한국가금학회지 제 52권 제 2호, 105～121 (2025)
Korean J. Poult. Sci. Vol.52, No.2, 105～121 (2025)
https://doi.org/10.5536/KJPS.2025.52.2.105

The Role of Artificial Lighting in Laying Hen Management

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ABSTRACT Artificial lighting is critical in laying hen management by regulating biological rhythms, reproductive performance, and overall welfare. This review examines the effects of key lighting parameters, light source, intensity, wavelength, and photoperiod on egg production, feed efficiency, and welfare. The transition from traditional incandescent and fluorescent lighting to energy-efficient LED systems has introduced new considerations regarding spectral composition, light distribution, and long-term productivity. Research suggests that red-spectrum LED light enhances ovarian activity, whereas blue and green wavelengths may influence growth and eggshell quality. Light intensity is another essential factor, as excessively high levels can induce stress, whereas inadequate lighting may impair productivity. Optimizing photoperiods, including intermittent lighting and extended dark phases, can enhance reproductive hormone regulation and eggshell formation. Emerging technologies, such as LED spectral manipulation and phased lighting programs, offer new opportunities for improving both productivity and sustainability in commercial layer operations. This review highlights the need for strategic lighting management to optimize performance while maintaining hen welfare.

(Key words: artificial lighting, egg production, laying hen, light intensity, photoperiod)

INTRODUCTION

Global egg production has grown steadily in response to increasing consumer demand for high-quality protein sources. The efficiency and sustainability of layer farming have become critical concerns, prompting extensive research into optimizing various management factors, including nutrition, housing, and environmental conditions (Lewis and Morris, 2000; Xin et al., 2021). Among these, lighting management plays a fundamental role in regulating physiological and behavioral processes in laying hens. Proper lighting not only influences feed intake and sleep cycles but also affects reproductive performance, stress levels, and overall welfare (Kristensen et al., 2007; Rodenburg et al., 2010). As commercial poultry production advances, optimizing artificial lighting strategies has become essential for improving productivity and ensuring sustainable farming practices.

Light is a crucial environmental factor for regulating biological rhythms in poultry, affecting key physiological functions such as feeding behavior, oviposition, and rest cycles. Chickens naturally consume most of their feed during the photophase when light is available, with minimal feeding activity occurring in darkness (Buyse et al., 1996). Additionally, their activity levels decrease significantly during the scotophase, highlighting the importance of photoperiod management in commercial layer operations (Ohtani and Leeson, 2000). Given the reliance of poultry on light cues for regulating reproductive cycles, the quality and duration of artificial lighting play a pivotal role in maximizing egg production and maintaining hen welfare.

Over the past few decades, technological advancements have transformed lighting systems in poultry production, with light-emitting diodes (LEDs) gradually replacing traditional incandescent and fluorescent bulbs. LEDs offer numerous advantages, including energy efficiency, extended lifespan, and controlling light intensity and spectral output (Benson et al., 2013; Hassan et al., 2014). These attributes make LED lighting a highly adaptable and cost-effective alternative to conventional lighting sources. However, as the poultry industry increasingly transitions to LED-based lighting systems, understanding their long-term effects on production performance, feed efficiency, and hen welfare remains a

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critical research area (Long et al., 2016a; Liu et al., 2018a).

The biological response of chickens to light is influenced by their unique visual system, which differs significantly from that of humans. Chickens possess five types of cone photoreceptors in the retina, allowing them to perceive a broader spectrum of light, with peak sensitivities at approximately 415, 450, 550, and 700 nm (Osorio and Vorobyev, 2008). In addition to retinal photoreceptors, chickens have extra-retinal photoreceptors in the pineal gland and hypothalamus, which play a key role in regulating reproductive hormones (Mobarkey et al., 2010). Unlike retinal receptors, extra-retinal photoreceptors respond primarily to long-wavelength radiation capable of penetrating the skull and surrounding tissues, influencing sexual maturation and egg-laying cycles (Lewis and Morris, 2000).

Multiple factors must be considered when implementing artificial lighting in poultry facilities, including light source, intensity, spectrum, and photoperiod. Traditionally, incandescent bulbs were widely used in poultry farming due to their broad spectral output, which closely mimics natural sunlight. However, these bulbs are highly energy-inefficient and are being phased out in favor of more sustainable alternatives (Siopes and Wilson, 1980; Chignell et al., 2008). Fluorescent bulbs, which are more energy-efficient than incandescent lighting, have limitations such as flickering, poor dimmability, and mercury content, requiring specialized disposal procedures (Benson et al., 2013). In contrast, LED technology provides stable spectral output, is fully dimmable, and offers superior energy efficiency, making it a preferred choice in modern poultry production (Steranka et al., 2002; Liu et al., 2018a).

Light intensity is another critical factor in layer management. Studies have shown that illuminance levels below 5 lx may fail to adequately stimulate hens, whereas excessively high intensities exceeding 50 lx can induce stress and negatively affect welfare (Lewis and Morris, 1999). Furthermore, the spectral composition of light influences laying performance, with red-spectrum light enhancing ovarian activity and metabolic efficiency due to its deeper tissue penetration and stimulation of reproductive hormones (Baxter et al., 2014; Baxter and Bédécarrats, 2019). Recent studies have also investigated the use of LED strip lighting to improve light uniformity in multi-tier cage systems, demonstrating potential benefits for egg production consistency across different cage levels (de SG Barros et al., 2020).

Given the growing interest in optimizing lighting conditions for commercial layer operations, this review explores the effects of artificial lighting on laying hen performance, welfare, and egg quality. This study provides insights into how different lighting strategies influence production efficiency and hen well-being by examining key lighting parameters, including light source, intensity, spectrum, and photoperiod. Additionally, emerging technologies such as LED-based spectral manipulation and phased lighting programs are discussed, highlighting their potential applications in modern poultry farming. Ultimately, this review aims to contribute to the development of more effective, sustainable, and welfare-conscious lighting practices for improved egg production and farm efficiency.

LIGHT SOURCE

Light sources are essential in poultry production by influencing the stimulation of retinal and extraretinal photoreceptors, ultimately affecting laying hen performance. Different light sources, including incandescent, fluorescent, and LED lights, vary in spectral composition, impacting reproductive activity, feed efficiency, and egg quality. Compact fluorescent and incandescent lighting have been associated with higher egg production than standard fluorescent lighting, with compact fluorescent lights offering additional economic benefits due to lower energy consumption (Felts et al., 1992; Ahmad et al., 2010). While LED and fluorescent lighting result in similar egg production rates, differences in spectral output may influence feed efficiency, feather condition, and long-term egg quality (Long et al., 2016a; Liu et al., 2018a). LED lighting has been linked to improved early egg quality but potential trade-offs in eggshell strength over time (Liu et al., 2018b). In addition to spectral composition, the distribution and uniformity of light can further impact production efficiency. Advancements such as linear LED strip lighting have demonstrated the potential to improve light uniformity in cage systems, leading to enhanced egg production, particularly at different cage levels (de SG Barros et al., 2020). These findings highlight the importance of selecting appropriate light sources to optimize both productivity and hen welfare in commercial poultry operations. The effects of light sources on laying hens are summarized in Table 1.

Building on this, a com'parative study examined how different light sources influence the production performance of White Leghorn hens, focusing on economic and efficiency factors (Ahmad et al., 2010). Proper lighting conditions influenced egg production, with compact fluorescent and incandescent lighting resulting in significantly higher hen-day egg production than fluorescent lighting (Felts et al., 1992). Feed efficiency was best in the incandescent group, suggesting improved energy utilization under this lighting type (Lewis and Morris, 1998). However, no significant differences were observed in feed intake, body weight, or mortality among the treatment groups, indicating that light sources primarily affected production efficiency rather than overall bird health (Siopes, 1984). Economic analysis revealed that compact fluorescent lighting yielded the highest net profit due to lower electricity consumption, making it a cost-effective option for layer farming (Ahmad et al., 2010).

While the previous study highlighted the economic aspects of different light sources, another study specifically compared LED and fluorescent lighting in terms of long-term productivity and welfare (Long et al., 2016a). Hens under LED lighting showed similar egg weight, hen-day egg production, feed intake, and mortality rates to those under fluorescent lighting but had fewer eggs per hen housed and poorer feed efficiency, indicating potential productivity trade-offs. These differences may stem from LED spectral composition affecting metabolism (Min et al., 2012). Additionally, LED hens had reduced feather uniformity and insulation at 36 weeks, possibly due to increased feather pecking or altered thermoregulation (Bilcik and Keeling, 1999). They also exhibited greater avoidance distance at 36 weeks, suggesting

Table 1. Effects of light source on layers

Light source	Experimental hens	Observations	References
Conventional LED lamps and linear LED strips	Hy-line Brown (week 19−48)	LED strips → ↑ egg production after peak lay (28−48 wk). No effect on egg quality and thermal environment in cages	de SG Barros et al. (2020)
Incandescent, fluoroscent, and compact fluoroscent	White Leghorn (week 40−48)	Compact fluorescent & incandescent → ↑ egg production Incandescent → ↑ feed efficiency	Ahmad et al. (2010)
LED and fluorescent	Dekalb White (week 27−70)	No effect on egg weight, hen-day egg production, feed intake, and mortality rates. LED → ↓ eggs/hen housed, ↓ feed efficiency. Inferior feather uniformity and insulation at 36 weeks Greater avoidance distance at 36 weeks, but no difference at 60 weeks	Long et al. (2016a)
	Dekalb White (week 27−60)	LED → ↑ egg weight & albumen quality (27 wk), ↑ shell thickness (40 wk), ↓ egg weight (60 wk). No effect on yolk cholesterol, lipids, FA composition, or shelf-life	Long et al. (2016b)
	W-36 pullets (week 0−14)	LED → ↑ activity levels. No effect on body weight, uniformity, mortality, feather and comb conditions	Liu et al. (2018b)
	W-36 laying hens (week 17−41)	LED → ↓ eggshell thickness & strength (41 wk); ↓ yolk cholesterol. No effect on egg production, feed intake, and feed efficiency	Liu et al. (2018a)
Incandescent, fluorescent, and white LED	ATAK-S layers (week 0−52)	LED → No effect on growth, intake, efficiency, livability, production, or shell quality; ↑ shape index & albumen index	Kamanli et al. (2015)
	Lohmann LSL-Lite (week 14−69)	Red-spectrum LED → ↑ ovarian activity, ↑ feed efficiency; no effect on egg production	Baxter and Bédécarrats (2019)

heightened alertness, though this effect diminished by 60 weeks (Graml et al., 2008). While LED lighting is a viable alternative to fluorescent, its effects on feed efficiency, feather condition, and behavior require further study.

In addition to comparing LED and fluorescent lighting, another study explored how incandescent, mini fluorescent, and white LED lighting impact egg quality and production in ATAK-S hens (Kamanli et al., 2015). While no significant differences were observed in egg production, egg weight, or eggshell quality, LED-lit hens exhibited a higher shape index and albumen index compared to those under incandescent and mini fluorescent lighting, suggesting that spectral differences may influence albumen quality (El-Aggoury et al., 1989). Previous studies indicate that the spectral composition of LED lighting can modulate endocrine responses, potentially affecting albumen formation (Prescott and Wathes, 1999). Additionally, LED lighting reduced energy consumption compared to other lighting types, highlighting its economic advantages for layer production (Huber-Eicher et al., 2013). These findings support the use of LED lighting in poultry facilities whereas emphasizing the need for further research on its effects on egg quality and physiological responses.

Beyond laying hens, researchers have also investigated how LED lighting affects the growth performance and activity levels of pullets, providing insight into its potential long-term benefits (Liu et al., 2018b). Pullets reared under LED lighting exhibited higher activity levels than those under compact fluorescent lighting, potentially due to differences in spectral composition and perceived intensity (Prescott et al., 2003; Saunders et al., 2008). Despite variations in body weight gain at certain ages, no significant differences were observed in final body weight, uniformity, or cumulative mortality rate between the two lighting treatments. Feather and comb conditions remained comparable across treatments, suggesting no adverse effects of LED lighting on bird welfare. These findings contribute to optimizing lighting strategies in modern poultry production, emphasizing the potential role of LED lighting in enhancing pullet activity without compromising growth performance.

Further investigating the impact of LED lighting on egg quality, Long et al. (2016b) examined its effects on albumen height, egg weight, and shell thickness over time. Shell thickness was higher at 40 weeks under LED, possibly due to improved calcium metabolism from prolonged exposure to specific wavelengths. However, overall egg quality during storage remained comparable to fluorescent lighting, suggesting that spectral differences have limited effects on long-term stability. Similarly, total yolk lipids and fatty acid composition were unaffected, indicating that while LED lighting affects early egg quality, its impact on long-term egg composition is minimal (Hansen et al., 2015).

Similarly, another study focused on poultry-specific LED lighting, evaluating its influence on eggshell strength and metabolic responses in W-36 layers (Liu et al., 2018a). Hens under poultry-specific LED lighting showed comparable egg production rates, feed intake, and feed efficiency to those under fluorescent lighting (Kamanli et al., 2015). However, LED hens laid eggs with lower shell thickness and strength at 41 weeks, suggesting possible trade-offs in eggshell quality. This may be related to differences in spectral composition affecting calcium metabolism (Min et al., 2012). Additionally, yolk cholesterol content tended to be lower in eggs from LED hens at 41 weeks, indicating possible metabolic differences influenced by lighting conditions (Lewis and Morris, 2000). These findings suggest poultry-specific LED lighting as an alternative to fluorescent lighting, though its impact on eggshell quality warrants further study.

Expanding on the physiological effects of LED lighting, Baxter and Bédécarrats (2019) investigated the impact of red-spectrum LED lighting on reproductive hormone regulation and metabolic efficiency. While overall egg production remained similar across lighting sources, hens under red-spectrum LED exhibited a more pronounced second peak in plasma estradiol at 52 weeks, suggesting enhanced ovarian activity, potentially due to the deeper penetration of red wavelengths stimulating hypothalamic photoreceptors (Pang et al., 1974; Foster and Follett, 1985; Baxter and Bédécarrats, 2019). Additionally, red light may support calcium metabolism and eggshell formation, minimizing metabolic costs associated with bone resorption and shell synthesis (Bain et al., 2016; Baxter and Bédécarrats, 2019). As a result, hens exposed to red-spectrum LED consumed less feed while maintaining production levels, indicating improved feed efficiency. These findings support the idea that red-dominant

LED lighting may enhance reproductive hormone regulation and metabolic efficiency in laying hens, though its direct impact on cumulative egg production remains limited.

Conventional punctiform lamps used in vertical poultry production systems enable low uniformity of light distribution because there is high illuminance in regions close to the lamps and low illuminance in the farthest regions; uneven light distribution happens vertically and horizontally (Thomson and Corscadden, 2018). Beyond spectral composition, the uniformity of light distribution is another crucial factor affecting egg production. Recent advancements in LED strip lighting aim to address this issue by improving light consistency in cage systems (de SG Barros et al., 2020). Hens reared under LED strips exhibited significantly higher egg production after peak lay (28−48 weeks) than those under conventional LED lamps, particularly at the lowest and highest cage tiers. The improved light distribution within cages likely enhanced egg production (Yildiz et al., 2006). In contrast, no significant differences were observed in egg quality. Enhancing light uniformity with a linear LED system appears to promote sustained egg production while maintaining egg quality, offering a practical lighting strategy for commercial layer operations.

LIGHT INTENSITY

Light intensity is a key factor in laying hen management, influencing physiological development, egg production, and overall welfare. Proper lighting conditions during early growth are essential for chick adaptation, feed intake, and uniform flock development. An initial light intensity of 30−50 lx is recommended in the st week, followed by gradual adjustments to optimize laying performance (Hy-Line Brown Guidebook, 2024). Managing light intensity throughout the production cycle helps regulate reproductive function, energy balance, and behavioral patterns. The effects of light intensity on laying hens are summarized in Table 2.

Since light intensity plays a crucial role from an early age, its effects on nest selection behavior have also been investigated. A study by Zupan et al. (2007) explored how early exposure to different light intensities influences nest preference in later life. Chicks were exposed to either high or low light intensity during the first 12 days of life, and their nest preference was tested at 20−23 weeks of age. Hens reared under high light intensity consistently selected specific nests, whereas those raised under low light intensity displayed a more random nest selection pattern with no distinct preference (Appleby et al., 1984). These findings suggest that early exposure to light intensity influences nest selection behavior in laying hens, providing insight into how environmental conditions during early development affect later laying behavior (Huber-Eicher, 2004).

In addition to nest selection, light intensity also affects behavioral patterns and stress responses. The effects of low light intensity (5 lx) on the behavior, physiological stress indicators, and egg production of Hy-Line Brown laying hens (16−24 weeks) were examined (O'connor et al., 2011). Hens

Table 2. Effects of light intensity on layers

Light intensity	Experimental hens	Observations	References
5, 20, 50, and 100 lx (LED)	Hy-Line W-80 (week 25−36)	No effect on egg production, egg weight, and eggshell quality Light exposure time influenced cloacal and surface temperatures, feed intake, body weight, and albumen percentage in egg.	Bahuti et al. (2023)
121.8, 57.4, and 11.9 lx (compact fluorescent)	Lohmann-Brown (week 20−40)	Higher intensity → earlier sexual maturity Higher intensity → lighter yolk color, ↑ egg production, ↓ egg size, ↑ feather condition	Erensoy et al. (2021)
5 and 150 lx (fluoroscent)	Hy-line Brown (week 16−24)	5 lx: ↓ activity, ↑ preening & dust-bathing 5 lx: ↓ egg production, delayed onset of full lay	O'connor et al. (2011)
333, 118, 59, and 20 lx during early life	Laying hens (week 20−23)	Higher intensity during rearing → stronger nest preference Lower intensity → no clear nest preference	Zupan et al. 2007)
4.7−44.5, 52.6−54.5, and 89.8-151.9 lx	ISA Brown (week 75−83)	Higher intensity → ↑ egg production Egg quality varied depending on light intensity	Yildiz et al. (2006)

exposed to lower light intensity were less active but engaged in more preening and dust-bathing, consistent with findings that dim environments encourage comfort behaviors (Davis et al., 1999; Blatchford et al., 2009). Although no strong physiological stress response was observed, hens in low-light conditions laid fewer eggs and took longer to reach full lay, possibly due to reduced photophase contrast, which is crucial for regulating reproductive cycles (Morris and Bhatti, 1978; Renema et al., 2001a). These findings highlight the negative impact of dim lighting on early egg production and behavioral activity in laying hens.

While low light conditions impact behavior, varying LED light intensities may have different physiological effects. The effects of different LED light intensities (5, 20, 50, and 100 lx) on the physiological responses, productivity, and egg quality of 25－36 weeks old Hy-Line W-80 laying hens were evaluated in a climate-controlled setting (Bahuti et al., 2023). Light intensity alone did not significantly affect hen performance or egg quality. However, exposure time influenced physiological parameters such as cloacal and surface temperatures, feed intake, body mass, and albumen percentage, suggesting a 28-day acclimation period at the peak laying period is necessary (Ma et al., 2016; Ribeiro et al., 2020). No adverse effects were observed at any illuminance level, with 5 lx being sufficient for hens to access feeders and drinkers without production losses, highlighting potential energy-saving benefits for poultry operations (Olanrewaju et al., 2019; de SG Barros et al., 2020).

Beyond LED lighting, another study examined a broader range of light intensities in different production systems. The effects of varying light intensity (121.8, 57.4, and 11.9 lx) on the performance, egg quality, and feather condition of Lohmann-Brown laying hens (20－40 weeks) were evaluated in a battery cage system (Erensoy et al., 2021). Hens exposed to higher light intensity reached sexual maturity earlier and showed higher egg production but lower egg weight compared to those under lower light intensity, likely due to differences in physiological responses affecting growth and reproductive development (Lewis and Morris, 1999). While feed intake remained unaffected, light intensity influenced yolk color, with higher intensities resulting in lighter yolks, possibly due to dilution of carotenoid reserves as more eggs were produced (Cayan and Erener, 2015). This effect may also be attributed to increased metabolic activity and nutrient utilization under higher light intensity, altering carotenoid absorption and deposition in the yolk (Lewis and Morris, 1999). Additionally, increased light intensity improved overall feather maintenance, suggesting reduced stress and better welfare (Rodenburg et al., 2010; Yamak and Sarica, 2012). These findings support 50－60 lx lighting for optimizing egg production and hen welfare in battery cage systems.

In a study with 225 ISA Brown hens housed in a multitier system, hens were placed in cages with different light intensities, artificially illuminated (51.0－54.5 lx), near windows (89.8－151.9 lx), and in corridors with the least light exposure (4.7－44.5 lx), to examine the effects of light intensity on egg production and quality (Yildiz et al., 2006). Hens exposed to higher light intensity produced more eggs, likely due to enhanced reproductive hormone activity (Cavalchini et al., 1976; Abdelkarim and Biellier, 1982). Egg weight was also higher under brighter conditions, suggesting improved feed intake and metabolism (Renema et al., 2001a). However, eggshell strength was highest in lower light conditions, possibly due to reduced stress and better calcium utilization (Lewis and Leeson, 2004). Albumen index and Haugh unit were highest in eggs from hens with moderate light exposure, indicating better protein structure and water retention (Pavlovski and Mašić, 1991). These results highlight optimizing light conditions to balance egg production and quality.

Summarizing these findings, several studies indicate that light intensity affects multiple aspects of egg production and hen welfare. While high-intensity lighting promotes earlier sexual maturity, lower intensities may improve eggshell quality. Studies suggest that while light intensity alone may not drastically affect egg production, it can influence growth rate, yolk pigmentation, and eggshell quality (Erensoy et al., 2021; Bahuti et al., 2023). Higher intensities have been associated with earlier sexual maturity and increased egg production, whereas lower intensities may promote better eggshell quality but delay laying onset (Yildiz et al., 2006; O'connor et al., 2011). Additionally, light intensity plays a role in hen welfare, affecting activity levels, nesting behavior, and stress responses (Blatchford et al., 2009; Rodenburg et al., 2010). Balancing light intensity is crucial for sustaining high productivity while maintaining hen welfare.

LIGHT WAVELENGTH

Light wavelength has a crucial role in influencing the physiological responses and productivity of laying hens, as it determines both light color and the depth of tissue penetration. Longer wavelengths, such as red light (600−700 nm), are associated with enhanced ovarian activity and egg production due to their ability to stimulate extra-retinal photoreceptors in reproductive hormone regulation. In contrast, shorter wavelengths, such as blue (450−490 nm) and green light (490−570 nm), have been linked to improved growth and eggshell quality by influencing calcium metabolism and muscle development (Rozenboim et al., 1998; Gongruttananun and Guntapa, 2012; Hassan et al., 2013; Li et al., 2014; Kim et al., 2018; Baxter and Bédécarrats, 2019). Beyond the visible spectrum, far-infrared radiation (FIR, 3−100 μm) has gained attention for its potential role in improving metabolic activity and reducing microbial contamination in poultry housing systems. Additionally, phased spectral lighting programs, such as blue-green light during early growth followed by yellow-orange light during reproductive maturation, have supported immune function, bone strength, and reproductive development (Lewis and Morris, 2000; Wei et al., 2020). The effects of light wavelength on layers are summarized in Table 3.

Table 3. Effects of light wavelength on layers

Light wavelength	Experimental hens	Observations	References
LED: 650±10 nm FIR: 15±10 μm	Hy-line Brown (week 30−39 and 45−54)	LED + FIR → ↓ serum cholesterol, HDL-C, triglyceride LED + FIR → ↓ *E. coli*, *Salmonella*, total microbes in feces LED + FIR → No effect on laying performance or egg quality	Lim et al. (2023)
Red (630−750 nm), blue (450−490 nm), green (490−570 nm), and white LED	Hy-line Brown (week 47−53)	Red LED → ↑ egg-laying rate Green LED → ↓ egg number, ↑ egg weight Blue LED → ↑ eggshell strength All → No effect on feed intake or efficiency	Kim et al. (2018)
Blue LED (week 1−18) → Red LED (week 19−31) and normal LED	Hy-Line W-36 (week 1−31)	Blue LED → ↑ body weight during pullet phase Red LED → ↑ yolk %, ↓ albumen % during laying phase	Poudel et al. (2022)
White (400−760 nm) and green (560 nm)	Brown-Nic k layers (week 48−56)	White LED → No effect on egg production, egg quality Green LED → ↑ yolk pigmentation (a*, b*) Green LED → ↓ serum albumin	Yenilmez et al. (2021)
White (400−700 nm), blue-green (435−565 nm), yellow-orange (565−630 nm), continuous yellow-orange, and continuous blue-green LED	Jinghong layers (week 1−20)	Blue-green LED → ↑ immune function Yellow-orange LED → ↑ bone density Yellow-orange LED → ↑ reproductive development	Wei et al. (2020)
White, green, red, red-green LED	Lohmann LSL lite layers (week 33−50)	Red LED → ↑ egg production, ↑ feed efficiency Green LED → ↑ body weight White LED → ↑ egg mass	Raziq et al. (2020)
Red and white LED	White Leghorn (week 18−72)	Red LED → ↓ plasma corticosterone Red LED → ↓ H/L ratio, ↓ asymmetry scores White LED → No effect on production, egg weight	Archer (2019)
Red (660 nm), green (560 nm), blue (480 nm), and white LED	Local mountainous laying hens (week 19−63)	Red LED → ↑ egg shape index, ↑ fertility, ↑ hatchability Green LED → ↑ eggshell strength, ↑ pigmentation Green LED → ↓ total egg production Blue LED → No effect White LED → Maintained standard production and quality	Li et al. (2014)

Building on this, research has examined the effects of specific LED light wavelengths on laying hen performance. Implementing specific LED light wavelengths can influence egg production, egg quality, and reproductive hormone levels in Hy-line brown laying hens housed on the floor (Kim et al., 2018). Hens exposed to red LED light exhibited the highest egg-laying rates, likely due to increased plasma 17β-estradiol concentrations, which play a crucial role in follicular development and ovulation (Hassan et al., 2013; Baxter et al., 2014). In contrast, hens under green light produced fewer eggs but exhibited greater egg weight, suggesting that shorter-wavelength light may shift energy allocation toward egg size rather than production (Rozenboim et al., 1998; Gongruttananun and Guntapa, 2012). Additionally, blue LED light enhanced eggshell strength by affecting calcium metabolism and eggshell mineralization (Gongruttananun and Guntapa, 2012; Hassan et al., 2014). No significant differences were observed in feed intake or feed efficiency across treatments, indicating that the changes were primarily driven by physiological responses to light color rather than alterations in nutrient intake (Lewis and Morris, 2000). These findings suggest that LED lighting strategies, particularly red light, may be a viable approach to sustaining egg production in aging hens while maintaining overall egg quality.

A study investigated the effects of blue and red LED lighting on the growth, egg production, egg quality, behavior, and hormone concentration of Hy-Line W-36 laying hens (Poudel et al., 2022). Over 31 weeks, 1,000 hens were reared in two identical rooms: one with blue LED from 1 to 18 weeks, red LED from 19 to 31 weeks, and the other with normal LED throughout. Hens raised under blue LED exhibited higher body weight during the pullet phase, consistent with previous findings that blue light reduces locomotion and promotes growth (Prayitno and Phillips, 1997; Sultana et al., 2013). Hens exposed to red LED had a higher yolk percentage and lower albumen percentage, aligning with studies indicating that red light stimulates ovarian activity and influences egg composition (Pyrzak et al., 1987; Reddy et al., 2012). However, hen-day egg production, hormone concentration, and behavior showed no significant differences across treatments. Based on the study, blue LED may enhance early growth, while red LED may influence egg composition, potentially affecting egg quality parameters relevant to commercial production.

In addition to blue and red light, the effects of green light on egg quality have also been examined. Exposure to monochromatic light can affect egg production, egg quality, and physiological parameters in laying hens (Yenilmez et al., 2021). In an 8-week study, Brown-Nick laying hens were housed under either white (400−760 nm) or green (560 nm) fluorescent light with a 16L:8D photoperiod. No significant differences were observed in feed intake, feed conversion ratio, egg production, total egg weight, or yolk cholesterol levels, aligning with previous findings that green light has minimal impact on overall laying performance (Rozenboim et al., 1998; Lewis et al., 2007). However, yolk pigmentation increased under green light, as indicated by higher a* (redness) and b* (yellowness) values, suggesting enhanced carotenoid deposition (Hassan et al., 2013; Long et al., 2014). Additionally, serum albumin concentration decreased under green light, which may reflect changes in protein metabolism or stress response (Ruot et al., 2000). These results indicate that while green monochromatic light does not significantly alter production efficiency, it may enhance yolk color.

Further supporting the role of specific light wavelengths, Li et al. (2014) investigated how different wavelengths of LED light, red (660 nm), green (560 nm), blue (480 nm), and white, affect reproductive performance in 552 laying hens from 19 to 63 weeks of age. Birds reared under green light produced fewer eggs than those under other treatments, while red light was associated with a greater egg shape index, higher fertility, and improved hatchability. These findings align with research showing that red light enhances reproductive performance, whereas green light may improve egg quality (Pyrzak et al., 1987; Rozenboim et al., 1998). Light wavelength influenced egg weight, but overall egg production rate remained unaffected. Notably, green light produced the highest egg quality, as indicated by better eggshell strength and pigmentation. Green light likely improved eggshell strength by enhancing calcium metabolism and shell gland activity, while increased pigmentation may be due to its effect on porphyrin deposition (Pyrzak et al., 1987; Mobarkey et al., 2010). These findings highlight the importance of wavelength selection in optimizing lighting strategies for commercial laying hen production.

Beyond single-wavelength studies, some researchers have investigated phased spectral lighting programs. A phased spectral lighting program using light-emitting diode illumination can influence immune response, skeletal development, and reproductive maturation in layer chickens (Wei et al., 2020). In a 20-week study, Jinghong layer chickens were assigned to one of four lighting treatments: continuous white light (400−700 nm) as the control, blue-green light (435−565 nm) from one to thirteen weeks followed by yellow-orange light (565−630 nm) from fourteen to twenty weeks, continuous yellow-orange light, and continuous blue-green light. At thirteen weeks, chickens exposed to the blue-green and blue-green to yellow-orange lighting treatments exhibited higher immunoglobulin G concentrations than those under white light, indicating enhanced immune function, which aligns with previous findings on the immunomodulatory effects of short-wavelength light (Xie et al., 2008; Hassan et al., 2013; Zhang et al., 2014). By twenty weeks, chickens reared under yellow-orange light had significantly higher bone mineral density than those in the control group, supporting evidence that long-wavelength light enhances skeletal development (Zhang et al., 2006; Amoroso et al., 2013). Furthermore, the transition from blue-green to yellow-orange light promoted ovarian and oviduct development, while continuous yellow-orange light led to an earlier onset of fifty percent egg production compared to other treatments, consistent with research showing that red-orange light stimulates sexual maturation and reproductive activity (Lewis and Morris, 2000; Li et al., 2014; Baxter and Bédécarrats, 2019). These results suggest that a strategically phased lighting program incorporating blue-green light during early growth and yellow-orange light during sexual maturation may support immune function, bone strength, and reproductive development in layer chickens, ultimately optimizing their long-term production potential.

While visible light wavelengths have been extensively studied, non-visible radiation, such as FIR, has also been explored for its potential benefits in poultry production. FIR with wavelengths ranging from 3−100 μm have recently gained attention as an innovative technology in housing management systems in poultry production (Hayat et al., 2024). The LED + FIR illumination may enhance laying hen health by decreasing serum cholesterol, high-density lipoprotein cholesterol, and triglyceride concentrations due to the warming effect induced by vibration in tissues and organs, similar to the exercise activity of FIR (Yamashita, 2012; Didi and Yanmei, 2021; Lim et al., 2023). Additionally, LED + FIR might positively influence hygienic conditions by reducing the total microbial count and pathogenic bacteria such as *Escherichia coli* and *Salmonella* in feces. This is because organic matter is vibrated by FIR, which deactivates pathogenic microflora and causes the internal temperature to rise (Huang, 2004). Furthermore, LED +FIR illumination maintains laying performance, feed efficiency, and egg quality comparable to those observed under LED-only lighting conditions. FIR illumination might be one approach to enhancing nutrient utilization without dietary interventions in layers.

Since light influences not only production but also bird welfare, Raziq et al. (2020) investigated how different LED light colors affect production performance, egg quality, welfare, and hormonal profiles in Lohmann LSL Lite laying hens. Over 17 weeks, 200 hens were assigned to four lighting treatments: white, monochromatic green, monochromatic red, and dichromatic red-green LED light. Hens reared under red LED light exhibited the highest egg production and feed efficiency, aligning with previous findings that red light stimulates ovarian activity and reproductive hormone secretion (Hassan et al., 2013). Green LED light increased body weight gain, supporting that short-wavelength light enhances growth performance through androgen stimulation (Halevy et al., 1998; Cao et al., 2008). White LED light produced the highest egg mass, while the red-green combination showed no clear production advantage. Additionally, red LED light increased cortisol levels, suggesting a potential stress response, while hens under green LED exhibited higher thyroxine levels, indicating metabolic activation (Klandorf et al., 1978). These results suggest that while red LED light may optimize egg production, potential stress effects should be considered, whereas green LED light could benefit body weight gain without compromising welfare.

Further examining the welfare implications, Archer (2019) investigated the effects of red LED light on production performance, fear, and stress in White Leghorn hens over a full laying cycle (18−72 weeks), housing birds under either red LED (650 nm) or white LED light. No significant differences between treatments were found in egg production, egg quality, or feed efficiency. However, hens reared under red LED exhibited lower plasma corticosterone levels, lower heterophil-to-lymphocyte ratios, and reduced composite asymmetry scores compared to those under white LED, suggesting decreased physiological stress (Svobodová et al., 2015; Archer, 2019). These findings contradict prior studies linking red light to increased ovarian activity and higher egg production (Pyrzak et al., 1987; Hassan et al., 2013). Additionally, no significant effects were observed in fear response as measured by tonic immobility and inversion tests. While red light appears brighter to birds and stimulates extra-retinal photoreceptors, its impact on fear behavior remains inconclusive (Svobodová et al., 2015; Baxter and Bédécarrats, 2019). The study suggests that red LED lighting may not enhance production efficiency but could improve welfare by reducing stress susceptibility.

LIGHT PROGRAMS AND PHOTOPERIODS

Light programs are fundamental to optimizing laying hen performance by regulating reproductive development, feed intake, and egg production. A structured lighting schedule ensures synchronized sexual maturation and stable laying persistency. Gradually increasing day length to 16 hours by 30 weeks of age is recommended to maximize egg production while minimizing stress (Hy-Line Brown Guidebook, 2024). During the rearing phase, intermittent or extended lighting promotes uniform growth, with a stepwise transition to a stable laying schedule ensuring smooth adaptation. Aligning light duration between the rearing and laying phases helps minimize stress and support reproductive readiness when hens reach the target body weight. The effects of light programs and photoperiods on laying hens are summarized in Table 4.

Circadian rhythmic behaviors, such as feeding, egg-laying, and sleeping, play a crucial role in maintaining optimal reproductive performance in laying hens and are significantly influenced by light regimes (Kristensen et al., 2007). Given the importance of light programs, research has explored how different lighting schedules affect reproductive function and behavior. The impact of different light regimes on these behaviors and reproductive parameters was investigated in Beijing You Chicken during the early laying period (Geng et

Table 4. Effects of light program and photoperiods on layers

Light regime	Experimental hens	Observations	References
Continuous: 16L:8D, 14L:10D, 12L:12D Intermittent: 12L:2D:4L:6D, 10L:2D:4L:8D, 8L:4D:4L:8D	Beijing You Chicken (week 56−64)	Continuous lighting → ↑ ovarian weight, oviduct weight/length, and follicle number Lighting → altered circadian behaviors (feeding, laying, sleeping) No effect on laying performance	Geng et al. (2022b)
Continuous: 16L:8D, 12L:12D Intermittent: 12L:2D:4L:6D	Beijing You Chicken (week 19−34)	Intermittent (12L:2D:4L:6D) → ↑ pineal Opn4 expression Continuous (12L:12D) → ↓ Opn4 expression Intermittent lighting → negative correlation between Opn4 and melatonin Lighting → influenced circadian behaviors No effect on laying performance	Geng et al. (2022a)
Continuous: 16L:8D Long dark phase: 9L:15D	ISA hens (week 56−64)	9L:15D → ↑ shell hardness, Ca & P deposition 9L:15D → ↑ serum Ca & P during dark phase 9L:15D → ↓ feed intake, ↓ egg weight No effect on laying performance	Xin et al. (2021)
Continuous: 16L:8D Intermittent: 20 min/h light pulses + 40 min/h dark, 40 min/h light pulses + 20 min/h dark	Rhode Island Red (week 20−36)	Shorter light pulses (20 m) → ↑ laying rate, ↑ egg mass, ↑ shell thickness → ↑ antioxidant capacity, ↓ oxidative stress No effect on feed intake, BW, egg weight, Haugh unit, or yolk index	Farghly et al. (2019)

al., 2022b). The study compared continuous lighting schedules (16 hours of light and 8 hours of darkness, 14 hours of light and 10 hours of darkness, and an equal light-dark cycle of 12 hours each) with intermittent lighting schedules (12 hours of light followed by 2 hours of darkness, 4 more hours of light, and 6 hours of darkness; 10 hours of light followed by 2 hours of darkness, 4 hours of light, and 8 hours of darkness; and 8 hours of light followed by 4 hours of darkness, 4 hours of light, and 8 hours of darkness). The results showed that continuous lighting led to significantly higher ovarian weight, oviduct weight, oviduct length, and the number of large yellow follicles and small yellow follicles compared to intermittent lighting, suggesting that continuous light may be more beneficial for reproductive development. This effect may be attributed to the extended photoperiod, which promotes follicular development and reproductive organ growth, as increased light exposure has been linked to enhanced ovarian activity and hormone secretion (Renema et al., 2001b). However, no effect on egg-laying rate was observed during 22−30 weeks, indicating that while photoperiod and lighting patterns influence reproductive organ development, these changes may not immediately translate into increased egg production in the early laying period. Additionally, different light regimes significantly affected feeding, egg-laying, and sleeping behaviors, likely due to variations in energy allocation and behavioral adaptations to different light-dark cycles (Schwean-Lardner et al., 2012; Raap et al., 2015). These findings underscore the significance of photoperiod management in enhancing hen welfare and performance.

Beyond direct reproductive effects, lighting also influences hormonal regulation and photoreception. Another study investigated the impact of various lighting regimes on laying performance, pineal melanopsin expression, and melatonin levels in Beijing You Chicken hens (Geng et al., 2022a). The study compared continuous lighting schedules (16 hours of light and 8 hours of darkness) with an equal light-dark cycle, and an intermittent lighting schedule (12 hours of light, followed by 2 hours of darkness, 4 more hours of light, and 6 hours of darkness). The results showed that lighting regimes did not affect egg mass, laying rate, or feed efficiency but significantly influenced feed intake. Specifically, feed intake was significantly higher in the 12L:12D group, suggesting that variations in light-dark cycles may regulate feeding behavior (Ma et al., 2001). Additionally, pineal melanopsin mRNA expression was upregulated in the 12L:2D:4L:6D group and downregulated in the 12L:12D group, indicating that intermittent lighting may enhance photoadaptation in poultry (Hannibal et al., 2007). Moreover, melatonin levels varied across lighting treatments, with the lowest levels observed in the 16L:8D group at 29 weeks of age. A significant negative correlation was detected between melanopsin expression and melatonin concentration at 34 weeks, supporting previous findings that melanopsin plays a key role in light signal detection and melatonin regulation (Reiter, 1991; Hattar et al., 2002). These findings suggest intermittent lighting may promote melanopsin expression and modulate melatonin secretion, potentially improving photoadaptation in (Beijing You Chicken) BYC hens.

In addition to reproductive and hormonal changes, lighting schedules can also impact productivity and eggshell quality. An intermittent lighting regime can enhance egg production and eggshell thickness in Rhode Island Red laying hens by optimizing rest periods and metabolic efficiency (Farghly et al., 2019). The study compared a continuous lighting schedule of 16 hours of light and 8 hours of darkness with two intermittent lighting schedules using light pulses. In the first intermittent schedule, hens were exposed to short light pulses of 20 minutes per hour, followed by 40 minutes of darkness, while the second schedule provided longer light pulses of 40 minutes per hour, followed by 20 minutes of darkness. Hens subjected to an intermittent schedule with shorter light pulses exhibited significantly higher egg-laying rates and egg mass than those under continuous lighting or longer light pulses, likely due to reduced physical activity in darkness and increased energy conservation (Ma et al., 2013). Additionally, eggshell thickness was greatest under shorter light pulses, suggesting improved calcium utilization, possibly through enhanced calcium deposition mechanisms during extended scotophase (Geng et al., 2014). These effects were accompanied by an increase in total antioxidant capacity and a reduction in oxidative stress markers, indicating potential benefits to overall physiological health (Metwally et al., 2021). However, no significant differences were observed in feed consumption, body weight, or other egg quality parameters, such as egg weight, Haugh unit, and yolk index (Yuri et al., 2016). These findings indicate intermittent lighting with brief, frequent light exposures may enhance production efficiency while maintaining egg quality in commercial layer systems.

While intermittent lighting optimizes energy utilization, extending the dark phase may further enhance eggshell quality by affecting calcium metabolism. Prolonging the dark phase in a 24-hour light cycle influenced eggshell quality by modifying calcium and phosphorus metabolism in laying hens (Xin et al., 2021). Extending scotophase from 8 to 15 hours reduced feed intake and egg weight but significantly improved eggshell hardness, likely due to enhanced calcium and phosphorus deposition. During the extended dark period, blood calcium and phosphorus levels remained elevated, while enzyme activity related to bone resorption was lower, suggesting a shift in calcium mobilization dynamics (Ren et al., 2019). Additionally, the upregulation of calcium transporters, such as calbindin-D28k and osteopontin, in the eggshell gland further supports the role of prolonged scotophase in facilitating mineralization (Pines et al., 1995; Athanasiadou et al., 2018). Aligning the photoperiod with the physiological demands of eggshell formation through an extended dark phase may serve as an effective strategy to enhance shell strength in laying hens.

Taken together, these findings emphasize that light programs not only influence egg production and quality but also regulate circadian rhythms, hormonal balance, and metabolic efficiency. Beyond productivity, light programs also regulate circadian behaviors, including feeding, egg-laying, and sleeping patterns (Kristensen et al., 2007). Different photoperiods impact ovarian development, hormone secretion, and metabolic balance. While continuous lighting has been linked to enhanced ovarian and oviduct development, its effect on egg production remains inconclusive (Renema et al., 2001b; Geng et al., 2022b). Light schedules also influence melatonin secretion and photoadaptation mechanisms (Reiter, 1991; Geng et al., 2022a). Additionally, extending the dark phase (scotophase) improves eggshell hardness by enhancing calcium and phosphorus deposition (Ren et al., 2019; Xin et al., 2021), while intermittent lighting optimizes energy use, increasing egg mass and eggshell thickness while reducing oxidative stress (Farghly et al., 2019; Metwally et al., 2021). These findings underscore the importance of well-managed lighting programs in enhancing production efficiency and welfare.

CONCLUSION

Artificial lighting has a significant impact on the productivity, welfare, and physiological responses of laying hens. Advances in LED technology have enabled precise control over light intensity, spectrum, and duration, allowing for tailored lighting strategies that enhance reproductive efficiency and egg quality. Red-spectrum LED lighting has the potential to improve ovarian function and feed efficiency, while blue and green light may support growth and eggshell strength. Proper light intensity management is crucial, as both excessively bright and dim environments can negatively impact hen behavior and stress levels. Additionally, well-structured photoperiods, including intermittent lighting and extended dark phases, can optimize reproductive hormone regulation and calcium metabolism. While LED lighting offers numerous advantages, further research is needed to refine lighting protocols that balance economic efficiency with hen welfare. Optimized lighting programs in commercial poultry production can improve sustainability, productivity, and welfare.

ACKNOWLEDGMENTS

This research study was funded by the project (RS-2024-00400914) of the Rural Development Administration, Republic of Korea.

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Received Jun. 4, 2025, Revised Jun. 16, 2025, Accepted Jun. 16, 2025