doi:10.1017/S0043933918000934

The implication of lighting programmes in intensive broiler production system

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The intensive production system for broiler chicken is characterised by the provision of a suitable micro-climatic condition such as temperature, airflow, relative humidity and light for proper bird's management which always, together with appropriate feeding and nutrition, favours the full growth and production potentials of the birds. Lighting, amongst other factors, is a potent and critical micro-climatic component in broiler houses as it influences many behavioural, physiological and metabolic processes in birds. To optimise the intensive system for broiler production, various lighting programmes (regarding light duration and its distribution, light colour/wavelength and light intensity) have been explored. This review compares the effects of different elements of lighting regimen on the growth performance, health, and welfare and carcass characteristics of broilers. Considering this, various degrees of intermittent photo-period (*i.e.* mixing photo- and scoto- periods within 24 hours) rather than one continuous photoperiod have been proven to significantly improve broilers' weight gain by 3.4-5.8%, feed to gain ratio up to 7.3%, mobility up to 46.5%, decrease mortality rate ranging between 0.43% and 0.72%, and finally, increase carcass yield. Short wavelength lights and light intensity of ≥5 lux after the initial brooding period are said to stimulate birds' metabolism and growth thereby, enhancing the production system. In conclusion, the lighting programme, apart from improving broiler productivity, could reduce cost expended on energy in an intensive production system.

Keywords: broiler; lighting regimen; photoperiod; scotoperiod; production performance

Introduction

The lighting programme used in broiler production is one of the major aspects of management techniques that can impact the birds' welfare, performance and productivity amongst others (Yang *et al.*, 2015; El Sabry *et al.*, 2015; Bovera *et al.*, 2013; Schwean-Lardner and Classen, 2010; Deep *et al.*, 2010). According to Aviagen (2014), there are four important elements of lighting regimen; the length of photoperiod

© World's Poultry Science Association 2018

Received for publication June 29, 2018
Accepted for publication November 27, 2018

https://doi.org/10.1017/S0043933918000934 Published online by Cambridge University Press

and scoto-period (*i.e.*, the period of darkness) together with their distribution within 24 hours, the colour/wavelength of the light provided and lastly, light intensity. Light is inherent to the sight of birds and allows birds to simultaneously control many essential and various metabolic processes that facilitate feeding and digestion, body temperature and reproduction (Olanrewaju *et al.*, 2006). In many parts of the world, broilers under intensive care management are provided with continuous light or 23 hours light and 1-hour darkness to maximise access to feed, enhance intake, FCR and growth rate (Lien *et al.*, 2007; Buyse *et al.*, 1996). In contrast, there are conflicting observations stating that broiler performance is not optimised by providing continuous or near continuous light rather that it has negative effects on growth rate, body weight gain, feed intake, feed efficiency, health, mortality, broiler welfare and processing performance (Schwean-Lardner *et al.*, 2016; Škrbić *et al.*, 2015; Zheng *et al.*, 2013). Moreover, a continuous lighting programme has been characterised by high incidence of leg abnormalities, sudden death syndrome, sleep fragmentation and increasing ocular pathologies (Schwean-Lardner *et al.*, 2016; Olanrewaju *et al.*, 2006) leading to poor welfare of the birds. The intermittent photoperiod or split darkness has a great influence on the performance of broilers and again, is superior to when the period of darkness is provided once within 24 hours (Duve *et al.*, 2011; Yang *et al.*, 2015; El Sabry *et al.*, 2015). In the studies of Schwean-Lardner *et al.* (2016), Yang *et al.* (2015) and Aviagen (2014), improved body weight, feed conversion efficiency, melatonin production (which regulates the production of other hormones related to growth and immune functions), eviscerated carcass weight, serum total proteins, bone elastic modulus and leg health were observed in birds subjected to split darkness when compared to the continuous light group.

The wavelength/colour of light used during the photoperiod has shown to have an influence on the behaviour and growth of broilers (Yang *et al.*, 2016; Kristensen *et al.*, 2007). Birds sense light through their eyes (retinal photoreceptors) and *via* photosensitive cells in the brain (extra-retinal photoreceptors). The retinal photoreceptor possesses five cones of different types comprising of four single cones that support the tetrachromatic colour vision and one double cone (Yang *et al.*, 2016). Kram *et al.* (2010) stated that these four single cones are maximally responsive to violet, blue, green and red light. On the other hand, the effects of the intensity of these lights are reported to be insignificant on the growth performance of broilers, but a carcass, thigh, and drum yield as a percentage of live weight are influenced positively (Olanrewaju *et al.*, 2011; Deep *et al.*, 2010).

Impact of photo-period and its distribution

GROWTH PERFORMANCE

The assumption and practice of subjecting broiler chickens to continuous or nearly continuous light regimen to maximise their growth performance through free and long-hour access to feed and water have been proven not only to be false, but can also reduce the bird's ability to grow to their full potential within a stipulated period. Schwean-Lardner and Classen (2010) reported that birds given 20 hours light (20L) had a higher live-weight gain when compared to those on constant light for 23 hours (1.74 kg *vs*. 1.70 kg) at 31-32 days of age, with feed intakes of 2.68 kg/bird and 2.61 kg/bird in 20L and 23L groups respectively. The same trend was observed at 38-39 days of age (live-weight 2.34 kg *vs*. 2.29 kg and feed consumption of 3.87 and 3.78 kg/bird) and 48-49 days old (live-weight of 3.27 kg *vs*. 3.16 kg and feed consumption of 6.15 and 5.89 kg/bird). This shows that provision of near continuous light for long time access to feed by the birds

https://doi.org/10.1017/S0043933918000934 Published online by Cambridge University Press

will not necessarily result in increased feed intake, but can adversely affect the growth performance. Fidan *et al.* (2017b) observed improvements in weight gain in a group of broilers subjected to increasing duration of photoperiod at 42 d compared to the birds on 23L: 1D treatment (2947.36 g *vs*. 2916.72 g) even though there was no significant difference in the feed consumed by the two groups. Subsequently, the distribution of photoperiod (light hours) and scotoperiod (dark hours), which is one of the components of lighting programme for broilers, has been reported to influence growth performance. For example, Duve *et al.* (2011) conducted an experiment to compare the effects of the split darkness of 8 h (4 h in the first half and 4h in the second half of the day) and continuous 8 h darkness. The authors reported significantly increased feed intake (3222 g/bird) and weight gain (2086 g/bird) in broilers subjected to split scoto-period compared to those on continuous 8 h darkness (feed intake, 3072 g/bird; weight gain, 2004 g/bird respectively) at 36 d of age. Also, El Sabry *et al.* (2015) reported improved feed intake and body weight gain in birds reared under the split darkness of 14L:4D : 2L:4D compared to constant photo and scoto-period of 16L:8D though, with the interaction of chicks' parent stock age. As a result, the authors suggested that split darkness programme could be used to improve the live weight of broiler chicks from young breeders. In addition, Yang *et al.* (2015) investigated the effects of intermittent lighting (*i.e.* intermittent 2L:2D or 4L:4D) and continuous lighting (CL) on Ross 308 broiler strain and discovered that birds on treatment 4L:4D at 42 d had the highest bodyweight gain (2531 g) with the least average daily feed consumption (149.4 g) compared to 2L:2D (BW 2466 g and ADFI of 150.2 g) and CL (BW 2496 g and ADFI of 156.8 g) respectively. Improved body weight observed in 4L:4D regime could be as a result of energy conserved by the birds during the longer period of rest (low activity in dark hours). In addition, better FCR was observed in birds on 2L:2D (2.30) compared to CL, which had almost all-day access to feed and water. This supported the observation of Rutz and Bermudez (2004) which stated that intermittent lighting synchronised better feed intake with feed passage through the digestive tract of broilers. The scoto-period, which is characterised by reduced activity, corresponded with the non-feeding period, whereby the passage rate of feed digesta was reduced and there were delays in emptying the digestive tract of birds (Ramão *et al.*, 2011; Summers and Leeson, 1979; Duke *et al.*, 1969). This will allow optimum digestion, nutrient availability and utilisation, contrary to what has been seen when the feed passage rate is fast due to continuous feed intake, as observed during continuous photoperiods (Unpublished report). This report is consistent with the findings of Abbas *et al.* (2008), who reported significantly improved bodyweight gain by 10% with lower feed consumption and, hence, better FCR, in birds exposed to intermittent light of 2L:2D when compared to the near continuous light group. Conversely, Parvu *et al.* (2014) showed that when birds were given intermittent lighting of 16 h light (2L:1D) and combined programme of 16 h light (6L and six period 2L:1D) from one-day-old had respectively 10.5% and 8.5% decreased bodyweight compared to the group subjected to 23L:1D at 21 days. The same trend was observed for feed intake. However, this could be as a result of differences in the start-up lighting programme adopted by the researchers.

Providing continuous lighting for broilers may be advantageous in their early life (1 d - 7 d) to allow free access to feed and improve feed intake, which is essential for the early intestinal growth and development. It has been reported that the intestinal microbial community is established in chicks shortly after initial feeding (Naqui *et al.*, 1970) which aids early intestinal development. Deep *et al.* (2013) reported high mortality rate and low weight gain in chicks subjected to extremely low light intensity (0.1-0.5 lux) within first seven days post-hatch as a result of the inability of the chicks to feed. Poor feeding activities and intakes, and poor intestinal and immune system development

https://doi.org/10.1017/S0043933918000934 Published online by Cambridge University Press

at an early stage may have negative effects on final productivity of broilers reared intensively.

HEALTH, WELFARE AND MORTALITY

Lighting programmes have been reported to have major implications for the welfare of broiler chickens (Schwean-Lardner *et al.*, 2016). For example, many species, including poultry, possess a circadian rhythm which is a biological process that displays an endogenous oscillation of about 24 hours. In simple terms, it is a 24-hour internal clock of living organism and cycles between sleepiness and alertness at regular intervals. The circadian rhythm, which is controlled by the hypothalamus in the brain, is influenced by external cues called Zeitgebers which include light, temperature and redox cycles (Kristensen *et al.*, 2006; Rattenborg *et al.*, 2005; Middleton *et al.*, 1996). However, during the scotoperiod, the eyes send a signal to the hypothalamus which, in turn, alerts the pineal gland to secrete melatonin (a neuro-hormone that makes the body feel tired and initiates sleep). Melatonin regulates the production of other hormones (including those related to growth and immune function), stimulates lymphocyte proliferation (Zheng *et al.*, 2013; Pang *et al.*, 1996; Phillips and Berger, 1992) and assists in scavenging oxidising free radicals (Reiter *et al.*, 2014; Tomás-Zapico and Coto-Montes, 2005) in tissues. During the cellular metabolic process, the reactive oxygen species (ROS) are produced which react and destroy important lipid and protein molecules within the cell hence, posing a health challenge to the birds. Based on this, near continuous lighting for broilers suppresses melatonin production which can negatively affect the health and welfare of the birds as a result of stress induction, alteration of brain function, reduction of immune function, increased pathological diseases and reduction of alertness, all of which could arise from sleep deprivation or fragmentation (Everson *et al.*, 2008; Boerema *et al.*, 2003). Birds' instincts show that some dark periods are required for their proper wellbeing. This is supported by the findings of Coban *et al.* (2014), whereby birds progressively subjected themselves to some hours of darkness in a self-photoperiod treatment with no significant effect on live weight gain when compared to birds on continuous lighting treatment.

Schwean-Lardner *et al.* (2016; 2013) measured the health of a flock of broilers by the mortality and culling rate and observed that photoperiod augmented with dark periods significantly reduced both metabolic and skeletal disorders in broilers which in turn, lowered the mortality and morbidity rate. Moreover, the dark period addition can be beneficial to bird's health by delaying early high weight gain to a later period, because fast growth condition of commercial broilers negatively impacts broiler's health and is associated with leg problems, sudden death syndrome and ascites (Zheng *et al.*, 2013; Schwean-Lardner *et al.*, 2016). As reported in the study of Schwean-Lardner *et al.* (2013) in which groups of birds were subjected to light treatments of 14L, 17L, 20L and 23L between 7 d and 32 d, the rate of mortality caused by metabolic and skeletal disorders decreased with increasing level of augmented darkness (i.e. metabolic- 1.23 1.20 1.82 and 1.73%; skeletal- 0.38 0.25 0.50 and 0.71% for 10 h, 7 h, 4 h and 1 h dark periods in the treatments, respectively). This is consistent with the observations of Mlaba *et al.* (2015). Furthermore, Zheng *et al.* (2013) observed the influence and implication of light treatment on serum melatonin concentration, lipid peroxidation in serum and liver and antioxidant status of broilers. They reported significant increases in serum melatonin in groups of broilers under intermittent light (INL) of 18L and 6D compared to a CL group at 21 d (INL I 16L:2D: 1L:2D: 1L:2D 3.8 pg/ml; INL II 17L:3D: 1L:3D 3.85 pg/ml vs. CL 24L 3.7 pg/ml). Besides, the researchers observed that INL significantly improved the total antioxidant capacity at 21 d in the liver, in relative units (INL II 0.69, INL I 0.68) and serum (INL II 5.01, INL I 4.71) compared to the CL (liver: 0.53, serum: 4.56). This

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may have arisen as a result of the important role of melatonin in antioxidant status of broilers by directly eliminating free radicals and the stimulation of some enzymes that metabolise free radicals and their breakdown products from the system (Tomás-Zapico and Coto-Montes, 2005). Melatonin, which is secreted during the scoto-period in broilers to initiate sleep, is a non-enzymatic antioxidant because of its tendency to eliminate potential ROS from cells (Tomás-Zapico and Coto-Montes, 2005).

Another important indicator of broiler's welfare status is the extent of mobility, because inability or difficulty in walking due to severe pain or paralysis affects access to feed and water (Škrbić *et al.*, 2012), and, hence, performance. This, at most times, is determined by gait scoring. Schwean-Lardner *et al.* (2016; 2013) used a technique described by Garner *et al.* (2002) to assess mobility and footpad dermatitis subjectively. This method consists of gait scores ranging from 0 depicting perfect mobility and 5 depicting the total loss of mobility, but the range of 0 to 2 was used for footpad assessment. However, results of their assessment showed that birds subjected to longest hours of darkness had the least mean values of gait score at 28 d and these values increased with decreasing hours of dark periods (10D: 0.62, 7D:0.81, 4D:0.93, 1D:1.16). The same trend was also experienced at 35 and 45 d of age.

Škrbić *et al.* (2015) and Fidan *et al.* (2017a) evaluated the incidence of footpad dermatitis and hock burns using different photo-period duration. Their observations were consistent with the findings of Schwean-Lardner *et al.* (2013; 2016) whereby increasing photoperiod instead of CL reduced the frequency of leg health associated problems thus, improved broiler welfare. Furthermore, Schwean-Lardner *et al.* (2013) concluded that lack of darkness itself in broiler production system negatively affects skeletal health, especially in the legs, rather than the fast growth rate associated with a long light period, as it is commonly believed.

CARCASS CHARACTERISTICS

The practical assessment of various characteristics of an animal's carcass part and organs (in poultry this includes head/eyes, neck, breast, back, wing, thigh, drumstick, kidney, gizzard, liver, etc.) is one of the major ways to study the effects of management regimes. The carcass characteristics of broilers concerning their performance are influenced by the length of photo-period and its distribution adopted during the rearing phase. However, the effects are not consistent among different studies. For example, Sun *et al.* (2017), observed a significant increase in the breast muscle yield from chickens subjected to intermittent lighting of 16L:2D: 2L:4D compared to those on constant 16L:8D regimen, but similar when compared with CL treatment. Conversely, intermittent lighting treatment effects reported by Das and Lacin (2014) caused lower breast yield in broilers when compared to CL (42.62% *vs*. 44.76%). It is noteworthy to state that the intermittent lighting regimen defined in these two studies were different. In addition, differences in the strains of male broilers used could be a factor in the conflicting results. Nevertheless, different photoperiod duration (CPL- 23L:1D for 42 d; IPL- 23L:1D from 1 to 8 d, 14L:10D from 9 to 15 d, 16L:8D from 16 to 22 d, 18L:6D from 23 to 29 d, 20L:4D from 30 to 36 d, followed by 23L:1D from 37 to 42 d) and light intensity (bright intensity BLI or dim intensity DLI) (BLI: 20 lux for 42 d; DLI: 5 lux from 1 d to 8 d, 2.5 lux from 9 d to 15 d and 1.25 lux from 16 d to 42 d) interactions were seen to have effects on whole leg yield as a percentage of live-weight, with CPLxDLI interaction having the highest value (38.44%) which was significantly different from CPLxBLI (36.61%), IPLxBLI (37.87%) and IPLxDLI (37.73%) values respectively (Fidan *et al.*, 2017a), despite no effect for photoperiod length alone on carcass characteristics. This result was consistent with the findings of Downs *et al.* (2006), who reported no significant effect in the cold carcass yield of birds exposed

https://doi.org/10.1017/S0043933918000934 Published online by Cambridge University Press

to different lighting programme, but did see an increase in leg yield percentage with increased photoperiod length. Coban *et al.* (2014), reported no significant effect on carcass percentages when birds were exposed to 24 hours of CL, CL of 16l:8D and self-photoperiod. However, Schwean-Lardner and Classen (2010) reported increased carcass yield with increasing length of photoperiod, although this effect is age-dependent (i.e., no significant effect of light on carcass yield at age 31-32 d but significant increase in carcass yield was recorded at 38-39 d and 48-49 d). At 48-49 d, carcass yield, as a percentage of the live-weight, in broilers exposed to 20L was significantly higher (72.5%) followed by the group exposed to 23L (71.5%) then, 17L (71.0%) and 14L (70.5%) being the lowest. Furthermore, these researchers observed an increase in breast meat yield and decreased whole leg percentage (especially, the left drum meat yield) with increasing photoperiod length, in parallel to what was obtained from the studies of Downs *et al.* (2006) and Fidan *et al.* (2017b). In addition, photoperiod duration was observed to have a significant effect on the percentage weights of blood, feather, and gizzard relative to the BW of broiler (Coban *et al.*, 2014; Das and Lacin, 2014).

Impact of light wavelength or colour

GROWTH PERFORMANCE

The highly specialised visual system of poultry has been proven to be essential for increased productivity of broiler chickens (Mendes *et al.*, 2013). Light is a potent and critical climatic component of broiler housing facility, as it influences many behavioural, physiological and metabolic processes in birds. Different wavelength outputs from light in the visible spectrum determine its colour (Riber, 2015). Senaratna *et al.* (2008), stated that the colour of light is one of the important features of light in the broiler's environment. Yang *et al.* (2016) and Rozenboim *et al.* (2004) suggested that short wavelength monochromatic light colours, light colour switching, and mixture systems can be used to manipulate and stimulate broiler growth and metabolism. Nonetheless, the short wavelength lights (green and blue) are said to make chickens calmer and reduce their level of activities (Prayitno *et al.*, 1997; Rodenboog *et al.*, 2001) which could explain improved growth performance reported by researchers. For example, green and blue LED mixed light system was reported to have a significant improvement on broiler body weight, FCR, circulating glucose levels and carcass yield when compared to normal white light (Yang *et al.*, 2016). This improvement could be explained by the important role of insulin-like growth factor-I (IGF-I) in promoting broiler satellite cell myogenic processes, as its circulation levels are enhanced by green and blue, compared to white and red light (Liu *et al.*, 2010). Despite several reports of significant improvements in performance of broilers raised under green and blue lights, Senaratna *et al.* (2012), concluded that broiler chicken preferred red and white light colours to blue and green after their sensitivity to light colours was observed after 21 days of age. In contrast, Prayitno *et al.* (1997) reported that birds preferred blue light over other colours, after been raised under blue, green, red and white light colours for five weeks, except those initially raised under blue light. Furthermore, Rozenboim *et al.* (2004) observed significant increases in bird growth rates when colour was changed from green to blue at 10 d of age and from blue light to green light at 20 d when compared with white light, suggesting that green light stimulated growth of birds at an early age, and shifting birds to a different light environment at 10 or 20 d of age might further stimulate their growth. At the same time, Mendes *et al.* (2013), reported a significant increase in feed intake in birds reared under white LED light (500 nm) compared to the yellow LED

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light (635 nm) between 21 to 35 days of age. The authors suggested that this could be as a result of the birds' special spectral sensitivity which could have made them perceive more brightness from the white LED bulbs. However, Pan *et al.* (2015) conducted further research on more human-friendly light colours on broiler's performance as short wavelength lights (*i.e.*, green light with 514 nm and blue light, 455 nm) that have been observed to stimulate bird's growth and reported that this treatment could have negative effects on broiler house workers. The researchers discovered that broilers reared under yellow light (580 nm; which is more human-friendly) had similar growth parameters with those on green and blue lights treatments. This is consistent with the findings of Sultana *et al.* (2013), who reported increased feeding behaviour in broilers reared under yellow-red coloured light, which was similar to results from green light, but more than that observed under blue light. However, more studies are needed to ascertain these claims.

HEALTH AND WELFARE

Aside from the effects of light wavelength on growth performance of broilers, various studies have shown that light colour could influence immune and stress responses which in turn, affect the health and welfare of broiler chickens. Xie *et al.* (2008), observed an increased proliferation of blood T lymphocytes and elevated level of immune responses to Newcastle disease virus in the serum of birds reared under green light compared to blue and red light treatments at 21 and 28 d of age. However, at 49 d, these parameters were higher in the blue light group, with significantly decreased level of serum interleukin-β when compared to green and red light treatments. The age-related influence of the blue light on the improved immune and reduced stress responses of the birds could be explained by calmer behaviour under blue light in mature broilers (Hesham *et al.*, 2018; Rozenboim *et al.*, 2004). Sultana *et al.* (2013) stated that long wavelength light (*i.e.*, red and red-yellow mixed lights), when compared to the short wavelength lights (blue and green), induced fear responses in broiler. This might pose a negative impact on the birds' welfare as a result of stress. Contrarily, from another perspective, Senaratna *et al.* (2016) opined that increased activity, such as intense movement which is facilitated by the red light treatment, could improve welfare through the decreased incidence of leg disorders, instead of the lengthened sitting behaviour observed in blue light treated birds. Reiter and Bessei (1998) stated that increased birds' locomotion could stimulate bone development. In addition, Sørensen *et al.* (2000) mentioned that restricted activity may lead to increased incidence of leg problems in broilers. Moreover, prolonged sitting may result in lesions on the skin, hocks, feet, breast, lameness and sometimes, paralysis especially if on poor quality litter.

CARCASS CHARACTERISTICS

To the authors' knowledge, few works have been conducted to show the influence of light wavelength/ light colour on broiler carcass characteristics. However, the studies available reported significant effects that were, in most cases, as a result of increased body weight gain of the birds under certain light wavelength conditions, which is indirectly related to carcass quality or weight. For example, Liu *et al.* (2008), reported increased breast and thigh muscle weight in the range of 16-25% in birds exposed to blue and green light when compared to other light colours (red and white) at 49 d of age. This is similar to what was seen by Li *et al.* (2015), where breast muscle weight was higher in birds reared under green light when compared to those raised under red light. Previous studies have shown positive effects of blue and green lights on broilers regarding final body weight as a result of stimulation of myofiber growth compared to other light colour treatments (Velo and Ceular, 2016). Narinc *et al.* (2015) stated that, as

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broiler chicken have been selected for fast growth which yields more breast muscle, therefore, carcass parts weight, such as breast and thigh muscles and fat content might be influenced by factors that promote increased final body weight gain in broilers (Aksoy *et al.*, 2010; Grashorn, 2006).

Impacts of light intensity

GROWTH PERFORMANCE

Light intensity, as stated by Olanrewaju *et al.* (2016) aids steady physiological growth and developments in broilers before accruing maximum muscle mass. Likewise, Prescott *et al.* (2004) indicated that intensity of light could affect broiler performance. However, in literature, on average, no substantial effect of variation of light intensity on broiler growth performance has been reported, except in extremely low light intensity situations (*e.g.* below 1 lux) which caused ill effects on the birds (Olanrewaju *et al.*, 2011; Deep *et al.*, 2010; 2013). However, Deep *et al.* (2013), conducted a study to set a minimum standard of light intensity for the optimum performance of birds reared intensively. The authors used a range of light intensity level from 0.1, 1, 5 and 10 lux, and discovered that birds with 0.1 lux intensity had poor growth rate (77 g against 267 g, 268 g, and 263 g for 1, 5, 10 lux treatments respectively) and higher mortality (3.32%) between 7 d and 14 d of age. In another experiment by the same authors, feed intake (FI; 3.468, 3.489 or 3.477 kg), body weight gain (BW: 2.214, 2.237 or 2.202 kg) and FCR of broilers were slightly different when subjected to light intensities of 1, 5 or 10 lux, which were significantly higher compared to results obtained in the group under 0.5 lux (FI 3.38 kg; BW 2.153 kg). Based on these results, the researchers recommended at least 5 lux light intensity should be maintained after the initial brooding period. In addition, a study conducted and reported by Blatchford *et al.* (2009), showed that high light intensity treatments such as 50 lux and 200 lux had no significant effect on broiler body weight gain when compared to 5 lux intensity. Further, these authors indicated increased activities of birds reared under high light intensities. However, FI and FCR were not shown in the report, but it was likely that the birds reared under high light intensity (50 and 200 lux) would have higher feed intake in order to compensate for their increased activities in order to achieve the same weight gain as those under low light intensity (5 lux). Kristensen *et al.* (2006), opined that varying intensity of light between 5 lux and 100 lux might have no or little effect on broiler growth. Although, the authors pointed out certain factors that could be responsible for their observations, one of which was low replications.

HEALTH AND WELFARE

Eyes are one of the important organs of the body that are vulnerable to a certain number of external factors, one of which is light intensity. Extreme light intensities (too low or high) have been observed to cause poor eye health, negatively affecting the welfare of animals. However, in broiler chickens, little or no health effects of different artificial light intensities in a closed housing system have been reported (Olanrewaju *et al.*, 2007; Blatchford *et al.*, 2009). Although, a few reports have indicated that exposure to continuous high-intensity light in the early life of chicken may result into severe hyperopia, corneal flattening and avian glaucoma (Cohen *et al.*, 2008; Lauber and McGinnis, 1966). In addition, complete dark rearing may result in mild hyperopia and minor changes in corneal curvature (Cohen *et al.*, 2008). Increased light intensity (ranging from 100 lux $\leq$ 500 lux) has been shown to improve the activeness of broiler chickens, such as intense birds' movement, compared to low light intensity (5-6

https://doi.org/10.1017/S0043933918000934 Published online by Cambridge University Press

lux) (Newberry *et al.*, 1988; Blatchford *et al.*, 2009). This enhanced activity may improve broiler health and welfare through prevention or reduced incidence of paralysis, skin bruises or lesions and heart problems which would have occurred as a result of prolonged sitting and greater body mass accretion in a low light intensity environment, but consequently, increase the energy expended for additional activities instead for growth. Moreover, ensuring adequate and improved welfare in broilers may be at the expense of faster growth rate, which remains the focus for a poultry producer.

CARCASS CHARACTERISTICS

According to Fidan *et al.* (2017a), light intensity had significant influence on the yield of cold carcass (BLI 76.59% *vs*. DLI 75.97%), whole breast (BLI 31.96% *vs*. DLI 31.13%) and whole leg (BLI 37.24% *vs*. DLI 38.09%) after exposing the birds to either bright light, BLI (20 lux for 42 d) or dim light, DLI (5 lux from 1 d to 8 d, 2.5 lux from 9 d to 15 d and 1.25 lux from 16 d to 42 d). This report was in agreement with Deep *et al.* (2013) and Downs *et al.* (2006) that total carcass weight and breast meat yield increased in line with light intensity. However, the study of Fidan *et al.* (2017b), showed that thigh, drum, and whole leg weights were not influenced by light intensity, which contradicted what was reported by Fidan *et al.* (2017a), where DLI significantly increased the proportion of the whole leg as a percentage of live-weight than BLI. This is in agreement with the fact that either individual or combination of genotype, gender, light intensity, photoperiod length, and other environmental factors could be responsible for the differences in the responses observed in carcass characteristics in many studies (Fidan *et al.*, 2017b).

Conclusions

Light management tools are an important aspect of commercial broiler production systems. However, it has been established that increasing photoperiod and/or intermittent lighting rather than constant or near continuous photoperiod has a significant effect in improving broiler performance, such as FI, BW and FCR. Roles of light intensity and colour/wavelength in enhancing production cannot be underestimated, as they stimulate growth and metabolism in broilers. Light intensity above 5 lux after the brooding stage are recommended to improve productivity and welfare. The manipulation of shortwave monochromatic lights at different growing stages has been proven to be effective in enhancing broiler production, although long wavelengths improve activity and bone development. Interestingly, lighting programme involving a reasonable scotoperiod have been shown to enhance welfare through the normal functioning of the biological process of circadian rhythms which, in turn, regulate the production of melatonin thereby improving the immune capability and total health of the birds. More importantly, light management could assist in reducing the cost of production, especially on the energy expended in commercial intensive broiler production system where electric power energy is sourced from the nation's power grid or alternatively, from generators.

References

ABBAS, A.O., ALM EI-DEIN, A.K., DESOKY, A.A. and GALAL, M.A.A. (2008) The effects of photoperiod programmes on broiler chicken performance and immune response. *International Journal of Poultry Science* **7**: 665-671.

https://doi.org/10.1017/S0043933918000934 Published online by Cambridge University Press

AVIAGEN (2014) Lighting for broiler, housing, and environment. *Arbor Acre broiler management: handbook,* No. 100**.**

BLATCHFORD, A., KLASING, K.C., SHIVAPRASAD, H.L., WAKENELL, P.S., ARCHERAND, G.S. and MENCH, J.A. (2009) The effect of light intensity on the behavior, eye and leg health, and immune function of broiler chickens. *Poultry Science* **88**: 20-28.

BOEREMA, A.S., RIEDSTRA, B. and STRIJKSTRA, A.M. (2003) Decrease in monocular sleep after sleep deprivation in the domestic chicken. *Behaviour* **140**: 1415-1420.

BOVERA, F., LESTINGI, A., PICCOLO, G., IANNACCONE, F., ATTIA, Y.A. and TATEO, A. (2013) Effect of water restriction on growth performance, feed nutrient digestibility, carcass and meat traits of rabbits. *Animal* **7**: 1600-1606.

BUYSE, J., KÜHN, E.R. and DECUYPERE, E. (1996) The use of intermittent lighting in broiler raising. 1. Effect on broiler performance and efficiency of nitrogen retention. *Poultry Science* **75**: 589-594.

COBAN, O., LACIN, E. and GENC, M. (2014) The Effect of Photoperiod Length on Performance Parameters, Carcass Characteristics and Heterophil/Lymphocyte-Ratio in Broilers. *KafKas Universitesi Veteriner Fakultesi Dergisi* **20**: 863-870.

COHEN, Y., BELKIN, M., YEHEZKEL, O., AVNI, I. and POLAT, U. (2008) Light intensity modulates corneal power and refraction in the chick eye exposed to continuous light. *Vision Research* **48**: 2329-2335.

DAS, H. and LACIN, E. (2014) The effect of different photoperiods and stocking densities on fattening performance, carcass and some stress parameters in broilers. *Israel Journal of Veterinary Medicine* **69**: 211-220.

DEEP, A., RAGINSKI, C., SCHWEAN-LARDNER, K., FANCHER, B.I. and CLASSEN, H.L. (2013) Minimum light intensity threshold to prevent negative effects on broiler production and welfare. *British Poultry Science* **54**: 6686-6694.

DEEP, A., SCHWEAN-LARDNER, K., CROWE, T.G., FANCHER, B.I. and CLASSEN, H.L. (2010) Effect of light intensity on broiler production, processing characteristics and welfare. *Poultry Science* **89**: 2326-2333.

DOWNS, K.M., LIEN, R.J., HESS, J.B., BILGILI, S.F. and DOZIER, W.A. (2006) The effects of photoperiod length, light intensity, and feed energy on growth responses and meat yield of broilers. *Journal Applied Poultry Research* **15**: 406-416.

DUKE, G.E., DZIUK, H.E. and HAWKINS, L. (1969) Gastro-intestinal transit-times in normal and blue-comb diseases turkeys. *Poultry Science* **49**: 835-842.

DUVE, L.R., STEENFELDT, S., THODBERG, K. and NIELSEN, B.L. (2011) Splitting the scotoperiod: effects on feeding behaviour, intestinal fill and digestive transit time in broiler chickens. *British Poultry Science* **52**: 1-10.

EL SABRY, M.I., YALÇIN, S. and TURGAY-İZZETOĞLU, G. (2015) E□ect of breeder age and lighting regimen on growth performance, organ weights, villus development, and bursa of Fabricius histological structure in broiler chickens. *Czech Journal of Animal Science* **60 (3)**: 116-122.

EVERSON, C.A., THALACKER, C.D. and HOG, N. (2008) Phagocyte migration and cellular stress induced in liver, lung, and intestine during sleep loss and sleep recovery. *America Journal of Physiology- Regulatory, Integrative and Comparative Physiology* **295**: R2067-R2074.

FIDAN, D.E., NAZLIGÜ, A., TÜRKYILMAZ, M.K., AYPAK, S.U., KILIMCI, F.S., KARAARSLAN, S. and KAYA, M. (2017a) Effect of photoperiod length and light intensity on some welfare criteria, carcass, and meat quality characteristics in broilers. *Revista Brasileira de Zootecnia* **46**: 202-210.

FIDAN, D.E., NAZLIGÜL, A., TÜRKYILMAZ, M.K., KARAARSLAN, S. and KAYA, M. (2017b) E□ects of photoperiod length and light intensity on performance, carcass characteristics and heterophil to lymphocyte ratio in broilers. *Kafkas Universitesi Veteriner Fakultesi Dergisi* **23**: 39-45.

GARNER, J.P., FALCONE, C., WAKENELL, P., MARTIN, M. and MENCH, J.A. (2002) Reliability and validity of a modified gait scoring system and its use in assessing tibial dyschondroplasia in broilers. *British Poultry of Science* **43**: 355-363.

GRASHORN, M.A. (2006) Fattening performance, carcass and meat quality of slow and fast growing broiler strains under intensive and extensive feeding conditions. *Proceedings 12nd European Poultry Conference,* September 10-14, Verona, Italy.

HESHAM, M.H., EL SHEREEN, A.H. and ENAS, S.N. (2018) Impact of different light colors in behavior, welfare parameters and growth performance of Fayoumi broiler chickens strain. *Journal of The Hellenic Veterinary Medical Society* **69**: 951-958.

KRAM, Y.A., MANTEY, S. and CORBO, J.C. (2010) Avian cone photoreceptors tile the retina as five independent, self-organizing mosaics. *PLoS One* **5**: e8992.

KRISTENSEN, H.H., PRESCOTT, N.B., PERRY, G.C., LADEWIG, J., ERSBOLL, A.K., OVERAD, K. C. and WATHES, C.M. (2007) The behaviour of broiler chickens in different light sources and illuminances. *Applied Animal Behavior Science* **103**: 75-89.

https://doi.org/10.1017/S0043933918000934 Published online by Cambridge University Press

KRISTENSEN, H.H., AERTS, J.M., LEROY, T., WATHES, C.M. and BERCKMANS, D. (2006) Modelling the dynamic activity of broiler chickens in response to step-wise changes in light intensity. *Applied Animal Behavior Science* **10**: 125-143.

LAUBER, J.K. and MCGINNIS, J. (1966) Eye Lesions In Domestic Fowl Reared Under Continuous Light. *Vision Research* **6**: 619-624.

LI, Y., SUN, Y., HUA, D., WANG, Q., WANG, C., BAI, H., LIU, N., LI, D., LUO, Q., CHEN, C. and CHEN, J. (2015) Effects of Light Color on Production and Carcass Performance and Sexual Characteristics in Yellow-feathered Broilers. *Acta Veterinaria et Zootechnica Sinica* **46**: 1169-1175.

LIEN, R.J., HESS, J.B., MCKEE, S.R., BILGILI, S.F. and TOWNSEND, J.C. (2007) Effect of light intensity and photoperiod on live performance, heterophil-to-lymphocyte ratio, and processing yields of broilers. *Poultry Science* **86**: 1287-1293.

LIU, W., WANG, Z. and CHEN, Y. (2010) Effects of monochromatic light on developmental changes in satellite population of pectoral muscle in broilers during early posthatch. *Anatomical Record (Hoboken)* **293**: 1315-1324

LIU, W., CHEN, Y., WANG, Z., DONG, Y., CAO, J., XIE, D. and JIA, L. (2008) Effect of Monochromatic Light on the Muscle Growth and Muscle Fiber Development and Testosterone Secretion in Broilers. *Acta Veterinaria et Zootechnica Sinica* **39**: 1759-1764.

MENDES, A.S., PAIXÃO, S.J., RESTELATTO, R., MORELLO, G. M., DE MOURA, D.J. and POSSENTI, J.C. (2013) Performance and preference of broiler chickens exposed to different lighting sources. *Journal of Applied Poultry Research* **22**: 62-70.

MIDDLETON, B., ARENDT, J. and STONE, B.M. (1996) Human circadian rhythms in constant dim light (8 lux) with knowledge of clock time. *Journal of Sleep Research* **5**: 69-76.

MLABA, P.P., CIACCIARIELLO, M. and GOUS, R.M. (2015) The effect of dietary protein on breast meat yield of broilers reared on different day lengths. *South African Journal of Animal Science* **45**: 1.

NAQUI, S.A., LEWIS, D.H. and HALL, C.F. (1970) Intestinal microflora in turkeys. *Avian Diseases* **14**: 620-625.

NARİNÇ, D., AKSOY, T., ÖNENÇ, A. and İLASLAN ÇÜREK, D. (2015) The Influence of Body Weight on Carcass and Carcass Part Yields, and Some Meat Quality Traits in Fast- and Slow-Growing Broiler Chickens. *KafKas Universitesi Veteriner Fakultesi Dergisi* **12**: 527-534.

AKSOY, T., ÖNENÇ, A., NARINÇ, D., ÇÜREK, D.İ., YAPIC, N. and BAYLAN, D. (2010) Effect of Different Slaughter Weights, Genotype and Sex on Sensory Attributes of Chicken Breast Meat. *Journal of Agricultural Faculty of Uludag University* **24**: 103-113.

NEWBERRY, R.C., HUNT, J.R. and GARDINER, E.E. (1988) Influence of light intensity on behavior and performance on broiler chickens. *Poultry Science* **67**: 1020-1025.

OLANREWAJU, H.A., MILLER, W.W., MASLIN, W.R., THAXTON, J.P., DOZIER, W.A., PURSWELL, J. and BRANTON, S.L. (2007) Interactive Effects of Ammonia and Light Intensity on Ocular, Fear and Leg Health in Broiler Chickens. *International Journal of Poultry Science* **6**: 762-769.

OLANREWAJU, H.A., MILLER, W.W., MASLIN, W.R., COLLIER, S., PURSWELL, J.L. and BRANTON, S.L. (2016) Effects of light sources and intensity on broilers grown to heavy weights. Part 1: Growth performance, carcass characteristics, and welfare indices. *Poultry Science* **95**: 727-735.

OLANREWAJU, H.A., PURSWELL, J.L., COLLIER, S.D. and BRANTON, S.L. (2011) Effect of varying light intensity on growth performance and carcass characteristics of broiler chickens grown to heavy weights. *International Journal of Poultry Science* **10**: 921-926.

OLANREWAJU, H.A., THAXTON, J.P., DOZIER, W.A., PURSWELL, J., ROUSH, W.B. and BRANTON, S.L. (2006) A review of lighting programmes for broiler production. *International Journal of Poultry Science* **5**: 301-308.

PAN, J., YANG, Y., YANG, B., DAI, W. and YU, Y. (2015) Human-friendly light-emitting diode source stimulates broiler growth. *PLoS One* **10**: e0135330.

PANG, S.F., PANG, C.S., POON, A.M.S., WAN, Q., SONG, Y. and BROWN, G.M. (1996) An overview of melatonin and melatonin receptors in birds. *Poultry and Avian Biology Revolution* **7**: 217-228.

PARVU, M., ANDRONIE, L.C., SIMION, V.E. and AMFIM, A. (2014) The bio-productive effect of broiler lighting programme. *Animal Science and Biotechnologies* **47**: 286.

PHILLIPS, N.H. and BERGER, R.J. (1992) Melatonin infusions restore sleep suppressed by continuous bright light in pigeons. *Neuroscience Letters* **145**: 217-220.

PRAYITNO, D., PHILLIPS, C. and OMED, H. (1997) The effects of the colour of lighting on the behaviour and production of meat chickens. *Poultry Science* **76**: 452-457.

PRESCOTT, N.B., WATHES, C.M. and JARVIS, J.R. (2004) Light, vision and the welfare of poultry. *Animal Welfare* **12**: 269-288.

RAMÃO, I.B., NUNES, R.V., BRUNO, L.D.G., TSUTSUMI, C.Y., SILVA, W.T.M. and POZZA, M.S.S. (2011) Evaluation of different pre-slaughter light intensities and fasting duration in broilers. *Brazilian Journal of Animal Science* **13**: 4.

https://doi.org/10.1017/S0043933918000934 Published online by Cambridge University Press

RATTENBORG, N.C., OBERMEYER, W.H., VACHA, E. and BENCA, R.M. (2005) Acute effects of light and darkness on sleep in the pigeon. *Physiology Behaviour* **84**: 635-640.
REITER, K. and BESSEI, W. (1998) Effect of locomotor activity on bone development and leg disorders in broilers. *Archiv für Geflügelkunde* **62**: 247-253.
REITER, R.J., TAN, D.X. and GALANO, A. (2014) Melatonin: Exceeding expectations. *Physiology* **29**: 325-333.
RIBER, A.B. (2015) Effects of color of light on preferences, performance, and welfare in broilers. *Poultry Science* **94**: 1767-1775.
RODENBOOG, H., NOORD and OOST, P. (2001) Sodium, green, blue, cool or warm-white light. *World Poultry* **17**: 22-23.
ROZENBOIM, I., BIRAN, I., CHAISEHA, Y., YAHAV, S., ROSENSTRAUCH, A., SKLAN, D. and HALEVY, O. (2004) The effect of a green and blue monochromatic light combination on broiler growth and development. *Poultry Science* **83**: 842-845.
RUTZ, F. and BERMUDEZ, V.L. (2004) Fundamentos de um programmea de luz para frangos de corte, in: MENDES, A.A., NAAS, I.A. & MACARI, M. (Eds) *Produção de frangos de corte*, pp.157-168 (Campinas: facta).
SCHWEAN-LARDNER, K. and CLASSEN, H. (2010). Lighting for broilers. Aviagen *Arbor Acre broiler management: handbook,* No. 8.
SCHWEAN-LARDNER, K., FANCHER, B.I., GOMIS, S., VAN KESSEL, A. and CLASSEN, H.L. (2013) Effect of day length on the cause of mortality, leg health and ocular health in broilers. *Poultry Science* **92**: 1-11.
SCHWEAN-LARDNER, K., VERMETTE, C., LEIS, M. and CLASSEN, H.L. (2016) Basing Turkey Lighting Programmes on Broiler Research: A Good Idea? A Comparison of 18 Day-length effects on broiler and turkey welfare. *Animals (Basel)* 6: 27.
SENARATNA, D., SAMARAKONE, T., ATAPATTU, N.S.B.M. and NAYANARASI, H.A.D. (2008) Effect of the colour of light on growth performance, behaviour and bone parameters of broiler chicken. *Tropical Agricultural Research* **20**: 185-192.
SENARATNA, D., SAMARAKONE, T., MADUSANKA, A.A.P. and GUNAWARDANE, W.W.D.A. (2012) Preference of broiler chicken for different light colours in relation to age, session of the day and behaviour. *Journal of Tropical Agriculture Research* **23**: 193-203.
SENARATNA, D., SAMARAKONE, T.S. and GUNAWARDENA, W.W.D.A. (2016) Red Color Light at Different Intensities Affects the Performance, Behavioral Activities and Welfare of Broilers. *Asian-Australasian Journal of Animal Sciences* **29**: 1052-1059.
ŠKRBIĆ, Z., PAVLOVSKI, Z., LUKIC, M. and PETRICEVIC, V. (2015) Incidence of footpad dermatitis and hock burns in broilers as affected by genotype, lighting programme and litter type. *Annals of Animal Science* **15**: 433-445.
ŠKRBIĆ, Z., PAVLOVSKI, Z., LUKIC, M., PETRICEVIC, V., MILJKOVIC, B. and MARINKOV, G. (2012) The effect of the diet on incidence of footpad lesions and productivity of broilers. *Biotechnology Animal Husbandry* **28**: 353-360.
SØRENSEN, P., SU, G. and KESTIN, S.C. (2000) Effects of age and stocking density on leg weakness in broiler chickens. *Poultry Science* **79**: 864-870.
SULTANA, S., HASSAN, M.R., CHOE, H.S. and RYU, K.S. (2013) The effect of monochromatic and mixed LED light colour on the behaviour and fear responses of broiler chicken. *Avian Biology Research* **6**: 207-214.
SUMMERS, J.P. and LEESON, S. (1979) Comparison of feed withdrawal time and passage of gut contents in broiler chickens held in crates or litter pens. *Canadian Journal of Animal Science* **59**: 63-66.
SUN, Y.Y., LI, Y.L., LI, D.L., CHEN, C., BAI, H., XUE, F.G. and CHEN, J.L. (2017) Responses of broilers to the near-continuous lighting, constant 16-h lighting, and constant 16-h lighting with a 2-h night interruption, *Livestock Science* **206**: 135-140.
TOMÁS-ZAPICO, C. and COTO-MONTES, A. (2005) A proposed mechanism to explain the stimulatory effect of melatonin on antioxidative enzymes. *Journal of Pineal Research* **39**: 99-104.
VELO, R. and CEULAR, A. (2016) Effects of stocking density, light and perches on broiler growth. *Animal Science Journal* **88**: 386-393.
XIE, D., WANG, Z.X., DONG, Y.L., CAO, J., WANG, J.F., CHEN, J.L. and CHEN, Y.X. (2008) Effects of monochromatic light on immune response of broilers. *Poultry Science* **87**: 1535-1539.
YANG, H., XING, H., WANG, Z., JINLONG, X., YAN, W., BANGHONG, H. and ZHANG, J. (2015) Effects of Intermittent Lighting on Broiler Growth Performance, Slaughter Performance, Serum Biochemical Parameters and Tibia Parameters. *Italian Journal of Animal Science* **14 (4)**: 4143.
YANG, Y., YU, Y., PAN, J., YING, Y. and ZHOU, H. (2016) A new method to manipulate broiler chicken growth and metabolism: Response to mixed LED light system. *Scientific Reports* **6**: 25972.
ZHENG, L., MA, Y.E., GU, L.Y., YUAN, D., SHI, M.L., GUO, X.Y. and ZHAN, X.A. (2013) Growth performance, antioxidant status, and nonspecific immunity in broilers under different lighting regimens. *Poultry Science* **22**: 798- 807.

https://doi.org/10.1017/S0043933918000934 Published online by Cambridge University Press