Light regimen on health and growth of broilers: an update review

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ABSTRACT The importance of lighting regimen is increasing with the industrialization of poultry production, as lighting has been intimately associated with not only the establishment of rhythm and synchronous physiology of broiler chickens, but also the secretion of hormones associated with broiler maturation and growth. In recent years, increasing attention has been paid to the effects of lighting management on growth performance, immune status, and welfare of broilers. An appropriate lighting regimen, including proper source of lighting, intensity, duration, and wavelength (color) of light, is crucial to improve the growth performance and welfare of broilers. In this review, we updated the impacts of different light regimens on health and growth performance of broilers.

Key words: light regimen, light source, light intensity, light duration, light color

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INTRODUCTION

Broiler industry is regarded as a crucial source of animal protein contributing to the rapidly growing world population. In recent decades, the farm environmental factors on broiler production efficiency are well emphasized due to their wide impacts on broiler feed conversion efficiency and growth performance. Apart from the applicable temperature, humidity, air velocity and radiation, reasonable light regimen serves as another indispensable environmental factor for broilers' growth in modern farms (Lewis, 2010).

As the useful and inexpensive tool, emerging studies have indicated that manipulation of appropriate light regimen for broilers can help to stimulate the feed intake (De Oliveira and Lara, 2016), modulate the systematic immune response (Hajrasouliha and Kaplan, 2012), and reduce the broilers' physiological aggressive behaviors (Parvin et al., 2014), consequently improving their health outcomes and welfare (Riber, 2015). Therefore, a rational light regimen appears to be indispensable to maximize the growth potential for broilers and the economic benefits.

The source, intensity, duration, uniformity, and color (wavelength) of light are considered as 5 basic aspects of light regimen (Çapar Akyüz and Onbaşilar, 2019). With the increasing concern of production efficiency and broiler welfare, emerging studies have explored the effects of different light characteristics on growth, immunity and behavior of broilers (Zheng et al., 2013; Yang et al., 2016b). Thus, an integral light regimen for broilers coordinating the light source, intensity, color and duration to achieve the best animal performance and welfare turns to be imperative.

Studies on the different light aspects for broilers seem to be consecutive and scattered in the past decades. In the present article, we reviewed the physiological characteristics of the vision system of broilers, updated the effects of light regimen on health outcomes and growth performance of broilers, including light sources, light intensity, light color and light duration.

PHYSIOLOGY OF VISION SYSTEM IN BROILERS

In chickens, light penetrates through not only the eyes, but also the pineal gland and pituitary gland next to the hypothalamus. These basic mediators can affect vision system of broilers, including the light detection and transduction (Dawson et al., 2001). Once detected, the light information can be converted into biological signals, affecting neuroendocrine system, especially the hypothalamic-pituitary-gonadal axis, which consequently exert on the circadian rhythms and other various physiological activities (Kuenzel et al., 2015).

Light can be perceived by 2 types of photoreceptors, rods and cones, in broiler retina (Wilson and Lindstrom, 2011). Cones can recognize different light rays (blue, green, red and ultraviolet) and brighter light, while rods are characterized to better perceive the

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objects in the dark, but fail to distinguish the colors of light (Kram et al., 2010). Taken together, broilers have a more sensitive vision system with better visual skills than humans, due to their larger color spectrum, wider visual field and higher vision sensitivity of harmony (Prescott et al., 2003). Specially, light can penetrate through the skull of broilers and be detected by extraretinal photoreceptors (Baxter et al., 2014).

The pineal gland, a photosensitive region between cerebral hemisphere and cerebellum, can receive light signals and have promotive effect on the secretion of serotonin and melatonin hormones, therefore, playing significant roles in circadian rhythm and various endocrinology functions (Csernus et al., 2007). The hypothalamus located in the pre-optic section of the forebrain can directly modulate the secretion of gonadotropin releasing hormone (**GnRH**), thereby regulating the pituitary and downstream gonad to secrete endocrine hormones and then participating in the circadian rhythms, physiological activities and growth performance of broilers (Baxter et al., 2014).

Table 1. Comparative analysis of advantage and limitations of different light sources in poultry farms*.

Light sources	Advantages	Limitations
Incandescent lamps (ICD)	Lowest initial price	Highest total cost
	Dimmable	Least efficient light source
	Basic lamp technology	High energy usage
	Visible colors	High heat load
	No mercury in product	Short life span (1,000 h)
Compact fluorescent lamps (CFL)	Longer life	Higher price
	More efficient	Contains mercury
	Less energy usage	Color rendering
	Uses same socket	Color temperature
	More colors	Dimmability
		Fragile
		Heat and vibration susceptible
Light emitting diodes (LED)	Lower initial cost	Higher initial cost
	No mercury	Low-end, low quality products
	Lowest total cost	
	Low energy usage	
	Smooth dimming to 1%	
	Longer life expectancy	
	Sturdy, no filament	
	Instant on and off	

*Cited from (Baxter et al., 2014).

EFFECTS OF LIGHT PARAMETERS ON HEALTH AND GROWTH OF BROILERS

Light Sources

In the past decades, incandescent (**ICD**) has been widely used as the standard light bulbs in poultry farms of many countries (Lewis and Morris, 1998). However, based on the Energy Independence and Security Act (2007), ICD light bulbs were phased out from the marketplace and poultry houses due to the high energy-consumption. In recent years, with the urgency of energy-saving strategies around the world, many new lighting technologies are emerging as potential alternatives for ICD light sources, such as cold cathode fluorescent lamps (**CCFL**), compact fluorescent lamps (**CFL**), light emitting diodes (**LED**) and others (Olanrewaju et al., 2018). The major benefits of these bulbs are high energy-efficiency, long operating life, moisture resistance and availability in differing peak wavelengths (Tracy and Mills, 2011; Chang and Lu, 2013). The detailed advantages and limitations of different light sources were listed in Table 1.

The effects of different light sources on poultry production have been evaluated multidimensionally in last decades. The CFL and LED light in poultry facilities were found to have better performances in saving energy utilization compared to the ICD light (Olanrewaju et al., 2018; Bennato et al., 2021). CCFL light is better than ICD light in terms of energy utilization efficiency and working life-span, but not as good as LED light (Alberts et al., 2010). Besides, the body weight, feed conversion and mortality rate of birds did not differ significantly when raised under either ICD or LED light (Olanrewaju et al., 2015; Olanrewaju et al., 2016), but broilers reared under CCFL light exhibited lower body weight and higher heterophil to lymphocyte (**H:L**) ratios, indicating the occurrence of chronic stress (Rogers et al., 2015a,b).

Recently, LED light has been regarded as a novel source of monochromatic lighting approach to improve the health outcomes and growth performance of broilers (Parvin et al., 2014). Providing LED light during incubation can improve hatchability and chick quality of broilers, thereby reducing the stress susceptibility of broilers post-hatch (Huth and Archer, 2015). Enhanced lymphocyte proliferation and macrophages activation indicated that LED light exposure improved the immune function of broilers (Hassan et al., 2016; Seo et al., 2016). Comparatively, yellow LED light, characterized as human-friendly light source, might be a good alternative to green LED light, blue LED light and ICD light applied to broiler production, because of the higher body weight gain of broilers and lower amount of manure (Yang et al., 2016a).

In summary, LED light may be the potential replacement to benefit better growth performance and yields of broilers over other conventional light sources in the broiler production, along with lower energy costs.

Light Intensity

In the United States, a typical broiler lighting regimen refers to the continuous 20 lx light intensity during the early post hatch period (1−7 d), and 3 to 5 lx for the remaining period (National Chicken Council, 2005). While in commercial broiler production of European countries, 20 lx is the minimum intensity before 7 d of age, and then gradually reduce to 10 lx between 7 and 21 d of age, and 10 lx thereafter. Alternatively, intensity can be kept at 15 to 20 lx throughout the growing period

(Commission, 2000). Exposure to continuous lighting at 20 lx during the early life stage ensure chicks to adapt to the environment, feed and water intakes properly, and implementing low intensity during remainder of grow-out period can restrict the agitation and movement of broilers, as a result, growing to be heavier (Olanrewaju et al., 2006).

A great deal of trials has been conducted to explore the effects of different light intensities on broiler growth, health, immunity and especially welfare. Regarding the minimum standard for production and welfare of intensively housed broilers, a consensus was reached that 5 lx of light intensity should be maintained as the minimum level to ensure the productivity and welfare of broiler chickens. Improved the performance, breast meat yield and welfare conditions of broilers were found with the increased light intensity (Deep et al., 2013; Yang et al., 2018). Compared to 5 lx, broilers reared under a light intensity of 20 lx were more active with slower growth and lighter eye weight, while the welfare parameters or leg health were not affected (Rault et al., 2016). Birds exposed to a lower light intensity threshold of 1 lx had more rest and less preen with increased ulcerative foot-pad lesions and eye size, which was associated with reduced welfare state (Deep et al., 2010; Deep et al., 2012). In addition, preference for different intensities varies with age advancement, temporal variation of the day and certain behaviors (mainly walking and lying) of broiler birds. Older birds were characterized as less active by more lying and sleeping behaviors under dim intensity (5 lx) (Senaratna et al., 2015).

Considering the growth performance and welfare, 5 lx is the minimum light intensity suggested for broiler production. Moreover, varieties of other factors, such as broiler breeds, stocking density and the chicken house types should also be taken into consideration to choose the optimal light intensity.

Light Color (Wavelength)

Light color is determined by light wavelength. The wavelength of visible light range from 380 nm to 740 nm, locating between shorter invisible ultraviolet rays (**UV**) and longer invisible infrared rays (**FIR**) (Parvin et al., 2014). With their specie-specific visual system, birds are able to receive the color of light in the range of 315 to 750 nm with the most sensitive wavelength of 562 nm (Lewis, 2006; Soliman and El-Sabrout, 2020). In addition, the spectral distribution and susceptibility to the color of light vary with broiler age. In the earlier stages of development, short wavelengths (blue, green) have a stimulating effect on rapid development. When approaching maturity, long wavelengths (orange, red) have an accelerating effect on development and sexual maturity (Çapar Akyüz and Onbaşilar, 2019). Furthermore, red and red-yellow lights increase mobility of chickens and fear responses, while blue and green-blue lights reduce activity of broilers (Sultana et al., 2013).

The effects of light color (wavelength) on broiler behavior, welfare, growth and performance were studied previously (Riber, 2015; Cao et al., 2017; Table 2). By giving monochromatic light, birds were found to prefer green and blue light during certain growth periods (Khosravinia, 2007; Cao et al., 2008). Stimulation with monochromatic green light increased somatotropic axis activity (Dishon et al., 2021a) and plasma prolactin levels during embryonic phase (Dishon et al., 2017), especially after 15 d of hatching (Dishon et al., 2018). Also, green light stimulation during embryogenesis improved the post-hatch body weight, breast muscle growth and feed conversion ratio of broilers (Zhang et al., 2012, 2016). Interestingly, broiler embryos exposed to green light from embryonic 18 d until hatching exhibited the same performance as obtained by photostimulation from 0 d of incubation (Dishon et al., 2021b). Red, white, and blue light stimulation during incubation may have potential impacts on immunity and energy metabolism in broiler embryos (Li et al., 2021). In addition, providing photoperiodic blue light during incubation improved the production parameters of broilers during the first week post-hatch (Li et al., 2021).

During the rearing period post-hatch, green light enhanced T lymphocytes proliferation and had promotive effects on immunity (Avesta et al., 2011).

Table 2. Different monochromic light colors (wavelength) on broiler performance and welfare.

Light color	Performance or welfare	References
Ultraviolet ray	Body weight ↑; Mortality ↓; Wing flapping ↓; Physical asymmetry ↓ Plasma corticosterone ↓; Heterophil: lymphocyte ratio ↓	(House et al., 2020; James et al., 2020)
Purple light	Body weight ↓; Meat quality ↓	(Yang et al., 2016a)
Blue light	Body weight gain ↑; Feed efficiency ↑; Hydrocarbons from litter ↓ Gizzard weight ↑; Breast muscle weight ↑; GIT weight ↑; Heat stress ↓ Melatonin ↑; Corticosterone ↓	(Abdo et al., 2017; Abdel-Azeem and Borham, 2018; Oke et al., 2021)
Green light	Body weight ↑; T lymphocytes proliferation ↑; Walking ability ↑ Adrenocorticotropic hormone ↓; Eating ↑; Drinking ↑; Walking ↑ Aggression ↓; Preening ↑; Body shaking ↑; Feather pecking ↓	(Avesta et al., 2011; Gharahveysi et al., 2019; Helva et al., 2019)
Yellow light	Meat quality ↑; Walking ↓; Eating ↓	(Kim et al., 2013; Hesham et al., 2018; Lim et al., 2019)
Orange light	Movement ↓; Droppings ↓	(Khosravinia, 2007)
Red light	Eating ↓; Drinking ↓; Flying ↓; Sitting ↓; Walking ↑; Head movement ↑ Wing flapping ↑; Melatonin ↓; IGF-1 ↓	(Sultana et al., 2013; Ning et al., 2019)
Far infrared ray	Body weight gain ↑; Feed efficiency ↑; Ammonia emission ↓ Hydrocarbons from litter ↓	(Son, 2015)

Interestingly, replacing white light with blue light have been reported to modify the activities of heat shock biomarkers, and confer higher resistance to heat stress on broilers (Abdo et al., 2017). These beneficial effects might be attributable to the enhanced expression of clock genes in the pineal gland and upregulation of melatonin synthesis induced by green or blue lighting, therefore contributing to improve antioxidant capacity and immune function of broilers (Ke et al., 2011; Li et al., 2014; Jiang et al., 2016).

Furthermore, emerging studies focused on synergetic effects of different combined monochromatic light. Providing the combination of white and red light during incubation is associated with increased hatchery efficiency, lower susceptibility to fear and stress during post-hatch period and better animal welfare (Archer et al., 2017). The combination of green and blue monochromatic light can effectively enhance lymphocytes proliferation, thereby alleviating the stress response and improving the immune function of broilers (Zhang et al., 2014). Besides, broilers reared under green and blue mix lighting had improved body weight and muscle growth, as well as meat quality (Karakaya et al., 2009). The optimal ratio of mixed green-blue light might produce the optimized production performance, whereas the optimal ratio of mixed green-yellow light may result in the optimized meat quality (Yang et al., 2018).

From the published studies, from embryonic phase to post-hatch period, the synergetic green and blue light might be the optimal light color for the broiler growth, immune function and animal welfare. What's more, exposure to FIR might improve protein metabolism and decrease the emission of ammonia of broilers, as a result, reducing the secretion of nitrogen to environment (Son, 2015). Moreover, broilers reared under UV light have lower stress susceptibility and fear responses, which may be critical to maximize welfare and growth performance of broilers (House et al., 2020; James et al., 2020).

Light Duration

The light duration can impact on broiler performances from embryo phase to marketing time. At embryogenesis, the duration of light exposure has important implications on behavioral phenotypes and welfare in post-hatch period (Archer and Mench, 2017). Providing a light-dark rhythm of 12 L:12 D daily during embryogenesis resulted in long-term reduction in fearfulness (Archer and Mench, 2017) and a stimulating effect on leg health, while 24 L had a detrimental effect on embryonic leg bone development and later life leg bone strength (van der Pol et al., 2019). Therefore, a circadian incubation lighting schedule is crucial to the leg health in broilers (van der Pol et al., 2017). Providing light stimulation of 12 h per day at embryogenesis stage may help to improve hatching traits and post-hatch performance of broilers (Riaz et al., 2021). In the post-hatch period, broilers reared under a 16 L: 8 D photoperiod had improved welfare due to more uninterrupted resting behavior during the dark phase (Alvino et al., 2009).

According to the way of light-darkness transition, the illumination pattern can be categorized as either continuous illumination or intermittent illumination. Continuous exposure to varying light intensities for broiler chickens had a minor effect on blood physiological variables, whereas short photoperiod markedly affected most blood physiological variables without inducing physiological stress in broilers (Olanrewaju et al., 2013). In contrast, intermittent lighting program promotes the drumstick and thigh yields (Abreu et al., 2011). When lighting hours was up to 3 L:1 D, it would be more contributive to enhance feed efficiency, innate immunity and oxidative status compared with continuous lighting programs on broilers (Ghanima et al., 2021). By the way, negative impact on broiler productivity is linked to day length and near-continuous light, particularly at older marketing ages.

Photoperiod from 16 to 24 h had no effects on thyroid gland development or functions in terms of both biochemical and morphometric parameters in broilers (Ozkanlar et al., 2021), indicating that the photoperiod could be slightly shorten in the broiler production. Furthermore, intermittent lighting program did not hinder the performance of broilers and promoted energy economy (Manfio et al., 2020). Although long photoperiod programs might reduce mortality and improve feed efficiency, negative impacts on body weight at young marketing ages could not be ignore. Based on this, 16 L:8 D light duration was suggested for the broiler production. However, it should be adjusted by the season changes and chicken house types with different opening and luminous degrees.

CONCLUSIONS AND PERSPECTIVES

The impacts of light on broilers mainly depend on the light source, light color (wavelength), light intensity and light duration (program). A comprehensive understanding about the potential interactions between the light characteristics and broiler physiology is essential to optimize the lighting program in poultry production. In addition, light regimen selection depends on many other indispensable factors, including rearing house type, feeding mode, rearing density, diet nutritional level and season. To maximize the benefits of broilers by applying a suitable lighting regimen, our understanding about the interactions between light implement, rearing house types and broiler dietary nutrients is expected to be further deepen.

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DISCLOSURES

The authors declare that there is no conflict of interest.

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