios, however, in addition to this technology

showing the lowest ratios on average, the ratios should be largely stabilized at this age and valid for comparison purposes. Had feed restriction and blood collection been performed at an earlier age, even day 35, there would be significant cause for concern of validity.

It is unclear at this time what is causing such large differences between the CCFL lamps and the control incandescent lamps. There are a variety of possibilities that are worth consideration, most compelling of which may be the wavelengths of light emitted by the fluorescent lamps. There is a chance that the broilers perceive the light emitted from these lamps to be stronger at certain wavelengths, and that this may behaviorally decrease feed consumption. Chickens are sensitive to wavelengths in the spectrum of 580-650 nm (orange-red) and 400-480 nm (green-blue), with a peak sensitivity at approximately 560 nm (yellow), and may be responding to lights that emit more, or less, light within these wavelengths (Saunders et al., 2008, 921-932). Studies conducted by Prayitno et al. (1997, 452-457) pointed to the fact that white light typically emits a greater proportion of longer wavelengths (red, orange), which is more easily absorbed through the skull to the pineal gland. Prayitno et al. also found that broilers raised under red light early in growth showed increased weights compared with those raised under blue light during the same time period. Additional research on laying hens suggest that red and white light provided by LED technology may be more stimulatory to growth and physiological development than green light provided by the same technology (Bedecarrats, 2011, 1-6). The possibility exists that the incandescent

and LED lamps may be emitting more long wavelength light during a critical period for growth and development, which is affecting subsequent growth in the broilers even after light intensity has been decreased. Further studies utilizing a spectrophotometer would be necessary to determine the specific proportions of each light wavelength being emitted from the light lamps used in this study.

No distinguishable lumen depreciation occurred in the lamps used, however, all lamps used in the study were cleaned thoroughly prior to each trial. No LED or CCFL lamps were lost due to the lifespan of the technology, with the only losses occurring during Trial 1 due to a brief power surge as the result of a thunderstorm, and with the lamps immediately replaced to avoid negative experimental effects.

Differences were observed between the technologies' pattern of light distribution throughout the house, with some lights casting a wider area of luminance than others. LED A and B, for example, exhibited markedly different light distributions due to the shape of the lamp and the presence of a reflector to further scatter light; LED A had a more narrow area of luminance than LED B, resulting in dark areas around the perimeter of the enclosure. Differences like this could contribute to the chronic stress of the broilers without affecting their body weight performance. Thus, factors including light distribution, lamp height from the ground, and spacing of lamps should be considered when installing an alternative lighting technology in a commercial house.

A disparity in results may be witnessed due to inconsistency exhibited by the CCFL lamps. The CCFL lamps installed provided lower initial luminance compared to both LED and incandescent lamps, and required installation of additional CCFL lamps in order to achieve an appropriate brooding light levels in the houses. This technology also dimmed erratically and was found to “jump” up and down in luminance when held at grow-out conditions, resulting in inconsistent illumination within these test houses. The CCFL lamps also have visible flicker during changes in the electrical loading of the house, such as when heaters or fans turn on or off. The flicker may be visually, and possibly physiologically, disturbing to the birds, and this should be taken into consideration (Nuboer et al., 1992, 123-133). This subject is still debated however, with conflicting research suggesting that chickens either may not be able to perceive flicker, or may find fluorescent lighting preferable to incandescent (Widowski et al., 1992, 203-211). CCFL technology may also further exaggerate poor growth in birds from younger breeding flocks, or insufficiently stimulate growth during brooding due to a lack in longer-wavelength light. Further behavior and wavelength output research is warranted to investigate these theories.

## **Chapter 5**

### **CONCLUSIONS**

This study was designed to evaluate the effect of incandescent, light-emitting diode, and cold cathode fluorescent technology on commercial broiler chicken production performance and stress. Lighting technology significantly impacted the market age body weight and physiological stress of the broilers in this study, refuting the hypothesis that no differences would be observed in performance or stress under the four lamps tested (incandescent, LED A, LED B, and CCFL). The weight of the broilers under CCFL technology at 42 days of age showed a significant, negative difference compared with the control (incandescent), with broilers raised under incandescent, LED A, and LED B lamps exhibiting similar weights.

Light-emitting diode technology is proving to be a reasonable replacement for incandescent lamps in broiler production houses. LEDs provided sufficient luminance during brooding, as well as a relatively reliable dimming curve and stable light output during the grow-out period throughout all trials. The broilers exhibited body weights similar to the industry standard technology (incandescent); however, differences were observed between the two LED lamps, which may motivate poultry producers to select one lamp over another. These differences, which included improved feed conversion and H:L ratios under LED B versus LED A, could be indicative of an improved physiologic response to the light emitted by LED B. According to the manufacturer, LED B is designed to produce light at wavelengths that align with the spectral

sensitivity pattern of chickens at full luminance, which is used during brooding, and to emit more light in the blue wavelengths when dimmed during the grow-out period (Appendix A, Once Innovations, Inc.). In contrast, LED A has a proprietary spectral output, and the impact of dimming on this spectral emission pattern is not published; therefore, it is difficult to speculate on the differences between these two LED lamps that may contribute to physiological responses in the broilers. With this taken into consideration, however, it is important to note that there were no significant differences between LED A and B when analyzing production parameters such as body, breast and organ weight, feed conversion, and relative mortality. Given this information, choice of lamp could be left to producers based on the cost and availability of the lamps.

Use of cold cathode fluorescent technology is not recommended in commercial production based on the results of this study. CCFL lamps were found to be difficult to work with, and resulted in birds with significantly decreased body weights, as well as increased feed conversion and H:L ratios. The unpredictable dimming performance of the CCFL lamps, as well as the wavelengths emitted during brooding and grow-out, is speculated to have challenged the broilers behaviorally and physiologically. Further research using a spectrophotometer will be important in mapping the spectral emission of these lamps at full luminance, and when they are dimmed.

Incandescent lamps have been the industry standard for decades; however, they are being replaced due to their short life span and low energy efficiency. Their uniform dimming capability has historically allowed for ease of control throughout the life of the broilers, but improvements on the design of LED technology are quickly making LEDs an attractive option. The individual diode technology of LED's creates

an opportunity for manufacturing based on the production animal at hand. Additional research on the effect of light wavelength on broiler growth, health, genetics, and behavior is needed, and will inevitably lead to further progress by LED manufacturers. Alignment of energy efficient light technology with broiler production needs in the future will not only decrease costs for growers, but also improve the performance and welfare of the poultry they raise.

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## Appendix A

### LUMINOUS EMISSION OF ONCE AGRISHIFT PL LED LAMP

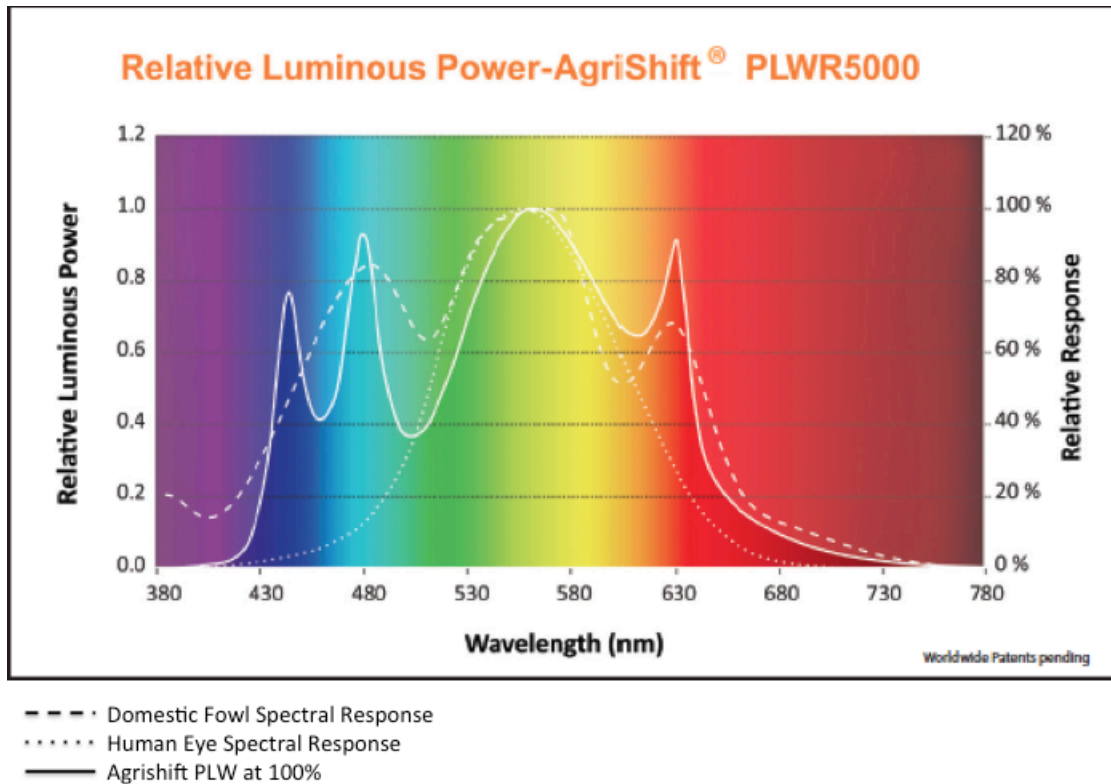


Figure 15 Spectral emission of Once AgriShift PLW at full luminance (Once Innovations Inc., 2010, 1-6).

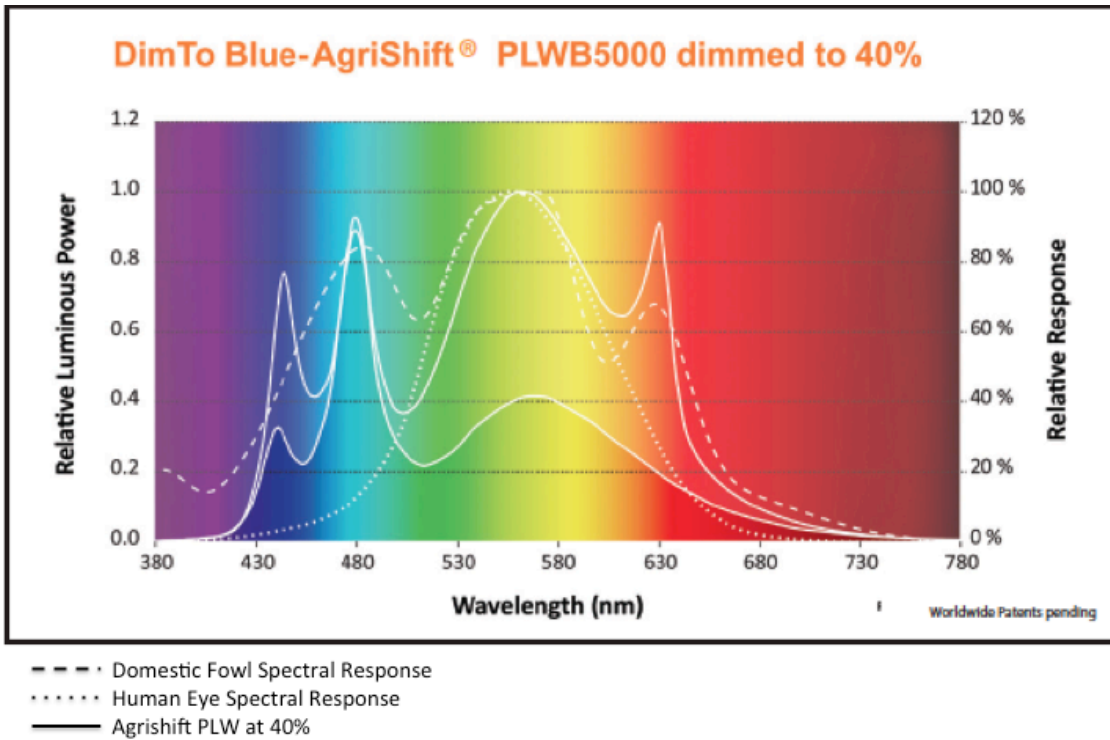


Figure 16 Spectral emission of Once AgriShift PLW at 40% luminance (Once Innovations Inc., 2010, 1-6).

Appendix B

AACUC APPROVAL LETTER

UNIVERSITY OF DELAWARE  
COLLEGE OF AGRICULTURE AND NATURAL RESOURCES  
AGRICULTURAL ANIMAL CARE AND USE COMMITTEE

Application for Use of Agricultural Animals  
In Teaching or Research

AACUC Protocol Number: (33) 04-17-12R

TITLE OF PROJECT: USPEA: Impact of Incandescent, CFL, Cold Cathode, and LED Lamps on Bird Health

INSTRUCTOR/PRINCIPAL INVESTIGATOR

Eric Benson  
Printed Name

  
Signature

5/7/2012  
Date

.....  
(This section for Committee use only)

Application Approved (date) 5-1-2012

Application Rejected (date) \_\_\_\_\_

Reason for Rejection \_\_\_\_\_

  
Signature, Animal Care and Use Committee

5/8/2012  
Date