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Optimization of the Light Environment for Broiler Chickens

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Optimization of the Light Environment for Broiler Chickens

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by

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ABSTRACT

The use of artificial light sources has been necessitated by the use of fully enclosed rearing facilities for improved environmental control. Light Emitting Diodes (LED) have been developed as a light source that reduce the utilities required to provide equal light to that of incandescent sources. The following reports were carried out to investigate the effects of two light color temperatures, light intensity and light intensity gradients on broiler chicken production and behavior. The first investigation consisting of two consecutive trials investigated the effect of two light color temperatures (2700 K and 5000 K) in addition to the preference for each. It was found that broilers provided a choice between 2700 K and 5000 K had greater ($p<0.05$) BW than those reared using only 2700 K while those under 5000 K were intermediate. Further, broilers displayed a preference for 2700 K during the first and last hour of the light period and no preference during the other monitored hours. In the second report light intensity was investigated using 5, 10 or 20 lux (lx) in addition to access to all three intensities. It was found that birds reared using 5 lx and those given access to all three intensities had lower ($p<0.05$) feed:gain compared to those reared under 20 lx with 10 being intermediate. Further no difference ($p>0.05$) was found between BW or BW CV for each of the treatments. In the final report the use of feed line lighting was compared to conventional overhead lighting. The effect of the gradient (90 lx to 30 lx) resulted in similar production to that of a conventional uniform lighting environment of 20 lx. The use of preference and choice in light environments has been suggested to improve the production and wellbeing of broiler chickens in all three of the reports using light color temperature, light intensity, and light intensity gradients.

DEDICATION

I would like to dedicate this work to my wife Courtney and my son Ellis. Thank you for all your continual love and support.

TABLE OF CONTENS

PUBLICATIONS

Aldridge, D. J. Scanes, G. C. Kidd, M. T. 2019. Performance and Preference of Broilers Provided Dual Light Warmth. Poult. Sci. Chapter 2. Submitted

Aldridge, D. J. Scanes, G. C. Kidd, M. T. 2019. Performance and Preference of Broilers Provided Choice of Light Intensity. Poult. Sci. Chapter 3. In preparation

Aldridge, D. J. Scanes, G. C. Kidd, M. T. 2019. Feed Line Lighting in Commercial Broiler Production. Poult. Sci. Chapter 4. In preparation

CHAPTER 1

LITERATURE REVIEW

INTRODUCTION

Light and vision have long been topics of interest (Zubairy, 2016). Early philosophers understood the importance of vision yet were unable to describe the mechanisms in which it is carried out (reviewed: Ackerman, 1998). More recently, the subtle effects of varied lighting on both humans and animals are beginning to be researched with the need for such work being driven by issues related to the transition from natural light environments to those of artificial lighting (Edwards and Torcellini, 2002; Rozenboim et al., 2004; Lewis, 2006; Boyce, 2010; Olanrewaju et al., 2014, 2018; Huth and Archer, 2015; Westland et al., 2017; Tähkämö et al., 2018).

Advances in housing of poultry in fully enclosed rearing facilities made the use of artificial light a necessary. Understanding the effects of different types of artificial light takes into account the attributes of photoperiod, intensity and color (reviewed: Lewis and Morris, 2006). Photoperiod is the duration of light versus that of darkness in a 24 hour cycle. It is denoted as a ratio with the photophase (light or L) on the left and the scotophase (dark or D) on the right. Light intensity is often measured in lux or foot candles. However, there are inherent problems with these measures for poultry (discussed in detail in the following chapters). Color is measured in two ways: first - in nanometers describing the wavelength and is sufficient for monochromatic light; second - Kelvin temperature is used to describe types of white light that are comprised of a spectrum on different wave lengths (nm) of light.

Experimental designs of exposing groups of poultry to different lighting treatments have traditionally yielded knowledge of the effects of light on growth, physiology and behavior (reviewed Olanrewaju et al., 2006; Oliveira and Lara, 2016). New concerns for the preferences of poultry for different lighting regimens have led to the development of new designs in testing light and its effects on growth and behavior.

The use of side by side comparisons are commonly employed to determine the effects of lighting in poultry (Lien et al., 2008; Alvino et al., 2009; Olanrewaju et al., 2015a; Archer, 2015, 2018; Rault et al., 2017). Choice and preference testing has been less common. However, choice and preference testing for poultry has proven useful in optimization of forage materials (Weeks and Nicol, 2006), feeders (Deines, 2016), nesting (Kruschwitz et al., 2008) and perching (Bailie et al., 2018). Its use as an approach to determine the most appropriate lighting should yield information to questions arising about environmental complexity and how it effects poultry production and well-being. To better understand literature of the effects of light on poultry production, wellbeing and behavior a clear knowledge of light and avian vision is first needed.

VISION IN POULTRY

Light and Vision

Vision can be defined as the special sense by which the qualities of an object, constituting its appearance are perceived through the process in which light rays enter the eye are transformed by the retina into electrical signals that are transmitted to the brain via the optic nerve (Merriam-Webster, 2019). The occurrence of vision as stated above depends upon light. Light occurs in the form of wave energy along a spectrum of wave lengths. This spectrum is large in range, from 1 m radio waves to 10 $^{-13}$ gamma rays (NASA, 2019). Only a small fraction of light is able to be received by the eye and transmitted to the brain as an electrical signal (Grand, 1975; Prescott and Wathes, 1999). Impacts of visible light on poultry take on multiple forms as discussed in general above and specifically in the following sections.

Biology of Vision

The eyes of poultry species are much larger than that of those of humans and other mammals when compared as eye to brain weight ratio (Gunturkun, 2000). The physical structures that light must traverse are similar for avian species as compared to other with light passing through the cornea, anterior chamber, lens, vitreous body and finally coming to the retina and its photoreceptors where its converted to electrical signals (Gunturkun, 2000). Birds, like mammals, have two types of photoreceptors cells in the retina; these being rods and cones (Hunt et al., 2009). Cones function predominantly during well-lit periods and are responsible for the perception of color (Goldsmith, 1990). In contrast, rods provide non-color vision during conditions of low light intensity (Hunt et al., 2009). These differences are reflected in the number of cells present within the eye (Hunt et al., 2009). The rods being numerous with multiple connected to a single nerve while cones, fewer in number each connected to a single nerve (Lewis and Morris, 2006). The reception of light is made possible in avian (as well as mammalian) species by different types of opsin (Gunturkun, 2000). Rhodopsin is found in rods while other opsins (iodopsins in avian species) of specific spectral sensitivity ranges are found in cones (Hunt et al., 2009).

The color vision of avian species is developed to a greater extent than that of mammals where rods dominate vision (Hunt et al., 2009). Avian species (non-nocturnal) employ cone dominated vision and four cone types: short wave sensitive 1 (max sensitivity of 360-380 nm) (SWS1), short wave sensitive 2 (max sensitivity of 440-460 nm) (SWS2), middle wave sensitive (max sensitivity of 500-510 nm) (MWS) and long wave sensitive (max sensitivity of 565-570) (LWS) which occurs as a double cone (Bowmaker and Hunt, 2006). The reception of light by spectrally sensitive pigments in cones is further by the presence WHERE? of oil droplets (Lind et al., 2013). These oil droplets have specific transparence clarities that filter for specific wave lengths of light before it reaches the photoreception pigments (Lind et al., 2013). These act to reduce dangerous extreme UV light and focus the light for the receptor (Armington and Thiede, 1995; Gunturkun, 2000). However, birds can perceive light within part of the UV spectrum; this being useful for the identification of other individuals together with seeds, berries and insects (Burkhardt, 1982; Chen et al., 1984).

The oil droplets, in combination with the additional cone type, result in different perception of both color and intensity compared to the human eye (Prescott et al., 2003). This is due to the unimodal peak in sensitivity to light color for humans at approximately 540 nm, used as relative sensitivity of one if spectrum were to be along the x axis and relative sensitivity along the y axis (Grand, 1975). However avian species are reported to have a multimodal distribution of relative sensitivities along the spectrum of light. The greatest peak (approximately 1.1 relative sensitivity compared to that of humans 1) occurs at 550 nm. The second (0.9 relative sensitivity) at 460 nm. The third (0.7 relative sensitivity) occurring at 640 nm and the final (0.2 relative sensitivity) occurring at 370 nm (Prescott and Wathes, 1999). Thus, poultry perceive light at or around three peak sensitivities as either much brighter or even present compared to people (Prescott and Wathes, 1999). This supports the need for research on effects of both the optimal intensity and color of light in poultry.

PHOTOPERIOD AND BROILER PRODUCTION

Photoperiod is one of the main variables in lighting programs for poultry. Until recently the use of near continuous (23L:1D) or continuous (24L:0D) lighting programs were used by the broiler industry due to increased production performance (Bean et al., 1962; Renden et al., 1993; Ingram et al., 2000). However, this practice has been replaced with reduced photophase through adoption of mandates of a minimum 6 hour scotoperiod in the European Union (Council of the European Union, 2007). In the United States of America, the National Chicken Council (2004) requires a 4 hour period of darkness. While a reduction of the length of the photophase is thought to improves well-being of broiler, some aspects of welfare (ocular development and behavioral patterns) are negatively affected if the photophase is reduced excessively (Jenkins et al., 1979). Additional lighting regimens include night interruption or intermittent photoperiods as well as increasing the photophase (Buyse et al., 1996a; b; Kühn et al., 1996; Buys et al., 1998; Apeldoorn et al., 1999; Schwean-Lardner et al., 2007). Intermittent photoperiods consist of more than one photophase and scotoperiod within a 24 hour cycle (Lewis and Morris, 2006). Photoperiods are more variable and include those that increase from day of placement as well as those that are shortened after brooding (most commonly d 7) and extend through the production period (Renden et al., 1996; Schwean-Lardner et al., 2007; Lewis et al., 2008).

Extended Photophase

The practice of continuous or near continuous lighting was widely adopted due to the increased growth compared to 16L:8D lighting (Moore, 1957; Bean et al., 1962; Weaver and Siegel, 1968). Further, the practice of continual illumination enabled chicks to feed at times when it was most comfortable e.g. pre and post natural light periods especially when environmental temperatures were high (Heywang, 1944). However, this practice has been shown to have negative effects compared to more moderate photoperiods (Stone et al., 1995; Li et al., 2000; Sanotra et al., 2002; Liu et al., 2004; Abbas et al., 2008; Lewis and Gous, 2009; Lewis et al., 2009; Das and Lacin, 2014; Yang et al., 2015). Effects of continuous and near continuous lighting have been reported to have negative impacts on the ocular development (Jensen and Matson, 1957; Lauber et al., 1961). Furthermore, the use of continuous lighting was found to interrupt the diurnal rhythm of the eye causing retinal abnormalities (Stone et al., 1995; Liu et al., 2004).

When broiler chickens were reared under a range of photoperiods from 2 to 24 hours of light, those under continuous light were found to have abnormally heavy eyes (Lewis and Gous, 2009). The view that broiler production is improved under continuous light has been challenged (Blair et al., 1993; Rozenboim et al., 1999b; Lewis et al., 2009). Blair and colleagues (1993) reported that broiler chickens reared under an increasing day length of 4 h weekly increases starting at d 4 at 6L:18D) had lower mortality, feed conversion and similar BWG compared to those reared under continuous light. In addition, improved livability was reported for broilers reared under increased day lengths regardless of intensity (Charles et al., 1992). Downs and colleagues (2006) reported reduced mortality using reduced day lengths early in the production cycle and attributed this to reduced early growth and improved skeletal development (Downs et al., 2006).

Intermittent Lighting

Intermittent lighting programs have been of interest since at least the 1950's (Barott and Pringle, 1951; Clegg and Sanford, 1951; Moore, 1957). This was due to the findings that chicks reared under supplemental light hours had slower growth compared to natural day lengths (Paulino, 1949). Clegg and Sanford (1951) reported improved growth of broiler at 6 weeks of age using a 6L:6D lighting schedule compared to 12L:12D (516g vs. 450 g BW respectively) (Clegg and

Sanford, 1951). Additionally in a separate trial within the same report, broilers reared under 2L:2D intervals had improved growth over those under 12L:12D at 6 weeks (768g vs. 666g) (Clegg and Sanford, 1951). It was concluded that the growth increase of broilers reared using intermittent light was due to a more uniform provision of nutrients to the birds over time (Clegg and Sanford, 1951). Similarly the use of intermittent light was reported to have varied effects on growth dependent on the patter or durations used (Barott, and Pringle 1951). The use different intermittent lighting periods of 8L:4D, 6L:6D, 4L:4D, 3L:5D, 3L:3D, 2L:6D, 2L:4D, 2L:3D, 1L:5D, 1L:4D, 1L:3D and 1L:2D were evaluated (Barott and Pringle, 1951). The use of the 1L:4D schedule resulted in the highest growth followed by 1L:3D and 2L:3D. (Barott and Pringle, 1951). It was thought that the chicks were able to fill their crops within an hour of light yet were emptied and ready to consume again after 4 hours of darkness (Barott, and Pringle 1951). However, it was suggested that the optimal situation for production would be continuous lighting allowing chicks to access feed at will instead of risking chicks becoming hungry during the dark period (Barott, and Pringle 1951). Similar results were reported by other researchers (e.g. Moore, 1957). The highest growth rate was obtained using continuous light however similar growth was seen using intermittent light with "*4 to 6 periods per day*" of light, though durations were not reported (Moore, 1957). However, not all reports agreed. Cherry and Barwick (1962) reported no difference in growth for chicks reared under near continuous 23L:1D and intermittent periods of 1L:2D, 1L:3D, 1L:5D and 1L:7D.

The use of intermittent lighting has been reported to result in positive welfare outcomes. Simon, (1982) found improved leg health through the reduction in twisted legs of chicks reared in batter cages when comparing continuous and 1L:2D regimens (Simon, 1982). This was later confirmed by Wilson and colleges (1984) who reared male broiler chicks in floor pens using the same lighting treatment previously mentioned finding fewer abnormalities under intermittent light. Moreover, the use of a gradually increasing light period during the flock was found to reduce the occurrence of sudden death syndrome compared to near continually lit (23L:1D) birds, with similar growth and FCR (Classen and Riddell, 1989). A similar conclusion was reached by each investigator that the improved health of the intermittently illuminated birds was likely due to increased activity during the light periods compared to the relatively low activity across all times on continuously lit birds (Simmons, 1982; Wilson et al., 1984; Classen and Riddell, 1989).

More recently the physiological effects of intermittent light have been investigated (Ohtani and Leeson,; Kühn et al., 1996; Apeldoorn et al., 1999; Abbas et al., 2008; Zheng et al., 2013; Das and Lacin, 2014; Olanrewaju et al., 2018). Birds reared using intermittent light have been reported to have increased plasma levels of growth hormone (GH) than those under 23L:1D (Kühn et al., 1996). Apeldoorn and colleagues (1999) reported that the pattern of heat production was altered for broilers reared under intermittent light in addition to improved energy metabolization. Similar heat production patterns have been reported in other studies with intermittent light; levels of metabolizable energy intake being higher and growth improved c (Ohtani and Leeson, 2000). Circulating plasma concentrations of corticosterone (CORT) are reduced in broilers reared under intermittent lighting (Abbas et al., 2008). In addition, there were elevated white blood cell counts and T_3 concentrations (Abbas et al., 2008). Furthermore, Zheng and colleagues (2013) reported increased serum melatonin levels for broilers reared under intermittent light as well as superior thymus and bursa indexes (Zheng et al., 2013). However in a very recent study, no differences were found in humeral immune response (Olanrewaju et al., 2018).

Reduced day length

Early findings (discussed above) found improved growth using continuous lighting programs (Moore, 1957). However, the early literature was not in concordance as some reports found no difference in growth of broilers reared using 24 or 12 h of light (Skoglund et al., 1966). In an early behavioral study, Squibb and Collier (1979) found that the feeding times of broilers housed under 24 h was 12 min/h while the feeding time of broilers housed under 12 h of light was 25 min/hr. While the use of continuous light was shown to improve growth (Robbins et al., 1984; Renden et al., 1996; Ingram et al., 2000), much of the gain in BW was found to be comprised of fat rather than muscle (Robbins et al., 1984). An increase of 12% greater body fat was reported for broilers reared under 24 h of light compared to those reared under 16L:8D as well as reduced leg abnormalities (Robbins et al., 1984).

The use of continuous lighting was reported to have negative effect on the immune function of cockerels compared to those reared under 12L:12D (Kirby and Froman, 1991). In addition, extended photoperiods increased mortality rate (Gordon and Tucker, 1995), induced corneal flattening (Li et al., 2000), decreased leg health (Sanotra et al., 2002), and reduced comfort behavior (preening and wing shaking) (Bayram and Özkan, 2010). A 23L:1D lighting regimen reduced displays of comfort behaviors to a undetectable level (Schwean-Lardner et al., 2012). There was no improvement with behavioral indices with more than 10 h of darkness was compared over 8 h (Schwean-Lardner et al., 2012).

It has been demonstrated that lighting can optimize BW and while maintaining acceptable wellbeing (Lien et al., 2007). A lighting schedule of 16L:8D was used from 8 to 43 d followed by a 23L:1D from 44 to 49 d. The birds had lower BW at 43 d compared to those under 23L:1D from 8 d. However, at 49 d birds from both treatments were of similar BW (Lien et al., 2007).

The durations of light used in broiler production has changed with increased understanding of its effect on the growth and wellbeing have increased (Moore, 1957; Prescott et al., 2003). While intermittent lighting the use of intermittent lighting has provided similar growth and improved wellbeing compared to extended day lengths it has been over shadowed by the adoption of relegation of photoperiods of reduced day length (Council of the European Union, 2007; National Chicken Council, 2014). However, the adoption of new technology as discussed further below has allowed for similar and improved production under the new guidelines of day length (Archer, 2015).

LIGHT COLOR IN BROILER PRODUCTION

The perception and reception of color light in poultry is different to that of humans as discussed earlier (Biology of Vision). These differences in perception and reaction to color necessitate the investigation of the effects of color on poultry. In broiler production, the use of colored light has been of interest to producers for some time. Early reports suggest that the use of red paint over production facility windows or red colored incandescent bulbs increased the feed consumption and growth in young chickens (Bowlby, 1957). Since that time the development of new affordable light source technology such as Light Emitting Diodes (LED) have enabled producers and scientists further investigate the effect of both monochromatic colors as well as spectral compositions of light that can easily be adopted into commercial practices (Rozenboim et al., 2004; Liu et al., 2017; Archer, 2018).

Red light

Some of the earliest reports on the effects of color on the rearing of broilers from producers using field trials to improve understanding of growth and behavior of broilers (Bowlby, 1957). The reduction in aggression and flighty activity was reported for broilers reared using red lights (Bowlby, 1957). The induction of behavioral changes in the birds was attributed to the inability to distinguish blood within the environment that triggered aggression and cannibalism (Bowlby, 1957). Further, the use of blue lights following red light was found to render broilers almost blind during catching, further depressing activity (Bowlby, 1957). While red light reduced aggression and other behavioral issues, red incandescent light during development resulted in decreased sperm production compared to equal intensity unfiltered incandescent (Carson et al., 1958). This work has been followed by numerous others demonstrating the reduction in growth and efficiency of broilers reared under red light (Foss et al., 1972; Prayitno et al., 1997; Rozenboim et al., 1999a).

Blue and Green Light

The application of other colors have also been investigated. Rozenboim and colleagues (1999a) found that broiler chickens reared using green light had increased growth under green light compared to those under blue, red or white as early as 3 d. However, those birds reared under blue light had later onset of growth and eventually achieved similar BW at 35 d (Rozenboim et al., 1999a). This work was further confirmed by a later report where birds reared under green light from 1 to 20 d and switched to blue light till 40 d had great BW than those reared under just blue or green light alone (Rozenboim et al., 2004). In similar trials, Cao and colleges found improved growth till 26 d under green light and those under blue light had greater BW gains from 27 to 49 d (Cao et al., 2008).

Increased levels of T lymphocytes were reported in broilers reared under green light at 21d while similar levels were seen in birds reared under blue or green at 49 d, both being higher than birds reared under red light (Xie et al., 2008b). To better understand the increased growth of broilers reared under green light, Liu and colleagues (2010) measured satellite cell mitotic activity as well as insulin-like growth factor compared to those reared under red and blue light. There was increased satellite cell activity = under green compared to blue and red light. However, both blue and green had improved IGF levels compared to red (Liu et al., 2010)

White Light

When a combination of light wavelengths is received by the eye the color is perceived as white. The wave lengths that make up white light are not always equal resulting in different appearance.

The appearance of these different combinations of light have described as black body temperatures measured in Kelvin (K). This is simply the color of light emitted from an ideal black body at a specific temperature (K). However, LED light does not follow the same form as incandescent lights and therefore assigned correlated color temperatures also K that match the closest black body temperature appearance as seen by the human eye. The use of lights of differing spectrums in poultry production has under gone limited investigations.

Olanrewaju et al.,(2015) found that the use of 2700 K and 5000 K color temperature LED light sources were acceptable for rearing broilers with no blood physiological variables were found to be outside of homeostatic ranges. LED sources of 4100 K and 6065 K were evaluated for preference and production performance by Riber (2015). No preference was reported on three (4, 10 and 22) of the six monitored d while a preference for 6,065 K was found on d 16, 28 and 34 (Riber, 2015). Further those birds reared using 6065 K were found to be heavier (67±19.2 g) than those under 4100 K (Riber, 2015). Archer (2017) evaluated the production performance as well as welfare parameters of broilers reared under two LED bulbs at 2700 K or 5000 K commonly used in the poultry industry. Birds reared under 5000 K were found to have more favorable bilateral asymmetry, plasma corticosterone concentrations, heterophil/lymphocyte ratio, tonic immobility, wing flapping, and vocalization than 2700 K birds (Archer, 2018). Further, those birds reared under 5000 K light had greater BW and lower feed:gain than those birds reared using 2700 K lights(Archer, 2018).

INTENSITY OF LIGHT AND BROILER PRODUCTION

Understanding of the effects light intensity has on broiler production have long been in question. Much of industry practices and trends come from two basic ideas about light intensity and how it effects the behavior of broiler chickens. First, that broilers reared under too dim of light will have suppressed feed intake (Cherry and Barwick, 1962; Lien et al., 2007). Second, that excessive intensity result in lower feed:gain due to increased activity (Cherry and Barwick, 1962). These two general ideas are thought to be true, the levels at which light intensities are optimized is often debated due to the negative welfare states such as increased eye myopathies and reductions comfort behaviors (preening) in broilers house under reduced intensities (Bercovitz et al., 1972; Alvino et al., 2009). While a portion of the early investigations were focused on optimization of light environments for production of broiler chickens much of the later work has been in response to the European Union's adoption of a mandated 20 lux intensity requirement for broiler production (Council of the European Union, 2007).

Minimum Intensity Limits

Early investigations suggested that the acceptable range of light intensity for poultry be from 1.08 lx to 10.76 lx(Cherry and Barwick, 1962). However, more recent works have reported mixed results that include reduction in BW, behavioral synchronization, and increased foot pad lesion at 1 lx (Deep et al., 2010, 2011, 2013; Blatchford et al., 2012). Deep and colleges (2010) reared birds under 1, 10, 20 and 40 lx for 35 d and reported no effect on performance however as light intensity increased the occurrence of foot pad ulcerations decreased. In a longer grow out of 56 d in a similar trial, no differences were reported for performance between 20 and 5 lx (Olanrewaju et al., 2016). However, not all reports agree. When rearing birds under 1, 5 and 10lx a quadratic response for BW and feed:gain were reported for broilers reared to 35 d (Deep et al., 2013).

Intensity Gradients

While the establishment of minimum light intensities has been the focus of many investigations others have focused on the differences in intensity or gradients, able to induce behavioral rhythms (Alvino et al., 2009; Blatchford et al., 2012). The use of 0.5 lx dark period (sometimes used when light intrusion from passing cars or other outside sources) was found to be distinguishable by broilers when a 1 lx light period was used (Blatchford et al., 2012). Moreover, Alivino and colleges (2009) found similar results using a 1 lx dark period and a 5 lx light period that increased the activity of broilers during the dark period compared to those provided a 20 lx light period. However, the use of greater (20 lx vs 10 lx) gradients between dark and light periods has also been reported to increase the fearfulness of broilers for those reared under 20 lx (Robles, 2010).

Preference testing has also been used to better under stand optimal light intensities for rearing broilers (Davis et al., 1999a; Raccoursier, 2016). When broilers were provided a preference of 6, 20, 60 and 200 lx at 2 wk birds preferred 200 lx for all observed behaviors (Davis et al., 1999a). However at 6 wk a preference for 200 lx was only observed for active behaviors while 6 lx was preferred for resting behaviors (Davis et al., 1999a). In a similar investigation Raccoursier (2016) reported that broilers at 40 d consumed more feed an area lit at 20 lx compared 5 lx when given a free choice. Additionally, birds were observed to occupy an area without feed and water at 1 lx in the greatest density within the test system (Raccoursier, 2016).

CHOICE AND PREFERENCE TESTING IN POULTRY

Beginning in the 1960's, the welfare of poultry in commercial production systems began to be questioned, particularly in Europe beginning with the Brambell Report (Brambell, 1965).

Since then, animal welfare has developed into a major field of study with multiple journals currently. Poultry production has been extensively examined, especially table egg production (Wegner, 2009). Some of the earliest research on animal welfare was conducted with poultry (Dawkins, 1977). Studies of welfare and well-being can generally be divided into two aspects, physiological and behavioral (Nicol et al., 2009). Physiological welfare parameters are most closely associated with stress physiology. Measures of physiological welfare in poultry include the following: heart rate, body temperature, asymmetry, immune function (heterophil to lymphocyte ratios), and circulating concentrations of CORT in birds (Broom, 2011; Scanes et al., 2018). These measures paired with behavioral traits have yielded significant contributions and their use has been increasing (Broom, 2011; Sales et al., 2015; Liu et al., 2017; Pettersson et al., 2017).

Choice or preference trials are a means to investigate well-being in a non-invasive manner (Dawkins, 2015). Such studies have provided insights to improve poultry welfare and potentially optimize well-being (Ma et al., 2015). Some of the earliest work in advancing animal welfare was on laying hens (Hughes, 1973). The preference of hens for different housing types was examined addressing the question: *"do hens housed in battery cages suffer"* (Dawkins, 1977 Hughes, 1976). This early work has proven to be influential for preference trials to follow as its approaches have been employed in numerous other studies (Davis et al., 1999; Kruschwitz et al., 2008; Riber, 2015; Weeks and Nicol, 2018).

An area that has received attention is investigating what of “feelings” of animals together with their use and importance to production. Further, it was stated (Dawkins, 1977) that while a preference or choice trials may indicate “likes” or “dislikes”, a measure was needed to quantify how much the hens “liked” or “disliked” the battery cage. Much attention in these early works were given to convincing the science community that the “feelings” and emotions of animal were both real and worthy of investigation beyond social responsibility. Feelings were and are thought to have developed as critical evolutionary tool aiding survival (Dawkins, 1977) If so, the guidance from these early works should be heeded. Results from preference studies in poultry need to be placed in context and their “generality established” for different environments, ages, sexes, and genetic strains (Dawkins, 1977).

Design and applications of choice and preference testing in poultry

Choice and preference investigations have expanded beyond the early investigations of layer housing to include the wide range of variables in poultry production. These include cage type, bedding material, feed types and regimes, light intensity and color, mates, foraging, heat, and even social companionship (Nicol, 2011).

Free choice investigations provide a basic understanding of what birds will choose at a given time. The measures employed are simple, such as number of choices made between options or the duration of time spent in an area or environment. However, even early in the development of poultry preference and choice investigations, it was recognized that there is a need to measure the strength or preference (Dawkins, 1977, 1983; Nicol et al., 2009). Early investigations attempted to assess the true needs of poultry with much of the discussion focusing on dust bathing of caged hens. One method applied used the economic theory of customer demand to hens in cages with hens provided with a choice between litter and wire flooring (Dawkins, 1983).

To better understand the value of each, birds were feed deprived for set amounts of time and then provided a choice with feed available in only one of the choices (Dawkins, 1983). Without food deprivation, hens consistently chose the litter flooring over the wire but as the duration of food deprivation increased, the hens would choose feed over the preferred flooring (Dawkins, 1983). Thus, while hens would choose litter, they valued feed over litter. The challenge with this study, as with all choice welfare trials, was in the interpretation of the results. Dawkins (1983) stated that just because the hens preferred litter over wire, it did not explicitly mean they were suffering without it. It is important to note that there was not, and is not now, a single definition of welfare or suffering. While some consider that welfare is the ability to exhibit of all natural behaviors (Duncan, 1980), others suggest that those activities that animals have an intrinsic drive to perform must be allowed (Dawkins, 1983).

In the 1990s, the approaches employed in preference and choice studies in poultry welfare began to change. In the place of multiple options to choose, birds were hindered or separated from the test variable (food, litter, social interaction). The amount of effort the bird was willing exert to reach or complete the variable was assessed as the "cost" it was willing to "pay" in place of feed restriction known as resource ranking (Olsson, 2002). The measure of effort exerted provided a quantifiable measure for the preference of poultry. However this method was not without flaw. The use of multiple variables to be compared were not able to be validated and a more simplistic design was employed known as resource ranking. Instead of birds choosing with feed as a measure of motivation or need, choice trials began to measure the preference between two usually similar variables. This is in part due to the complications associated with resource value testing such a test sequencing, observer interference and the possibility of observing a simple scanning or monitoring behavior of birds as a choice in its self (Nicol et al., 2009).

Determining the preference for feed and feeders

The use of choice trials to investigate the preference of poultry has yielded important information on welfare and has resulted in improved production. Most studies use simple measures of feed consumption, growth, and feed conversion to determine what poultry preferred when provided with different options. One interesting series of trials explored choice for different nutrient. Various genetic lines were presented with feeds either nutrient replete or with deficiencies of different amino acids (lysine, methionine and tryptophan). While Leghorn type chickens did not show a preference between the deficient and balanced diet, White Rock type chickens showed a clear preference for the balanced diet (Noble et al., 1993). Additionally, it was found that meat type chickens (broilers) would discern between high and low energy and protein levels in feed (Noble et al., 1993). Not only could they detect the difference but broilers showed clear preference to diets of higher energy over those containing higher protein (Siegel et al., 1997).

Some of the most influential work done with preferences in poultry feeding was with particle size (Jensen et al., 1962; Savory, 1980; Portella et al., 1988). It had previously been established that birds fed pelleted feed could consume their desired amount of feed in less time than those fed mash (Jensen et al., 1962). This was followed by the investigation of bird preference to particle size. Results showed that the broiler chickens would first eat the larger particles of feed at the same rate (pecks) to that of smaller particles (Fujita, 1972). These studies demonstrated that with the use of pelleted feed increased feed availability within a flock, due to shorter feeding bouts. A similar approach was employed to investigate the preference of feed particle size and texture with inclusion of new ingredients and whole grain feeding (Elling-Staats et al., 2017).

Preference testing has been applied to wet and dry feeding types. During the first seven days of production, broiler chickens demonstrated a strong preference to feed with equal parts water and feed compared to a conventional feed (Elling-Staats et al., 2017). While these findings may not be applicable directly to commercial feeding practices, it may have a sizable impact on the development of hatch basket feeding program development (Shane, 2017). This preference was also observed through the rest of the production cycle although to a less extent (Elling-Staats et al., 2017). However, it is important to note that the measure of water diluting the nutrient density in the feed may be the driving factor of increased consumption and were not reported (Elling-Staats et al., 2017).

There have been other studies on preferences of broiler chickens. Deines (2016) examined preference of feeder colors for Cobb 500 female broiler chickens. Feed consumption was greater for green feeders for the first 5 days of life and red feeders thereafter (Deines, 2016). However, there was no difference in feed consumption when birds were not given a choice (Deines, 2016). This trial is an example of the major drawback when using free preference testing of "out of sight, out of mind." While the two control treatments and the preference treatment provide some insight, an additional set of titrated treatments may provide insight into the value of preference to each of the colors.

BEHAVIORAL PREFERENCES OF POULTRY

Perching

Much of the research on choice in poultry has evaluated perching behavior in laying hens. Perching preference trials usually employ two types of studies: 1. the preference between types of perch such as height, diameter and material and 2. the use or lack of use for a perch. Some work has evaluated the preference to certain types of perch (Appleby et al., 1998). It is argued that much greater understanding is gained by examining the preference to perch *per se*. Hens will work and exert force to be able to perch during the day but particularly at night (Olsson and Keeling, 2000). However, there are challenges when investigating the value the hens put on perching. Social interaction appears to play a critical role in the effort birds will exert to access a perch. Some hens do not exert force to perch if another bird was already perching even if the perch was not completely full (Olsson and Keeling, 2000). The use of perches by broilers not been subject investigation until recently. Broilers, unlike laying hens, do not utilize classical perch designs but prefer to use elevated platforms (Bailie et al., 2018).

Nesting

In addition to perching, nesting and pre-oviposition behaviors have been investigated. Hens have been reported to prefer a nest area that is enclosed (Cooper and Appleby, 1995). Hens were shown to work for up to 40 minutes before lay to reach a nest when a weight loaded door separated the two. In addition, hens would pass through a small space of 95 mm^2 to reach a nest before laying when their average body width was 120 mm (Cooper and Appleby, 1995). The same hens withstood up to 8 hours of food deprivation before passing through the same size opening to reach food (Cooper and Appleby, 1995). The difference in preference for nesting and the effort to be exerted to reach a nest is not thought to be related to a weak drive to nest yet a difference in what constitutes a satisfactory nest; for example, a dark enclosed separated area (Weeks and Nicol, 2006).

Dustbathing

Poultry exhibit a drive to dustbathe and will do so when provided with the proper environmental conditions (Weeks and Nicol, 2018). These behaviors will also exist as a void or sham execution where the animal goes through the motion when there is no actual substrate (Weeks and Nicol, 2006). The preference of birds for different substrates to dustbathe has been investigated. It was found that the preference of hens is largely driven by their previous experience (Van Liere and Siard, 1991). Hens prefer astro-turf over wire floor, and particulate matter over astro-turf (Weeks and Nicol, 2006). The value that broilers place on dustbathing has been more elusive as some choose to sham dustbathe rather than work for access to substrate (Van Liere 1992).

Foraging

There has been interest in foraging for the same reasons as dusting. Birds kept in an area where foraging does not occur will execute sham foraging while feeding (Weeks and Nicol, 2018). This is applied to the disposition of birds to “contra free load” where food is worked for even when offered without work (Weeks and Nicol, 2006). While there is a clear drive to execute forage behavior with or without substrate there is no clear evidence of a preferred substrate (Weeks and Nicol, 2006).

Lighting choice and broiler production

The use of artificial lighting sources has become a necessity in the production of broiler chickens since the adoption of the solid side wall house. Additionally, artificial light is used to improve production in turkeys and other poultry. The use of light in poultry production and how it is used can divided into three different categories: intensity, color/wavelength and duration.

Light Intensity and Broiler Production

Light intensity has been of increasing interest in broiler production. The use of dim lighting (<5 lux) was common until recently (Ingram et al., 2000). These low light intensities were used to improved feed to gain ratio with reduced energy expenditures. However, more recently these practices have come under scrutiny due to skeletal issues, reduced eye health and altered behavior (Rault et al., 2017). While increasing light intensity is a new adaption in commercial production, there is evidence that broilers prefer dim light later in production compared to bright light. Davis and colleagues (1999) subjected broilers to a free choice of 6, 20, 60 and 200 lux at either two or six weeks of age. Two week old chickens spent the majority of their time under 200 lux. However at 6 weeks of age, the birds chose to spend most of their time in 6 lux (Davis et al., 1999). It is noted that incandescent lights were used in this trial; these producing a wide and even distribution of light spectrum resulting in a white light (Lewis and Morris, 2006). However, incandescent lights are generally not used commercially in the United States instead LEDs are used (The Poultry Site, 2015). LEDs produce varied levels of different wave lengths of light (Archer, 2017). Additionally, and of equal importance, is that that broilers were subjected to continuous light (24L:0D) (Davis et al., 1999) which may be considered physiologically abnormal and affecting such behaviors as sleep (Bayram and Özkan, 2010).

Color

With the adaption of LEDS as the predominant light source in poultry production, the importance of understanding the effect of light color on poultry have increased. When broilers were given a chance to occupy space lit by yellow or white LEDs, no difference in distribution between the two were seen even (Mendes et al., 2013). However, there was improved production under white light (Mendes et al., 2013). In a similar test, broilers were exposed to blue, red, and green lights for 28 days and then provided a free choice between the three. After 3 hours, birds raised on red or green light displayed a preference to blue light (Prayitno et al., 1997). However, broiler chickens reared under blue light exhibited a preference to green light (Prayitno et al., 1997).

Photoperiod

As mentioned above the daylengths employed have changed over time. In the past lighting was commonly provided continually or on a near continual 24 hour cycle (20L:0D). Due to increased concern about sleep deprivation, skeletal health and immune function (Downs et al., 2006; Brickett et al., 2007), longer dark periods have been implemented in modern broiler production. Hens when given free choice spend on average 10 hours within 24 hours in very low light intensity (<1 lux) (Ma et al., 2015). However, the hens were actively laying and more eggs were laid in the <1 lux area (Ma et al., 2015). This may suggest that hens spend time at low light intensity for resting and for egg laying with seclusion (Ma et al., 2015). When hens were trained to switch on a light in a dark room, they would spend 80% of their time in a lit environment (Savory, 1982). However, when trained to turn off a light in a lit room, they spent only 1% of time in the dark (Savory, 1982). The testing of photoperiod through choice is challenging, due to the short life span of poultry and the time taken for training.

Conclusion

The use of preference testing has enabled improvements to the lives of poultry. It has also led to a prioritization of needs in poultry environments. However, more work is needed to further understand the preferences of poultry not only for improved well-being but also increased efficiency. Although technology available to producers is changing, research-based inputs are continuing to be critical to the progress of the poultry industry. The use of new approaches for the optimization of lighting environments is critical for continuing improvements.

CHAPTER 2

PERFORMANCE AND PREFERENCE OF BROILERS PROVIDED DUAL LIGHT WARMTH

INTRODUCTION

The use of artificial light in poultry rearing has been necessitated with the enclosure of facilities for improved environmental temperature control through tunnel ventilation. New technology has also developed to change the source of light used in most poultry rearing facilities from incandescent to LED. These new sources have been demonstrated to improve utility consumption and production performance of broiler chickens (Archer, 2016). The understanding of the effects light colors have on poultry production have grown (Rozenboim et al., 1999a, 2004; Archer, 2018). While some reports have focused on the preferences of poultry for specific light colors other than production (Prayitno et al., 1997; Riber, 2015; Raccoursier, 2016). The current study was designed to incorporate both production performance and preference for a better understanding of their interactions.

PERFORMANCE AND PREFERENCE OF BROILERS PROVIDED DUAL LIGHT WARMTH

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EFFECTS OF LIGHT WARMTH ON BROILERS

MANAGEMENT AND PRODUCTION

ABSTRACT

The use of light emitting diodes (LED) have been widely adopted within the broiler chicken industry. LED come in a range of colors and color warmth specific for poultry production. Different colored LED lights have been shown to alter the production performance of broiler chickens. The present studies reevaluated the use of two common poultry specific LED bulbs of differing light warmth (2700 k and 5000 k). Additionally, the studies evaluated the effect of providing a choice between the two LED bulbs of differing light warmth to broilers for both production as well as distribution, feeding, and drinking behavior. Chicks were housed in choice systems each consisting of two rooms of separate illumination. Systems were divided into two treatments: 1. cool-cool illuminated at 5000 k on both sides. 2. warm-warm illuminated at 2700 k on both sides and 3. cool-warm with onside illuminated at 2700 k and the other at 5000 k. Distribution and consumptive (feeding and drinking) behaviors were observed for the cool-warm treatment using a remote video system. Production was accessed for all treatments and two consecutive trials were conducted. The BW on the cool-warm (study 1: 2.954 kg and study 2: 3.240 kg) were greater ($P \leq 0.05$) than those on the warm-warm (study 1: 2.816 kg and study 2: 3.110 kg) while those on cool-cool were intermediate (2.867 kg and 3.164 kg). There was no effect of treatment on feed:gain in ether trial. The birds reared under the cool-warm treatment exhibited a clear preferential ($P \leq 0.05$) pattern for warm light during the first and last hour of the light period. This preference was either not seen or in some cases reversed during the 5th and 11th hour of light. No clear pattern of differences ($P \leq 0.05$) were observed between warm and cool environments in the feeding and drinking behaviors. The use of dual light warmth LEDs improved the BW chickens. The mechanism for this is not clear.

INTRODUCTION

Improvements in technology have reduced utility use for illumination of poultry reared in climate-controlled facilities. Formerly, compact fluorescent (CFL) sources were adopted due to the increased efficiencies compared to incandescent lights. Currently, light emitting diodes (LED) are widely used. It is important to ensure that use of LED light sources is optimized for both poultry and utility energy use. Perception of intensity and color differs between poultry species and that of people (Lewis and Morris, 2000). For example humans have three cones with maximal sensitivities for red, green and blue light, birds have a fourth category of cones with light perception in the UV-A range (320 nm) (Lewis and Morris, 2000; Yokoyama et al., 2000; Lind et al., 2013; Viets et al., 2016).

It is known that there are differences in perception of specific wavelengths (Lewis and Morris, 2000) yet light is most often composed of multiple wavelengths resulting in white light. Light color temperature is used to describe these combinations of wavelengths resulting in white light produced during the emission of electromagnetic radiation from an ideal black body. The unit assigned is the temperature of the surface of the ideal black body in Kelvin (K). While this is the original measure of light color temperature, LED sources do not primarily use electromagnetic radiation as light. Therefor a new measure is needed. The correlated color temperature (CCT) is assigned to alternative light source by their closeness in appearance to the original black body temperatures as perceived by the human eye and retains the original unit.

The use of both monochromatic and white light from LED sources has been the focus of numerous investigations. A recent study that evaluated the effect of mixed color LED lights in "Meihuang" broiler chickens native to China (Yang et al., 2016) found that feed efficiency was improved in chickens raised under blue and green light compared to florescent light. In the same strain of broilers, feed efficiency was further improved under yellow LED lights as compared to blue and green LED lights at 45 and 60 d (Pan et al., 2015). The use of monochromatic blue and green lights were previously found to improve growth performance of Anak broiler chickens (Rozenboim et al.1999).

The efficacy of different warmth LED lights have also been evaluated in a common broiler strain (Ross 960 x Ross 708) comparing warm (2,700K), cool1 (5,000K) and cool 2 (5,000K) LED lights together with incandescent lights (2,010K) (Olanrewaju et al., 2015b). Increased growth using cool LED lights in comparison to the incandescent light treatment was reported (Olanrewaju et al., 2015b). However, there were no differences between the LED treatments in the following: feed intake, feed:gain, carcass yield, fat weight, fillet weights, tender weight or plasma concentrations of corticosterone (Olanrewaju et al., 2015b). It was concluded that poultry could be raised under utility saving LED lights with no effect to feed efficiency yet with improved BW gain (Olanrewaju et al., 2015b). Similarly, Archer (2015) reported improved growth performance and welfare of broiler chickens (Cobb) reared under LED lights compare to CFL or incandescent lights.

When tested under a near continuous d length (23L:1D) lighting regime for 7 wk, broilers chickens showed a 44.0% reduction in the serum concentration of interleukin-1b under blue lights compared to red lights (Xie et al., 2008a). Differences in both physiological and welfare indicator tests were reported for broilers reared under 2,700 K or 5,000 K LED lights has been shown in broilers (Archer, 2018). Further it has been shown broilers reared under cool light (5000 K) exhibited less vocalization during isolation, reductions in latency to right, flapping intensity, composite asymmetry, plasma concentrations of corticosterone and heterophil to lymphocyte ratio (Archer, 2018). These results differ from those of Olanrewaju et al. (2015).

An investigation was conducted to evaluate the preferences of broilers for 4,100 K and 6,065 K (Riber, 2015). Locations of the birds provided free access to each of the light warmths was recorded every 15 minutes during sample d. The preference for light the two light warmths were inconsistent across d. Broilers spent a greater percentage of time under 6,065 K on 16, 28 and 34 d and no differences were seen on 4, 10 and 22 d (Riber, 2015). However broilers reared using 6,065 K LED lights had improved BW at d 34 compared to the 4,100 K (Riber, 2015).

The present studies evaluate the effects of dual light warmth (2,700 K and 5,000 K) environments from two LED light sources on performance in broilers compared to those reared using a single light warmth (2,700 K or 5,000 K). In addition, preference of broiler chickens for differing warmth (2,700 K and 5,000 K) and behavior preference for feed and water intake were evaluated.

MATERIALS AND METHODS

Commercial broiler (360 straight run Cobb 700) chicks were distributed into 18 pens (20 birds per pen) within a single commercial broiler house at the University of Arkansas's Applied Broiler Research Farm in each of the two trials. Pens constructed of PVC, wire, and black plastic covering, consisted of two 121.92 cm x 121.92 cm rooms separated by a divider of the same material (Figure 1). This divider prevented light from "polluting" the adjacent room but allowed broilers to freely move between the two rooms. A single feeder, water line, and light source were provided within each room. Commercial diets were supplied by the contracted integrator. The 18 pens were divided into the three following treatments (6 replicates each): 1. treatment cool-cool with both rooms illuminated by a 5000 K light (L6A19DIM 6W, 5000 K; Overdrive, Roanoke, VA, USA); 2. treatment warm-warm consisting of both rooms of the pen illuminated using a 2700 K (6W, Overdrive) light, 3. treatment warm-cool consisting of one room illuminated by a 2700 K light source and the other by a 5000 K light. Lighting of each pens was supplemented with an incandescent heat bulb for the first 14 d. A 23L:1D lighting schedule was used from 0 till 3 d and from d 4 to completion of the flock a 16L:8D lighting schedule was used. Intensity was set at 60 lux from 0 to 13 d. At 14 d the light intensity was set at 20 lux at bird level.

Feed consumption was measured from d 1 post hatch 15, 23, 32 and 40 d in trial 1 and from d 1 post hatch 15, 23, 32 and 43 d in trial 2 (Table 1). Further, consumption was measured within the individual pens of the warm-cool treatment on the respective days (Table 2). BW were measured on d 40 in trial 1 and d 43 in trial 2. Additionally, for the warm-cool treatment, remote video observations were taken of bird distribution, feeding and drinking (n=5 trial 1, n=6 trial 2). These observations were collected on d 16, 24 and 33 for both trials in addition to d 41 (trial 1) and 44 (trial 2). Each of the observations used scan sampling at four evenly spaced time points during the 16 hr light period (1, 6, 11 and 16). Due to camera failure during trial 1 video only five of six warm-cool systems were observed (n=5) in trial 1. Mortality were weighed and subtracted from final pen feed consumption to calculate mortality corrected feed:gain.

A one way ANOVA was performed on data from each trial and differences were separated using Tukey's HSD test in JMP Pro 14 (SAS Institute Inc., Cary, NC). Differences were considered significant when $p \leq 0.05$. Confidence intervals were calculated for 0.95 confidence level. Trials were conducted in accordance with University of Arkansas Institutional Animal Care and Use Committee protocol 18095.

RESULTS AND DISCUSION

Table 1 summarizes production data. In trial 1, BW of birds from warm warm systems (2.816 ± 0.032 kg) were lower ($p<0.05$) than that of warm-cool (2.954 ± 0.032 kg) with cool cool being intermediate (2.867 ± 0.032 kg). There were no differences in feed consumption between treatments until d 32-40 when more ($p<0.05$) feed was consumed in warm-cool (1.813 ± 0.034 kg) than cool (1.684 ± 0.034 kg) with warm being intermediate (1.700 ± 0.034 kg) (Table 1). No differences were observed in FCR.

Similar results were observed in the second trial (Table 1). BW was greatest ($p<0.05$) for warm-cool (3.240 ± 0.042 kg) and lower for warm warm (3.110 ±0.042 kg) with cool being intermediate (3.164 ± 0.042 kg). No differences in feed consumptions ($p>0.05$) were seen until d 32-43 when birds under a warm cool environment had higher ($p<0.05$) consumption (2.334 ± 0.029 kg) compared to warm warm (2.219 ± 0.029 kg) and cool cool (2.253 ± 0.029 kg) (Table 2). These results (table 1) agree with earlier findings (Pan et al., 2015; Archer, 2017) that growth and performance of broiler chickens can be manipulated using light wave length. However, we found no difference is growth between treatments warm warm and cool cool unlike the report from Archer (2017). However, that study did not employ combinations of the two light warmths (2700 K and 5000 K) (Archer, 2018). This study suggest that the provision of LED sources with two light warmth temperatures increased the growth of broilers.

To further understand the effect of light warms on feed consumption, feed consumption was monitored within each pen of the warm-cool treatment (table 2). For the first trial, more ($p<0.05$) feed was consumed under cool light (0.500 ± 0.014 kg) than warm (0.448 ± 0.014 kg) from d 15-23 but no differences were seen at other time points within the trial. In the second trial, there was greater ($p<0.05$) feed consumption occurred on the cool side of the choice system than the warm both from d 0-15 and d 15-23. In contrast, the opposite occurred between d 23 and 32 with increased ($p<0.05$) feed consumption under the warm light side of the choice system compared to the cool side (see table 2). These results are similar to the findings of Rozenboim et al. (2004) who found an increase in growth by changing monochromatic light sources during the flock from green to blue. This suggests that the preference of broilers change over time.

Video observation and sampling were used to further investigate the way in which broilers would distribute within the two pens with different light warmths. A clear pattern of distribution was observed with a greater ($p<0.05$) percentage of birds present under warm light than cool during the first hour of the photoperiod and the last hour of the photoperiod (see Tables 3 and 4). In contrast during the 6 and 11th hour, there were either no preference for warm light (Trial 1) or a preference ($p<0.05$) for cool light (Trial 2) (Tables 3 and 4). There was a lack of light preference for either feeding and drinking behaviors. This suggests that any preference of light warmth ranks below the need to freely feed and drink (*i.e.* feed and drinker space).

The distributions of broilers between warm and cool light both trials align with natural light (Granzier and Valsecchi, 2014). During dawn and dusk hours, light warmth is commonly between 2000-3000 K due to the scattering of light waves but 5000-7000k during daylight conditions. The physiological mechanisms that drive these preferences is unknown. Further work is needed to better understand the differences in growth seen between broilers reared under a single light color warmth and those provided choice and optimization between two.

These studies clearly show that the use of novel lighting programs utilizing dual light warmth are able to increase growth, but not feed:gain.

REFERENCES

Archer, G. S. 2017. Color temperature of light-emitting diode lighting matters for optimum growth and welfare of broiler chickens. Animal:1–7

Granzier, J. J. M., and M. Valsecchi. 2014. Variations in daylight as a contextual cue for estimating season, time of day, and weather conditions. J. Vis. 14:1–23

Lewis, P. D., and T. R. Morris. 2000. Poultry and coloured light. Worlds. Poult. Sci. J. 56:189–207

Lind, O., M. Mitkus, P. Olsson, and A. Kelber. 2013. Ultraviolet vision in birds: The importance of transparent eye media. Proc. R. Soc. B Biol. Sci. 281

Olanrewaju, H. A., J. L. Purswell, S. D. Collier, and S. L. Branton. 2015. Effects of color temperatures (Kelvin) of LED bulbs on blood physiological variables of broilers grown to heavy weights. Poult. Sci. 94:1721–1728

Pan, J., Y. Yang, B. Yang, W. Dai, and Y. Yu. 2015. Human-friendly light-emitting diode source stimulates broiler growth. PLoS One 10:1–13.

Riber, A. B. 2015. Effects of color of light on preferences, performance, and welfare in broilers. Poult. Sci. 94:1767–1775

Rozenboim, I., I. Biran, Y. Chaiseha, S. Yahav, A. Rosenstrauch, D. Sklan, and O. Halevy. 2004. The effect of a green and blue monochromatic light combination on broiler growth and development. Poult. Sci. 43:344-354.

Rozenboim, I., I. Biran, Z. Uni, B. Robinzon, and O. Halevy. 1999. The effect of monochromatic light on broiler growth and development. Poult. Sci. 78:135–138

JPM®, Version 14. SAS Institute Inc., Cary, NC, 1989-2019.

Viets, K., K. C. Eldred, R. J. Johnston, and R. J. Johnston. 2016. Mechanisms of Photoreceptor Patterning in Vertebrates and Invertebrates. Trends Genet. 32

Xie, D., Z. X. Wang, Y. L. Dong, J. Cao, J. F. Wang, J. L. Chen, and Y. X. Chen. 2008. Effects of monochromatic light on immune response of broilers. Poult. Sci. 87:1535–1539

Yang, Y., Y. Yu, J. Pan, Y. Ying, and H. Zhou. 2016. A new method to manipulate broiler chicken growth and metabolism: Response to mixed LED light system. Sci. Rep. 6

Yokoyama, S., F. B. Radlwimmer, and N. S. Blow. 2000. Ultraviolet pigments in birds evolved from violet pigments by a single amino acid change. Proc. Natl. Acad. Sci. U. S. A. 97:7366–71

TABLES AND FIGURES

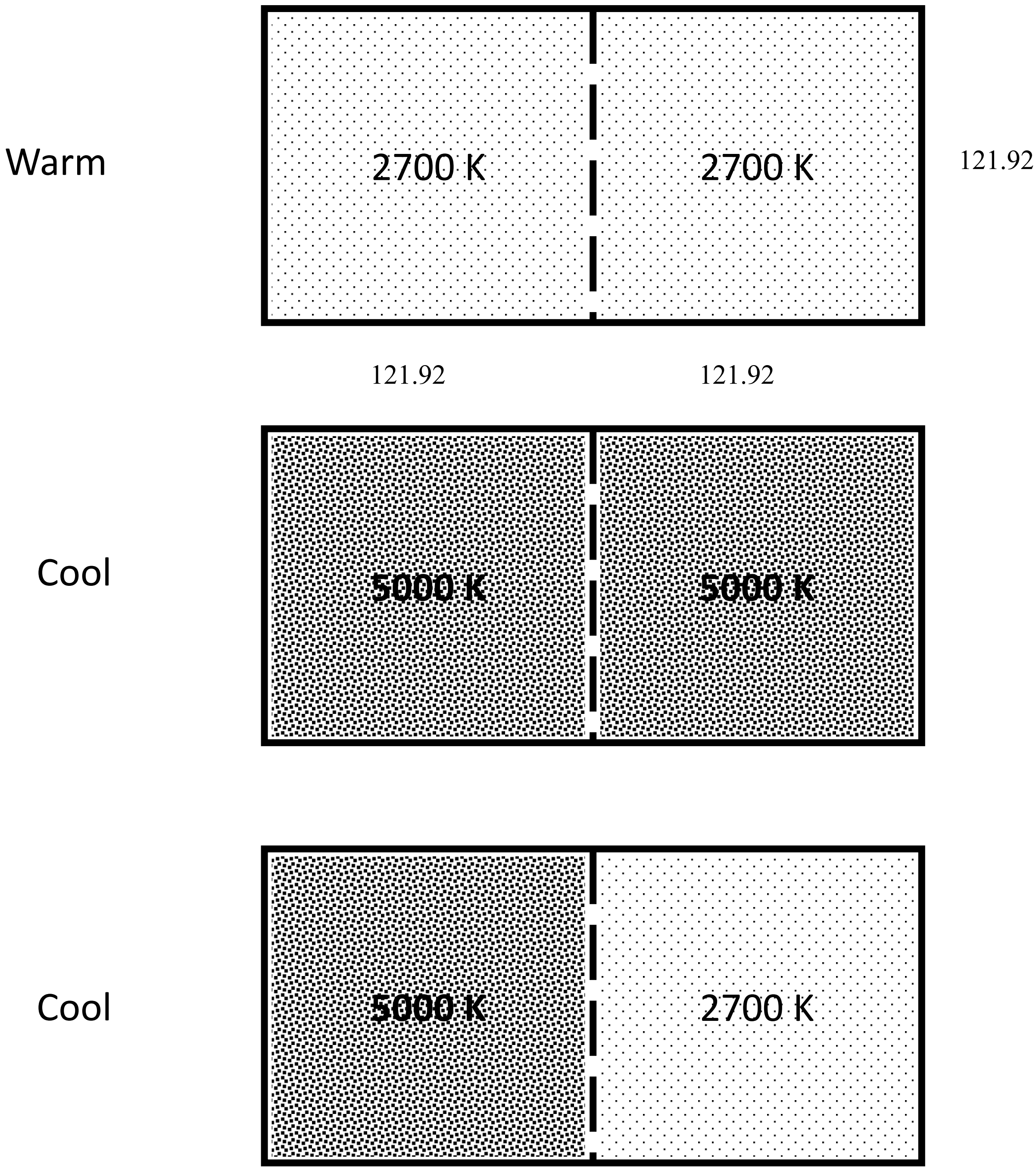

Figure 1. Schematic of choice system and treatment pen configurations.

Table 1. The effect of rearing broiler chickens in choice pens with different light warmth LEDs on production

	Pens each with two rooms with LEDs as below[1]			
	Cool-Cool	Warm-Warm	Warm-Cool	SEM
Trial 1				
Feed consumption				
0-15 d	0.669	0.689	0.688	0.013
15-23 d	0.927	0.927	0.945	0.018
23-32 d	1.440	1.413	1.463	0.018
32-40 d	1.684^{b}	1.700^{ab}	1.813^{a}	0.034
0-40 d	4.720	4.728	4.909	0.065
BW 40 d	2.867^{ab}	2.816^{b}	2.954^{a}	0.032
Feed:Gain[2]	1.650	1.678	1.667	0.022

Trial 2				
Feed consumption				
0-15 d	0.771	0.767	0.755	0.017
15-23 d	0.942	0.903	0.933	0.019
23-32 d	1.448	1.404	1.416	0.029
32-43 d	2.253^{b}	2.219^{b}	2.344^{a}	0.029
0-40 d	5.413^{ab}	5.293^{b}	5.448^{a}	0.044
BW 43 d	3.164^{ab}	3.110^{b}	3.240^{a}	0.042
Feed:Gain[2]	1.696	1.705	1.695	0.013

[a, b] Different superscript letter indicates difference within each row ($p<0.05$)
[1] Treatment arrays represent pens containing light emitting diodes (LED) as Cool-Cool at 5000 K (n=6), as Warm-Warm at 2700 K (n=6), and Warm- Cool at 2700 K and 5000 K (n=6).
[2] Feed :Gain corrected for mortality by the subtraction of total mortality weight from feed consumption

Table 2. Feed consumption of broilers reared in a choice system with two LED lights of different light warmth.

Day	Feed consumption per bird (kg)		
	Cool[1]	**Warm[2]**	**SEM**
Trial 1			
0-15 d	0.344	0.344	0.012
15-23 d	0.500[a]	0.448[b]	0.014
23-32 d	0.732	0.731	0.032
32-40 d	0.934	0.900	0.044
0-40 d	2.507	2.402	0.065
Trial 2			
0-15 d	0.407[a]	0.349[b]	0.013
15-23 d	0.487[a]	0.438[b]	0.011
23-32 d	0.678[b]	0.739[a]	0.014
32-43 d	1.173	1.171	0.015
0-43 d	2.744	2.696	0.031

[a, b] Different superscript letter indicates difference ($p<0.05$)

[1] Cool light at 5000 K produced by a light emitting diode (LED)

[2] Warm light at 2700 K produced by a light emitting diode (LED)

Table 3. Feeding and drinking behavior as measured by video observation at 4 hours at 15, 23, 33 and 41 d of broilers reared in choice pens with different light warmth LEDs[1] (Trial 1)

		% Birds Feeding			% Birds Drinking			% Birds Not Feeding or Drinking		
Day	**Hour**	**Cool**	**Warm**	SEM	**Cool**	**Warm**	SEM	**Cool**	**Warm**	SEM
16	**1**	7.33	9.10	1.98	1.42	3.23	0.63	32.15^{b}	49.33^{a}	2.86
	6	11.72	12.04	1.88	0.80	3.01	0.85	33.40	38.73	3.32
	11	11.92^{a}	5.44^{b}	1.47	0.81	1.62	0.39	37.47	42.74	3.34
	16	10.84	7.43	2.28	1.01	2.61	0.57	28.73^{b}	49.38^{a}	2.92
	SEM	2.07	1.77		0.37	0.81		2.97	3.26	
23	**1**	5.76	9.86	1.29	1.86	3.52	0.98	37.13	41.88	2.85
	6	7.05	9.06	0.89	2.07	2.89	0.76	43.24	35.68	2.94
	11	10.55	9.28	1.76	1.03	2.25	0.79	39.44	37.44	4.31
	16	10.42	12.34	2.25	1.43^{b}	4.34^{a}	0.81	38.23	46.02	2.53
	SEM	1.53	1.72		0.64	1.00		3.88	2.91	
33	**1**	8.54^{yz}	9.73	1.41	3.34	3.56	1.08	29.35$^{b\ z}$	45.49^{a}	2.95
	6	5.64^{z}	5.81	1.42	1.87	1.85	0.99	35.17^{yz}	49.65	4.79
	11	6.43^{z}	3.75	1.22	1.46	1.65	0.58	42.93^{y}	43.78	1.51
	16	11.46^{y}	7.92	1.17	2.07	3.14	0.66	31.36$^{b\ yz}$	44.04^{a}	2.30
	SEM	0.99	1.56		0.89	0.67		3.03	3.23	
41	**1**	11.08	11.93^{y}	1.12	2.37	3.03	0.61	29.68$^{b\ z}$	41.91^{a}	1.82
	6	5.64	5.68^{z}	1.51	0.87	0.88	0.22	43.08^{y}	43.86	1.73
	11	5.19	5.64^{z}	1.09	1.97	1.95	0.48	40.26^{y}	44.99	4.59
	16	11.32	6.96^{z}	2.31	2.16	2.57	0.72	29.42$^{b\ z}$	47.57^{a}	3.23
	SEM	1.94	1.12		0.48	0.59		2.59	3.50	

[1]Light emitting diodes (LED) at 2700 K (warm) and 5000 K (cool) color temperatures

[a, b] Superscripts denote differences ($p<0.05$) between cool and warm for individual day and time samples

[y, z] ANOVA repeated measures plus Tukey's down/column within behavior, day and light warmth

Table 4. Feeding and drinking behavior as measured by video observation at 4 hours at 15, 23, 33 and 44 d of broilers reared in choice pens with different light warmth LEDs[1] (Trial 2)

		% Birds Feeding			**% Birds Drinking**			**% Birds Not Feeding or Drinking**		
Day	**Hour**	**Cool**	**Warm**	SEM	**Cool**	**Warm**	SEM	**Cool**	**Warm**	SEM
16	**1**	8.31	7.15	0.89	1.69	1.37	0.53	32.15^{b}	49.33^{a}	2.15
	6	7.61	4.37	1.56	2.26	1.72	0.67	38.19	45.85	3.97
	11	5.61	4.74	0.94	1.83	1.04	0.43	44.76	42.02	2.78
	16	8.40	6.90	1.68	1.67	0.83	0.80	31.13^{b}	51.07^{a}	6.43
	SEM	1.17	1.25		0.79	0.38		4.36	3.97	
23	**1**	9.60^{y}	12.47^{y}	1.47	1.39	1.38	0.58	32.91$^{b\ z}$	42.25^{a}	2.43
	6	4.29^{z}	3.61^{z}	1.43	1.01	1.39	0.44	49.36$^{a\ y}$	40.34^{a}	2.27
	11	4.48^{z}	3.60^{z}	0.79	1.08	0.69	0.52	49.80^{y}	40.34	5.74
	16	5.93^{yz}	7.00^{z}	1.49	2.07	1.42	0.54	38.31^{yz}	45.27	2.45
	SEM	1.15	1.49		0.62	0.41		3.12	3.90	
33	**1**	10.01	13.94^{y}	1.59	1.21^{b}	3.28^{a}	0.44	34.12^{z}	37.44	2.27
	6	4.49	3.84^{z}	0.76	2.11	2.61	0.64	45.25^{y}	41.71	1.69
	11	5.80	5.71^{z}	0.85	1.91	1.20	0.45	45.18^{y}	40.19	2.59
	16	9.27	10.82^{y}	1.66	2.81	2.13	0.81	36.89^{z}	38.09	1.73
	SEM	1.51	1.02		0.68	0.52		1.94	2.25	
44	**1**	6.84^{yz}	8.28	1.49	1.62	2.28	0.76	41.73^{yz}	39.30	2.40
	6	5.06^{yz}	4.91	0.87	2.32	2.14	0.58	44.23^{yz}	41.15	1.80
	11	4.62^{z}	4.55	1.14	1.76	2.27	0.34	46.62^{y}	40.18	2.22
	16	10.01^{y}	7.06	1.34	2.99	2.49	0.66	37.35^{z}	40.10	1.76
	SEM	1.30	1.16		0.69	0.51		1.97	2.14	

[1]Light emitting diodes (LED) at 2700 K (warm) and 5000 K (cool) color temperatures

$^{a,\ b}$ Superscripts denote differences ($p<0.05$) between cool and warm for individual day and time samples

$^{y,\ z}$ ANOVA repeated measures plus Tukey's down/column within behavior, day and light warmth

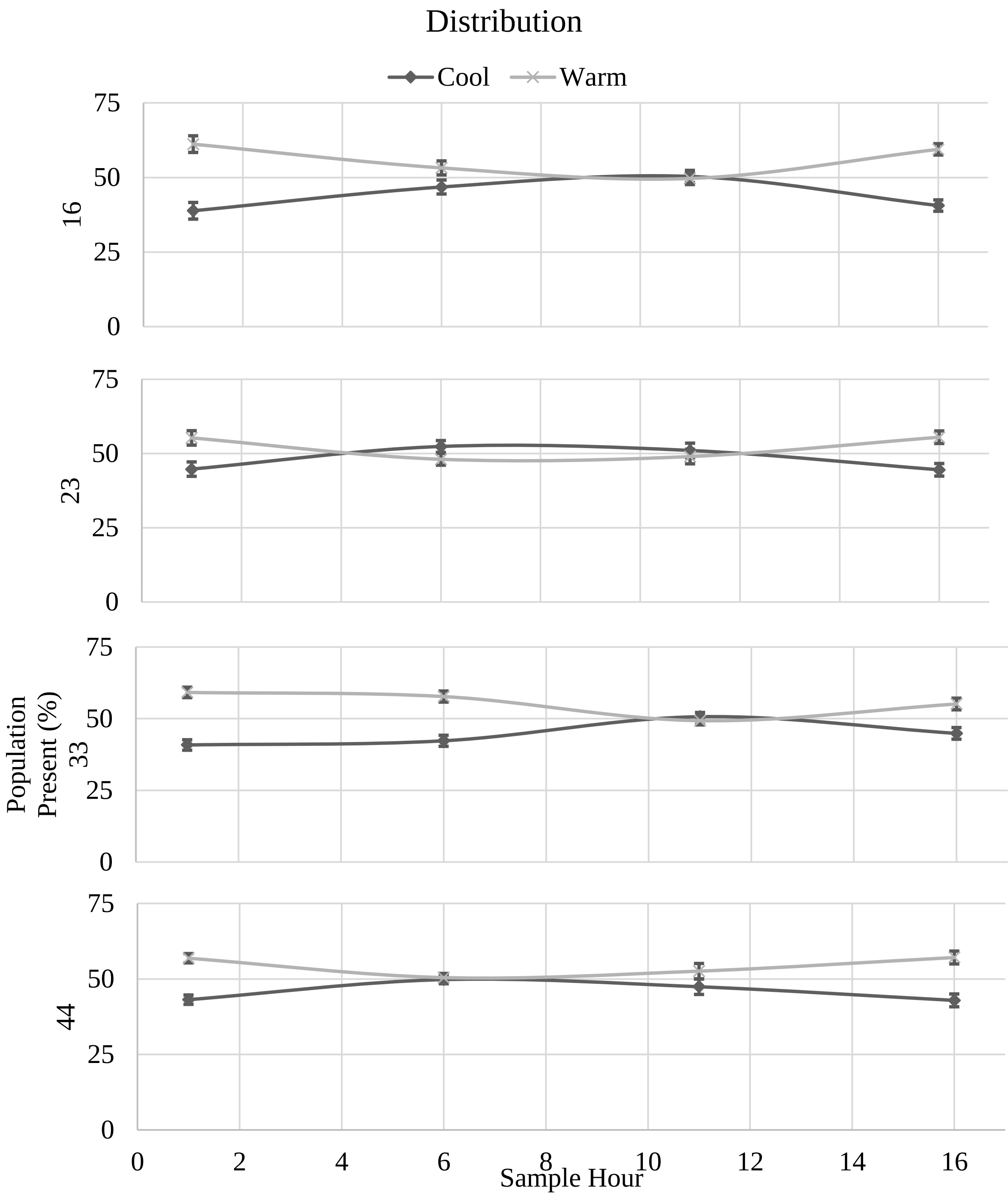

Figure 2. Distribution as measured by video observation at 4 hours at 15, 23, 33 and 41 d of broilers reared in choice pens with different light warmth LEDs[1] (Trial 1)

[1]Light emitting diodes (LED) at 2700 K (warm) and 5000 K (cool) color temperatures
Error bars represent confidence intervals calculated at 0.95. Those not reaching 50% determine preference for the respective light warmth.

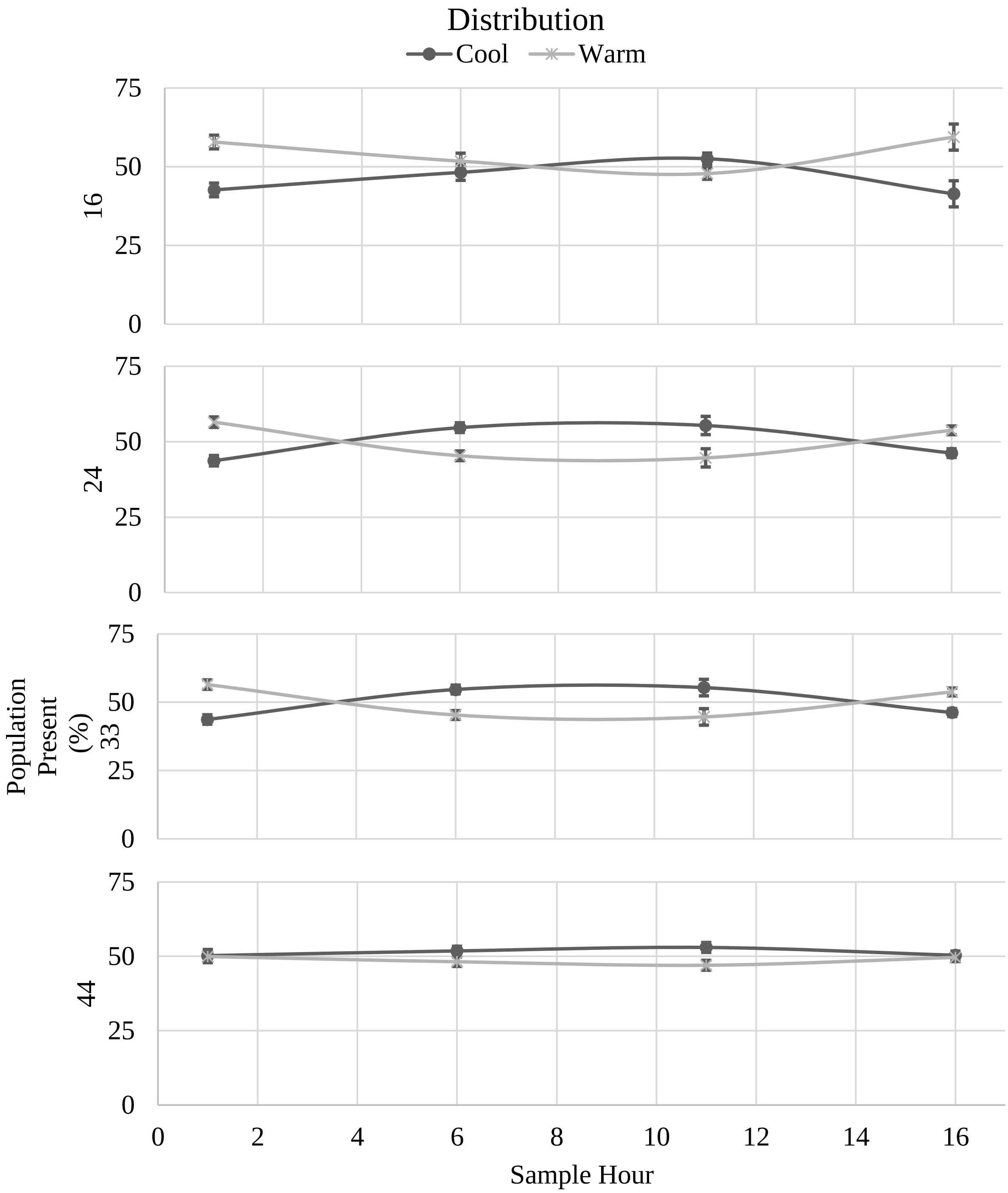

Figure 3. Distribution as measured by video observation at 4 hours at 15, 23, 33 and 44 d of broilers reared in choice pens with different light warmth LEDs[1] (Trial 2)

[1]Light emitting diodes (LED) at 2700 K (warm) and 5000 K (cool) color temperatures
Error bars represent confidence intervals calculated at 0.95. Those not reaching 50% determine preference for the respective light warmth.

CONCLUSION

The distributions of broilers between warm and cool light both trials align with natural light (Granzier and Valsecchi, 2014). During dawn and dusk hours, light warmth is commonly between 2000-3000 K due to the scattering of light waves but 5000-7000k during daylight conditions. The physiological mechanisms that drive these preferences is unknown. Further work is needed to better understand the differences in growth seen between broilers reared under a single light color warmth and those provided choice and optimization between two. While birds were reared within a commercial broiler house the densities were reduced from those commonly found in production settings to provide a choice minimally influenced by density. Further work is needed to better understand the effects of providing dual light colors in a commercial production setting.

These studies clearly show that the use of novel lighting programs utilizing dual light warmth are able to increase growth, but not feed:gain.

CHAPTER 3

PERFORMANCE AND PREFERENCE OF BROILERS PROVIDED CHOICE OF LIGHT INTENSITY

INTRODUCTION

The use of dim (<10 lx) has commonly been used for the rearing of broiler chickens due to the improvements in production performance (Cherry and Barwick, 1962; Deep et al., 2013). However, this practice has been reported to have possible negative effects on wellbeing such as leg health, foot pad lesions and behavioral rhythms (Blatchford et al., 2009; Robles, 2010; Deep et al., 2011, 2013). Due to the potential for compromised wellbeing the European Union has mandated a minimum of 20 lx be provided during the light phase for broiler rearing (Council of the European Union, 2007). While in the United States the National Chicken Council requires the conciliation of qualified professional in the design of lighting program citing a lack of conclusive research on minimal intensities to set a minimum threshold for all production settings (National Chicken Council, 2014). The current study was designed to first investigate the preference of broiler chickens for industry relevant intensities (5, 10 and 20 lx) provided from a LED source. Second it was designed to access the production performance of broiler chickens reared under uniform 5, 10 or 20 lx compared to those enabled to optimize their light environment between the three intensities.

PERFORMANCE AND PREFERENCE OF BROILERS PROVIDED CHOICE OF LIGHT INTENSITY

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EFFECTS OF LIGHT INTENSITY ON BROILERS

MANAGEMENT AND PRODUCTION

ABSTRACT

The appropriate light intensities for broiler production has been investigated for some time. The use of a minimum 20 lux (lx) has been mandated within the European Union. However, there have been mixed results about the effects of light intensities below 20 lx, commonly used in the United States. The present study evaluated the use of 5 10 and 20 lx as well as a choice between the listed intensities for production performance, processing attributes and preference. The feed:gain was lowest for birds reared using 5 lx and the choice of 5, 10 and 20 lx (1.71 and 1.70) compared to 20 lx (1.81) with 10 lx being intermediate (1.74). All other live production parameters (BW and BW CV) were similar. Further, no differences were observed in carcass yield, breast yield or abdominal fat. Preference was determined through the use of a remote video system placed above the choice pens. On d 20 birds observed to be feeding preferred 10 and 20 lx over 5 lx. All other birds (drinking and not feeding or drinking) preferred 20 lx over both 5 and 10 lx. On d 31 birds feeding no longer displayed a preference while all other (drinking and those not feeding or drinking) preferred 10 and 20 lx over 5 lx. On the final observation d 41 only those birds not feeding or drinking showed a preference for 10 lx over 5 and 20 lx. This report agrees with past reports that the preference of broiler chickens for light intensities changes from high to low over time. Further the use of choice lighting environments was able to provide the desired light intensity of broilers at a young age while maintaining production parameters of those reared using low intensity (5 lx).

INTRODUCTION

It has long been know that light impacts growth, behavior and reproduction of avian species (Lashley, 1916; Baldwin et al., 1938; Heywang, 1944; Paulino, 1949). However, the understanding of the effects of light on poultry production can be masked by the differences in reception and perception of light by poultry compared to that of humans (Govardovskiĭ and Zueva, 1977; Prescott and Wathes, 1999; Lewis and Morris, 2006). These differences are due to the clarity of the lens and the presence of an additional cone type in the avian eye (Govardovskiĭ and Zueva, 1977; Lewis and Morris, 2006). While the human eye has three cones perceiving red (700 nm) green (550 nm) and blue (450 nm), the avian eye has a fourth cone which is sensitive to light at 415 nm (Lewis and Morris, 2006). Furthermore, the clarity of the avian lens from 400 to 320 nm also enables the reception of UV portions of the light spectrum (Burkhardt, 1982). While these differences can produce challenges in design, interpretation and understanding on studies. Knowledge of the effect of light on poultry has grown in recent years (Rault et al., 2017; Christensen et al., 2018; Hesham et al., 2018; Kang et al., 2018; Arowolo et al., 2019). Investigations to characterize the effects of light on broilers fall focus on three major areas applicable to poultry production: day length (L:D), color (nm) and intensity (lux). The practices of continuous (24L: 0D) and near continuous (23L:1D) lighting have largely been abandoned due to negative effects on wellbeing parameters such as mortality (Gordon and Tucker, 1995; Lewis et al., 2009), eye development (Li et al., 2000; Liu et al., 2004; Lewis and Gous, 2009), leg health (Sanotra et al., 2002) and displays of comfort behavior (Bayram and Özkan, 2010; Schwean-Lardner et al., 2012). This has been reflected in the adoption of guidelines and regulations by the European Union (2007) and National Chicken Council (2014) mandating minimum lengths of dark periods for broiler chicken production.

The use of lights with specific spectral compositions have been used to influence production and behavior of broiler chickens (Rozenboim et al., 2004; Xie et al., 2008, 2011; Liu et al., 2010). Rozenboim and colleagues (2004) reported increased growth of broilers reared under green light from 1 to 10 d followed by blue light from 11 to 46 d. In addition, there is increased satellite cell activity (Liu et al., 2010), villus height (Xie et al., 2011) and immune function (Xie et al., 2008) in broiler chickens reared using green monochromatic light. Others have investigated the use of white lights with differing spectral compositions (Sultana et al., 2013; Archer, 2015; Huth and Archer, 2015; Olanrewaju et al., 2015). There has been disagreement between reports about the effect of light color temperature. Olanrewaju and colleagues (2015) found no differences in feed intake, feed: gain, carcass yield, fat weight, fillet weight, tender weight or plasma concentrations of corticosterone for broilers reared under 2700 kelvin (K) and 5000 K lights. However, Archer (2017)reported differences in vocalization during isolation, latency to right, flapping intensity asymmetry, plasma concentrations of corticosterone, heterophil to lymphocyte ratio, BW and feed: gain for broilers housed under 2700 K and 5000 K. The preference of broilers for light color temperatures have also been evaluated (Riber, 2015; Aldridge et al., 2019). When broilers were provided with a choice of 6,065 K and 4,100 K light, there was a preference for 6,065 K at 16, 28 and 34 d but no difference was observed on 4, 10 and 22 d (Riber, 2015). When broilers were provided with a choice between 5,000 K and 2,700 K light sources, there was a preference for 2,700 K during the first and last hour during the 16 h L period but no consistent difference was reported during two evenly spaced time points (6 and 11 h) during the light period (Aldridge et al., 2019). Additionally, improved BW was observed for those broilers provided a choice in comparison to those reared using 2700 K while broilers under 5000 K wer intermediate (Aldridge et al., 2019).

Common industry practices in regards to the use of low (< 1 lx) intensity have begun to change to follow with early work that suggested the use of light intensities between 1.08 and 10.76 lx (e.g. Cherry and Barwick, 1962). This shift in practice is warranted as the use of 1 lux has negative effects on measures of wellbeing e.g. (preening, foot lesions and behavioral rhythms) compared to more moderate intensities (5 and 10 lx) (Lien et al., 2008; Deep et al., 2011, 2013). The effect of higher intensities (>10 lx) have yielded inconclusive results from different investigators. Deep and colleagus (2010) reported no effect on production parameters when rearing birds under 1, 10, 20 and 40 lx. Similarly, both Olanrewaju and colleagus (2016) and Archer (2016) found no differences in broilers reared under either 5 or 20 lx. However, Rault and colleagues (2017) found that broilers reared under 20 lx exhibited poorer feed:gain in comparison to broilers reared under 5 lx. Furthermore, birds raised under 20 lx were observed to be more fearful than those reared under 10 lx (Robles, 2010).

When provided a choice of light intensities of 6, 20, 60 and 200 lx at 2 wk broilers have been reported to prefer 200 lx regardless of behaviors displayed (Davis et al., 1999a). When preference was evaluated at 6 wk, broilers were observed to carry out active behaviors under 200 lx while resting and perching were observed to take place under 6 lx, suggesting that uniform light intensity distribution may not be optimal for broiler production environments (Davis et al., 1999a). In a similar investigation, Raccoursier (2016) reported that 40 d old broilers consumed more feed when given a free choice, in an area lit at 20 lx compared to 5 lx. Additionally, birds were observed to occupy an area without feed and water at 1 lx at a greatest density than within the areas of other illuminance of the test system (Raccoursier, 2016). However, in each report only singular light intensities were evaluated for production performance.

The present study employed a preference pen design for commercial broilers to evaluate the effect of preference in light intensity (5, 10 and 20 lx) for production performance, processing attributes and behavior.

MATERIALS AND METHOD

A test pen was designed consisting of three freely accessible rooms, each being independently illuminated (see Figure 1.). Each room within the pens were illuminated using a single 5000 K Light Emitting Diode (LED) source commonly used in commercial production facilities (L6A19DIM 6W, 5000 K; Overdrive, Roanoke, VA, USA). Pens (3.658 m x 0.914) were constructed of PVC, plastic coated wire and a black plastic covering. Each pen consisted of three rooms (0.914 m x 0.914 m). Rooms were separated by a divider constructed of similar materials to that of the pens and prevented light from “polluting” between rooms. Each room in the pens contained a single feeder and nipple drinker line. The 24 total pens were distributed in two commercial broiler houses at the University of Arkansas’ Applied Broiler Research Farm. A total of 480 straight run Cobb 700 broilers, provided by the contracted integrator, were distributed (20 per pen). Commercial diets provided by the contracted integrator were fed ad libitum. The 24 pens were divided into four treatments: Treatment 1 (5 lx) with all 3 rooms illuminated at 5 lx, Treatment 2 (10 lx) with all 3 rooms illuminated to 10 lx, Treatment 3 (20 lx) with all 3 rooms illuminated to 20 lx and Treatment 4 (5, 10 and 20 lx) with one room illuminated at each of 5, 10 and 20 lx light intensities within the pen. From 0 to 3 d, a 23L:1D lighting schedule was used followed by 16L:8D schedule from 4 to 42 d. From 0 to 13 d, a light intensity of 60 lx was used in all rooms and treatments were initiated at d 14.

Feed consumption and BW were measured on d 42 (Table 1). Mortalities were weighted and subtracted for the pens total feed consumption to calculate mortality corrected feed: gain. Ten birds were randomly selected from each pen at 42 d for processing. During processing, carcass weight, breast weight and abdominal fat were measured. Furthermore, breast tissue was accessed for two common muscle myopathies: woody breast and white striping. Myopathies were grouped into categories of not present, mild and severe. To better understand any differences in preference for feeding consumption at 5, 10 and 20 lx, feeding consumption was determined in each room with different light intensities (Table 3). Additionally, video observations from cameras (Hikvision DS-2CD2141FWD-IS-2.8MM) placed over the pens and behaviors were collected on the 5, 10 and 20 lx on 20, 31 and 41 d. Observations were made every 15 min during four evenly spaced h of the L period (1, 6, 11 and 16 h). The distribution of birds within in each room with different light intensities was determined as was the number of birds eating, birds drinking and birds neither eating nor drinking (Table 2).

A one way ANOVA was performed on data from each trial and differences were separated using Tukey's HSD test in JMP Pro 14 (SAS Institute Inc., Cary, NC). Differences were considered significant when $p \leq 0.05$. Confidence intervals were calculated for 0.95 confidence level. Trials were conducted in accordance with University of Arkansas Institutional Animal Care and Use Committee protocol 18095.

RESULTS

Table 1 summarizes live parameters, processing attributes and breast muscle myopathies in broilers reared under three light intensities or a choice of light intensities. No differences were seen for BW between any of the light intensities or the preference treatment. Similarly, BW CV's were no different between treatments. The feed:gain ratio was superior ($p<0.05$) both for birds reared under 5 lx and those given a preference (5, 10 and 20 lx) compared to those under 20 lx. Feed efficiency for 10 lx was intermediate. No differences were found between treatments for carcass weight, carcass yield, breast yield, abdominal fat or muscle myopathies.

Video observations are summarized in Table 2 and Figure 2. Overall distributions of birds within the pen were observed to change with age. On d 20, a preference for 20 lx (0.05 CI > 33%) compared to 5 and 10 lx where no preference was observed. This difference was no longer present on d 31. However, there was a decline in the percentage of birds under 20 lx compared to d 20 observations. By d 41, the preference of the birds shifted to 10 lx from 20 lx following the trend observed between d 20 and 31. Similar trends were observed for birds drinking, birds feeding and birds neither feeding nor drinking. A greater number ($p<0.05$) of birds were observed to be drinking under 20 lx than 5 or 10 lx on d 20. Similarly on d 31, more ($p<0.05$) birds were observed to be drinking under 10 and 20 lx than those under 5 lx. On d 41, no differences were observed but numbers birds drinking (0.62% - 5lx, 1.31% - 10 lx and 1.17% - 20 lx) followed the pattern of change observed on the two prior observation d (31) as well as in the total distribution of birds. The percentage of birds observed to be feeding was greater ($p<0.05$) under 10 and 20 lx compared to 5 lx on d 20 while no differences were observed on 31 and 41 d. The number of birds observed to be neither feeding nor drinking followed the pattern of change seen by those drinking. On d 20 a greater ($p<0.05$) number of birds were observed under 20 lx compared to 10 and 5 lx. By d 31, both 10 and 20 lx was preferred ($p<0.05$) over 5 lx. On d 41, differences were observed as the pattern of a shifting preference could be seen with the number of birds under 10 lx being greater ($p<0.05$) than both 5 and 20 lx. Feed consumption under each of the light intensities tended ($p>0.05$) to follow a similar pattern to the total distribution of birds within the pen (see Table 3)

DISCUSSION

The production data differ from those of Raccoursier (2016), who reported no differences in production performance when broilers were reared under 5, 10 or 20 lx from incandescent light sources. Moreover, we observed no differences in the consumption of feed under each light intensity in contrast to the increased consumption under 20 lx compared to 5 lx (Raccoursier, 2016). These differences may reflect the different light sources (LED in the present studies vs incandescent employed by Raccoursier (2016). These light sources have difference spectral output composition. Incandescent and LED have been demonstrated result in different production performance of broilers (Archer, 2016). Furthermore, Archer (2016) found that broilers reared under incandescent lighting were more susceptible to stress than those reared under LED lights. This may also account for the greater number idle birds under 1 lx (Raccoursier, 2016).

The current results agree with an earlier report that the preference of broiler chickens change over time from initially high intensity to a lower intensity later in development (Davis et al., 1999b). Due to the facilities used being under a commercial production contract the length of current trial could not be extend to determine if the preference of broilers for low intensities would continue with age.

The mechanism responsible for the improved feed:gain when provided choice in light intensity compared to 5 lx is unknown. However, improved BW with no effect to feed:gain were recently reported when broiler chickens were provided a choice between two light color temperatures (2700 K and 5000 K) (Aldridge et al., 2019). This in combination with the present results suggest that provision of variable lighting may be superior to a uniform light environment for broiler production. The use of choice and preference in light intensity up to 20 lx appears to improve feed:gain without changing BW or processing attributes. Further, this work suggest a chaning in commercial broilers preference of high to low light intensity with advancing age.

REFERENCES

Aldridge, D. J., C. G. Scnaces, and M. T. Kidd. Performance and Preference of Broilers Provided Dual Light Warmth. Poult. Sci.:In review.

Archer, G. S. 2015. Comparison of Incandescent, CFL, LED and Bird Level LED Lighting: Growth, Fear and Stress. Int. J. Poult. Sci. 14:449–455.

Archer, G. S. 2016. Comparison of Raising Broiler Chickens Under Light Emitting Diode or Incandescent Light at Differing Intensities on Growth, Stress and Fear. Int. J. Poult. Sci. 11:425–431.

Archer, G. S. 2018. Color temperature of light-emitting diode lighting matters for optimum growth and welfare of broiler chickens. animal 12:1015–1021.

Arowolo, M. A., J. H. HE, S. P. HE, and T. O. ADEBOWALE. 2019. The implication of lighting programmes in intensive broiler production system. Worlds. Poult. Sci. J. 75:1–12.

Baldwin, S. P., S. C. Kendeigh, W. W. Bowen, L. G. Wor,] Ey, D. E. Johnson, C. Johnson, J. Stevenson, T. C. Kramer, and R. W. Franks. 1938. Variations in Bird Weights. AUK 55:416–467.

Bayram, A., and S. Özkan. 2010. Effects of a 16-hour light, 8-hour dark lighting schedule on behavioral traits and performance in male broiler chickens. J. Appl. Poult. Res. 19:263–273.

Burkhardt. 1982. Birds, Berries and UV. Naturwissenschaften 69:153–157.

Cherry, P., and M. Barwick. 1962. The effect of light on broiler growth. I Light intensity and colour. Br. Poult. Sci. 3:31–39.

Christensen, K., S. Kang, D. Aldridge, and W. Kuenzel. 2018. Effects of light intensity and dual light choice treatments on growth performance of male broilers. Poult. Sci. 97:93.

Council of the European Union. 2007. Council Directive 2007/43/EC. Off. J. Eur. Union:19–28.

Davis, N. J., N. B. Prescott, C. J. Savory, and C. M. Wathes. 1999. Preferences of Growing Fowl for Different Light Intensities in Relation To Age, Strain and Behaviour. Anim. Welf. 8:193–203.

Deep, A., C. Raginski, K. Schwean-Lardner, B. I. Fancher, and H. L. Classen. 2013. Minimum light intensity threshold to prevent negative effects on broiler production and welfare. Br. Poult. Sci. 54:686–694.

Deep, A., K. Schewan-Lardner, T. Crowe, B. Fancher, and H. Classen. 2011. Effect of light intensity on broiler behaviour and diurnal rhythms. Appl. Anim. Behav. Sci. 136:50–56.

Deep, A., K. Schwean-Lardner, T. G. Crowe, B. I. Fancher, and H. L. Classen. 2010. Effect of light intensity on broiler production, processing characteristics, and welfare. Poult. Sci. 89:2326–2333.

Gordon, S., and S. Tucker. 1995. Effect of Daylength on Broiler Welfare. Br. Poult. Sci. 36:844–845.

Govardovskiĭ, V. I., and L. V. Zueva. 1977. Visual pigments of chicken and pigeon. Vision Res. 17:537–543.

Hesham, M., A. EL Shereen, and S. Enas. 2018. I mpact of different light colors in behavior , welfare parameters and growth. J. Hell. Vet. Med. Soc. 69:951–958.

Heywang, B. 1944. The effect of artificial light on chicks brooded during hot weather. Poult. Sci. 23:481.

Huth, J. C., and G. S. Archer. 2015. Comparison of Two LED Light Bulbs to a Dimmable CFL and their Effects on Broiler Chicken Growth, Stress, and Fear. Poult. Sci. 94:2027–2036.

Kang, S., K. Christensen, D. Aldridge, and W. Kuenzel. 2018. Effects of light intensity and dual light choice treatments on plasma corticosterone and breainstem serotonergic activity on male broilers. Poult. Sci. 97:72.

Lashley, K. S. 1916. The Color Vision of Birds I. The Spectrum of the Domestic Fowl. J. Anim. Behav. 6:1–26.

Lewis, P. D., R. Danisman, and R. M. Gous. 2009. Photoperiodic responses of broilers. I. Growth, feeding behaviour, breast meat yield, and testicular growth. Br. Poult. Sci. 50:657–666.

Lewis, P. D., and R. M. Gous. 2009. Photoperiodic responses of broilers. II. Ocular development. Br. Poult. Sci. 50:667–672.

Lewis, P. D., and T. R. Morris. 2006. Poultry Lighting the Theory and Practice. Northcot, Cowdown Lane.

Li, T., H. C. Howland, and D. Troilo. 2000. Diurnal illumination patterns affect the development of the chick eye. Vision Res. 40:2387–2393

Lien, R. J., J. B. Hess, S. R. Mckee, and S. F. Bilgili. 2008. Effect of Light Intensity on Live Performance and Processing Characteristics of Broilers. Poult. Sci. 87:853–857.

Liu, J., K. Pendrak, C. Capehart, R. Sugimoto, G. F. Schmid, and R. A. Stone. 2004. Emmetropisation under continuous but non-constant light in chicks. Exp. Eye Res. 79:719–728.

Liu, W., Z. Wang, and Y. Chen. 2010. Effects of monochromatic light on developmental changes in satellite cell population of pectoral muscle in broilers during early posthatch period. Anat. Rec. 293:1315–1324.

National Chicken Council. 2014. National Chicken Council animal welfare guidelines and audit checklist for broilers.

Olanrewaju, H. A., J. L. Purswell, S. D. Collier, and S. L. Branton. 2015. Effects of color temperatures (Kelvin) of LED bulbs on blood physiological variables of broilers grown to heavy weights. Poult. Sci. 94:1721–1728.

Paulino, L. 1949. Effects of varying lengths of Illumination on rate of growth and mortality of chicks. Philipp. Agric. 33:63–70.

Prescott, N. B., and C. M. Wathes. 1999. Spectral sensitivity of the domestic fowl (Gallus g. domesticus). Br. Poult. Sci. 40:332–339.

Raccoursier, M. F. 2016. Effect of Light Intensity on Production Parameters and Feeding Behavior of Broilers Masters Thesis. Available at http://scholarworks.uark.edu/etd

Rault, J. L., K. Clark, P. J. Groves, and G. M. Cronin. 2017. Light intensity of 5 or 20 lux on broiler behavior, welfare and productivity. Poult. Sci. 96:779–787

Riber, A. B. 2015. Effects of color of light on preferences, performance, and welfare in broilers. Poult. Sci. 94:1767–1775.

Robles, S. 2010. The Effect of Lighting Intensity on Activity and Tonic Immobility Response of Broiler Chickens (Gallus gallus domesticus).Masters Thesis. University of California, Davis.

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

Sanotra, G. S., J. D. Lund, and K. S. Vestergaard. 2002. Influence of light-dark schedules and stocking density on behaviour, risk of leg problems and occurrence of chronic fear in broilers. Br. Poult. Sci. 43:344–354.

Schwean-Lardner, K., B. I. Fancher, and H. L. Classen. 2012. Impact of daylength on behavioural output in commercial broilers. Appl. Anim. Behav. Sci. 137:43–52.

Sultana, S., R. Hassan, H. S. Choe, and K. S. Ryu. 2013. The effect of monochromatic and mixed LED light colour on the behaviour and fear responses of broiler chicken. AVIAN Biol. Res. 6:207-214.

Xie, D., J. Li, Z. X. Wang, J. Cao, T. T. Li, J. L. Chen, and Y. X. Chen. 2011. Effects of monochromatic light on mucosal mechanical and immunological barriers in the small intestine of broilers. Poult Sci 90:2697–2704.

Xie, D., Z. X. Wang, Y. L. Dong, J. Cao, J. F. Wang, J. L. Chen, and Y. X. Chen. 2008. Effects of Monochromatic Light on Immune Response of Broilers. Poult. Sci. 87:1535–1539.

TABLES AND FIGURES

Table 1. Production performance and processing performance of Cobb 700 broiler chickens reared under 5, 10, 20 lux, or a choice of intensities to 42 d.

	Treatments (lx)				
Live Parameters	**5**	**10**	**20**	**5, 10, 20**	**SEM**
BW (kg)	2.64	2.57	2.53	2.65	0.44
BW CV[#] (%)	14.24	11.88	14.76	13.97	1.01
Feed:Gain[*]. (kg:kg)	1.71[a]	1.74[ab]	1.81[b]	1.70[a]	0.03
Processing Attributes					
Carcass (kg)	1.87	1.90	1.83	1.90	0.04
Carcass (%)	73.83	74.17	73.92	73.63	0.27
Breast[+] (%)	24.62	25.02	24.82	24.75	0.28
Abdominal Fat (%)	1.53	1.42	1.47	1.50	0.05
Muscle Myopathies					
Woody Breast Total[α]	47	50	44	46	
Normal	13	10	13	14	
Mild	37	42	32	38	
Sever	10	8	12	9	
White Striping Total [α]	44	48	46	47	
Normal	16	12	11	13	
Mild	41	44	41	43	
Severe	3	4	5	4	

[ab] Superscripts denote differences between treatment for noted measure

[*]Feed: Gain corrected for mortality by subtracting weight of mortality from feed consumed

[+]Combine weight of pectoralis major and minor muscle

[#] Coefficient of variation for BW

[α]Woody Breast and White Striping - scores from 0-3 by palpation

Table 2. Preferences of feeding, drinking and neither feeding nor drinking under 5, 10 or 20 lx for Cobb 700 broilers on 20, 31 and 40 d

		Day		
	Intensity	**20**	**31**	**41**
Drinking (%)	5	0.39[b]	0.42[b]	0.62
	10	0.90[b]	1.36[a]	1.31
	20	1.57[a]	1.62[a]	1.17
	SEM	0.28	0.23	0.22
Feeding (%)	5	5.19[b]	8.44	4.97
	10	8.01[a]	6.47	5.39
	20	8.14[a]	6.70	4.19
	SEM	0.66	0.60	0.50
Not Feed or Drinking (%)	5	23.21[b]	20.99[b]	23.70[b]
	10	22.13[b]	25.13[a]	31.15[a]
	20	28.49[a]	27.81[a]	23.62[b]
	SEM	1.27	1.02	0.97

[a, b] Denote differences within day and behavior

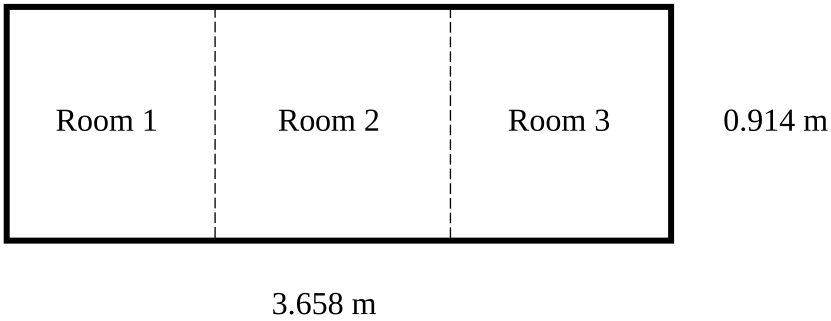


Figure 1. Schematic of preference test pen design

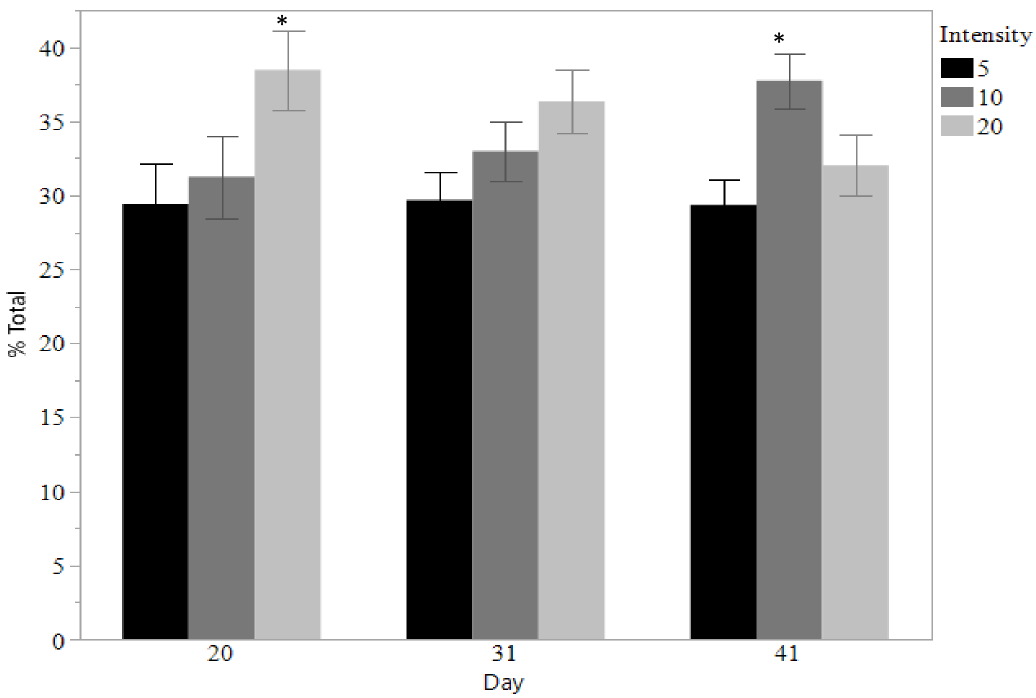


Figure 2. Distribution of birds within preference pens on 20, 31 and 41 d.

*Denote differences in preference (95% CI) by more than 33% of the total population occupying the indicated intensity.

Table 3. Feed consumption (kg/bird) of broilers provided a choice of 5, 10 and 20 lx.

	Days		
	14-22	23-34	35-42
5 lux	0.196	0.586	0.535
10 lux	0.216	0.604	0.541
20 lux	0.205	0.582	0.477
SEM N=6	0.019	0.035	0.019

CONCLUSION

These findings differ from those of Raccoursier (2016), who reported no differences in production performance when broilers were reared under 5, 10 or 20 lx from incandescent light sources. Further, we observed no difference in the consumption of feed under each light intensity while increased consumption was reported under 20 lx when provided free choice by (Raccoursier, 2016). Yet these differences in findings could be expected as the sources (LED vs incandescent) have difference spectral output composition and therefor perception. Incandescent and LED have been demonstrated result in different production performance of broilers (Archer, 2016). Furthermore, Archer (2016) found that broilers reared under incandescent lighting were more susceptible to stress than those reared under LED lights accounting for the greater number idle birds reported under 1 lx by Raccoursier, (2016). However the current results agree with an earlier report that the preference of broiler chickens changes over time from that of a high intensity to a lower intensity (Davis et al., 1999b). Though we did not employ as extreme intensities (200 lx) to test the preference of broilers yet a shift in preference was clearly demonstrated using industry relevant intensities (5, 10 and 20 lx).

The mechanism responsible for the improved feed:gain when provided choice in light intensity are not currently known. However, improved BW with no effect to feed:gain were recently reported when broiler chickens were provided a choice between two light color temperatures (2700 K and 5000 K) (Aldridge et al.,). This in combination with the present results suggest that choice or preference in lighting environment applied after 14 d may be superior to a uniform light environment for broiler production.

The use of choice and preference in light intensity have been demonstrated to improve feed:gain without changing BW or processing attributes. Further, the change in preference from high to low intensities as age increased was confirmed.

CHAPTER 4

FEED LINE LIGHTING IN COMMERCIAL BROILER PRODUCTION

INRODUCTION

The preference of broilers for different light color warmth and intensity has been suggested to change with age and time as discussed above. The present investigation begins to explore the initial steps of investigation gradient or choice lighting applications. This is accomplished by the use of a feed line lighting system that provides a gradient of light intensity from high intensity at the feeder to a lower intensity lateral to the feed line. The feeding and drinking behavior and distribution of birds reared under conventional and feed line lighting are explored. Additionally the results of an investigation comparing overhead common LEDs and feed line lighting on production performance are presented.

ABSTRACT

The practice of rearing broilers under uniformly distributed low light intensities has been demonstrated to have negative effects on development and wellbeing. However some reports have suggested increased uniform light intensity during rearing suppress production efficiency of broilers. Yet more recent studies have found that broilers preference for light intensity may undergo changes with age. Three separate investigations were under taken. The feeding, drinking behaviors and over all distributions of commercially reared broilers were characterized when reared using a feed line lighting system. Similarly, the. The feeding, drinking behaviors and over all distributions of commercially reared broilers were characterized when reared using conventional lighting. Finally, production parameters and processing attributes were evaluated for broilers reared under 20 lx or a gradient of 90 to 30 lx. In the first trial the number of birds resting near the feeders decreased with age. However, the number of birds sitting near feeders in the second trial increased with age. This is thought to be influenced by a preference for reduced light intensity during idle behavior with advancing age. In the third trial it was demonstrated that similar production performance (BW feed:gain) could be achieved using a gradient lighting system of higher light intensity (30 to 90 lx) than a lower (20 lx) uniform light intensity.

INTRODUCTION

The ability of light to influence the production performance and wellbeing of poultry has long been an area of interest for researchers (Bowlby, 1957; Cherry and Barwick, 1962; Foss et al., 1972). The use of low intensity (< 10 lux) has been reported to have negative impacts on behavioral rhythms (Alvino et al., 2009), ocular development (Lauber et al., 1965) and food pad health (Deep et al., 2010). However, others have reported no difference in welfare parameters when comparing 5 and 20 lux (lx) (Olanrewaju et al., 2016; Archer, 2016). Further, some reports suggest suppressed production performance when rearing broilers under higher (< 20 lx) intensities (Cherry and Barwick, 1962; Rault et al., 2017). The effects of light intensity within the literature are not clear, yet they can be aided in the understanding that the effect of intensity is influenced by the light source (LED and incandescent) (Olanrewaju et al., 2016; Archer, 2016). It has been suggested that LED lights are able to be used at higher intensities than incandescent achieving similar production performance (Huth and Archer, 2015).

The use of Light Emitting Diodes (LED) has been widely adopted in poultry rearing facilities. LED as the main light sources have been demonstrated to have numerous benefits to poultry and producers. Watkins (2016) reported a reduction of utility use by LEDs compared to incandescent as 80 to 85%. Broilers reared under LED have been reported to have greater BW and improved feed:gain compared to broilers reared under incandescent light (Olanrewaju et al., 2016; Archer, 2016). Further broilers reared under incandescent were reported to be more susceptible to stress susceptibility compared to those reared using LEDs (Archer, 2016). While the use of LED lights have been demonstrated to improve utility efficiency and production performance further adaptation of LED technology may yield further improvements by providing a more appropriate lighting environment for broilers.

Through preference testing, recent reports have suggested that the optimal light environment for broiler production may not be uniform in distribution of intensities. Davis and colleagues (1999) found that the preference of broilers changed from 200 lx at 2 wks for all behaviors to 6 lx for inactive behaviors and 200 lx for active behaviors at 6 wks. Similarly, Raccoursier (2016) found when provided choice that broilers at more feed under 20 lx than 5 lx when and those idle congregated under 1 lx. Further, when broilers reared under uniformly distributed 5, 10 or 20 lx were compared to those provided a choice (5, 10 or 20 lx) similar feed:gain was reported for 5 lx and choice (Aldridge et al., 2019). To better understand the differences in production and behavior of broilers reared using a gradient of intensities 3 separate trials were under taken employing a commercially available LED fixture (AviLighting AHPharma, Hebron MD, USA) designed to provide high intensity near feed lines within a commercial broiler house and reduced intensities in the lateral areas of the house.

MATERIALS AND METHODS

A total of 960 Cobb 700 straight broiler chickens were reared in 8 pens in each two trials. In each trial pens were distributed within a commercial broiler house on the Applied Broiler Research Farm at the University of Arkansas. Pens were constructed of a PVC frame and plastic coated wire and measured 1.524 m x 6.096 m (half the width of the commercial house) and were constructed to include two feeder pans and two nipple drinker lines (see Figure 1). In trial one a single AviLighting fixture (AHPharma, Hebron MD, USA) was attached to the feeder line between the to the manufacturers' instructions (height). A 23L:1D lighting schedule was employed from 0 to 2 d. On d 3, a 16L:8D schedule was implemented and remained for the duration of the rearing period. Light intensity from d 0 to 13 were measured 110 lx directly under (23 cm from light to litter) the AviLighting fixture and gradually reduced to 30 lx at the edge of each pen furthest from the fixture (see Figure 1.1) while conventional overhead LED bulbs were used (Overdrive, Clifton NJ USA). From 14 to 40 d light was supplied from the AviLighting only. Light intensities were measured as 100 lx directly under the fixture and 4 lx at the furthest point from the fixture within the pen (see Figure 1). In trial two the same pen design and lighting schedule was use however uniform light intensities at 30 lx were used from 0 to 13 d with an intensity of 11 lux used from 14 to 40 d.

A remote video observation system (Hikvision DS-2CD2141FWD-IS-2.8MM) was installed over each of the pens. Observations were taken using scan sampling. Birds were observed every 15 min during the first (AM), a random (R) and last (PM) h of the light period. Birds were assigned into one of seven categories: feeding, drinking, standing near (within 0.4 m) of feeder (0.914 m2), sitting near (within 0.4 m) feed (0.914 m2), standing near (within 0.4 m) water (1.819 m2), sitting near (within 0.4 m) water (1.819 m2) and other (outside the view or the camera). Observations were taken on d 15, 21, 35 and 40.

In a third trial, 1240 Cobb 700 broiler chickens were distributed into 20 pens within in a single commercial broiler house at the University of Arkansas Applied Broiler Research Farm. Pens (3.66 m x 1.22 m) were of constructed of a PVC frame, plastic coated wire and covered with black plastic to prevent light from "polluting" neighboring pens. Each pen was equipped with a single hanging tube feeder and a nipple drinker line (see Figure 4). Pens were divided into two treatments: Conventional, being illuminated using two common LED light bulbs (Overdrive, Clifton NJ USA) and AVI Lighting, being illuminated using a single Avi Lighting fixture placed near the feeder. A 23L:1D lighting schedule was employed from 0 to 2 d. On d 3, a 16L:8D schedule was implemented and remained for the duration of the rearing period. During brooding the Avi Lighting intensity from d 0 to 13 were measured 110 lx directly under (23 cm from light to litter) the Avi Lighting fixture and gradually reduced to 40 lx at the edge of each pen furthest from the fixture and were supplemented with 2 over head LED bulbs. For the conventional treatment light intensity was measure as a uniform 40 lx from 0 to 13 d. On d 14 light intensities were reduced. Avi Lighting intensities were measure at 90 lx directly under (23 cm) under the fixture and gradually reduced to 30 lx at the furthest points from the light source. In the conventionally lit pens a uniform intensity of 20 lx was achieved. Birds were weighed on 14 and

40 d. On d 40 16 birds were randomly selected from each pen for processing. During processing carcass weights, carcass yield, breast weight and yield were collected.

One way ANOVA was performed and differences, considered as $p<0.05$, were separated using Tukey's HSD test. All procedures were carried out in accordance with University of Arkansas Institutional Animal Care and Use Committee protocol 18095.

RESULTS

Trial 1

Observations for each day of broilers reared using a feed line lighting system are summarized in Table 1. The percentage of birds feeding decreased from d 15 to d 21 while no further decrease was observed Standing near feed decreased from d 15 to 21 and 21 to 35 while no difference was observed for d 40. Birds setting near feed increased from d 15 to 21 before decreasing on d 40, d 35 being intermediate. No differences occurred in the number of birds drinking between d. Standing near water decreased as age increased from d 15 to 35 with d 35 and 40 being similar. Sitting near water increased with age after d 21. The effect of time for each behavior is summarized in Table 2. Birds feeding was highest for AM followed by PM while the fewest birds feeding occurred during R. Standing near feed and setting near feed followed similar patterns with the greatest number of birds in each being at AM and decreasing for R and PM. This same pattern was observed for birds drinking, decreasing from AM to R while R and PM being similar. No effect for time of day was observed for birds standing near water or the birds outside the view of the camera (other).

The effect of time of within each of the sample d is summarized by Figure 2. On d 15 feeding was greatest during AM and decreased for R and PM compared to AM. However as age increased the difference between birds feeding during AM and PM diminished yet remained for

R. The effect of time within each d is summarized by Figure 2. A pattern of increased drinking during AM was observed on d 15, and 40.

Trial 2

Behavioral observations by d for birds housed under common commercial lighting are summarized in Table 3. The number of birds feeding decreased from d 15 to 21 and remained at a similar level through d 40. The occurrence of standing near feed decreased with age from d 15 to 35 before plateauing on d 40. As standing near feed decreased with age the opposite occurred for sitting near feed. An increase in sitting near feed occurred from d 15 to 21 and again on 40 while d 35 was intermediate. A single increase occurred for drinking on d 21 before returning to similar levels as d 21 for the remainder of the trial. Birds standing near water followed the same pattern as those standing near feed (decreasing with age). Sitting near water also followed a similar pattern of increase with age as setting near feed. Table 2 summarizes each behavior by the time of day (AM, R or PM). Feeding was greatest during AM followed by PM and being lowest during R. No differences occurred for standing or sitting near feed. Drinking, like feeding, was highest during AM however decreased to a similar level for R and PM. However sitting near water increased for AM to R with R and PM being similar. The greatest number of birds within the view of the camera were during AM and PM.

Trial 3

Production and processing attributes are summarized in Table 5. No differences were observed in BW, feed:gain, or BW CV. Further no difference were observed in carcass, breast or tender yield.

DISCUSSION

The observation of broilers feeding and standing near feed by d were similar for trial 1 and 2. However broilers sitting near feed displayed distinct differences as age progressed. Those reared using increased with while those using gradient lighting were similar on 15, 35 and 40 d. This agrees with earlier reports that broilers prefer a lower light intensity when idle as age progresses (Davis et al., 1999a; Raccoursier, 2016). For drinking there was a single increase for those birds reared using conventional light on 21 d while no differences were observed for broilers reared using feed line lighting. Similar patterns were observed between trial 1 and 2 for both standing near water (decreasing with age) and sitting near water (increasing with age).

Similar patterns of feeding by time of day occurred in trial 1 and 2 however, differences were seen in standing near feed during AM compared to R and PM for trial 1 and no differences were present during trial 2. This may suggest that birds during the peak feeding time are more likely to be approaching the feeder. For all other measured behaviors similar patterns were observed between trial 1 and 2.

No differences occurred in BW, feed:gain, BW CV, carcass yield, breast yield or tender yield. This was likely due the inability to achieve a gradient with a low intensity similar to of past reports (1-5 lx). However, it is suggested that broilers could be reared using gradient lighting, suggested to improve wellbeing of broiler chickens (Kang et al., 2018), of higher minimal intensity (30 lx) with similar production performance to those reared under 20 lx. Further work is needed to better understand the effects of gradient lighting at different levels of intensity on production performance and behavior.

These investigations suggest that broilers can be reared using higher intensities if a gradient in light intensities is used with similar production performance as those reared using lower intensities.

REFERENCES

Aldridge, D. J., C. G. Scanes, B. A. Mallmann, C. M. Owens, and M. T. Kidd. 2019. Performance and Preference of Broilers Provided Choice of Light Intensity. In Review.

Alvino, G. M., G. S. Archer, and J. A. Mench. 2009. Behavioural time budgets of broiler chickens reared in varying light intensities. Appl. Anim. Behav. Sci. 118:54–61.

Archer, G. 2016. Comparison of Raising Broiler Chickens Under Light Emitting Diode or Incandescent Light at Differing Intensities on Growth, Stress and Fear. Int. J. Poult. Sci. 15:425–431.

Bowlby, G. 1957. Some preliminary investigations into the effect of light on broilers. World's Poult. Sci. 13:214–226 .

Cherry, P., and M. Barwick. 1962. The effect of light on broiler growth. I Light intensity and colour. Br. Poult. Sci. 3:31–39.

Davis, N. J., N. B. Prescott, C. J. Savory, and C. M. Wathes. 1999a. Preferences of Growing Fowl for Different Light Intensities in Relation To Age, Strain and Behaviour. Anim. Welf. 8:193–203.

Davis, N. J., N. B. Prescott, C. J. Savory, and C. M. Wathes. 1999b. Preferences of Growing Fowls for Different Light Intensities in Relation to Age, Strain and Behaviour. Anim. Welf. 8:193–203.

Deep, A., K. Schwean-Lardner, T. G. Crowe, B. I. Fancher, and H. L. Classen. 2010. Effect of light intensity on broiler production, processing characteristics, and welfare. Poult. Sci. 89:2326–2333.

Foss, D., L. Carew, and E. Arnold. 1972. Physiological Development of Cockerels as Influenced by Selected Wavelengths of Environmental Light. Poult. Sci. 51:1922–1927.

Huth, J. C., and G. S. Archer. 2015. Comparison of Two LED Light Bulbs to a Dimmable CFL and their Effects on Broiler Chicken Growth, Stress, and Fear. Poult. Sci. 94:2027–2036.

Kang, S., K. Christensen, D. Aldridge, and W. Kuenzel. 2018. Effects of light intensity and dual light choice treatments on plasma corticosterone and brainstem serotonergic activity on male broilers. Poult. Sci. 97:72

Lauber, J. K., J. McGinnis, and J. Boyd. 1965. Influence of miotics, Diamox and vision occluders on light-induced buphthalmos in domestic fowl. Proc. Soc. Exp. Biol. Med. Soc. Exp. Biol. Med. 120:572–577

Olanrewaju, H. A., W. W. Miller, W. R. Maslin, S. D. Collier, J. L. Purswell, and S. L. Branton. 2016. Effects of light sources and intensity on broilers grown to heavy weights. Part 1: Growth performance, carcass characteristics, and welfare indices 1. Poult. Sci. 95:727–735

Raccoursier, M. F. 2016. Effect of Light Intensity on Production Parameters and Feeding Behavior of Broilers Masters Thesis. Univesity of Arkansas.

Rault, J. L., K. Clark, P. J. Groves, and G. M. Cronin. 2017. Light intensity of 5 or 20 lux on broiler behavior, welfare and productivity. Poult. Sci. 96:779–787.

Watkins, S. 2016. Poultry Lighting: LED Bulbs Provide Energy Savings and Durability. Univ. Arkansas-Division Agric. Res. Ext.:1–2.

TABLES AND FIGURES

Table 1. Feeding drinking and distribution of commercially housed Cobb 700 broiler chickens as effected by age reared using a feed line lighting system

Day	Feeding (%)	Standing Near* Feed (%)	Sitting Near* Feed (%)	Drinking (%)	Standing Near* Water (%)	Sitting Near* Water (%)	Other[1] (%)
15	17.18[a]	5.46[a]	6.95[b]	7.37	2.22[a]	9.12[c]	51.69[b]
21	11.13[b]	2.41[b]	9.35[a]	8.46	1.47[b]	9.98[c]	57.19[a]
35	10.94[b]	0.56[c]	8.16[ab]	7.86	0.40[c]	12.73[b]	59.34[a]
40	11.85[b]	0.18[c]	7.91[b]	8.97	0.02[c]	15.57[a]	55.51[ab]
SEM	0.512	0.216	0.542	0.512	0.116	0.923	1.128

[a, b] Denote differences between d for each observed behavior

*Near is considered within 0.33 m

[1]Birds not within 0.3 m of the water lines or feed lines (outside the view of the camera)

Table 2. Effect of time of day on percentage of broiler chickens exhibiting feeding and drinking behaviors together with distribution of commercially housed Cobb 700 broiler chickens reared using a feed line lighting system

Time	Feeding (%)	Standing Near Feed (%)	Sitting Near Feed (%)	Drinking (%)	Standing Near Water (%)	Sitting Near Water (%)	Other[1] (%)
AM*	14.82^{a}	2.99^{a}	6.85^{b}	10.21^{a}	1.14	9.69^{b}	54.26
Random[+]	10.71^{c}	1.66^{b}	8.83^{a}	6.91^{b}	0.83	13.17^{a}	57.90
PM[#]	12.81^{b}	1.82^{b}	8.60^{a}	7.38^{b}	1.07	12.68^{a}	55.63
SEM	0.562	0.405	0.328	0.370	0.183	0.667	1.061

[a, b] Denote differences between time for each observed behavior

[*]The first hour of the light period (16L:8D)

[+]A randomly selected hour during the light period

[#]The last hour during the light period

[1]Birds not within 0.3 m of the water lines or feed lines (outside the view of the camera)

Table 3. Feeding drinking and distribution of commercially housed Cobb 700 broiler chickens as effected by age reared using conventional lighting

Day	Feeding (%)	Standing Near[*] Feed (%)	Sitting Near[*] Feed (%)	Drinking (%)	Standing Near[*] Water (%)	Sitting Near[*] Water (%)	Other[1] (%)
15	18.07[a]	3.68[a]	4.56[c]	7.00[b]	3.07[a]	9.00[c]	54.62[ab]
21	10.69[b]	1.80[b]	9.36[b]	9.54[a]	1.55[b]	14.22[b]	52.84[ab]
35	11.00[b]	0.42[c]	10.35[ab]	6.75[b]	0.57[c]	14.13[b]	56.79[a]
40	11.08[b]	0.19[c]	11.56[a]	6.98[b]	0.21[c]	18.26[a]	51.72[b]
SEM	0.581	0.133	0.395	0.514	0.135	0.644	1.067

[a, b] Denote differences between d for each observed behavior

[*]Near is considered within 0.33 m

[1]Birds not within 0.3 m of the water lines or feed lines (outside the view of the camera)

Table 4. Effect of time of day on percentage of broiler chickens exhibiting feeding and drinking behaviors together with distribution of commercially housed Cobb 700 broiler chickens reared using conventional lighting

Time	Feeding (%)	Standing Near Feed (%)	Sitting Near Feed (%)	Drinking (%)	Standing Near Water (%)	Sitting Near Water (%)	Other[1] (%)
AM*	15.21[a]	1.84	8.41	9.77[a]	1.73	11.79[b]	51.25[b]
Random[+]	9.90[c]	1.33	9.30	6.02[b]	1.09	15.30[a]	57.05[a]
PM[#]	13.01[b]	1.39	9.17	6.91[b]	1.23	14.61[a]	53.38[b]
SEM	0.638	0.271	0.581	0.395	0.225	0.762	0.884

[a, b] Denote differences between time for each observed behavior

[*]The first hour of the light period (16L:8D)

[+]A randomly selected hour during the light period

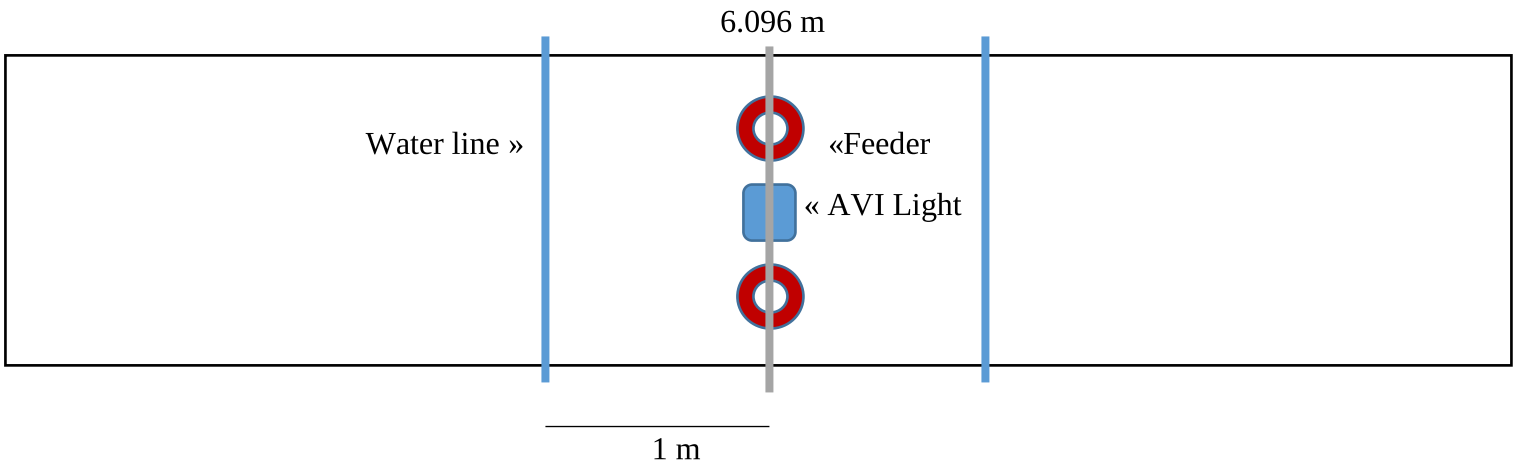
[#]The last hour during the light period

[1]Birds not within 0.3 m of the water lines or feed lines (outside the view of the camera)

Figure 1. Schematic of a pen one half the width of the commercial broiler house (Trial 1 and 2)

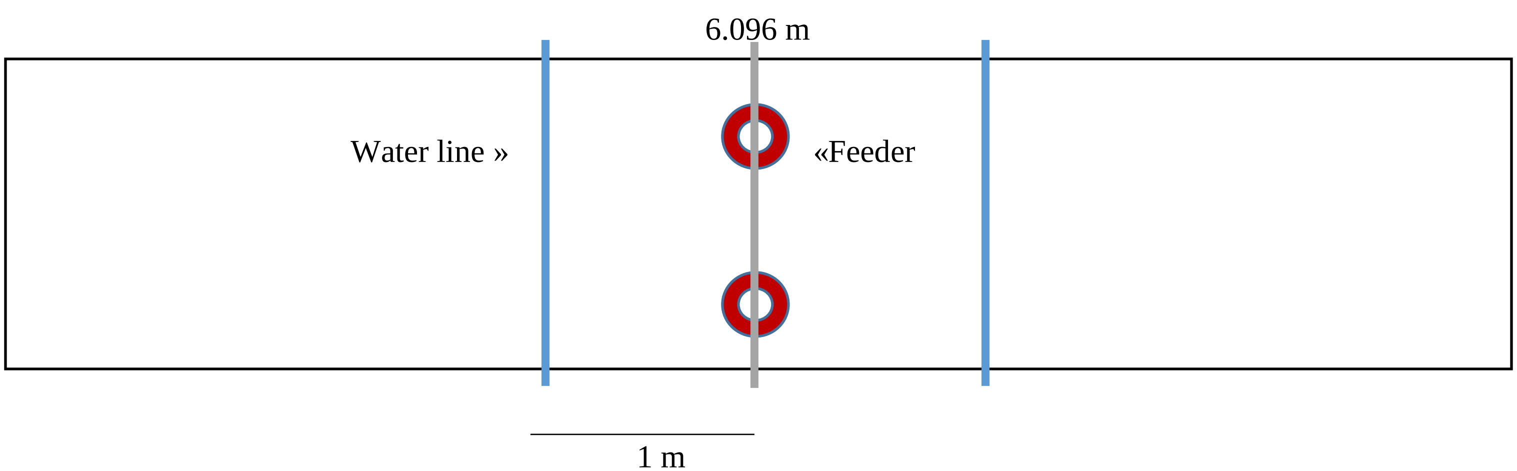
Trial 1.

1.524 m



Trial 2.

1.524 m



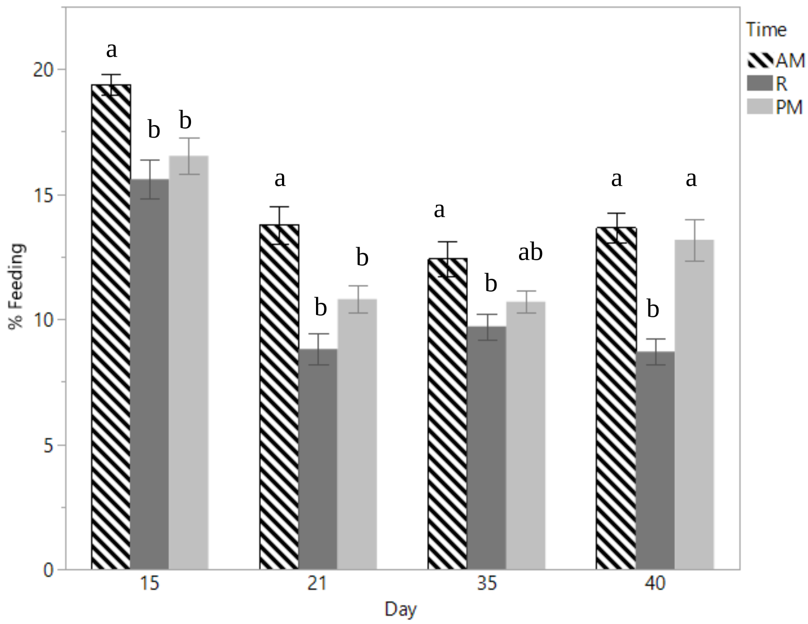


Figure 2. Percentage of Cobb 700 straight run broilers feeding on 15, 21, 35 and 41 d during the first (AM), a random (R) and last (PM) h of the 16 hour light period when reared using feed line lighting system.

[a, b] Denote differences of birds feeding by time, within each day.

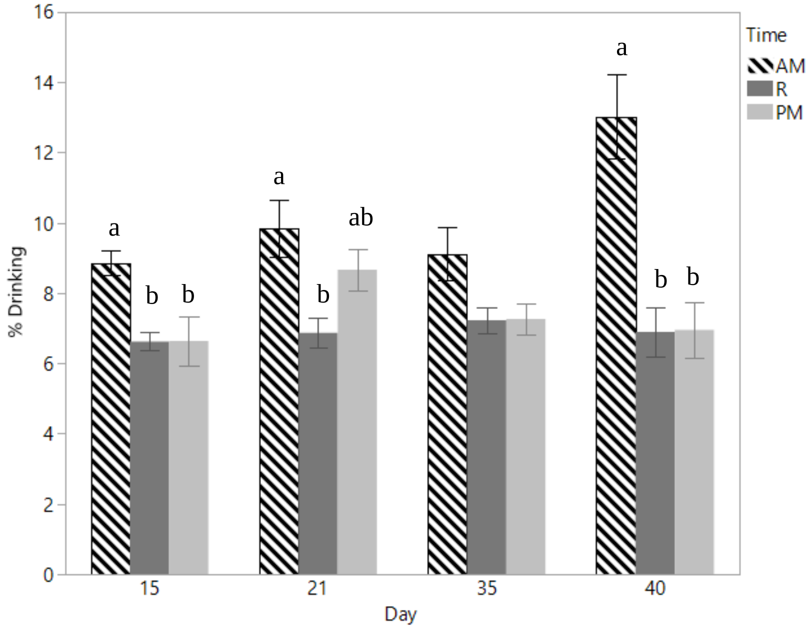


Figure 3. Percentage of Cobb 700 straight run broilers drinking on 15, 21, 35 and 41 d, during the first (AM), a random (R) and last (PM) h of the 16 hour light period when reared using feed line lighting system.

[a, b] Denote differences of birds feeding by time, within each day.

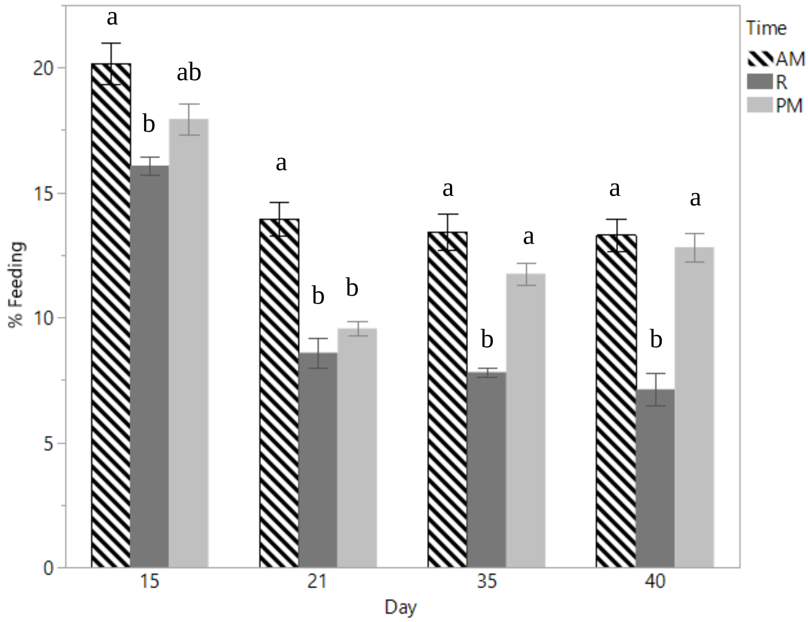


Figure 4. Percentage of Cobb 700 straight run broilers feeding on 15, 21, 35 and 41 d during the first (AM), a random (R) and last (PM) h of the 16 hour light period when reared using conventional lighting

[a, b] Denote differences of birds feeding by time, within each day.

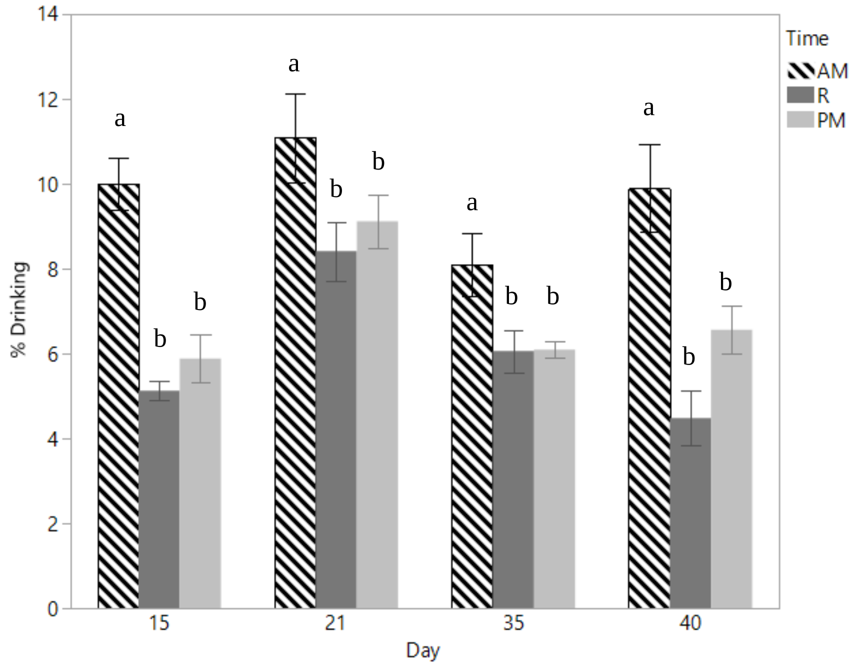


Figure 5. Percentage of Cobb 700 straight run broilers drinking on 15, 21, 35 and 41 d, during the first (AM), a random (R) and last (PM) h of the 16 hour light period when reared using conventional lighting

[a, b] Denote differences of birds feeding by time, within each day.

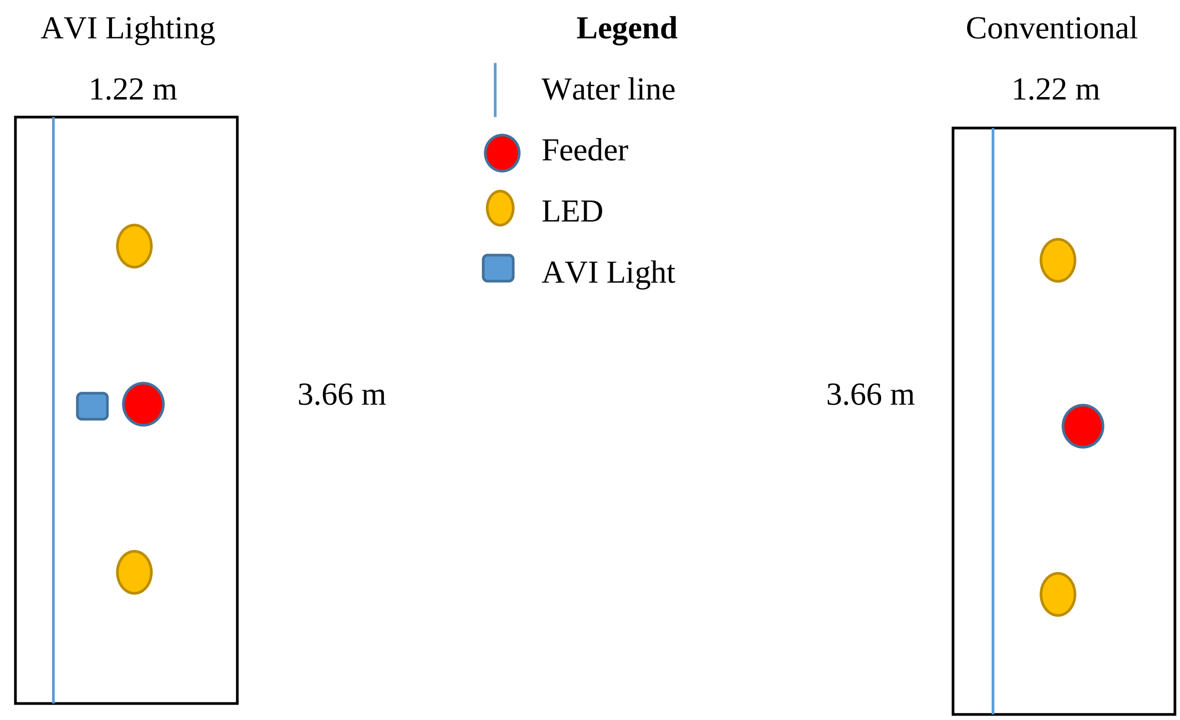


Figure 6. Schematic of pens using a feed line gradient lighting system (trial 3).

Table 5. Production performance and processing attributes of Cobb 700 broilers reared using conventional and feed line lighting to 40 d

Day 0-14	**Control**	**Avi Lighting**	SEM
BW (kg)	0.48	0.48	0.008
Feed:Gain	0.93	0.94	0.019
Day 0-40			
BW (Kg)	2.50	2.49	0.019
Feed:Gain+	1.67	1.65	0.014
BW CV %*	10.72	11.26	0.589
Carcass Yield %	76.34	76.15	0.215
Breast Yield %	19.87	19.50	0.237
Tender %	4.27	4.21	0.049

+Feed:Gain was corrected for mortality by subtracting mortality BW from total feed consumed
*Coefficient of variation

CONCLUSIONS

While the practice of rearing broilers under uniformly distributed low light intensities have been demonstrated to have negative effects on development and wellbeing, some reports have suggested increased uniform light intensity during rearing suppress production efficiency of broilers. Yet, more recent studies have found that broilers preference for light intensity may undergo changes with age. Three separate investigations were under taken. The feeding, drinking behaviors and over all distributions of commercially reared broilers were characterized when reared using a feed line lighting system. Similarly, the feeding, drinking behaviors and over all distributions of commercially reared broilers were characterized when reared using conventional lighting. Finally, production parameters and processing attributes were evaluated for broilers reared under 20 lx or a gradient of 90 to 30 lx.

In the first trial the number of broilers resting near the feeders decreased with age. This is thought to be a demonstration of decreasing preference for high light intensities while idle similar to the findings of (Davis et al., 1999). However, the number of broilers sitting near feeders in the second trial increased with age. In the third trial it was demonstrated that similar production performance (BW, feed:gain) could be achieved using a gradient lighting system of higher light intensity (30 to 90 lx) than a lower (20 lx) uniform light intensity.

CHAPTER 5

OVERALL CONCLUSIONS

The use of preference and choice for light environment optimizations was investigated. No negative effects were observed when providing broilers with free choice in light color temperature (K) of light intensity (lx). Further, the preference of broiler chickens for different light color temperatures was demonstrated to change with time of day following that of natural light.

The preference for light intensity was demonstrated to shift from a high intensity (20 lx) to a more moderate intensity (10 lx) as age increased. Similarly, the distribution of idle broilers reared using feed line lighting was shown to disperse away from areas of high intensity as age increased. These findings have the potential to further influence the distribution of broilers within the rearing environment. Moreover, improved feed:gain was demonstrated for broilers provided preference (5, 10 and 20 lx) of light intensities over broilers reared using 20 lx. The use of a gradient (30 to 90 lx) was found to have similar production parameters as a uniform 20 lx environment.

A critical principle often applied in other areas of rearing environment management (temperature) can be employed here. The use of human focused and driven environmental parameters are not necessarily appropriate for poultry. While the vast majority of both production, welfare and preference investigations have focused a determining a single light intensity and color to be applied evenly across both time (age) and space (the rearing environment), these may have been misguided. The use of a single color and intensity of light was demonstrated not to be preferred by broiler chickens. This is consistent with the natural light environment of the jungle fowl and the needs to avoid prey animals. Additionally, these results further demonstrate the importance of considering the past environments in which poultry developed. This is not to say that we should return to outdated and inefficient production systems. Yet when considering how to optimize the rearing environment ques able to elicit responses similar those found in original environments may have positive effects for both performance and wellbeing.

Further work is needed to better understand the mechanisms driving preferences for both light color temperatures and light intensity. However, the use of preference has been demonstrated to achieve equal levels of production efficiency while providing broilers with the ability to optimize their lighting environment.

REFERENCES

Abbas, A. O., A. K. A. El-Dein, A. A. Desoky, and M. A. A. Galal. 2008. The effects of photoperiod programs on broiler chicken performance and immune response. Int. J. Poult. Sci. 7:665–671

Ackerman, D. 1998. A Natural History of Vision. London.

Aldridge, D. J., C. G. Scnaces, and M. T. Kidd. Performance and Preference of Broilers Provided Dual Light Warmth. Poult. Sci.:In review.

Alvino, G. M., G. S. Archer, and J. A. Mench. 2009. Behavioural time budgets of broiler chickens reared in varying light intensities. Appl. Anim. Behav. Sci. 118:54–61.

Apeldoorn, E. J., J. W. Schrama, M. M. Mashaly, and H. K. Parmentier. 1999. Effect of melatonin and lighting schedule on energy metabolism in broiler chickens. Poult. Sci. 78:223–229.

Archer, G. S. 2015. Comparison of Incandescent, CFL, LED and Bird Level LED Lighting: Growth, Fear and Stress. Int. J. Poult. Sci. 14:449–455.

Archer, G. 2016. Comparison of Raising Broiler Chickens Under Light Emitting Diode or Incandescent Light at Differing Intensities on Growth, Stress and Fear. Int. J. Poult. Sci. 15:425–431.

Archer, G. S. 2018. Color temperature of light-emitting diode lighting matters for optimum growth and welfare of broiler chickens. animal 12:1015–1021.

Armington, J. C., and F. C. Thiede. 1995. Electroretinal Demonstration of a Purkinje Shift in the Chicken Eye. Am. J. Physiol. Content 186:258–262.

Bailie, C. L., M. Baxter, and N. E. O’Connell. 2018. Exploring perch provision options for commercial broiler chickens. Appl. Anim. Behav. Sci. 200:114–122.

Barott, H. G. Pringle, E. 1951. Effect of environment on growth and feed and water consumption of chickens The Effect of Light on Early Growth. J. Nutr.:265–274.

Bayram, A., and S. Özkan. 2010. Effects of a 16-hour light, 8-hour dark lighting schedule on behavioral traits and performance in male broiler chickens. J. Appl. Poult. Res. 19:263–273.

Bean, W., P. Siegel, and H. Siegel. 1962. The Effect of Light on Body weight and Feed Conversion of Broilers. Poult. Sci. :1350–1351.

Bercovitz, A. B., P. C. Harrison, and G. A. Leary. 1972. Iduced Alterations in Growth of the Avian Eye’ Pattern. Vision Res. 12:1253–1259.

Blair, R., R. C. Newberry, and E. E. Gardiner. 1993. Effects of lighting pattern and dietary tryptophan supplementation on growth and mortality in broilers. Poult. Sci. 72:495–502

Blatchford, R. A., G. S. Archer, and J. A. Mench. 2012. Contrast in light intensity, rather than day length, influences the behavior and health of broiler chickens. Poult. Sci. 91:1768–1774.

Blatchford, R. A., K. C. Klasing, H. L. Shivaprasad, P. S. Wakenell, G. S. Archer, and J. A. Mench. 2009. The effect of light intensity on the behavior, eye and leg health, and immune function of broiler chickens. Poult. Sci. 88:20–28.

Bowlby, G. 1957. Some Preliminary Investigations Into the Effect of Light on Broilers. World's Poult. Sci. J. 13:214–226 .

Bowmaker, J., and D. Hunt. 2006. Evolution of vertebrate visual pigments. Curr. Biol. 484–489.

Boyce, P. R. 2010. Review: The Impact of Light in Buildings on Human Health. Indoor Built Environ. 19:8–20.

Brickett, K., E. Dahiya, H. Clasen, C. Annett, and S. Gomist. 2007. The Impact of Nutrient Density, Feed Form, and Photoperiod on the Walking Ability and Skeletal Quality of Broiler Chickens. Poult. Sci. 86:2117–2125.

Broom, D. M. 2011. A History of Animal Welfare Science. Acta Biotheor. 59:121–137 Available at https://0-search-proquest-com.library.uark.edu/docview/867949674?pq-origsite=summon (verified 3 October 2018).

Burkhardt. 1982. Birds, Berries and UV. Naturwissenschaften 69:153–157.

Buys, N., J. Buyse, M. Hassanzadeh-Ladmakhi, and E. Decuypere. 1998. Intermittent Lighting Reduces the Incidence of Ascites in Broilers: An Interaction with Protein Content of Feed on Performance and the Endocrine System. Poult. Sci. 77:54-61

Buyse, J., E. R. Kühn, and E. Decuypere. 1996a. The use of intermittent lighting in broiler raising. 1. Effect on broiler performance and efficiency of nitrogen retention. Poult. Sci. 75:589–594.

Buyse, J., P. C. M. Simons, F. M. G. Boshouwers, and E. Decuypere. 1996b. Effect of intermittent lighting, light intensity and source on the performance and welfare of broilers. Worlds. Poult. Sci. J. 52:121–130.

Cao, J., W. Liu, Z. Wang, D. Xie, L. Jia, and Y. Chen. 2008. Green and blue monochromatic lights promote growth and development of broilers via stimulating testosterone secretion and myofiber growth. J. Appl. Poult. Res. 17:211–218.

Carson, J., W. Junnila, and B. Bacon. 1958. Sexual Maturity and Productivity in the Chicken as Addected by the Quality of Illumination. Poult. Sci. 37:102–112.

Charles, R., F. Robinson, R. Hardin, M. Yu, J. Feddes, and H. Classen. 1992. Growth, Body Composition, and Plasma Androgen Concentration of Male Broiler Chickens Subjected to Different Regimens of Photoperiod and Light Intensity. Poult. Sci. 71:1595–1605.

Chen, D.-M., J. S. Collins, and T. H. Goldsmith. 1984. The Ultraviolet Receptor of Bird Retinas.

Cherry, P., and M. Barwick. 1962. The effect of light on broiler growth. I Light intensity and colour. Br. Poult. Sci. 3:31–39.

Classen, H., and C. Riddell. 1989. Photoperiodic Effects on performance and leg Abnormalities in Broiler Chickens. Poult. Sci. 68:873–879.

Clegg, R., and P. Sanford. 1951. The Influence of intermittent periods of light and dark on the rate of growth of chicks. Poult. Sci. 30:760–762.

Council of the European Union. 2007. Council Directive 2007/43/EC. Off. J. Eur. Union:19–28.

Das, H., and E. Lacin. 2014. The Effect of Different Photoperiods and Stocking Densities on Fattening Performance, Carcass and Some Stress Parameters in Broilers. Isr. J. Vet. Med. 69:211–220.

Davis, N. J., N. B. Prescott, C. J. Savory, and C. M. Wathes. 1999a. Preferences of Growing Fowl for Different Light Intensities in Relation To Age, Strain and Behaviour. Anim. Welf. 8:193–203.

Davis, N. J., N. B. Prescott, C. J. Savory3, and C. M. Wathes. 1999b. Preferences of Growing Fowls for Different Light Intensities in Relation to Age, Strain and behaviour. Anim. Welf. 8:193–203

Dawkins, M. 1977. Do Hens suffer in Battery Cages? Environmental Preferences and Welfare.Anim. Behav. 25:1034-1046.

Dawkins, M. S. 2015. Advances in Poultry Welfare (J Mench, Ed.). 1st ed. Woodhead.

Deep, A., C. Raginski, K. Schwean-Lardner, B. I. Fancher, and H. L. Classen. 2013. Minimum light intensity threshold to prevent negative effects on broiler production and welfare. Br. Poult. Sci. 54:686–694.

Deep, A., K. Schewan-Lardner, T. Crowe, B. Fancher, and H. Classen. 2011. Effect of light intensity on broiler behaviour and diurnal rhythms. Appl. Anim. Behav. Sci. 136:50–56.

Deep, A., K. Schwean-Lardner, T. G. Crowe, B. I. Fancher, and H. L. Classen. 2010. Effect of light intensity on broiler production, processing characteristics, and welfare. Poult. Sci. 89:2326–2333.

Deines, J. 2016. Feeder Colour Preference of Broilers and its Effects on Performance - The Poultry Site.

Downs, K., R. Lien, J. Hess, S. Bilgili, and W. Dozier. 2006. The Effects of Photoperiod Length, Light Intensity, and Feed Energy. J. Appl. Poult. Res. 15:406.

Edwards, L., and P. Torcellini. 2002. A Literature Review of the Effects of Natural Light on Building Occupants.US. Department of Energy.

Elling-Staats, M. L., J. van Loon, M. M. P. Raaijmakers, A. F. . van der Poel, and R. P. Kwakkel. 2017. Diet preference tests for a wet versus dry feed, wheat structure and pellet size in broiler chickens.in 21th European Symposium on Poultry Nutrition.

Foss, D., L. Carew, and E. Arnold. 1972. Physiological Development of Cockerels as Influenced by Selected Wavelengths of Environmental Light. Poult. Sci. 51:1922–1927.

Goldsmith, T. 1990. Optimization, Constraint, and History in the Evolution of Eyes. Q. Rev. Biol. 65:281–322.

Gordon, S., and S. Tucker. 1995. Effect of Daylength on Broiler Welfare. Br. Poult. Sci. 36:844–845.

Grand, L. 1975. Measurement of the visual stimulus.in Handbook of Pecreption V: Seeing. Carterette, ed. Academic Press, London.

Granzier, J. J. M., and M. Valsecchi. 2014. Variations in daylight as a contextual cue for estimating season, time of day, and weather conditions. J. Vis. 14:1–23.

Gunturkun, O. 2000. Sensory Physiology: Vision.Pages 1–19 in Sturkie's Avian Physiology: Fifth Edition.

Heywang, B. 1944. The effect of artificial light on chicks brooded during hot weather. Poult. Sci. 23:481.

Hughes, B. O. 1976. The Preference of Domestic Hens for Different Types of Battery Cage Floor.App. Animl. Behav. 2:155-165

Hunt, D. M., L. S. Carvalho, J. A. Cowing, and W. L. Davies. 2009. Evolution and spectral tuning and visual pigment in birds and mammals. Source Philos. Trans. Biol. Sci. 364:2941–2955.

Huth, J. C., and G. S. Archer. 2015. Comparison of Two LED Light Bulbs to a Dimmable CFL and their Effects on Broiler Chicken Growth, Stress, and Fear. Poult. Sci. 94:2027–2036.

Ingram, D. R., L. F. Hatten, and B. N. Mcpherson. 2000. Effects of Light Restriction on Broiler Performance and Specific Body Structure Measurements. J. Appl. Poult. Sci.:501–504.

Jenkins, R. L., W. D. Ivey, G. R. McDaniel, and R. A. Albert. 1979. A darkness induced eye abnormality in the domestic chicken. Poult. Sci. 58:55–59.

Jensen, L. S., and W. E. Matson. 1957. Enlargement of avian eye by subjecting chicks to continuous incandescent illumination. Science 125:741.

Kirby, J., and D. Froman. 1991. Research Note: Evaluation of Humoral and Delayed Hypersensitivity Responses in Cockerels Reared Under Constant Light or a Twelve Hour Light: Twelve Hour Dark Photoperiod. Poult. Sci. 70:2375–2378.

Kruschwitz, A., M. Zupan, T. Buchwalder, and B. Huber-Eicher. 2008. Nest preference of laying hens (Gallus gallus domesticus) and their motivation to exert themselves to gain nest access. Appl. Anim. Behav. Sci. 112:321–330.

Kühn, E. R., V. M. Darras, Gysemans, Decuypere, Berghman, and J. Buyse. 1996. The use of intermittent lighting in broiler raising. 2. Effects on the Somatotrophic and Thyroid Axes and on Plasma Testosterone Levels. Poult. Sci. 75:589–594.

Lauber, J. K., J. V. Shutze, and J. McGinnis. 1961. Effects of exposure to continuous light on the eye of the growing chick. Proc Soc Exp Biol Med 106:871–872.

LED Bulbs: Much to Offer the Poultry Industry - The Poultry Site. 2015.

Lewis, P. D. 2006. A review of lighting for broiler breeders. Br. Poult. Sci. 47:393–404.

Lewis, P. D., R. Danisman, and R. M. Gous. 2008. Male broiler performance and nocturnal feeding under constant 8-h or 16-h photoperiods, and various increasing lighting regimens. South African J. Anim. Sci. 38:159–165.

Lewis, P. D., R. Danisman, and R. M. Gous. 2009. Photoperiodic responses of broilers. I. Growth, feeding behaviour, breast meat yield, and testicular growth. Br. Poult. Sci. 50:657–666 .

Lewis, P. D., and R. M. Gous. 2009. Photoperiodic responses of broilers. II. Ocular development. Br. Poult. Sci. 50:667–672.

Lewis, P. D., and T. R. Morris. 2000. Poultry and coloured light. Worlds. Poult. Sci. J. 56:189–207.

Lewis, P. D., and T. R. Morris. 2006. Poultry Lighting the Theory and Practice. Northcot, Cowdown Lane.

Li, T., H. C. Howland, and D. Troilo. 2000. Diurnal illumination patterns affect the development of the chick eye. Vision Res. 40:2387–2393.

Lien, R. J., J. B. Hess, S. R. Mckee, and S. F. Bilgili. 2008. Effect of Light Intensity on Live Performance and Processing Characteristics of Broilers. Poult. Sci. 87:853–857.

Lien, R. J., J. B. Hess, S. R. Mckee, S. F. Bilgili, and J. C. Townsend. 2007. Effect of Light Intensity and Photoperiod on Live Performance, Heterophil-to-Lymphocyte Ratio, and Processing Yields of Broilers. Poult. Sci. 86:1287–1293 .

Lind, O., M. Mitkus, P. Olsson, and A. Kelber. 2013. Ultraviolet vision in birds: The importance of transparent eye media. Proc. R. Soc. B Biol. Sci. 281.

Liu, J., K. Pendrak, C. Capehart, R. Sugimoto, G. F. Schmid, and R. A. Stone. 2004. Emmetropisation under continuous but non-constant light in chicks. Exp. Eye Res. 79:719–728.

Liu, W., Z. Wang, and Y. Chen. 2010. Effects of monochromatic light on developmental changes in satellite cell population of pectoral muscle in broilers during early posthatch period. Anat. Rec. 293:1315–1324.

Liu, K., H. Xin, and L. Chai. 2017. Choice Between Fluorescent and Poultry-Specific LED Lights by Pullets and Laying Hens. Trans. ASABE 60:2185–2195.

Merriam-Webster. 2019. Vision | Definition of Vision by Merriam-Webster.

Moore, C. 1957. The Effect of Light on Growth of Broiler Chickens. Poult. Sci. 36:1142–1143.

NASA. 2019. Visible Light | Science Mission Directorate.

National Chicken Council. 2014. National Chicken Council animal welfare guidelines and audit checklist for broilers.

Noble, D. O., M. Picard, E. Dunington, G. Uzu, A. Larsen, and P. Siegel. 1993. Food intake adjustment of chickens: Short term reactions of genetic stocks to defiviencies in lysine, methionine, or tryptophan. Br. Poult. Sci. 34:725–735.

Ohtani, S., and S. Leeson. 2000. The Effect of Intermittent Lighting on Metabolizable Energy Intake and Heat Production of Male Broilers.Poult. Sci. 79:167-171.

Olanrewaju, H. A., W. W. Miller, W. R. Maslin, S. D. Collier, J. L. Purswell, and S. L. Branton. 2016. Effects of light sources and intensity on broilers grown to heavy weights. Part 1: Growth performance, carcass characteristics, and welfare indices 1. Poult. Sci. 95:727–735.

Olanrewaju, H. A., W. W. Miller, W. R. Maslin, S. D. Collier, J. L. Purswell, and S. L. Branton. 2018. Influence of light sources and photoperiod on growth performance, carcass characteristics, and health indices of broilers grown to heavy weights. Poult. Sci. 97:1109–1116.

Olanrewaju, H. A., J. L. Purswell, S. D. Collier, and S. L. Branton. 2014. Effects of genetic strain and light intensity on blood physiological variables of broilers grown to heavy weights. Poult. Sci. 93:970–978.

Olanrewaju, H. A., J. L. Purswell, S. D. Collier, and S. L. Branton. 2015a. Effects of color temperatures (Kelvin) of LED bulbs on blood physiological variables of broilers grown to heavy weights. Poult. Sci. 94:1721–1728

Olanrewaju, H. A., J. P. Thaxton, W. A. Dozier, J. Purswell, W. B. Roush, and S. L. Branton. 2006. A review of lighting programs for broiler production. Int. J. Poult. Sci. 5:301–308.

Oliveira, R. G. De, and L. J. camargos Lara. 2016. Lighting programmes and its implications for broiler chickens. Worlds. Poult. Sci. J. 72:735–742.

Pan, J., Y. Yang, B. Yang, W. Dai, and Y. Yu. 2015. Human-friendly light-emitting diode source stimulates broiler growth. PLoS One 10:1–13.

Paulino, L. 1949. Effects of varying lengths of Illumination on rate of growth and mortality of chicks. Philipp. Agric. 33:63–70.

Pettersson, I. C., C. A. Weeks, K. I. Norman, and C. J. Nicol. 2017. The ability of laying pullets to negotiate two ramp designs as measured by bird preference and behaviour. PeerJ 5:e4069

Prayitno, D. S., C. J. Phillips, and H. Omed. 1997. The effects of color of lighting on the behavior and production of meat chickens. Poult. Sci. 76:452–457.

Prescott, N. B., and C. M. Wathes. 1999. Spectral sensitivity of the domestic fowl (Gallus g. domesticus). Br. Poult. Sci. 40:332–339 Prescott, N. B., C. M. Wathes, and J. R. Jarvis. 2003. Light, Vision and the welfare of poultry. Anim. Welf.:269–298.

Raccoursier, M. F. 2016. Effect of Light Intensity on Production Parameters and Feeding Behavior of Broilers Masters Thesis.

Rault, J. L., K. Clark, P. J. Groves, and G. M. Cronin. 2017. Light intensity of 5 or 20 lux on broiler behavior, welfare and productivity. Poult. Sci. 96:779–787.

Renden, J. A., S. F. Bilgili, and S. A. Kincaid. 1993. Research Note: Comparison of Restricted and Increasing Light Programs for Male Broiler Performance and Carcass Yield. Poult. Sci. 72:378–382.

Renden, J. A., E. T. Moran, and S. A. Kincaidt. 1996. Lighting Programs for Broilers That Reduce Leg Problems Without Loss of Performance or Yield 12. Poult. Sci.:1345–1350

Riber, A. B. 2015. Effects of color of light on preferences, performance, and welfare in broilers. Poult. Sci. 94:1767–1775.

Robbins, K., A. Adekunmisi, and H. Shirley. 1984. The effect of light regime on growth and pattern of body far accretion of broiler chickens. Growth 48:269–277.

Robles, S. 2010. The Effect of Lighting Intensity on Activity and Tonic Immobility Response of Broiler Chickens (Gallus gallus domesticus).Masters Thesis.

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

Rozenboim, I., I. Biran, Z. Uni, B. Robinzon, and O. Halevy. 1999a. The Effect of Monochromatic Light on Broiler Growth and Development. Poult. Sci. 78:135–138.

Rozenboim, I., B. Robinzon, and A. Rosenstrauch. 1999b. Effect of light source and regimen on growing broilers. Br. Poult. Sci. 40:452–457.

Sales, G. T., A. R. Green, R. S. Gates, T. M. Brown-Brandl, and R. A. Eigenberg. 2015. Quantifying detection performance of a passive low-frequency RFID system in an environmental preference chamber for laying hens. Comput. Electron. Agric. 114:261–268.

Sanotra, G. S., J. D. Lund, and K. S. Vestergaard. 2002. Influence of light-dark schedules and stocking density on behaviour, risk of leg problems and occurrence of chronic fear in broilers. Br. Poult. Sci. 43:344–354.

Scanes, C. G., Y. Vizzier-Thaxton, and K. D. Christensen. 2018. Biology of Stress and in Livestock and Poultry.Pages 266–318 in Biology of Domestic Animals. Scanes, C.G., Hill, R.A., eds. Taylor & Francis Group.

Schwean-Lardner, K., H. Classen, and B. Fancher. 2007. Increasing lighting program effects on production charachteristics of mader broilers. Poult. Sci. 86:165.

Schwean-Lardner, K., B. I. Fancher, and H. L. Classen. 2012. Impact of daylength on behavioural output in commercial broilers. Appl. Anim. Behav. Sci. 137:43–52.

Shane, S. 2017. Chick-News.com - Poultry Industry Information by Simon M. Shane.

Simmons. 1982. Effect of lighting Regimes on Twisted Legs, Fedd Conversion and Growth of Broiler Chickens. Poult. Sci. 61:1546.

Skoglund, W., C. Wabeck, and D. Palmer. 1966. Length of Light Period for Maximum Broiler Weight. Poult. Sci. 45:1185–1189.

Stone, R. A., T. Lin, D. Desai, and C. Capehart. 1995. Photoperiod, early post-natal eye growth, and visual deprivation. Vision Res. 35:1195–1202.

Tähkämö, L., T. Partonen, and A.-K. Pesonen. 2018. Systematic review of light exposure impact on human circadian rhythm. Chronobiol. Int.:1–20.

Viets, K., K. C. Eldred, R. J. Johnston, and R. J. Johnston. 2016. Mechanisms of Photoreceptor Patterning in Vertebrates and Invertebrates. Trends Genet. 32:638-659

Weaver, W., and P. Siegel. 1968. Photoperiodism as a Factor in Feeding Rhythms of Broiler Chickens. Poult. Sci. 47:1148–1154.

Weeks, C. A., and C. J. Nicol. 2006. Behavioural needs, priorities and preferences of laying hens. Poult. Sci. J. 62:296-307.

Westland, S., Q. Pan, and S. Lee. 2017. A review of the effects of colour and light on non-image function in humans. Color. Technol. 133:349–361.

Wilson, J., W. Weaver, W. Beane, and J. Cherry. 1984. Effects of light and feeding space on leg abnormalities in broilers. Poult. Sci. 63:565–567.

Xie, D., Z. X. Wang, Y. L. Dong, J. Cao, J. F. Wang, J. L. Chen, and Y. X. Chen. 2008a. Effects of Monochromatic Light on Immune Response of Broilers. Poult. Sci. 87:1535–1539.

Xie, D., Z. X. Wang, Y. L. Dong, J. Cao, J. F. Wang, J. L. Chen, and Y. X. Chen. 2008b. Effects of Monochromatic Light on Immune Response of Broilers. Poult. Sci. 87:1535–1539.

Yang, Y. F., S. F. Jin, Z. T. Zhong, Y. H. Yu, B. Yang, H. B. Yuan, and J. M. Pan. 2015. Growth responses of broiler chickens to different periods of artificial light. J. Anim. Sci. 93:767–775.

Yang, Y., Y. Yu, J. Pan, Y. Ying, and H. Zhou. 2016. A new method to manipulate broiler chicken growth and metabolism: Response to mixed LED light system. Sci. Rep. 6.25972

Yokoyama, S., F. B. Radlwimmer, and N. S. Blow. 2000. Ultraviolet pigments in birds evolved from violet pigments by a single amino acid change. Proc. Natl. Acad. Sci. U. S. A. 97:7366–7371.

Zheng, L., Y. E. Ma, L. Y. Gu, D. Yuan, M. L. Shi, X. Y. Guo, and X. A. Zhan. 2013. Growth performance, antioxidant status, and nonspecific immunity in broilers under different lighting regimens. J. Appl. Poult. Res. 22:798–807.

Zubairy, M. S. 2016. A Very Brief History of Light.Pages 3–24 in Optics in Our Time. Springer International Publishing, Cham.

APPENDIX

UNIVERSITY OF ARKANSAS

Office of Research Compliance

To:	Michael Kidd
Fr:	Craig Coon
Date:	March 5th, 2018
Subject:	IACUC Approval
Expiration Date:	March 1st, 2021

The Institutional Animal Care and Use Committee (IACUC) has APPROVED your protocol # **18095:** *Applied broiler research growouts*.

In granting its approval, the IACUC has approved only the information provided. Should there be any further changes to the protocol during the research, please notify the IACUC in writing (via the Modification form) prior to initiating the changes. If the study period is expected to extend beyond March 1st, 2021 you must submit a newly drafted protocol prior to that date to avoid any interruption. By policy the IACUC cannot approve a study for more than 3 years at a time.

The following individuals are approved to work on this study: Michael Kidd, Douglas Aldridge, Chad Hayes, and Colin Scanes. Please submit personnel additions to this protocol via the modification form prior to their start of work.

The IACUC appreciates your cooperation in complying with University and Federal guidelines involving animal subjects.

CNC/tmp