THE USE OF LED LIGHT DURING INCUBATION ON HATCHING AND POSTHATCH PERFORMANCE FOR DISTINCT CHICKEN LINES

by

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ABSTRACT

The aim of this study was to determine the effect of LED lights of different colors during incubation of chicken eggs on the hatch performance, chick quality, posthatch growth and slaughter yields for various chicken lines. Two replicate trials were performed using two commercial broiler lines, one commercial egg laying line and a 1978 random bred broiler line. All eggs were incubated in one of the following lighting regimes; red, blue, or white LED for 12 h per day and a dark control. Chicks began hatching earlier in incubators with red light and achieved 50 and 75% hatch sooner than white or dark. Chicks hatched under red light gained more weight in the first 6 h in the barn compared to the dark treatment. No differences were reported for overall growth and slaughter performance.
Light stimulation during incubation influenced early growth but these effects did not persist until market age.

LIST OF ABBEVIATIONS USED

12L:12D	12 hours of light: 12 hours of dark
AMC	Alberta meat control 1978 random bred broiler line
APRC	Atlantic poultry research centre
ACUC	Animal Care and Use Committee
BW	Body weight
CFL	Compact florescent
d	Day
ED	Embryonic day
K	Kelvin
LED	Light emitting diode
Layer	Lohmann Lite LSL strain
nm	Nanometers
RH	Relative humidity
SOP	Standard operating procedure
YFBW	Yolk free body weight

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CHAPTER 1 INTRODUCTION

Broiler chicken production in Canada has been an agriculture success story with the industry growing substantially over time. The consumption of chicken continues to increase, as it is a competitively priced protein source, and the lean property of breast muscle has gained popularity among consumers (Halevy et al., 2006a). Historically, before World War II most chicken was sold as a whole carcass, approximately 30 years later consumer preference started shifting from whole carcass to carcass parts, with the most desired cuts being breast and leg versus wings (Petracci et al., 2015). Most Canadian consumers prefer white meat over dark; this is demonstrated by rise in imported boneless skinless breast from 2016 to 2017 rising approximately 10 Mkg (Chicken Farmers of Canada, 2017). Breast meat has become increasingly popular due to its characteristic leanness which has resulted in producers recognizing the importance of good quality and high yields of this cut (Velleman, 2007). In recent years advances in genetics have resulted in broilers with increased breast meat yields that account for more than 20% of the total live bird weight, increasing 5% in both male and female birds (Aviagen, 2013). Even small advances in increased breast meat yields are beneficial, as breast meat is the most valuable and leading carcass cut in the United States (Scheuermann et al., 2003).

Significant changes in genetics, nutrition and management in broiler production since the mid 1950s has resulted in reduced rearing time to produce the desired carcass weight (Zuidhof et al., 2014). Since the average incubation time for chicken embryos has not change over the years, the period of incubation becomes a more prominent period in the life of a broiler (Halevy et al., 2006a). Thus, management practices regarding incubation

are becoming increasingly important for optimizing bird performance (Halevy et al., 2006a, 2006b).

Conventionally, most hatcheries have incubated and hatched broiler chickens in complete darkness. This differs from the natural incubation process where a clutch of eggs would receive light exposure when the hen leaves to feed and drink or turn the eggs (Mrosovsky and Sherry, 1980; Archer and Mench, 2014). With increasing knowledge of how light affects the avian species, potentially light should be incorporated before the bird hatches. Lighting may not only affect growth performance but also may influence health parameters and behaviors of birds.

This project aims to investigate the effect of providing light during incubation (*in ovo*) of four different strains of chickens for hatch success, chick quality, bird growth, and carcass parts yield. The following is a short literature review presenting findings from past and current research in incubation lighting with respect to broiler chicken production.

CHAPTER 2 LITERATURE REVIEW

2.1 Effect of light in the avian species

Vertebrates are known to have biological daily rhythms (i.e., circadian rhythms) that allow them to react to the environments they reside in (Underwood et al., 2001). Organs that are involved in circadian rhythms vary among species; the pineal organ, suprachiasmatic nucleus of the hypothalamus and eye have been reported to be the main components responsible for the organization of circadian rhythms in birds (Zeman and Herichová, 2011). Much is still unknown about circadian rhythms, in birds, and more specifically chickens. It is thought that chicks may establish rhythms to cope with life out of the mother as they do not receive direct endocrine signals from their mother (Tong et al., 2018). Past research has provided evidence that, even as embryos, chickens are able to respond to light exposure during development (Archer, 2017). It is known that light exposure is important for establishment of a circadian rhythm (Tong et al., 2018).

Avian species are more sensitive to light spectrum compared to humans (Prescott and Wathes, 1999). The anatomy of the cone and rods within the retina of chickens causes their visual capacity to be different compared to most other vertebrate species (Bruhn and Cepko, 1996). Human have 3 different types of cones within the eye whereas birds have 4, allowing for a broader color spectrum (Tong et al., 2018). Light has been shown to influence the embryo as early as day 3 of incubation (Erwin et al., 1971). Despite the many papers investigating light stimulation in poultry production, firm evidence has yet to be reported on which light wavelength is optimal for chick production parameters, such as increased hatchability, chick quality and welfare (Archer, 2017). Use of artificial

lighting within broiler production is known to be a stimulatory management tool, both during incubation and in the rearing environment (Dishon et al., 2017). Photoperiods of 12L:12D are sufficient for entrainment of circadian rhythms (Hill et al., 2004). Lighting studies involving different light spectra or colors are not new; older studies evaluated the effect of rearing broilers in different light spectra. Exposing avian species to differing wavelengths/colors of light may potentially result in physiological or behavioral responses (Archer, 2017). The use of colored lighting sources of different wavelengths, to improve avian production and performance, dates back as early as 1950 (Cao et al., 2012).

2.2 Environmental incubation conditions

Environmental factors can impact embryo development and subsequent hatch parameters such as percent hatch, spread of hatch, navel quality and posthatch growth (Archer et al., 2009; Huth and Archer, 2015; Archer et al., 2017; Clark et al., 2017). These environmental conditions during incubation can affect bird behaviors, health and growth later in life (Archer et al., 2009). Incubation environmental factors include temperature, humidity, physically turning the eggs and, more recently, light (Archer, 2017). *In ovo* photostimulation, defined as the use of light during incubation, has become a popular area of research for poultry, and key aspects are light duration (photoperiod), intensity and wavelength. Most incubation research has focused on temperature, humidity and turning whereas lighting has not been studied to the same extent as the other factors (Archer, 2017). Light is an environmental stimulus that should not be ignored as it is evident that embryos respond to light as highlighted by past research (Archer et al., 2017). Some of

the first work on the use of LEDs during incubation were started in 2015, as Huth and Archer (2015) reported that lighting during incubation can impact hatchability. However, LED technology had not been evaluated at that time for use in incubation units at a commercial level. Research by this group reported that broiler chicks incubated in light benefited from increased hatchability compared to the dark hatched chicks, 90.12% and 85.76% respectively (Huth and Archer, 2015). Differences in hatchability was not present for the white leghorn strain as was in the broiler strain. Not only did the light treatment improve hatch of fertile eggs but also had a lower percentage of chicks with defects compared to those incubated in the dark (Huth and Archer, 2015). Use of LED lighting could be superior to incandescent and CFL as they have reduced energy use and produce minimal heat or no heat. (Huth and Archer, 2015)

2.3 Effect of light during incubation on hatching performance

It is still unknown what light color best optimizes the hatch window (Archer, 2018). Yu et al. (2018) suggest that white and red light have been considered the spectra that improve hatchability. Archer (2017) evaluated red (max. 630 nm) and white light (7500 K) finding superior hatchability compared to eggs incubated in the dark. It is reported that wavelength of light filtering through broiler eggshells remains unchanged for red and green LED light spectrums, allowing both colors in (Archer, 2017). Inconsistent results have been reported between researchers studying the effect of green lighting during incubation of broilers. Archer (2017) has equated use of green lights in the incubator comparable to dark conditions in terms of hatchability and chick quality. Eggs incubated in white light had the greatest hatchability and heavier chick weights compared to chicks

who hatched from incubators with blue light and the control (dark) (Hluchý et al., 2012). Further studies were completed by Archer et al. (2017) to determine the effect of light during incubation on hatchability and embryo mortality. The study used a LED light fixture from Once Innovation® on a 12L:12D photoperiod, the light fixture was dimmed to 40% to give a combination of white and red LED. Their study evaluated three poultry types consisting of White Leghorns, an unnamed commercial broiler strain and Pekin duck hatching eggs. In all bird types the LED light treatment produced chicks with fewer defects and unhealed navels and a higher percent hatch of fertile than the respective types in the dark incubators (Archer et al., 2017). Other studies have reported no differences in hatchability when using different photoperiods of white light during incubation (Graham and Rathgeber, 2016; Graham et al., 2017b). Using monochromatic green light and blue light compared to a dark control also reported no differences in hatchability or hatch weight (Zhang et al., 2012). While some research groups have reported increases in embryo or eggshell temperatures when using monochromatic light stimuli in incubators (Rozenboim et al., 2004). Zhang et al. (2016) found no differences in weight loss of fertile eggs related to overheating from provision of light. Lighting treatments did not affect hatchability or hatch time either. (Zhang et al., 2016)

2.4 Effect of light during incubation on the spread of hatch

Spread of hatch commonly occurs over a 24 - 48 h span, this large range results in early hatching chicks being deprived of feed and water longer (Careghi et al., 2005; Wang et al., 2014). Excessive time in the hatcher and deprivation of feed can result in chick weight losses and can hinder future posthatch growth (Careghi et al., 2005). With this in

mind, spread of hatch is of high importance in chick production and should be a measurement taken when performing hatch studies. In a study conducted at Dalhousie University, chicks provided light (12L: 12D photoperiod) from d 9 of incubation reached 50% hatch of the asymptote quicker than those in the dark for 2 commercial layer strains (Lohmann LSL Lite and Lohmann Brown) and a heritage Barred Plymouth Rock (Hannah et al., 2019). Abeysinghe (2019) evaluated different light colors on hatching eggs from two commercial laying hen strains. Bird incubated with red light completed hatching 4 h before blue LED and dark conditions, and only 3 h before white lit birds. In the same study, it was reported that the red LED incubation treatment, had a narrower hatch window (Abeysinghe, 2019).

2.5 Chick quality and placement in the rearing facility

It is no surprise that hatcheries strive for high hatchability. However, it is key that along with high hatchability, there should be a high percentage of sellable chicks that have hatched within a narrow range of each other. This is connected closely with farmers' needs and wants; high growth rate, increased breast yields and superior feed conversion, valued characteristics in today's broilers (Decuypere and Bruggeman, 2007). In a review by Tona et al. (2005), broiler producers claimed that obtaining chicks of lesser quality can decrease the slaughter weight by 200 – 300 g compared to higher quality chicks. The number of unhealed navels was a key factor attributing to the differences reported in broiler chick quality in one study using white LED with a 12L:12D photoperiod compared to a dark treatment (Huth and Archer, 2015). Chick quality was improved when Once Innovation® dimming light fixtures containing high levels of red or blue wavelengths were used compared to hatching chicks in the dark (Archer, 2018). As with

other studies authored by Archer, the increased chick quality was mainly due to healed navels, however, there were fewer chicks with defects overall in the light treatments (Archer, 2018). Navel closure has become increasingly important as farmers are moving towards antibiotic-free production (Archer, 2018). Despite uncertainty of the true definition of chick quality and how it is affected, there is no doubt that traits such as chick weight and length are valuable and related to bird performance in some capacity (Tona et al., 2005). After performing research on eight different broiler breeder lines, Wolanski et al. (2006) also concluded that chick quality should not only include hatch weight but other factors such as navel closure, chick length and chick activity.

2.5.1 Chick quality scoring systems

Hatcheries aim to optimize the number of saleable chicks that are produced, as there has been a direct link between chick quality and bird performance (İpek and Sözcü, 2013). Improvements in growth performance and quality at slaughter begins with a better quality chick (Tona et al., 2003). Commonly used measurements for chick quality are chick weight, yolk free body weight and chick length (İpek and Sözcü, 2013).

There are many descriptions of what a good quality sellable chick is. This can be dependent on the type of scoring system used. In a review by Decuypere and Bruggeman (2007) it was agreed that criteria consist of a clean, dry chick free from deformities. Chicks must also have clean, closed navels free from protruding yolk sac remnants. As chicks with unhealed navel are poor quality and may be culled depending on the severity of the navel closure. Both quantitative and qualitative scoring systems have been used for determining a good quality day-old chick (Decuypere and Bruggeman, 2007). A common

quantitative measurement is hatchling weight. However, there have been discrepancies among studies, chick weight may not necessarily be a good indicator for quality but rather connected more closely to egg weight (İpek and Sözcü, 2013). Other measurements also include chick length. Qualitative scoring is more subjective as it relies on the person doing the measuring. To eliminate some of the bias associated with this method, scoring systems have been developed to create a quantitative score (Decuypere and Bruggeman, 2007). One research group proposed that along with chick quality scoring methods, that chick body weight up to d 7 posthatch also be considered in determining the broilers potential growth (Tona et al., 2003).

Research in the Netherlands reported that there is no clear correlation between the chick quality score and performance of sellable chicks or those classified with defects (van de Ven et al., 2012). Benefits to day-old chick quality and their posthatch performance have been observed with the addition of light during incubation. The inclusion of intermittent green light (15 mins on, 15 mins off) in incubators have resulted in chicks with increased weight and faster hatching rates compared to the dark treatment (Halevy et al., 2006b). Incubating broiler eggs under 12 h of white light per day reduced stress and fear responses in young broilers (Archer and Mench, 2014). Archer (2017) found that chicks incubated in dark conditions resulted in a greater number of unhealed navels compared to those in incubators with either white, red or green light. Addition of lighting to incubators could not only benefit performance, but potentially decrease the number of culls due to the improved chick quality (Archer, 2017).

2.5.2 Chick length

Petek et al. (2010) performed a study to determine if there was a correlation between a chick's length and their performance posthatch. They categorized their chicks into three groups; small (< 18.0 cm), middle (18.0 - 18.3 cm) and large (> 18.3 cm). Chick length was defined as the length from the beak to the middle toe of a stretched chick. Day old chick lengths were found to be related to chick weight; chicks in the large length category were also the heaviest. The difference between the small and large groups were 3.4 g in weight. Chicks that were in the middle and large categories for chick length were heavier at the end of the experiment than the small chicks (Petek et al., 2010).

2.5.3 Navel scoring

Incomplete navel closure or yolk sac absorption can leave a scab or wick of protruding membrane, this can lead to conditions such as leaky navel or yolk sac infections (İpek and Sözcü, 2013). Navel scoring is one of the most commonly incorporated measurements used in assessment of the quality of newly hatched chicks. In an Archer (2018) study, chicks hatched in incubators kept in the dark had higher incidence of unhealed navels compared to red or blue LED illuminated incubators. Chicks with poor quality navels weighed on average 80 g less at d 42 than chicks with superior navel quality (van de Ven et al., 2012).

2.5.4 Hatchling weight

Chick weight is said to be the most common measurement to assess chick quality (Petek et al., 2010). However, some think that it may not be an accurate way to predict posthatch growth as there is some unknown quantity of residual yolk in the abdomen of a day-old

chick (Wolanski et al., 2006; Molenaar et al., 2008). Some researchers are skeptical if chick weight at hatch is an accurate predictor of future broiler performance and market weight (Ulmer-Franco et al., 2010). It was suggested that chick weight should not be the only chick quality measurement taken when defining a good quality chick that will be productive (Wolanski et al., 2006). However, in a review by Noy and Sklan (1997) it was suggested that hatch weight is positively correlated with posthatch growth. Lights of various colors have been investigated over the past decade in relation to weight of chicks at hatch. Many have reported no differences in hatchling weight between their respective light treatments and dark control (Zhang et al., 2012; Rozenboim et al., 2013; Zhang et al., 2014; Graham et al., 2017b; Tong et al., 2018; Yu et al., 2018). Graham and Rathgeber (2016) used white LED light on a 12L:12D photoperiod for broiler hatching eggs and reported that chicks hatched in the dark were heavier than those provided a photoperiod throughout the incubation period. Li et al. (2017) also reported that dark hatched chicks were heavier (45.8 g) compared to chicks hatched in incubators with light (44.8 g). Yolk free body weight (YFBW) was reported to be the same for chicks hatched in the dark or with a photoperiod (16L:8D) of cool daylight (6 200 K) (Özkan et al., 2012). Contrary to Özkan et al. (2012), Yeager et al. (2005) reported that chicks provided near infrared light had increased yolk utilization and hatchling weight compared to chicks hatched in the dark.

2.6 Growth performance

2.6.1 Genetic improvements in broiler growth

Today's broilers outperform their past broiler counterparts, in terms of growth rate (Zuidhof et al., 2014). Changes in production performance can be attributed to the environmental conditions, however over 85% of these gains are the result of genetic

selection (Havenstein et al., 1994). Compared to the late 1950's, broilers are growing over four times the size in the same amount of time, while being more feed efficient (Zuidhof et al., 2014). Broilers along with other chicken strains and species, are known to exhibit sexual dimorphism such as differences in body weight and carcass part yield. In a study analyzing genetic components from Aviagen™ records, it was reported that, on average, males were 275 g heavier than females at d 35 (Maniatis et al., 2013). As chickens have been genetically selected, sexual dimorphism has become increasingly apparent. Differences in breast yield among sexes were not reported in Alberta Meat Control (AMC) 1957 strain but were in the more current 2005 strain (Zuidhof et al., 2014). Zuidhof et al. (2014), reported that the AMC-1957 strain had the highest residual feed intake and the poorest feed efficiency compared to the AMC-1978 and 2005 birds. This is evidence that as broiler breeder companies have selected for growth potential that feed efficiency has also been improved (Zuidhof et al., 2014).

2.6.2 Light and bird growth

Environmental management involving different light types and photoperiods is not new to broiler production. A study by Archer (2017), reported that Cobb 500 broilers grown to 45 d did not differ in body weight among various in *ovo* lighting treatments of white, red and green LEDs. In the study by Cao et al. (2008), body weight differences were reported among 23L:1D treatments at d 13, 18, 27 and 38 - 48 where birds grown under blue or green light were significantly larger than those grown under red or white light. The results by Archer (2017) differed compared to those found by Cao et al. (2008) differences could be due to Archer (2017) using lighting during incubation and Cao et al. (2008) using light

during the rearing period. As well different lines of birds were used for each study, Arbor Acres male broilers compared to Cobb 500 of both sexes.

Increased growth rates have been reported in young chicks as early as d 3 posthatch that have been incubated under green lighting (560 nm) compared to white or red (660nm) (Dishon et al., 2017). It is thought that the blue and green wavelength light sources could influence the epithelium of the small intestine and could result in improved feed conversion and superior growth (Cao et al., 2012). Other research supports the theory of improved feed conversion as birds incubated in green light had increased villus height and a decrease in crypt depth, helping improve feed conversion (Xie et al., 2011). Results on growth and breast muscle yields of birds grown in blue and green light, or a combination thereof, have yielded heavier birds and improved carcass part yields such as breast and thigh (Cao et al., 2012). In a review completed by Halevy et al. (2006a) it was concluded that an incubation lighting period (dark vs green light) paired with lighting treatment posthatch (white or green light) was most effective in providing superior development and growth in broilers. While lighting research has been active in the last decade, much is still unknown as to what spectra of lighting is best suited to improving certain production traits.

2.7 Breast Muscle

2.7.1 Embryonic Muscle Development

Most developmental potential of muscle fibers in the avian species is accomplished by the time the chick has hatched (Halevy et al., 1998; Velleman, 2007). During embryogenesis,

muscle development is attributed to hyperplasia, the increase of myoblast number (Velleman, 2007). During embryogenesis, muscle development is attributed to hyperplasia, the increase of myoblast number (Velleman, 2007). Myoblast development occurs while a chick is in the egg, cells originating from the mesoderm differentiate into myoblasts that contribute to muscle development (Halevy et al., 1998). Muscle growth in post-hatch chicks is hypothesized to be the result of satellite cell activity, either proliferation creating multinucleated fibers or differentiation that contributes to the hypertrophy of muscle fibers (Halevy et al., 1998; Velleman, 2007). There is a direct relationship between skeletal muscle growth post-hatch and the number of satellite cells present (Liu et al., 2010). The lifetime of a broiler chicken is relatively short and the most crucial period for muscle growth is during the first week posthatch (Halevy et al., 1998). Embryos exposed to green light during incubation had heavier breasts at day 6 posthatch than those incubated in the traditional dark treatment (Zhang et al., 2016). Halevy et al. (1998) were among the first to discover that external environmental factors aside from nutrition, such as monochromatic light exposure, could influence growth in broilers by targeting satellite cell proliferation. Muscle development measured as breast weight and expressed as a percentage of total embryo weight of birds incubated with green light was greater than those in dark incubation treatments (Rozenboim et al., 2004). These results were reported during most of the sampling time points from embryonic day (ED) 11 until hatch (Rozenboim et al., 2004).

2.7.2 Carcass part yield

Genetic selection for yields of various carcass part yields in chickens have been very successful. Breast muscle yields have changed significantly from 1957 to 2005. Pectoralis

major yields have increased 79% in males and 85% in females (Zuidhof et al., 2014). The number of birds marketed as a whole carcass has decreased over 85% from 1962 to 2005, as the market is wanting more cut-up and further processed products (Anonymous, 2011). A study using different bird strains was carried out to determine differences in carcass part yields; broilers had greater breast and thigh proportions while drum percent was comparable to layer and traditional strains (Sandercock et al., 2009). Strain differences have been reported for breast yields among Ross and Cobb birds, where Cobb birds consistently had larger breasts (Lewis et al., 2009). Differences between sexes are reported, however opposing results have been documented. Females yielded greater carcass and breast meat yields compared to males in two different studies (Young et al., 2001; Brickett et al., 2007). Scheuermann et al. (2003) had opposing results, reporting that males had significantly heavier body and breast muscle weights but not when expressed as a percentage yield.

2.7.3 Light and breast muscle yield posthatch

In terms of lighting studies, early findings by Halevy et al. (1998) reported that the only differences for absolute breast muscle weight were between green and red light; green resulted in significantly higher breast muscle weight than red but did not differ from either blue or white light treatments which were intermediate. When breast muscle weights were analyzed as a percentage of the body weight, there were no differences found within treatments (Halevy et al., 1998). Chicks, 6 d of age, hatched from incubators with the inclusion of fluorescent cool white light (4,000K), resulted in increased absolute breast muscle weights compared to chicks incubated in the commercial standard dark (Özkan et al., 2012). In a study by Cao et al. (2008), birds reared under 23L:1D blue light had

significantly increased carcass and breast muscle yields compared to those reared in green, white and red light. Green light was also found to increase body weights in early posthatch life, compared to red light thus benefitting bird performance later in life close to slaughter age (Cao et al., 2012). Liu et al. (2010) reported breast muscle in green light reared birds was greater than for all other treatments (blue, red and white). In a study birds were reared in different wavelength of light on a photoperiod of 23L:1D, it was reported that body weight and breast muscle weight significantly increased for birds incubated in monochromatic green compared to blue and dark until d 6 (Zhang et al., 2012).

With the breast meat being the most valuable component of a broiler carcass, it is generally beneficial to use practices that will increase the breast meat yield. It is known that posthatch lighting is also very important for influencing carcass parts yield. The general consensus is that continuous (24 h) or near continuous (23 h) lighting results in broilers with higher relative breast meat yield and lower leg meat yield (Lien et al., 2007) compared to photoperiods with longer periods of dark. Henry et al. (2017) reported that breast muscle yield was greater (22.4%) in 23L:1D photoperiods compared to 18L:6D. Shortening the number of hours that lights are on has been reported to reduce breast meat yield (Renden et al., 1991). The new codes of practice for production of broiler chickens require that producers provide at least 4 h of dark per day for a night period. A study by Schwean-Lardner and Classen (2010) reported that breast yield as a percentage of hot carcass weight increases when reared in long days. Body weight of broilers however are optimized at photoperiods of 20L:4D compared to 23L:1D (Schwean-Lardner and Classen, 2010). Provision of light during incubation to stimulate breast muscle

development could be a way to increase breast muscle yields on carcasses that have already been optimized in terms of body weight.

Studies indicated that the wavelength of light used during incubation of hatching eggs has an impact on muscle development on a molecular level (Halevy et al., 2006a; Liu et al., 2010). There is evidence that green light may change the number of stem cells destined to be breast muscle (Halevy et al., 2006a; Lui et al., 2010; Zhang et al., 2014). It has not been established how increasing the number of stem cells may influence the bird's response to posthatch photoperiods with longer dark hours. *In ovo* illumination or lighting during incubation should be investigated to determine if there is in an impact on the breast muscle tissue in newly hatched chicks and market age broilers of different bird lines. If positive results are found, this would benefit producers with a higher yielding bird while maintaining the welfare and abiding by the codes of practice recommended 4 h dark period per day.

CHAPTER 3 HATCH PERFORMANCE AND CHICK QUALITY OF DIFFERENT CHICKEN LINES PROVIDED LIGHT DURING INCUBATION

3.1 Abstract

Getting chicks off to a good start in the rearing environment is key to health and productivity of the flock. One method of measuring how chicks are adjusting to their environment is weighing a select group of birds at placement and again 6 h later to determine early weight gain. Hatchery practices are constantly changing, an example that has been under investigation is to provide light during incubation. The objective of this study was to determine if the use of LED lighting during incubation of multiple strains of chickens affected hatchability, embryo mortality, and chick quality parameters. Two replicate trials were performed using the following strains: Ross 308, Cobb 500, Lohmann LSL Lite and a 1978 random bred broiler line from the University of Alberta (AMC). Eight incubators were used, setting 824 eggs in trial 1 and 836 eggs in trial 2. Incubation lighting consisted of 4 treatments: dark (no light), white LED, dim to red LED, and dim to blue LED. Incubators with lights had a 12L:12D photoperiod and were replicated using 2 incubators for each trial. Incubators were opened briefly to count the number of chicks hatched in 3 h intervals starting at 461 h of incubation. Chicks were pulled from the incubators at 515 h and counted to calculate hatchability. All chicks were then batched weighed and navel scored. A subset group of chicks from each treatment were measured for chick length. No differences were found between light treatments for hatchability and embryo mortality. Significant differences were found between strains for: hatchability, mid and late dead embryo mortality. There was a significant difference in chick length among lighting treatments. Birds regardless of strain were longer in the dim to blue LED treatment and in the dark control compared to those incubated in white or red. Chick length differed among strains with Cobb being longer than the layers, while Ross and AMC birds were intermediate. There were no differences found between lighting treatments for navel scores. However, there were strain differences for navel scores, Ross birds had superior navels compared to the layers, with Cobb and AMC birds intermediate. Strain differences were expected as the genetic background differs greatly between the older genetics and current day broilers and layers. Lighting during incubation impacted rate of hatch and early chick weight gain differently depending on the light used but was not found to effect hatchability or embryo mortality for strains of chickens studied.

Key words: incubation, LED light, hatchability, hatch rate, chick size

3.2 Introduction

Hatcheries want to maximize their production of good quality chicks, as well with optimal hatchability, minimal embryo mortality and late hatching chicks. Historically most incubation units were not equipped with lights. In the broiler industry this is even more important as chicks spend a shorter time in the rearing facility to achieve the desired market weight. Historically when investigating the incubation environment there were three main factors of interest, temperature, relative humidity, and egg turning. The most recent incubation environment factor studied that should be added to the above list is light. Light has not only been effective in the rearing environment but also during the incubation phase, however results have been contradictory and inconsistent (Archer and Mench, 2014; Archer, 2017).

Typically, the hatching period occurs over a 24-48 h span, chicks that hatch at the first of this period reside in the incubator until the final chick hatched is dry (Careghi et al., 2005; Powell et al., 2016). Various factors can affect spread of hatch from environmental conditions to egg storage time, egg size and breeder age (Decuypere et al., 2001). Early studies used incandescent light during incubation, this older style of light bulb created excess heat from the wire filament that is required to heat up to create a glow. Incubating broiler hatching eggs under constant incandescent light caused chicks to hatch earlier than when a photoperiod of 12L:12D or dark were used (Walter and Voitle, 1972). Recent studies have evaluated LED lights and have shown that addition of LED photoperiodic light to incubators can shorten the incubation period (El-Sabrout and Khalil, 2017; Tong et al., 2018). Many light intensities, colors and photoperiods have been investigated but consistent results have yet to be found.

One of the key measurements to monitor is number of chicks are hatched from fertile eggs placed in the incubator, or hatchability. A study performed using Cobb 500 and Ross 308 broilers reported increases in hatchability from 85.76% hatch of fertile eggs in the dark incubators to 90.12% when using white LED light on a 12L:12D photoperiod (Huth and Archer, 2015). Fewer chicks had defects in the light treatment group, however the weight of these chicks was significantly lower at 46.05 $\pm$ 0.58 g compared to chicks hatched in the dark (47.46 $\pm$ 0.58 g) (Huth and Archer, 2015).

Chick quality is very important to broiler producers, as they are most interested in chicks with high growth potential (Willemsen et al., 2008). High importance is placed on chick quality results as they can indicate chicks that will require shorter rearing times from increased growth, and fewer mortalities during the grow out period. It is not only broiler farmers that value good quality chicks, hatcheries in Canada profit based on number of saleable chicks rather than number of chicks produced (Ulmer-Franco et al., 2010). Common measurements used to assess chick quality are chick weight, chick length, and navel score. Scoring systems have been developed over the years that consider more than one chick quality parameter and give a quantitative score on qualitative measurements (İpek and Sözcü, 2013). Many factors are known to affect chick quality, such as: age of breeders, size of egg, storage time of eggs, and incubation environment (Onagbesan et al., 2007). It has been suggested that quality may be affected by presence of light rather than a specific spectrum (Huth & Archer, 2015), however many studies show spectral differences (Hannah et al., 2019).

Studies have not been performed investigating light colour during incubation on multiple strains of chickens including commercial broilers, at the same time. Two commercial broiler lines and one commercial laying hen line were compared to a random-bred line of chickens to acquire more information on how hatch performance and chick quality of certain genetic strains of chickens will respond to incubation in different colors of light.

3.3 Objectives

The objectives of the study were to:

- To evaluate the use of LED lights of different colors during incubation on the hatching performance parameters: hatch window, hatchability and embryo mortality of four different bird strains.
- To evaluate chick quality of four different strains of chickens incubated with the use of different color of LED light.
- To evaluate how different lines of birds adapt to the rearing environment after being incubated in different colors of LED lights during incubation.

3.4 Hypotheses

It is hypothesized that hatching performance will be affected by LED light. Eggs incubated in light treatments will have a higher hatch of fertile eggs, with less embryo mortality; this is expected to be consistent across all four bird strains. The use of LED light during incubation will impact the hatch window, with red light producing a narrower range of time to complete the hatch than the dark treatment.

Chicks hatched in incubators under light conditions will be more robust and better suited for the rearing environment. Chicks hatched in light treatments will be developmentally advanced therefore being heavier, longer chicks with better healed navels.

The use of lighting during incubation will benefit chicks by allowing them to better adapt to their environment when placed in the rearing facility. This will result in increased weight gain as a percentage of total body mass during the first 6 h of placement.

3.5 Materials & Methods

The following experiment was performed using procedures approved by the Animal Care and Use Committee (ACUC) of Dalhousie University, Nova Scotia, Canada.

3.5.1 Experimental Design

The experiment was a completely randomized design. Experimental unit being incubator. A 4x4 factorial arrangement was used, the main effects were line of bird and incubation light treatment.

3.5.2 Hatching Eggs

Fertilized eggs from four different strains of birds were obtained to complete the experiment. Two commercial broiler lines available in Atlantic Canada, were used as these strains are relevant to the broiler industry. Both lines were fast feathering, sex could not be determined at hatch by feather sexing. Eggs were obtained from separate breeding companies, Ross 308 and Cobb 500. A commercial layer strain was included in the experiment to determine if they reacted to light differently than broiler strains, as they have not been selected for muscle development as the modern-day broilers have. The fourth

strain used was an unselected 1978 male line broiler that was obtained from the University of Alberta Poultry Research Centre. The Alberta meat control (AMC) line represents how broilers in 1978 would perform. This addition to the study allows for comparison of the effects of light before modern day broilers were highly selected for growth and feed conversion. The commercial broiler and layer eggs were transported by truck within Nova Scotia and AMC eggs were transported by air from Alberta. Eggs were stored at a temperature of 19°C upon arrival until setting in the incubators, Commercial eggs (Ross, Cobb, Layer) were collected from the same day while the AMC eggs were collected over a period of 10 days.

3.5.3 Incubation procedure

Chick Master® G09 incubators (Chick Master®, Medina, Ohio) were used for the experiment. Six of the eight incubators were equipped with LED lights on the left interior side of the unit. This location was chosen to allow for even light distribution and to avoid interference with air movement within the incubator. Three light colors used were a white full spectrum 4100K LED (Canarm®, Brockville, ON), dim to red LED (Once Innovations®, Plymouth, MN) and dim to blue LED (Once Innovations®, Plymouth, MN). The quality of the LED light bulbs was tested by the manufactures before releasing to the market for commercial use. The photoperiod and dim percentage of each of the dim light color treatments were controlled by the AgriShift® control panel to provide consistent light between incubators and trials. To achieve the same light intensity as the white LED the dim to red was dimmed to 60% and the blue dimmed to 40%. Figures 1 and 2 show the range in wavelength output in nanometers (nm), when dimmed to their respective percentages.

These light fixtures are not monochromatic as other studies have used, as reported in the literature review. The remaining two incubators were left without lights (dark) to represent the control, as lights are not commonly used in commercial hatcheries. Incubators equipped with lights were on a timer to provide a photoperiod of 12 h of light followed by 12 h of dark (12L:12D) set to an intensity of 250 lux at egg level. Lights were on at 7:00 am and off at 7:00 pm.

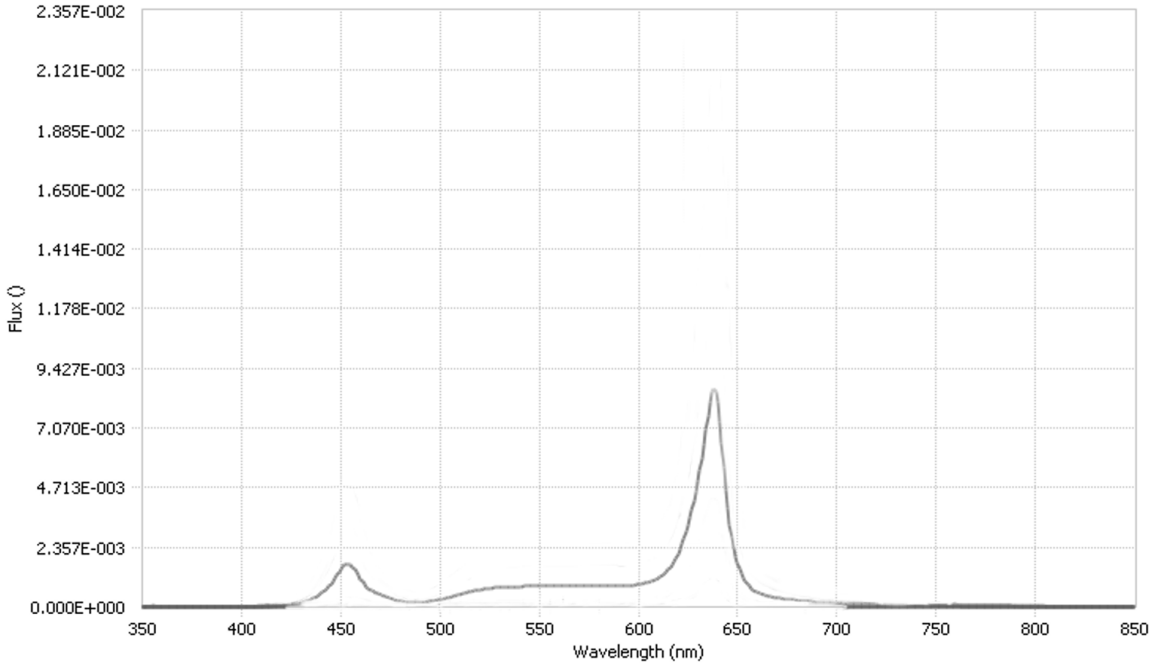

Figure 1. Wavelength output (nm) of Once Innovation® dim to red LED light fixture dimmed to 60%

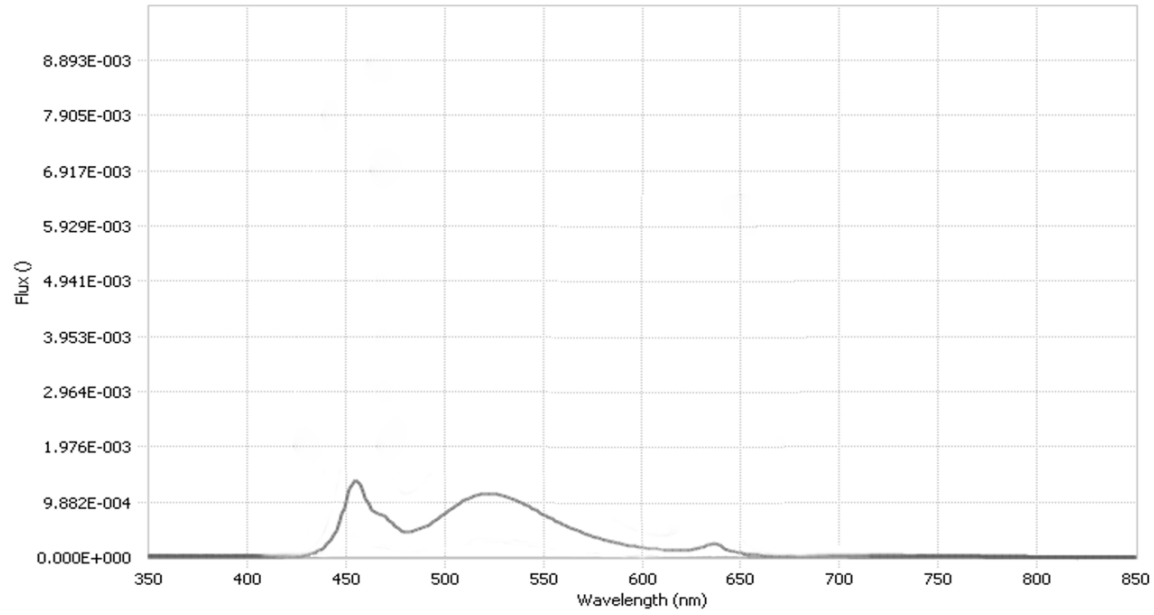

Figure 2. Wavelength output (nm) of Once Innovation® dim to blue LED light fixture dimmed to 40%

Incubators were preheated for 24 h prior to the setting of eggs to ensure that proper temperature and humidity were stable. During the setting phase (ED 0-18) the eggs were maintained at a dry bulb temperature of 37.5°C and RH of 55%. Trays of eggs were turned on a 90^{o} arc four times an hour from time of set until ED 18 when eggs were candled and transferred to hatch baskets. Hatchery checks were performed twice daily, and the temperature, humidity and time of day were recorded for each of the 8 incubators. All eggs were batched weighed prior to being placed in the incubator and at the time of transfer to the hatch baskets, to calculate egg weight loss. Egg weight loss is due to the diffusion of water from metabolic processes through the shell during the incubation period, it can affect the quality and hatchability of chicks (Tona et al., 2001). Therefore, egg weight loss was measured as incubation quality control aspect. All bird strains were represented in each incubator and were randomly assigned to separate trays within the respective incubator. Table 1. shows the average number of eggs set per incubator over the two trials used in the experiment. Number of eggs set per strain are not consistent due to removal of eggs that were dirty or had cracks.

Table 1. Average number of hatching eggs set per incubator

Strain	Trial 1	Trial 2
Cobb	52	53
Ross	52	54
Layer	50	50
AMC	52	52

Figure 3. Description of each day of embryonic development in the chick

On ED 18 trays were removed from the incubators and weighed, all eggs were candled in a dark room. Eggs with viable embryos were separated from infertile and nonviable eggs and reweighed prior to transfer to hatch baskets. All eggs removed from the incubators were labeled with treatment number and incubator and broke open after candling to determine stage of development. Three categories were used for mortality classification; early (ED 0-7), mid (ED 8-14) or late dead (ED 15-21), based on images showing the size and development of the embryo (Figure 3).

Hatch baskets were assembled on the incubator carts and returned to their respective incubators. Hatch baskets contained dividers to allow hatched chicks to be counted every 3 h to determine the spread of hatch. Spread of hatch or hatch window is defined as the number of h from the time the first chick hatches until the last chick hatches within a respective treatment. Hatch counts started at 461 h of incubation and were completed every 3 h until 512 h of incubation. Table 2. shows the temperature and relative humidity schedule that was manually set during the hatch phase (day 19 - hatch). At 512 h of incubation the hatch was pulled, and chick processing began. An additional count of chicks was made at 515 h although these chicks that hatched after 512 h were not included in the growth phase of the study.

Table 2. Temperature and relative humidity set points for incubation of chicks at DAL AC hatchery

Days of incubation	Temperature (°C)	Relative Humidity (%)
0	37.5	55
Day 17	37.5	55
Day 19	37.5	64
Day 20 am	37.5	72
Day 20 pm	37.5	82
Hatch day	37.5	55

3.5.4 Chick processing

Upon removal from the incubator, chicks from each basket were counted and batch weighed. They were then navel scored and measured for chick length to the nearest 0.1cm. Due to the differences in number of chicks between the two experiments, there were 12 chicks measured for length per treatment in trial 1 and 10 chicks per treatment in trial 2. Chick length was obtained by placing the chick on its ventral side and measuring from the

tip of the beak to the middle toe on the right leg. All chicks were navel scored with an average navel score being calculated for each treatment. Scoring system for navels was developed from Tona et al. (2003), a 3-point score system was used as described in Figure 4.

Figure 4. Navel scoring system used in assessing chick quality1

Navel score point	Description	Visual example[2]
1	Healed and clean	
2	Less than 2 mm scab or string attached	
3	Larger than 2 mm	

[1]*Navel scoring method adapted from Tona et al., 2003*
[2]*images by Kayla Graham*

After all measurements were performed, chicks were then placed in trays, for transport to the rearing facility. Before transport, 24 chicks per treatment (n=384) were tagged with a swift tag applicator in the back of the neck for individual identification. Tagged birds were weighed (to the nearest 0.00g) and sampled to analyze breast muscle yield throughout the trial.

3.5.5 Placement in rearing facility

Chicks were place in a truck cab and transported approximately 4 km to the Atlantic Poultry Research Centre (APRC). Two free run rooms were used for rearing of the birds, these rooms were maintained using the temperature and lighting intensities (Table 15). Birds were placed straight run (both sexes together) into two rooms, all light by strain combinations were represented, with 3 replicates in each room. Rooms were sectioned off for the first week with carboard chick guard to keep them close to the water line and feeders (Figure 5). In addition to tube feeders, cardboard boxes were assembled (dimensions of 37.5 cm x 37.5 cm x 5 cm) and filled with a starter diet to permit easy access to feed for the first 7 d. Water nipples were situated every 30.5 cm and feeders were placed 94 cm apart.

Figure 5. Barn set-up for day old chick rearing

Birds were placed at a stocking density of 11.5 birds/m^2, this changed throughout the rearing period as mortalities occurred and birds were removed for sampling. Chicks were individually weighed (to the nearest 0.00 g) and placed in each of the production rooms. Birds were left for 6 h and then gathered again for individual weights. Gain as an absolute value and as a percentage were calculated for analysis of 6 h post placement BW. All strains of birds were fed *ad libitum*, standard starter (days 0-14), grower (days 15-24) and finisher diets (days 25-35) (Table A1.) formulated for the most current strain of commercial broiler used during the trial. Routine health checks were performed twice daily by the APRC staff and research team; any birds presenting signs of illness, deformities, or lameness were humanely euthanized by cervical dislocation as described by the approved SOP.

3.6 Statistical Analysis

3.6.1 Statistical model for analysis of incubation performance parameters

Incubation performance and chick quality were a completely randomized designed analyzed using a generalized linear mixed model procedure (PROC GLIMMIX) in SAS (version 9.4, 2012, SAS Institute Inc., Cary, NC, USA).

$$Y_{ijk} = \mu + \tau_i + \sigma_j + (\tau\sigma)_{ij} + \beta_k + \varepsilon_{ijkl}$$

$Y_{ijk} = \mu$ + incubation lighting treatment$_i$ + strain of bird$_j$ + (incubation lighting treatment X strain of bird)$_{ij}$ + ε_{ijkl}

Where Y_{ijk} =chick length, μ = overall mean; incubation lighting treatment (i= white, red, blue or dark); strain of bird (j = Cobb, Ross, Layer, or AMC); $(\tau\sigma)_{ij}$ is the effect of light and strain interaction; β_k is the effect of block by room of incubators in each trial; ε_{ijkl} is the random effect of error.

Experimental unit for the set of data is the group of chicks from each treatment within an incubator. The random effect for the experiment is trial, incubation unit, and grow out room. Fixed effects being strain of hatching eggs, incubation lighting treatment. Standard error of means is reported with means in each table. Effects were considered significant when the *P*-value < 0.05. Tukey-Kramer means separation test was used when significant differences were found at an alpha level of 0.05.

3.7 Results

3.7.1 Hatching window & spread

Significant differences were found for both light and strain treatments for the spread of hatch and the start of hatching ($P < 0.05$). Chicks hatched under red lighting started hatching earlier compared to those in white and dark incubators ($P < 0.05$) (Table 3). Chicks in the blue lit incubators remained intermediate to both the early red and late white and dark chicks. Spread of hatch for red birds was broader as it took longer from start to finish of hatching compared to the traditional incubation in the dark, while white and blue incubated chicks were intermediate.

Table 3. Average times of hatch window points among light treatments during incubation

Treatment	Spread of hatch (h)	Start of hatch (h)	End of hatch (h)
Red	33.0 ± 1.6^{a}	476.9 ± 2.87^{b}	509.9 ± 2.0
Blue	28.3 ± 1.6^{ab}	480.7 ± 2.7^{ab}	509.0 ± 2.0
White	27.0 ± 1.6^{ab}	484.4 ± 2.7^{a}	511.4 ± 2.0
Dark	26.3 ± 1.6^{b}	484.4 ± 2.7^{a}	510.7 ± 2.0
P-value	0.0220	0.0028	0.07

[a-b] Mean time in hours of incubation ± SEM, means within a column with different superscripts differ significantly ($P < 0.05$). Light treatments were all on a 12L:12D photoperiod, dark was used as a control (0L:24D). Red and blue LED fixtures (Once Innovations®, Plymouth, MN), 4100K white LED Canarm®, Brockville, ON).

Birds strains differed significantly in when they started hatching and the spread of their hatch window ($P > 0.05$) (Table 4). Cobb and AMC birds were the first to start hatching but did not differ significantly from Ross chicks. Layers started hatching later compared Cobb and AMC birds, with Ross being intermediate. Layers had the most condensed spread of hatch compared to Cobb and AMC birds. Ross were again intermediate in terms of spread of hatch. No differences were reported for time when birds finished hatching between any treatments ($P > 0.05$).

Table 4. Mean time in hours of incubation of hatch window points among different bird strains

Treatment	Spread of hatch (h)	Start of hatch (h)	End of hatch (h)
Cobb	30.6 ± 1. 6 [a]	478.6 ± 2.8 [b]	509.2 ± 2.0
Ross	27.4 ± 1.6 [ab]	482.2 ± 2.8 [ab]	509.6 ± 2.0
Layer	23.4 ± 1.6 [b]	487.8 ± 2.8 [a]	511.3 ± 2.0
AMC	33.2 ± 1.6 [a]	477.9 ± 2.8 [b]	511.1 ± 2.0
P-value	0.0007	0.0001	0.07

[a-b] Mean time in hours of incubation ± SEM, means within a column with different superscripts differ significantly (P < 0.05). Two commercial broiler chicken lines were used Cobb 500 and Ross 308, a 1978 random bred broiler line from University of Alberta (AMC) and commercial laying hen line Lohmann LSL lite.

Chicks hatched sooner from red light treatments compared to dark and white, while blue was intermediate. The same trend was observed for time when 75% of birds hatched, red were the first to reach the 75% mark and different from the dark (Table 5). Blue hatched birds were slower to reach 75% but were significantly faster than chicks hatched from the dark to reach 75% (P < 0.05).

Table 5. Hours of incubation when 50 and 75% hatch were obtained across different incubation lighting treatments

Treatment	Time when 50% of birds hatched (h)	Time when 75% of birds hatched (h)
Red	496.4 ± 3.2 [b]	500.4 ± 3.1 [c]
Blue	497.0 ± 3.2 [ab]	501.3 ± 3.1 [bc]
White	499.1 ± 3.2 [a]	503.4 ± 3.1 [ab]
Dark	499.3 ± 3.2 [a]	503.8 ± 3.1 [a]
P-value	0.0060	0.0005

[a-c] Mean time in hours of incubation ± SEM, means within a column with different superscripts differ significantly (P < 0.05). Light treatments were all on a 12L:12D photoperiod, dark was used as a control (0L:24D). Red and blue LED fixtures (Once Innovations®, Plymouth, MN), 4100K white LED Canarm®, Brockville, ON).

The same hatch progression occurred when analyzing the hatch window by time at which birds reached 50 and 75% as it did with start and spread, where layers were the latest strain

of bird to reach 50% hatch (Table 6). Layers took longer to reach 75% hatched compared to AMC and Cobb but did not differ from the Ross birds.

Table 6. Hours of incubation when 50% and 75% hatch were obtained across different bird strains

Treatment	Time when 50% of birds hatched (h)	Time when 75% of birds hatched (h)
Cobb	495.2 ± 3.2 [b]	499.3 ± 3.1 [b]
Ross	496.5 ± 3.2 [b]	501.1 ± 3.1 [ab]
Layer	503.4 ± 3.2 [a]	507.1± 3.1 [a]
AMC	496.6 ± 3.2 [b]	501.5 ± 3.1 [b]
P-value	<0.0001	<0.0001

[a-b] Mean time in hours of incubation ± SEM, means within a column with different superscripts differ significantly (P < 0.05). Two commercial broiler chicken lines were used Cobb 500 and Ross 308, a 1978 random bred broiler line from University of Alberta (AMC) and commercial laying hen line Lohmann LSL lite.

3.7.2 Hatchability & embryo mortality

Percent of embryonic death did not differ among the various light treatments used in this study (P > 0.05) (Table 7).

Table 7. Embryonic mortality of eggs set in different incubation light treatments

Treatment	Early Dead (%)	Mid Dead (%)	Late dead (%)
Red	3.5 ± 0.8	0.1 ± 0.3	4.1 ± 0.7
Blue	5.1 ± 0.8	0.7 ± 0.3	3.1 ± 0.7
White	4.0 ± 0.8	0.8 ± 0.3	3.7 ± 0.7
Dark	4.1 ± 0.8	0.5 ± 0.3	2.4 ± 0.7
P-value	0.60	0.21	0.33

Mean embryonic mortality percentage ± SEM. No differences were reported among lighting treatments during incubation (P > 0.05). Light treatments were all on a 12L:12D photoperiod, dark was used as a control (0L:24D). Red and blue LED fixtures (Once Innovations®, Plymouth, MN), 4100K white LED Canarm®, Brockville, ON).

Embryonic mortality differences were observed at mid dead (ED 8-14) and late dead stages (ED 15-21) between strains ($P < 0.05$) (Table 8). The percent of early dead embryos was equal among all strains studied ($P > 0.05$). AMC birds had higher mid dead embryonic losses compared to both Cobb and Ross, and layers did not differ from any of the broiler lines. AMC birds had over twice the percent of late dead embryos compared to layers and Cobb birds; Ross was an intermediate.

Table 8.Table 8. Embryonic mortality of different genetic strains of chickens

Treatment	Early Dead (%)	Mid Dead (%)	Late dead (%)
Cobb	3.7 ± 0.8	0.2 ± 0.3 ^{b}	2.4 ± 0.7 ^{b}
Ross	4.3 ± 0.8	0.2 ± 0.3 ^{b}	2.9 ± 0.7 ^{ab}
Layer	4.5 ± 0.8	0.5 ± 0.3 ^{ab}	2.5 ± 0.7 ^{b}
AMC	4.1± 0.8	1.2 ± 0.3 ^{a}	5.5 ± 0.7 ^{a}
P-value	0.90	0.0336	0.0067

a-b Mean embryonic mortality percentage ± SEM, means within a column with different superscripts differ significantly ($P < 0.05$). Two commercial broiler chicken lines were used Cobb 500 and Ross 308, a 1978 random bred broiler line from University of Alberta (AMC) and commercial laying hen line Lohmann LSL lite.

No significant differences were observed among lighting treatments, no significant difference on egg weights at set, egg weight loss, hatchability or percent of infertile eggs ($P > 0.05$) (Table 9).

Table 9. Mean egg weights and hatchability from different incubation lighting treatments

Treatment	Average egg weight (g)	Average egg weight loss (%)	Hatchability of set eggs (%)	Hatchability of fertile eggs (%)	Infertile eggs (%)
Red	60.7 ± 0.7	12.5 ± 0.3	78.3 ± 2.2	84.7 ± 2.2	7.4 ± 1.0
Blue	60.7 ± 0.7	12.0 ± 0.3	76.0 ± 2.2	80.6 ± 2.2	6.1 ± 1.0
White	60.9 ± 0.7	12.1 ± 0.3	77.6 ± 2.2	81.4 ± 2.2	4.7 ± 1.0
Dark	60.8 ± 0.7	12.2 ± 0.3	74.4 ± 2.2	79.1 ± 2.2	5.9 ± 1.0
P-value	0.99	0.75	0.61	0.34	0.28

Mean egg weights, weight loss, hatchability and percent infertile ± SEM. No significant differences were found among lighting treatments for hatchery performance (P > 0.05). Light treatments were all on a 12L:12D photoperiod, dark was used as a control (0L:24D). Red and blue LED fixtures (Once Innovations®, Plymouth, MN), 4100K white LED Canarm®, Brockville, ON).

Average egg weights differed significantly among the genetic strains of birds when set in the incubator ($P < 0.05$) (Table 10). Cobb eggs were significantly heavier upon setting in the incubators, followed by Ross and the smallest eggs being from both the layer and AMC strains. No differences were reported for average egg weight loss ($P > 0.05$). Hatchability and percent of infertile eggs were different among bird strains ($P < 0.05$). Hatchability in percent of set eggs and fertile eggs presented the same differences ($P < 0.05$), both commercial broiler strains had higher hatchability than the AMC and the layers. The percentage of infertile eggs was highest in the random bred line compared to all other strains.

Table 10. Mean egg weights and hatchability of different genetic strains of birds

Treatment	Average egg weight at set (g)	Average egg weight loss at ED 18 (%)	Hatchability of set eggs (%)	Hatchability of fertile eggs (%)	Infertile eggs (%)
Cobb	66.3 ± 0.7 [a]	12.5 ± 0.3	85.1 ± 2.2 [a]	89.1 ± 2.2 [a]	4.5 ± 1.0 [b]
Ross	63.2 ± 0.7 [b]	12.0 ± 0.3	83.0 ± 2.2 [a]	87.7 ± 2.2 [a]	5.3 ± 1.0 [b]
Layer	57.0 ± 0.7 [c]	11.7 ± 0.3	67.6 ± 2.2 [b]	70.7 ± 2.2 [b]	4.8 ± 1.0 [b]
AMC	56.6 ± 0.7 [c]	12.6 ± 0.3	70.4 ± 2.2 [b]	78.3 ± 2.2 [b]	9.6 ± 1.0 [a]
P-value	<0.0001	0.15	<0.0001	<0.0001	0.0016

[a-c] Mean egg weights, weight loss, hatchability and percent infertile ± SEM, means within a column with different superscripts differ significantly (P < 0.05). Two commercial broiler chicken lines were used Cobb 500 and Ross 308, a 1978 random bred broiler line from University of Alberta (AMC) and commercial laying hen line Lohmann LSL lite.

3.7.3 Chick Quality

Navel score was unaffected by lighting treatment, no differences observed among LED light colors compared to the dark (P > 0.05). Significant differences were present for chick length (P < 0.05). Chicks that hatched in either the blue or dark treatments were significantly longer than chicks hatched in the red and white incubators (P < 0.05) (Table 11).

Table 11. Chick quality measurements of chicks that hatched from different incubation lighting treatments

Treatment	Chick length (cm)	Navel score	Percentage of chicks with a score of 1 (%)
Red	16.5 ± 0.1 [b]	1.9 ± 0.02	16.6 ± 2.3
Blue	16.9 ± 0.1 [a]	1.9 ± 0.02	20.3 ± 2.3
White	16.5 ± 0.1 [b]	1.9 ± 0.02	18.4 ± 2.3
Dark	16.9 ± 0.1 [a]	1.8 ± 0.02	22.0 ± 2.3
***P*-value**	0.0013	0.49	0.38

[a-b] Chick quality parameters ± SEM, means within a column with different superscripts differ significantly (P < 0.05). Light treatments were all on a 12L:12D photoperiod, dark was used as a control (0L:24D). Red and blue LED fixtures (Once Innovations®, Plymouth, MN), 4100K white LED Canarm®, Brockville, ON).

Cobb broilers were the longest chicks of all the strains studied in this experiment, followed by Ross chicks, the shortest chicks were the random bred AMC line and layers. Navel scores were rated using a 3 point score system, 1 being a clean closed navel and 3 having a scab 2 mm or larger (Figure 2). Ross birds had better navel closure than layers, while Cobb and AMC were intermediate. Ross birds also had a higher percent of chicks that scored 1 on their navels than the layers ($P < 0.05$) (Table 12).

Table 12. Chick quality measurements from chicks of different genetic backgrounds

Treatment	Chick length (cm)	Average navel score	Percentage of chicks with a score of 1 (%)
Cobb	17.5 ± 0.1^{a}	1.9 ± 0.02^{ab}	18.2 ± 2.3^{ab}
Ross	16.9 ± 0.1^{b}	1.8 ± 0.02^{b}	25.0 ± 2.3^{a}
AMC	16.2 ± 0.1^{c}	1.9 ± 0.02^{ab}	19.4 ± 2.3^{ab}
Layer	16.2 ± 0.1^{c}	1.9 ± 0.02^{a}	14.6 ± 2.3^{b}
P-value	<0.0001	0.0146	0.0195

[a-c] Chick quality parameters ± SEM, means within a column with different superscripts differ significantly (P < 0.05). Two commercial broiler chicken lines were used Cobb 500 and Ross 308, a 1978 random bred broiler line from University of Alberta (AMC) and commercial laying hen line Lohmann LSL lite.

3.7.4 Chick weight and six hour post placement gain

Lighting during incubation helped chicks gain weight when placed in the barn ($P < 0.05$) (Table 13). Red and blue lit incubators had chicks that gained more during the first 6 h in the barn than those hatched in the dark. Chicks hatched using white LED lights did not differ from the red, blue or dark treatments leaving them intermediate. The same differences among treatments were reported when body weight gain was calculated as a percentage of placement weight. Chicks weighed the same for all light treatments when placed in the barn and at 6 h postplacement ($P > 0.05$).

Table 13. Chick weight and early chick weight gain of chicks hatched in different incubation lighting treatments

Treatment	Body weight at placement (g)	Body weight at 6 h post placement (g)	Body weight gain (g)	Body weight gain (%)
Red	42.0 ± 0.4	44.9 ± 0.7	3.0 ± 0.6 [a]	6.9 ± 1.5 [a]
Blue	42.1 ± 0.4	45.0 ± 0.7	2.9 ± 0.6 [a]	6.8 ± 1.5 [a]
White	42.5 ± 0.4	45.0 ± 0.7	2.5 ± 0.6 [ab]	5.7 ± 1.5 [ab]
Dark	42.5 ± 0.4	44.6 ± 0.7	2.0 ± 0.6 [b]	4.5 ± 1.5 [b]
P-value	0.65	0.84	0.0010	0.0003

[a-b] Mean weights and percentages ± SEM, means within a column with different superscripts differ significantly (P < 0.05). Light treatments were all on a 12L:12D photoperiod, dark was used as a control (0L:24D). Red and blue LED fixtures (Once Innovations®, Plymouth, MN), 4100K white LED Canarm®, Brockville, ON).

Significant differences in chick weights at placement were observed among the strains (P < 0.05) (Table 14). Cobb chicks were the heaviest at placement and 6 h postplacement respectively. Although Ross birds were not as heavy as their commercial broiler counterparts, they were heavier than both the AMC line and the layers. AMC and layers did not differ significantly in their body weight at placement, however, at 6 h postplacement the AMC birds were significantly heavier than the layers. Body weight gain during the first 6 h in the barn was analyzed both as an absolute value in grams and as a percentage of initial placement weight. The various birds used in the study gained weight at different rates (P < 0.05). The commercial broiler strains gained weight equally during the first 6 h, followed by AMC and lastly the layers. Layers performed very poorly during the first 6 h, as a group gaining close to nothing.

Table 14. Chick body weight at placement and 6 h postplacement weight gain of different genetic strains of chickens

Treatment	Body weight at placement (g)	Body weight at 6hr post placement (g)	Body weight gain (g)	Body weight gain (%)
Cobb	46.7 ± 0.4 [a]	51.2 ± 0.7 [a]	4.7 ± 0.6 [a]	9.7 ± 1.5 [a]
Ross	44.5 ± 0.4 [b]	48.8 ± 0.7 [b]	4.2 ± 0.6 [a]	9.6 ± 1.5 [a]
AMC	39.5 ± 0.4 [c]	41.2 ± 0.7 [c]	1.6 ± 0.6 [b]	4.3 ± 1.5 [b]
Layer	38.3 ± 0.4 [c]	38.4 ± 0.7 [d]	0.0 ± 0.6 [c]	0.2 ± 1.5 [c]
P-value	<0.0001	<0.0001	<0.0001	<0.0001

[a-d] Mean weights and percentages ± SEM, means within a column with different superscripts differ significantly (P < 0.05). Two commercial broiler chicken lines were used Cobb 500 and Ross 308, a 1978 random bred broiler line from University of Alberta (AMC) and commercial laying hen line Lohmann LSL lite.

3.8 Discussion

3.8.1 Spread of hatch and performance

Significant effects of light during incubation on the start and spread of hatch. Chicks hatched under red lighting were first compared to white and dark incubators, while blue was intermediate. No difference was reported for end of hatch among light treatments this meant that the spread of hatch for red light was significantly longer than the dark. Abeysinghe (2019) evaluated different light colors on hatching eggs from two commercial laying hen strains. Bird incubated with red light completed hatching 4 h before blue LED and dark conditions, and only 3 h before white lit birds. In the same study, it was reported that the red LED incubation treatment, had a narrower hatch window (Abeysinghe, 2019), which is not what was found in this study as the red light treatment had the longest spread of hatch. Chicks in another experiment using far red (670 nm) LED light therapy pipped 2.92 h earlier than chicks in the dark treatment and had a shorter time between pip and time they emerged from their shell (Yeager et al., 2005). A green light program of 12L:12D for the first 18 d of incubation reportedly

caused chicks to hatch over 3 h earlier than those incubated in the dark (Tong et al., 2018). Chicks hatching early are thought to be developmentally advanced and ready to emerge from their shell (Hluchý et al., 2012). Red and green light appear to advance hatching time in broiler hatching eggs (Yeager et al., 2005; Tong et al., 2018). Further studies comparing red and green light could be useful to determine if one is superior. Using red light in our study produced chicks that appear to be more developmentally advanced resulting in earlier hatching.

The results from the present study showed that eggs incubated in red light reached 50% and 75% hatch quicker than the white and dark treatment. While dark and white incubators were the last to achieve 50 % hatch however at 75% blue was not different from red light. In early studies exploring the effect of light during incubation of broiler hatching eggs, it was reported that when using 24L:0D, chicks hatched earlier than those in 12L:12D or 0L:24D, no differences were observed for hatchability (Walter and Voitle, 1972). Incandescent bulbs were used in the above experiment; therefore, it is hard to determine if it was the effect of light or the extra heat production the incandescent bulb was producing. Currently it is more common to see LED lights used in incubation experiments. Hannah et al. (2019) investigated white LED 12L:12D photoperiod from d 9 of incubation reached 50% hatch of the asymptote quicker than those in the dark in layers. In the current study, it was reported that white lighting did not differ from the dark treatment, it was red light hatched chicks that were first to reach 50% hatch.

There were significant differences in the time at which chicks started hatching across the strains used in this study. Layers were the last to start hatching however they had the most

condensed spread of hatch compared to Cobb and AMC birds. Ross were intermediate in both when they started hatching and their spread. No differences were reported when chicks ended hatching. In a study using multiple chicken lines, layers also had a later start to hatching at 491 h which was 13 h later than either Cobb or Ross lines used (Druyan, 2010). In the Druyan (2010) study eggs were incubated in the traditional dark environment, no lighting treatments included. In the current study the Cobb and Ross birds hatched at a similar time and were comparable to the broiler chicks in the above-mentioned study by Druyan (2010), where both of their broiler lines started hatching at 478 h. Others have found differences among the broiler strains. Tona et al. (2010) found that Cobb birds reached 50% hatch quicker at 484 h of incubation compared to Ross birds at 486 h of incubation. In a study exploring the effect of light on different layer strains, Lohmann LSL Lite, Lohmann Brown and Barred Plymouth Rock all hatched at different rates (Hannah et al., 2019). This is consistent with present findings exploring embryo development among layers and broilers, reporting that there were differences in when different strains started hatching. Despite there being many findings of strains differing in hatching rate, in the current study there were no interaction effects between strain and light provision during incubation.

3.8.2 Hatchability and embryonic mortality

No differences were reported for differences in egg weights or hatchability among light treatments in the current study, or interaction of light and strain of bird. Many research groups have reported that the use of light during incubation produces a higher hatchability (Hluchý et al., 2012; Huth and Archer, 2015; Archer, 2017). The current study did not

support the theory that hatchability is superior in illuminated incubators. A number of different wavelengths and light colors have been explored. Broiler chicks incubated in light had superior hatchability compared to the dark hatched chicks, 90.12% and 85.76% respectively while no effect was reported for the white leghorn (Huth and Archer, 2015). Dim to red light fixtures that were used in the current study have provided superior hatchability compared to the dark in Cobb 500 broilers in another study by Archer (2017). The current study did not reproduce a similar result as hatchability did not differ between the incubators with dim to red lights compared to the dark. Despite not finding a benefit to the use of red and white LED lighting as Archer (2017) reported, both the current study and Archer's had similar and acceptable hatch of fertile. White LED light appears to have consistently resulted in superior hatchability, Hluchý et al. (2012) reported that eggs incubated in white light had higher hatchability than blue or dark incubators. Similarly, Zhang et al. (2012) reported that hatchability of eggs incubated in monochromatic green light, blue light, or dark all had similar hatchabilities and white provided a superior hatchability. The current study can agree that blue lighting did not differ from dark, however it was not found that white provided superior hatchability as these other studies have.

Egg weights were the same at set for all light treatments, and no differences were observed for mean egg weight loss. In an experiment evaluating the effects of high and low light intensity, it was also reported that there were no differences in egg weight loss percent (Shafey et al., 2005). No differences were found among light treatments for percent embryo mortality at any stage of embryo development. Other studies have reported continuous white lighting did not influence embryo mortality (Graham and

Rathgeber, 2016). Archer (2018) reported that hatching eggs set dim to red or blue light had fewer early dead embryo mortality, no differences in mid or late dead. In the current study the same dim to red and blue fixtures had no effect on embryo mortality at any stage of incubation. However, in Archer's study the embryo mortality in each category was much higher than the current study reported. The dark treatment in Archer's study had around 30% total embryo mortality, whereas the current study was 7% loss. Presence of light during incubation regardless of intensity was found to produce lower embryo mortality compared to the traditional dark treatment (Yu et al., 2018). Similarly, to the Archer study Yu et al., had greater embryo mortality (12.63%) in their study than reported in the current study (7%). Potentially on a weaker batch of eggs lighting may provide a benefit in reducing embryo mortality when compared to dark.

Strain differences were reported in the current study, this was expected due to the large range of genetics used in the study. However, egg weight loss did not differ between strains of hatching eggs. Keeping genetic selection in mind it is no surprise that egg weights among the drastically different bird strains would vary. The commercial broilers even differed from each other Cobb having the heaviest eggs. Layers and the random bred broilers had equal egg weights. All strains lost equal amounts of weight throughout the setting period. Hatchability was the highest in the two commercial broiler strains and lowest in the layers and AMC birds. AMC had significantly higher percent of eggs that were infertile compared to the other strains. When birds of the same breeder age but different strain were studied, Cobb birds still had the largest egg weights, followed by layers and then Ross (Druyan, 2010). In the present study Cobb birds also had the largest

mean egg weight at set; however, Ross eggs were larger than the layers. Tůmová and Gous (2012) also found broiler eggs to be significantly heavier than layer eggs.

Differences in embryonic mortality at mid and late dead stages as a percent of total eggs set were reported among strain. Mid dead percentage was highest in AMC compared to the commercial broiler strains and layers were intermediate. For late dead mortality AMC was still the highest compared to Cobb and layers but did not differ from the intermediate Ross. AMC was thought to be the highest in mortality as they were collected over a larger time frame to obtain the amount of eggs we needed to set. Differences reported among strain in the present study for hatchability could be due to the preincubation storage conditions before they arrived at the hatchery, as there was no light by strain interaction. Some AMC eggs would be stored longer as collection was over several days.

3.8.3 Chick quality

3.8.3.1 Effect of light and strain on chick length

In the current study the only difference that was reported on the effect of light on chick quality was in chick length. Chicks from dark and blue incubators were longer than those hatched in red and white. Findings from a European lighting study reported that chick length and navel score did not differ from dark incubators, however the 12L:12D photoperiod of 6050 K white LED enhanced leg bone health in broilers (van der Pol, 2017).

Significant differences were reported in the current study among the strains of bird. Cobb birds were the longest followed by Ross and then the AMC and layers who did not differ

from each other. Broilers have been found to be longer than laying hen chicks, 18.4 cm versus 17.0 cm respectively, for any given chick length there is typically a wide range of chick weights (Demming, 2005). Willemsen et al. (2008) reported in their study two different broiler lines were equal in length, this was not consistent with findings from the current study. Demming's (2005) study reported broilers were longer than layers, the same was found in the current study were commercial broiler lines were longer than layers and the 1978 broiler line.

3.8.3.2 Effect of light and strain on hatchling weight

Some of the initial work performed using incandescent light during incubation of broiler hatching eggs found no differences in chick weight at hatch (Walter and Voitle, 1972). Past research at Dalhousie University reported on two separate occasions that chicks hatched from incubators with lights weighed less than those incubated in the dark (Graham and Rathgeber, 2016; Li et al., 2017). A study using green light photostimulation during the first 18 d of incubation on Ross hatching eggs reported that, the hatch weight or chick quality were not affected (Tong et al., 2018). Similarly, no differences were reported for hatchling weight in Rozenboim et al. (2013) study using monochromatic green light compared to the dark control. Strain differences were reported in the current study and were consistent with findings from Willemsen et al. (2008). Ross chicks were consistently smaller than Cobb chicks at all ages; however, the Ross chick had superior chick quality than the Cobb chicks (Willemsen et al., 2008).

Despite differing views on the best chick quality measurement, chick length has also been reported to have a positive correlation with chick weight in a study using male Ross broiler chicks (Petek et al., 2010). A study using male Ross broilers found there was a positive

correlation, between chick length, slaughter weight and breast muscle yield (Molenaar et al., 2008). Other research has also supported the theory that chick length is a superior predictor of bird performance. A study using male chicks from eight different broiler strains reported a stronger correlation between hatchling length and body weight at 14 d compared to hatch weight (Wolanski et al., 2006). Contradictory findings have been reported by a research group using both Cobb and Ross broilers. Willemsen et al. (2008) reported that chick length had a low predictive value of how broilers would perform posthatch.

3.8.3.3 Effect of light and strain on navel score

Navel score was unaffected by the use of light during incubation. Navel score appears to be one of the chick quality parameters that is the least studied in incubation lighting experiments. Archer (2018) found benefit in red and blue LED lights, as chicks had more healed navels compared to those hatched in the dark. Most literature pertaining to navel score are using a scoring system or percentage of chicks that have acceptable navel closure. This type of data is hard to compare to our navel scores of 1-3. Differences were reported in the current study for navel score among different lines of birds. Ross birds had a superior navel average compared to layers, with Cobb and AMC intermediate. Same was reported for strain differences on percentage of total chicks who scored 1.

3.8.4 Early chick growth performance

The use of lighting during incubation helped chicks gain weight when placed in the barn. Chicks from all incubators were the same weight at placement and 6 hours later. However, chicks hatched in red and blue incubators had the greatest relative weight gains in the first 6 h in the barn. Birds hatched from white light in the current study were

intermediate to red, blue and the low performing dark. Early growth performance (i.e., weight gain) is extremely important in today's broiler industry as the first week of the life of a broiler accounts for around 20% of its lifetime (Wolanski et al., 2006). Within the last decade, LED light fixtures have been evaluated more. Chicks hatched in incubators using 12L:12D photoperiod with white LED stimulated chick development up to hatch but did not affect the growth performance later in life (van der Pol, 2017). The same effect was not present in the current study as all chicks weighed the same when removed from the incubator. Chicks hatched in continuous lighting treatments (24 h of white LED light) ahead of those in 12L:12D, these later hatching chicks had higher yolk free body weight (YFBW) suggesting that continuous lighting may actually reduce the rate of development in the chicks (van der Pol, 2017). Graham and Rathgeber (2016) showed that continuous lighting with white LED had a negative effect on 6 h postplacement weights in Ross 308 broilers. In these two studies with continuous white lighting there were negative effects to either weight or development compared to dark, in the current study white did not produced negative results compared to dark. When Li et al. (2017) hatched birds in blue LED light they did not differ from the dark treatment and white had the highest gains. In the current study it was reported that blue actually had higher body weight gains in the first six hours in the barn, which is different compared to Li et al. (2017).

Differences were seen among the strains, which came as no surprise as there were differences in egg weights which is commonly correlated with chick weight. Cobb birds were the heaviest and also gained more weight along with the Ross birds compared to the layers and AMC. AMC and layers were the same weight at placement, but the AMC birds

gained more than layers in the first 6 hours in the barn. According to Ohta et al. (2004), there is a difference in embryonic growth of broilers and layers. This statement is supported by their result on faster protein accumulation and yolk absorption in broilers. Broiler breeders have proportionally larger yolks than laying hen strain eggs, leading to a higher amount of protein that contributes to the faster growth rate during embryogenesis (Ho et al., 2011; Naugsuay et al., 2015). Not only can this increase yolk amount contribute to fast growth as an embryo but also in the first 6 h postplacement (Naugsuay et al., 2015). Broiler chicks were found to have heavier digestive and support organs which allow greater metabolic activity and in turn faster growth. Naugsuay et al. (2015) hypothesized that the thinner eggshells on broiler strains could allow more oxygen penetration for metabolic function. When using broiler yolk on layers *ex ovo*, development was accelerated most likely due to maternal egg factors instead of genetic components (Ho et al., 2011). The data from the current study shows significantly larger broiler chicks than layer chicks. Others have found contradictory results where broilers were lighter in body weight compared to layers (Demming, 2005). Some studies have reported that Cobb and Ross broiler chicks were similar in weight at hatch (Tona et al., 2010; Pascalau et al., 2017), compared to our findings where Cobb chicks were heavier than the Ross chicks. This is closely related to egg weight which can vary from flock to flock. Other researchers have findings supporting Cobb chicks being heavier at hatch compared to Ross chicks (Willemsen et al., 2008). Once in the barn, both broiler strains used in the current study, gained equally during the first 6 h postplacement, and more than that of AMC and layer birds.

3.9 Conclusion

Incubation lighting research is ongoing, firm evidence has not been proven repeatedly for attainting chicks of good quality from an acceptable hatch window period. Lights of different colors were found to be beneficial, however, the same effects were not present among all hatch parameters or chick quality measurements. Hatchability and embryo mortality were not affected by provision of light during incubation in the current study. Providing light during incubation affected the rate of hatch and how birds gain weight when first introduced into the barn which did not differ for birds of different genetic backgrounds. Light has been proven to be a factor that can be used to manipulate embryo development, however based on the results of this study a recommendation for a certain wavelength of light is not possible. However, it is evident that blue light had a positive effect on embryo development as chicks from blue light had the longest body length at hatch and gained the most in the first six hours in the barn.

CHAPTER 4 USE OF LIGHTING DURING INCUBATION IN DIFFERENT LINES OF CHICKENS ON GROWTH PERFORMANCE AND CARCASS YIELDS

4.1 Abstract

The objective of this study was to determine if the use of LED lighting during incubation of multiple strains of chickens affected growth performance, breast muscle growth and slaughter/carcass yields in birds grown to 36 d. Two replicate trials were performed using the following strains: Ross 308, Cobb 500, Lohmann LSL Lite and a 1978 random bred broiler line from the University of Alberta (AMC). Eight incubators were used, setting 824 eggs in trial 1 and 836 eggs in trial 2. Incubation lighting consisted of 4 treatments: dark (no light), white LED, dim to red LED, and dim to blue LED. Lighting treatments had a 12L:12D photoperiod and were replicated using 2 incubators for each trial. Birds of all strains were randomly assigned to one of two rooms and reared in free run environment with a starter diet and water *ad libitum*. A total of 768 birds were tagged at hatch and were individually weighed throughout the rearing period on d 7, 14, 21, 25, and 35. Breast sampling occurred on hatch day (d 0) and d 6. Slaughter was performed at d 36 to investigate effects of lighting treatments during incubation on slaughter performance and carcass part yields. There was no effect of light on the growth of birds throughout the rearing period or breast muscle yield. Strain differences were shown for body weight at all ages and slaughter carcass parts yield ($P < 0.05$). The use of lighting during incubation did not affect the slaughter carcass weight or parts yield ($P > 0.05$).

Key words: LED light, incubation, body weight, breast muscle yield, carcass parts

4.2 Introduction

The introduction of chicks into the rearing environment can be stressful. Chicks that are adequately prepared for the barn may start to eat and drink quicker, early feed access has resulted in better body weight gains (Prabakar et al., 2016). Over the years, a lot of work has been performed on different lighting schedules, bulbs types (incandescent and CFL), lighting intensity and some on light spectra during the rearing period (Olanrewaju et al., 2006). However little research has been performed until recently, on the effect that light exposure during incubation has on chick development, chick quality and growth to market weight.

Past research on photoperiods posthatch have reported that the traditional long day lengths of 23L:1D create an environment where birds express fewer natural behaviors than birds housed in 17L:7D (Schwean-Lardner et al., 2012). However, historically breast muscle yields were found to be highest in birds reared in longer daylengths such as 23L:1D or continuous lighting (Lien et al., 2007; Schwean-Lardner and Classen, 2010). Schwean-Lardner and Classen (2010), reported that birds reared in 20L:4D photoperiods actually were the heaviest in body weight compared to 14L:10D, 17L:7D or 23L:1D photoperiods. A study using 12L:12D as a short day length and 20L:4D as the long days during rearing, reported that breast muscle yield as a percent was lower in the short days compared to the long days (Brickett et al., 2007). Potentially by using light during incubation the decrease in breast muscle yield caused by rearing in short photoperiods could be spared. This would allow productive breast meat yields while rearing birds in a welfare friendly environment where the birds express natural behaviors while exhibiting

good growth performance. Maintaining optimal breast muscle yields are important to the industry as white meat has gain popularity over the years.

The aim of this research was to determine if using lighting of different colors in incubation on a 12L:12D photoperiod would influence bird growth performance and slaughter yields differently for distinct chicken lines.

4.3 Objectives

The objectives of the study were to:

- To evaluate the use of LED lights of different colors during incubation on the development and yield of breast muscle in four different bird strains.
- To evaluate the use of LED lights of different colors during incubation on the growth of four different bird strains throughout the rearing period up to 35 d.
- To evaluate carcass part yields of four different strains of chickens incubated with the use of different color of LED light.

4.4 Hypotheses

It is hypothesized that birds incubated with light will result in heavier birds at the end of trial, differences will be found across all bird strains.

Carcass part yields will differ among strains, as layers have not been selected for muscling as current day broilers. As well there is expected to be a difference between the older broiler genetics of the AMC line compared to that of the Ross and Cobb broilers. Birds hatched in incubators with light will have increased breast yield at the expense of wing, leg and thigh yield.

4.5 Materials and Methods

The following experiment was performed using procedures approved by the Animal Care and Use Committee (ACUC) of Dalhousie University, Nova Scotia, Canada.

4.5.1 Experimental design

The experiment was a complete block design, experimental unit being incubator and blocked by trial and incubation room (group of 4 incubators). A 4x4 factorial arrangement was used, the main effects were strain and incubation light treatment.

4.5.2 Animal husbandry

After hatching, chicks were placed in a truck cab and transported approximately 4 km to the APRC. Two free run rooms were used for rearing of the birds, these rooms were maintained using the temperature and lighting intensity set points (Table 15). Birds were placed straight run (both sexes together) into two rooms, all treatment combinations were represented, with 3 replicates in each room. Rooms were sectioned off for the first week with carboard chick guard to keep birds close to the water line and feeders. In addition to tube feeders, cardboard boxes were assembled dimensions of 37.5 cm x 37.5 cm x 5 cm and filled with a starter diet to permit easy access to feed for the first 7 d (Figure 5, Chp. 3). Water nipples were every 30.5 cm and tube feeders were placed 94 cm apart, the height of water lines and feeders were raised to accommodate birds as they grew. Birds were placed at a stocking density of 11.5 birds/m^2, this changed throughout the rearing period as mortalities occurred. Chicks were individually weighed and placed in groups in each of the production rooms. Chicks were weighed on d 7, 14, 25, and 35. All strains of birds were fed *ad libitum*, standard starter (0-14 days), grower (15-24 days) and finisher diets (25-35

days) (Table A1.) formulated for the most current strain of commercial broiler used during the trial. Routine health checks were performed twice daily by the APRC staff and research team; any birds presenting signs of illness, deformities, or lameness were humanely euthanized by cervical dislocation as described by the approved SOP in the APRC.

Table 15. Temperature and lighting intensity benchmarks for broiler rearing in the APRC

Broiler growing day	Temperature (°C)	In floor heating (°C)	Light intensity (lux)	Air Handling Unit (°C)
0 (Placement)	31	50	20	29
2	30.5	50	20	20
4	30	45	20	28
6	29	45	15	27
8	28	45	10	26
11	27	45	5	26
13	26	45	5	24
15	25	45	5	23
18	24	45	5	22
20	23	45	5	21
29	22.5	45	5	20

4.5.3 Data collection of growth performance

4.5.4 Breast muscle yield during broiler growth phase

On hatch day, 10 chicks per treatment combination (n = 160) were euthanized using carbon monoxide gas using the approved ACUC SOP. Euthanized chicks had the following measurements collected: chick weight, yolk weight, yolk-free body weight (YFBW), breast muscle weight. All weights during sample were to the nearest 0.01 g, and chick length (to the nearest 0.1 cm). Gender was determined on each chick during the dissection process. Breast muscle harvest was performed by the same people to ensure minimal variability due to personal technique. During dissection of hatch day and d 6 chicks, pectoralis major and supracoracoideus were harvested with the sternum intact due

to the small size. Slaughter age birds were killed in the provincially inspected facility at Dalhousie Faculty of Agriculture and a boneless, skinless breast weight was obtained using both pectoralis major and supracoracoideus muscle groups. Measurements on d 6 and d 36 sampling consisted of only bird weight and breast weight. Method of euthanasia for d 6 sampling was cervical dislocation, and slaughter aged birds were hung in shackles and electrically stunned before severing of the jugular vein.

4.5.5 Slaughter process

All remaining tagged birds were processed in the APRC, provincially inspected slaughter wing. Birds of all lines were slaughtered on d 36 to determine carcass and part yield. Once all tagged birds were caught, they were put in a pen in their respective room. Feed was withdrawn 8 h prior to slaughter. Birds were randomly chosen from the pen and weighed on a live balance scale. Birds were then transported to the slaughter wing. Birds were hung on the shackles and stunned using an electric knife. After stunning the jugular vein was cut to kill the bird, bleed out time of 90 s was used. Carcasses were then transferred to the scalder. Scalding temperature was 65°C for 90 s. Carcasses were placed in a mechanical plucker after scalding. Carcasses were re-hung on a moving shackle system to complete evisceration. Once on the line, the preen gland was removed as well as any feathers that were missed by the plucker. A buttonhole cut was made for the following person to be able to remove all visceral organs. Organs were removed manually, while a lung removal machine were used to vacuum the lungs and surrounding membranes from the carcass. Feet were removed from the carcass. Birds were hung again from their hock joint after removal of the feet. Birds were rinsed before being taken off the slaughter line. Birds were drained of any water that entered the body cavity during

processing and weighed to obtain a hot carcass weight. Weighed carcasses were hung on a cart and placed in the chilling room at 4°C overnight. Throughout the slaughter process a provincial slaughter inspector was present.

4.5.6 Carcass part cut up

The following morning, carcasses were re-weighed to obtain a cold carcass weight prior to cut up of the carcass into sellable parts. Carcass parts were removed manually, one person was kept consistent at the following stations on the line; wings, left breast, right breast, leg and thigh. Parts were weighed to allow yield to be calculated as a percent of live, hot and cold carcass weight. Wings were removed by separating the scapular joint, taking care not to cut into the breast muscle in the process. Each breast was removed by cutting along the clavicle and cutting in a smooth downward motion along the breastbone/keel. When the breast muscle was free from the skeleton the skin was removed, leaving a boneless skinless portion for weighing. The thigh and leg cuts were kept together, a cut along the feather tract was used to benchmark where the thigh would separate by the joint. Once approaching the hip joint the leg was disconnected from the hip socket and a cut through the muscle tissue completed the process. All carcass part weights were a combination of right and left sides.

4.6 Statistical Analysis

Breast muscle sampling data, carcass weights and part yields were analyzed using ANOVA in a generalized linear mixed model procedure (PROC GLIMMIX) in SAS (version 9.4, 2012, SAS Institute Inc., Cary, NC, USA).

$$Y_{ijk} = \mu + \tau_i + \sigma_j + (\tau\sigma)_{ij} + \beta_k + \varepsilon_{ijkl}$$

$Y_{ijk} = \mu$ + incubation lighting treatment$_i$ + strain of bird$_j$ + (incubation lighting treatment X strain of bird)$_{ij}$ + ε_{ijkl}

Where Y_{ijk} =live carcass weight, μ = overall mean; incubation lighting treatment (i= white, red, blue or dark); strain of bird (j = Cobb, Ross, Layer, or AMC); $(\tau\sigma)_{ij}$ is the effect of light and strain interaction; β_k is the effect of block by room of incubators in each trial; ε_{ijkl} is the random effect of error.

Body weights throughout the rearing period were analyzed using repeated measures in using PROC MIXED procedure in SAS with compound symmetry covariance structure (version 9.4, 2012, SAS Institute Inc., Cary, NC, USA).

Experimental unit for the set of data is the group of chicks from each treatment within an incubator. The random effect for the experiment is trial, incubation unit, and grow out room. Fixed effects being strain of hatching eggs, incubation lighting treatment. Standard error of means is reported with means in each table. Effects were considered significant when the *P*-value < 0.05. Tukey-Kramer means separation test was used when significant differences were found at an alpha level of 0.05.

4.7 Results

4.7.1 Breast muscle sampling

There was no effect of lighting treatment during incubation on chick weight, YFBW or breast yield as an absolute value or as a percent of body weight ($P > 0.05$; Table 16). No sex differences were reported for any of the hatch day sampling parameters of light or strain ($P > 0.05$).

Table 16. Chick weight, YFBW and breast muscle yield of day-old chicks incubated under different light treatments

Treatment	Chick weight (g)	YFBW %	D 0 Breast weight (g)	D 0 Relative Breast (% of BW)
Red	41.9 ± 0.5	87.0 ± 0.5	1.7 ± 0.1	4.7 ± 0.2
Blue	41.9 ± 0.5	86.8 ± 0.5	1.7± 0.1	4.6 ± 0.2
White	42.7 ± 0.5	87.4 ± 0.5	1.7 ± 0.1	4.6 ± 0.2
Dark	42.6 ± 0.5	87.3 ± 0.5	1.7 ± 0.1	4.6 ± 0.2
***P*-value**	0.4482	0.7555	0.9671	0.6877

Mean weights and breast percentages ± SEM. No differences were reported among lighting treatments during incubation (P > 0.05). Light treatments were all on a 12L:12D photoperiod, dark was used as a control (0L:24D). Red and blue LED fixtures (Once Innovations®, Plymouth, MN), 4100K white LED Canarm®, Brockville, ON).

Chicks sampled on day of hatch weights significantly differed between strain of bird (Table 17) ($P < 0.05$). Cobb birds were the heaviest, followed by Ross and the smallest chick weights were the AMC and layer birds, which did not differ from each other. YFBW was calculated as a percent of initial chick weight and differed between different lines of birds hatched in this study ($P < 0.05$). Cobb and layer birds had the lowest YFBW percentage, Ross chicks were intermediate, and AMC birds had the highest YFBW. Hatch day (d 0) breast weights, pectoralis major and supracoracoideus including the keel bone were significantly different among bird types ($P < 0.05$). Absolute breast weight (g) was

highest in the Cobb chicks and differed compared to the other commercial broiler Ross line. The random bred AMC line of broilers did not differ in breast weight compared to the layer. All of the modern commercial bird strains; Cobb, Ross and layers had the same relative breast weight at hatch as a percentage of body weight. The 1978 AMC strain had significantly lower relative breast weight compared to the commercial strains used in production today even considering a laying hen strain ($P < 0.05$)

Table 17. Chick weight, YFBW and breast muscle yields of day-old chicks of different genetic backgrounds

Treatment	Chick weight (g)	YFBW %	D 0 Breast weight (g)	D 0 Relative Breast (% of BW)
Cobb	47.0 ± 0.4 [a]	86.8 ± 0.5 [b]	1.9 ± 0.1 [a]	4.7 ± 0.2 [a]
Ross	43.9 ± 0.5 [b]	87.2 ± 0.5 [ab]	1.8 ± 0.1 [b]	4.7 ± 0.2 [a]
AMC	39.4 ± 0.4 [c]	88.4 ± 0.5 [a]	1.5 ± 0.1 [c]	4.4 ± 0.2 [b]
Layer	38.8 ± 0.5 [c]	86.0 ± 0.5 [b]	1.6 ± 0.1 [c]	4.7 ± 0.2 [a]
***P*-value**	<0.0001	0.0021	<0.0001	0.0002

[a-c] Mean weights and breast percentages ± SEM, means within a column with different superscripts differ significantly ($P < 0.05$). Two commercial broiler chicken lines were used Cobb 500 and Ross 308, a 1978 random bred broiler line from University of Alberta (AMC) and commercial laying hen line Lohmann LSL lite.

Light did not have any effect on chick weight, breast weight or relative breast on chicks at 6 d of age (P > 0.05) (Table 18).

Table 18. Bird weight and breast muscle yield of d 6 chicks hatched from different lighting treatments

Treatment	Chick weight (g)	D 6 Breast weight (g)	D 6 Relative Breast (% of BW)
Red	104.6 ± 3.3	10.7 ± 0.3	9.5 ± 0.1
Blue	105.7 ± 3.2	10.7 ± 0.3	9.6 ± 0.1
White	107.4 ± 3.2	11.0 ± 0.3	9.6 ± 0.1
Dark	103.3 ± 3.2	10.2 ± 0.3	9.3 ± 0.1
***P*-value**	0.1961	0.0800	0.1603

Mean weights and breast percentages ± SEM. No differences were reported among lighting treatments during incubation (P > 0.05). Light treatments were all on a 12L:12D photoperiod, dark was used as a control (0L:24D). Red and blue LED fixtures (Once Innovations®, Plymouth, MN), 4100K white LED Canarm®, Brockville, ON).

Table 19. Bird weight and breast muscle yield of d 6 chicks of different genetic backgrounds

Treatment	Chick weight (g)	D 6 Breast weight (g)	D 6 Relative Breast (% of BW)
Cobb	143.7 ± 3.2 [a]	16.2 ± 0.3 [a]	11.3 ± 0.1 [a]
Ross	132.9 ± 3.3 [b]	15.1 ± 0.3 [b]	11.3 ± 0.1 [a]
AMC	84.6 ± 3.2 [c]	7.3 ± 0.3 [c]	8.6 ± 0.1 [b]
Layer	59.7 ± 3.2 [d]	4.1 ± 0.3 [d]	6.8 ± 0.1 [c]
***P*-value**	<0.0001	<0.0001	<0.0001

[a-d] Mean weights and breast percentages ± SEM, means within a column with different superscripts differ significantly (P < 0.05). Two commercial broiler chicken lines were used Cobb 500 and Ross 308, a 1978 random bred broiler line from University of Alberta (AMC) and commercial laying hen line Lohmann LSL lite.

Birds of four distinct lines reared to 6 d of age were sampled for breast muscle yield, breast weights were pectoralis major and minor including the keel bone (Table 19). All of the bird lines studied different in their chick weight and breast weights (P < 0.05). Cobb birds weighed the most followed by Ross, AMC and layer. AMC birds were heavier than

the layers at d 6 whereas they did not differ in body weight at d 0. By d 6 breast sampling, absolute breast weights were different among all bird lines ($P < 0.05$). The breast weights followed the same pattern as the chick weights did for differences Cobb > Ross > AMC > Layer. Despite being an older broiler line, the AMC birds presented higher breast weights and relative breast percentage compared to the layers. When breast was analyzed as a percent of the body weight the two commercial broilers (Cobb and Ross) were the same but different from AMC and layer ($P < 0.05$).

4.7.2 Rearing period body weights

A strain by age interaction was found for growth performance through the rearing period ($P < 0.05$) (Table 20 & Figure 6). At all ages Cobb and Ross were the heaviest and did not differ from each other or the AMC birds. At d 7 AMC and layers were not different from each other, however from d 14 -35 the AMC birds weighed more than the layers.

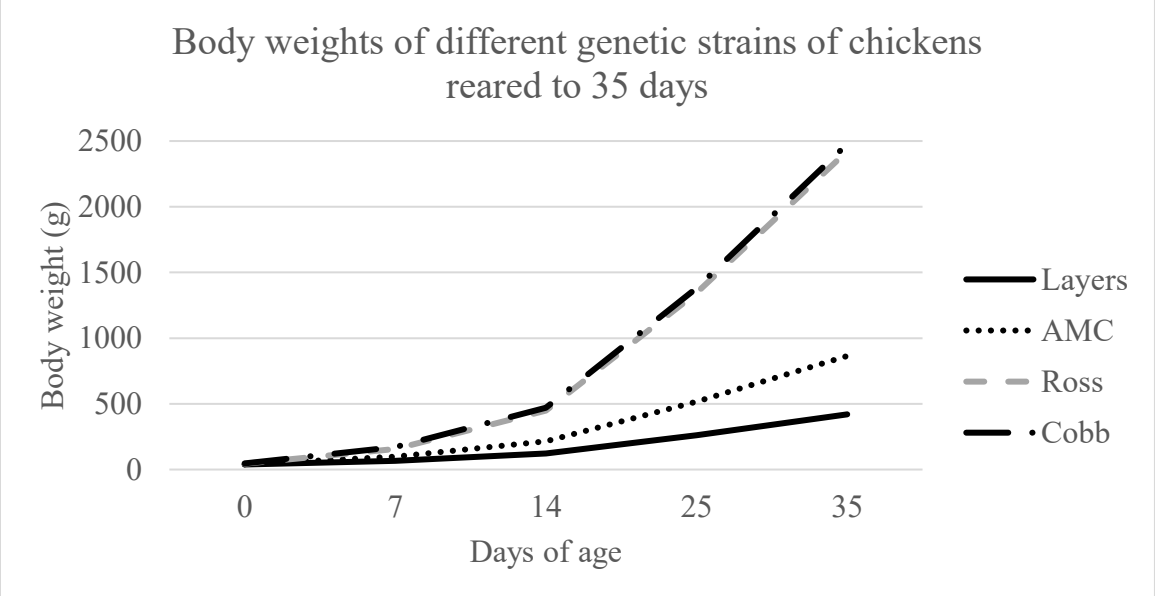

Figure 6. Graph showing body weights over a 35 day period in different genetic strains, same data is presented in Table 20.

Table 20. Live body weight (g) performance through the rearing period for different strains of chickens raised to 35 d

Day	Cobb	Ross	AMC	Layer
7	172.0 ± 14.9 [i]	155.8 ± 14.9 [i]	99.0 ± 14.9 [ij]	66.8 ±17.2 [j]
14	469.3 ± 14.9 [g]	448.3 ± 14.9 [g]	214.5 ± 14.9 [h]	122.5 ±17.2 [i]
25	1381.7 ± 14.9 [d]	1345.6 ± 14.9 [d]	515.7 ± 14.9 [e]	261.8 ±17.2 [f]
35	2477.1 ± 14.9 [a]	2423.3 ± 14.9 [a]	864.0 ± 14.9 [b]	419.8 ± 17.2 [c]
P-value		<0.001		

[a-j] Mean body weights ± SEM, means with different superscripts differ significantly (P ≤ 0.05). Two commercial broiler chicken lines were used Cobb 500 and Ross 308, a 1978 random bred broiler line from University of Alberta (AMC) and commercial laying hen line Lohmann LSL lite.

No significant differences were reported for any of the strains among the various lighting treatments used in this study for final rearing body weight (P > 0.05) (Table 21).

Table 21. Day 35 body weights (g) of different genetic strains of birds incubated in different light treatments

Light	Cobb	Ross	AMC	Layer
Blue	2478.0 ± 29.8	2424.2 ± 29.8	833.9 ± 29.8	425.4 ± 42.2
Dark	2387.4 ± 29.8	2405.4 ± 29.8	882.8 ± 29.8	421.7 ± 29.8
Red	2513.4 ± 29.8	2378.1 ± 29.8	924.3 ± 29.8	402.2 ± 34.4
White	2529.5 ± 29.8	2485.5 ± 29.8	814.9 ± 29.8	429.9 ± 29.8
P-value		0.09		

Mean body weights ± SEM. No differences were reported among lighting treatments during incubation (P > 0.05). Light treatments were all on a 12L:12D photoperiod, dark was used as a control (0L:24D). Red and blue LED fixtures (Once Innovations®, Plymouth, MN), 4100K white LED Canarm®, Brockville, ON).

4.7.3 Carcass weights of four strains of birds incubated in different light treatments

There were no effects of lighting treatment during incubation on the live body weights, hot or cold carcass weights (Table 22) ($P > 0.05$).

Table 22. Mean live, hot and cold carcass weights of birds incubated in different light treatments

Light	Live weight (g)	Hot carcass (g)	Cold carcass (g)
Blue	1541.9 ± 22.3	1110.3 ± 17.5	1060.4 ± 16.8
Dark	1509.0 ± 22.3	1084.0 ± 17.5	1041.9 ± 16.8
Red	1528.8 ± 22.3	1102.1 ± 17.8	1053.5 ± 16.8
White	1553.7 ± 22.3	1129.1 ± 17.5	1077.8 ± 16.8
P-value	*0.5307*	*0.3348*	*0.4955*

Mean weights ± SEM. No differences were reported among lighting treatments during incubation ($P > 0.05$). Light treatments were all on a 12L:12D photoperiod, dark was used as a control (0L:24D). Red and blue LED fixtures (Once Innovations®, Plymouth, MN), 4100K white LED Canarm®, Brockville, ON).

When birds reached 36 d of age, slaughter was performed, and birds were chilled before carcass parts cut up. By the end of the rearing period both Cobb and Ross birds achieved the same body weight, hot carcass and cold carcass weights (Table 23). The random bred broiler line had lower live and carcass weights then the commercial broiler strains but were significantly heavier than the layers ($P < 0.05$).

Table 23. Mean live, hot and cold carcass weights of different bird strains raised to 36 d

Strain	Live weight (g)	Hot carcass (g)	Cold carcass (g)
Cobb	2447.6 ± 22.3 [a]	1813.0 ± 17.5 [a]	1741.6 ± 16.8 [a]
Ross	2424.5 ± 22.3 [a]	1798.5 ± 17.5 [a]	1727.0 ± 16.8 [a]
AMC	847.1 ± 22.3 [b]	564.3 ± 17.5 [b]	526.5 ± 16.8 [b]
Layer	414.3 ± 22.3 [c]	249.7 ± 17.8 [c]	238.5 ± 16.8 [c]
P-value	*<0.0001*	*<0.0001*	*<0.0001*

[a-c] Mean weights ± SEM, means within a column with different superscripts differ significantly ($P < 0.05$). Two commercial broiler chicken lines were used Cobb 500 and Ross 308, a 1978 random bred broiler line from University of Alberta (AMC) and commercial laying hen line Lohmann LSL lite.

4.7.4 Carcass parts yields of four strains of birds incubated in different light treatments

No differences were reported for carcass parts yield of slaughter aged birds hatched from different lighting treatments of analysis in terms of percent live weight or cold carcass weight ($P > 0.05$) (Tables 24 & 26).

Table 24. Carcass parts yields in terms of percent live weight of birds incubated in different light treatments

Treatment	Wing	Breast	Leg/Thigh
Blue	8.0 ± 0.1	15.2 ± 0.1	20.1 ± 0.1
Dark	7.8 ± 0.1	15.4 ± 0.1	20.0 ± 0.1
Red	7.9 ± 0.1	15.3 ± 0.1	20.0 ± 0.1
White	7.9 ± 0.1	15.4 ± 0.1	20.0 ± 0.1
P-value	*0.3828*	*0.8496*	*0.9030*

Mean carcass part yields ± SEM. No differences were reported among lighting treatments during incubation ($P > 0.05$). Light treatments were all on a 12L:12D photoperiod, dark was used as a control (0L:24D). Red and blue LED fixtures (Once Innovations®, Plymouth, MN), 4100K white LED Canarm®, Brockville, ON).

Yield of common carcass parts are presented in terms of both a percentage of live bird weight as well as cold carcass weight (Tables 24-27). There was an effect of strain of bird on the carcass parts calculated as a percent of both live weight and cold carcass weight ($P < 0.05$) (Table 25 & 27 respectively). Layers and AMC had higher wing yield as a percent of live weight compared to Cobb and Ross. When analyzed as a percent of cold carcass layers had higher wing yield than AMC, both had larger wings as a percentage then the Cobb and Ross birds. Breast yields were reported highest in Cobb birds, followed by Ross, AMC and the lowest breast yields were reported for the layers. These breast differences were the same regardless of being expressed as a percent of live weight or cold carcass weight. Ross and Cobb birds differed in leg and thigh yield as a percent of live weight. The random bred line did not differ from Cobb birds, and layers presented

the smallest leg yields. When leg was analyzed as percent of cold carcass, the AMC birds had the greatest yield followed by layers and both commercial broiler strains were the smallest and not different from each other.

Table 25. Carcass parts yield in terms of percent of live weight for different bird strains raised to 36 d

Treatment	Wing	Breast	Leg/Thigh
Cobb	7.2 ± 0.1 [b]	21.9 ± 0.1 [a]	20.6 ± 0.1 [b]
Ross	7.1 ± 0.1 [b]	21.3 ± 0.1 [b]	21.2 ± 0.1 [a]
AMC	8.7 ± 0.1 [a]	9.8 ± 0.1 [c]	20.6 ± 0.1 [b]
Layer	8.5 ± 0.1 [a]	8.3 ± 0.1 [d]	17.6 ± 0.1 [c]
P-value	*<0.0001*	*<0.0001*	*<0.0001*

[a-d] Mean carcass parts yield ± SEM, means within a column with different superscripts differ significantly (P > 0.05). Two commercial broiler chicken lines were used Cobb 500 and Ross 308, a 1978 random bred broiler line from University of Alberta (AMC) and commercial laying hen line Lohmann LSL lite.

Table 26. Carcass parts yields in terms of percent cold carcass weight of birds incubated in different light treatments and raised to 36 d

Treatment	Wing	Breast	Leg/Thigh
Blue	12.4 ± 0.1	22.7 ± 0.2	30.8 ± 0.2
Dark	12.2 ± 0.1	22.8 ± 0.2	30.7 ± 0.2
Red	12.2 ± 0.1	22.7 ± 0.2	30.5 ± 0.2
White	12.3 ± 0.1	22.7 ± 0.2	30.7 ± 0.2
P-value	*0.4178*	*0.9751*	*0.8216*

Mean carcass part yields ± SEM. No differences were reported among lighting treatments during incubation (P > 0.05). Light treatments were all on a 12L:12D photoperiod, dark was used as a control (0L:24D). Red and blue LED fixtures (Once Innovations®, Plymouth, MN), 4100K white LED Canarm®, Brockville, ON).

Table 27. Carcass parts yields in terms of percent cold carcass weight of different bird strains raised to 36 d

Treatment	Wing	Breast	Leg/Thigh
Cobb	10.1 ± 0.1 [c]	30.8 ± 0.2 [a]	29.0 ± 0.2 [c]
Ross	10.0 ± 0.1 [c]	29.9 ± 0.2 [b]	29.7 ± 0.2 [c]
AMC	14.0 ± 0.1 [b]	15.8 ± 0.2 [c]	33.1 ± 0.2 [a]
Layer	14.9 ± 0.1 [a]	14.5 ± 0.2 [d]	30.8 ± 0.2 [b]
P-value	*<0.0001*	*<0.0001*	*<0.0001*

[a-d] *Mean carcass parts yield ± SEM, means within a column with different superscripts differ significantly (P < 0.05). Two commercial broiler chicken lines were used Cobb 500 and Ross 308, a 1978 random bred broiler line from University of Alberta (AMC) and commercial laying hen line Lohmann LSL lite.*

4.8 Discussion

4.8.1. Breast muscle sampling and yields

Similarly, as reported in Chapter 3, there were no light by strain interactions for any of the breast development, body weights or slaughter performance data. No differences were found in the current study for breast muscle yields or chick weight when birds were hatched in incubators that were equipped with LED lights compared to those hatched in the conventional dark incubators. Other studies have found that the use of monochromatic green light either used during the incubation or rearing period resulted in birds with superior breast yields at days 6 and 7 posthatch respectively (Rozenboim et al., 2013; Zhang et al., 2014). Zhang et al. (2014) used 560 nm green LED light at a light intensity of 15 lux on a continuous lighting schedule during incubation. The birds hatched in the green light had heavier d 7 body weights and breast yields as a percent of body weight which they attributed to satellite cell proliferation. Due to the experiment only containing data from birds until d 7 it was unable to be determined whether these differences persisted until market age. The current study did not evaluate LED lights on the green spectrum and that could be part of the reason that breast muscle development and subsequent yields differences were not

present. Most of the research contains rearing lighting programs alone or in combination with incubation lighting, this may be the reason the same results were not present in this study when using photostimulation during incubation.

Chicks differed in weight among strains which did not come as a surprise since we saw differences in egg weight and the two are usually related. AMC better utilized their yolk compared to the Ross and Layers, presenting higher YFBW. There were some differences among strains for breast weight, however when analyzed as a % of body weight all the commercial strains even the layers were equal. Zhang et al. speculated that Cobb broilers may be more sensitive to light stimulation than other strains (2014). Experiments by Rozenboim et al. (2013) used LED monochromatic lighting of different colors during incubation and rearing period. They reported that birds hatched from green light incubators had heavier breast muscle yields at hatch and at d6 posthatch. When birds were reared using green light there were 2 – 2.4 times the amount of satellite cells in the breast muscle when compared to birds grown in red or white light conditions (Rozenboim et al., 2013). It is possible that using a monochromatic light source would make a difference in how the embryos and birds respond to the photostimulation and could be the reason we did not see the same effect in this study.

It has been hypothesized that layers may develop slower than broilers due to the rate in which they absorb the remaining yolk. However, in a 2010 study layers and broilers had the same relative yolk weight (Druyan, 2010). Rates of embryonic development differ between broiler and layer strain. No differences were found among broiler and layer strains for breast muscle weight at any stage in embryo development (Druyan, 2010). These

findings agree with the findings from this study, whereby hatch day breast yield as a percentage of chick weight was the same for commercial broilers and layer. As the birds grew layers had significantly lower breast muscle weights and yields compared to the commercial broilers at d 6. These differences in breast yields were reported for both d 6 and slaughter. At hatch layer birds had similar breast weights as AMC birds, however AMC birds outperformed the layers for d 6 and slaughter breast yields.

4.8.2 Bird growth performance

No differences were found on the effect of light for body weight for either age or strain of bird in the current study. As found in the current study, Archer (2017), reported that providing LED light of red, white and green colors did not produce differences in body weights when grown to 45 d. Cao et al. (2008) reported that growing birds under blue or green light in the barn resulted in heavier birds than when red or white light was used. In the current study only lighting during incubation was investigated, potentially by supplementing in *ovo* lighting with a lighting of different colors during the rearing period would result in greater body weight differences than Cao et al. (2008) found with only rearing period lighting. Strain by age interaction differences were reported for growth performance in the current study. Ross and Cobb genetic strains are the most commonly used in the broiler industry worldwide (Tona et al., 2010) and their Cobb 500 and Ross 308 lines were chosen to be used in this study. Not all broiler strains are created equally and may need different incubation conditions to maximize the traits desired. By d 7 both commercial broiler strains were at the same body weight despite Cobb birds being heavier than Ross at hatch. Tona et al. (2010) reported the opposite where Cobb chicks weighed

more at d 7 than Ross birds but did not differ from each other at hatch. Findings by Pascalau et al. (2017) agreed with Tona et al. (2010) where Cobb birds had heavier d 7 body weights compared to Ross and in their experiment this difference persisted until d 42 when birds were slaughtered. Results of the present study were not the same as those of Pascalau et al. (2017) as Cobb and Ross birds weighed the same through d 7-35.

4.8.3 Slaughter and carcass yields

All lighting treatments had similar carcass and parts weights in the current study. Most lighting research has investigated the effect of light colors and photoperiod during the rearing period on slaughter aged bird's carcass parts yields rather than *in ovo* photostimulation. Potentially the use of lighting during incubation does not provide effects that last through the rearing period and until slaughter age, as the current study only found differences up to the weight gain in the first six hours postplacement. The use of green and blue light during the rearing period has been reported to create birds that yield heavier carcasses and breast muscle (Liu et al., 2010; Cao et al., 2012). Differences in slaughter weights and carcass parts yields were only present between strains of birds in this study. Carcass parts yields as a percentage of live weight in Cobb birds were the largest breast muscle yield followed by Ross, AMC and layers. This also meant that the Cobb birds had significantly lower leg and thigh yield compared to the Ross and layers but were the same as the AMC. Wing yields were consistently higher in the AMC and layers compared to Cobb and Ross birds regardless if measured as a percent of live bw or cold carcass weight.

4.9 Conclusion

Providing light during the incubation of hatching eggs in the current study was found to have no effect on the development of chicks or their yolk free body weight on day of hatch. Whether hatched in incubators containing lights or in the traditional dark environment, breast muscle yields were the same. Therefore, the LED lights in the current study did not promote large breast weights as seen in other incubation lighting work. Furthermore, as the birds reached market age the use of lighting during incubation also had no effect on the growth performance, slaughter weights or carcass part yields. This study did provide additional evidence that different genetic birds lines vary in their growth and carcass parts yields. Differences were found among the two commercial strains suggesting that the various breeder companies are producing broilers that have different growth patterns and carcass parts yields.

CHAPTER 5 PROJECT CONCLUSIONS AND RECOMMENDATIONS

Much has been discovered on the use of LED lights during incubation. However, it is crucial that research continue to ensure that a proper light color or wavelength is found for different production characteristics within bird strains. One light color may not be beneficial for both broilers and layers as they are selected for different production traits. In this study however, we did not find any strain by light interactions, despite the vast magnitude of strain differences. Lighting during incubation appeared to have an effect on embryo development and early chick weight gain. Red lighting caused chicks to hatch earlier than dark incubators, indicating they may be more developmentally advanced and ready to hatch earlier. Chick length however showed discrepancies as blue and dark chicks were actually longer than the red chicks that should have been more developmentally advance in relation to them hatching earlier. Once placed in the barn the red chicks along with chicks from blue lit incubators gained the most as a percent of their hatch weight.

Future work in continuation of this study would be to analyze histology of breast muscle samples to determine if there are changes at a microscopic level. Increased number of muscle cells per gram has been reported in the first few days posthatch when broiler hatching eggs were stimulated with green light during incubation versus dark (Halevy et al., 2006b). It is of interest to investigate to see if the lights used in this study produced similar results. It is questionable whether light does really impact muscle development in our study as we did not see breast muscle yield differences among light treatments at any age.

Recommendations for future studies would be to investigate the effect of a monochromatic green LED on different lines of chickens as others have found it to be beneficial to growth and breast muscle development in some broiler lines. Investigating the effect of light of different colors on different breeder age hatching eggs would be interesting, as it is known that breeder age can affect hatchability and embryo mortality. There is potential that certain colors would help keep hatchability of older breeder flocks in an optimal range. A project utilizing both incubation and posthatch lighting of Once Innovation™ light fixtures used in the current study would be of interest to see if continuing the red and blue light during growout could advance bird performance, as was found during the first 6 h postplacement.

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APPENDIX

Table A1. Composition of non-medicated starter, grower and finisher diet fed *ad lib* to birds

	Starter	***Grower***	***Finisher***
Ingredients (%)			
Corn	40.86	45.23	50.95
Soybean meal	40.29	35.30	30.10
Wheat	10.00	10.00	10.00
Ani/veg fat[u]	3.37	4.68	4.37
Limestone	1.96	1.67	1.60
DICAL PHOS 21P	1.43	1.24	1.15
DL Methionine Premix	0.59	0.49	0.43
Pellet binding agent	0.50	0.50	0.50
MCBS7[xy]	0.50	0.50	0.50
Salt	0.41	0.39	0.40
Lysine HCl	0.01	-	-
Calculated Analysis			
MEn (kcal/kg)	3025	3150	3200
Protein (%)	23	21	19
Calcium (%)	1.05	0.90	0.85
Avail. Phosphorus (%)	0.50	0.45	0.42
Dig. Tryptophan (%)	0.25	0.23	0.21
Dig. Lysine (%)	1.27	1.13	0.99
Dig. Methionine + cystine (%)	0.94	0.84	0.76
Dig. Threonine (%)	0.87	0.80	0.73
Sodium (%)	0.19	0.18	0.18
Determined analysis[z]			
Crude protein (%)	25.02	22.31	18.95
Total calcium (%)	1.15	1.03	0.98
Total phosphorus (%)	0.72	0.66	.64
Sodium (%)			

[u]Animal/vegetable blend

[x]Supplied per kg diet of starter; vitamin A 1.56 g, vitamin D3 premix 320.0 g, vitamin E 20 g, vitamin K 1.94 g, Riboflavin 2.15 g, DL Ca-pantothenate 6.00 g, vitamin B12 4.60 g, Niacin 8.08 g, folic acid 22 g, choline chloride 267 g, biotin 60 g, pyridoxine 1.09 g, thiamine 0.82 g, manganous oxide 40 g, zin oxide 30.5 g copper sulfate 12.8 g, selenium premix 14.85 g, ethoxyquin 16.6 g, ground corn 70.01 g, ground limestone 100 g.

[y]Supplied per kg diet of starter; vitamin A 1.56 g, vitamin D3 premix 320.0 g, vitamin E 20 g, vitamin K 1.94 g, Riboflavin 2.15 g, DL Ca-pantothenate 6.00 g, vitamin B12 4.60 g, Niacin 8.08 g, folic acid 19 g, choline chloride 267 g, biotin 50 g, pyridoxine 1.09 g, thiamine 0.82 g, manganous oxide 40 g, zin oxide 30.5 g copper sulfate 12.8 g, selenium premix 14.85 g, ethoxyquin 16.6 g, ground corn 83.0 1g, ground limestone 100 g.

[z]Diet samples were analyzed in duplicate for each trial.