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The effects of red and white LED lighting on laying performance in hens over 72 weeks of age

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Abstract

Artificial lighting has enabled improvements in egg production, and different types of light and wavelengths have been tested to achieve better production results in the past. It has been established that red light positively affects the laying performance of hens when such a lighting programme is applied prior to sexual maturation. However, few studies have investigated the effects of light colour on the performance of laying hens during the final stages of production. This study examined the effects of supplementing natural light with white or red lighting during the autumn–winter season on the laying performance, feed intake, average egg weight, egg mass, and feed conversion per egg of laying hens, and the albumen height, yolk colour, and Haugh units of their eggs. The effects on shell thickness, shell strength, body mass, ovary weight, and oviduct weight were also assessed. A total of 7680 70-week-old Lohmann LSL laying hens housed in four California-type sheds were used in the study. Hens exposed to the white light treatment had significantly heavier ovaries; however, no significant differences between red and white lighting were found among the other evaluated variables.

Keywords: egg production, light colour, photoperiod

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Introduction

Light is a crucial environmental factor that regulates various physiological processes in animals, particularly reproduction. In avian species, photoperiod plays an essential role in the regulation of reproductive cycles (Bédécarrats & Hanlon, 2017). Since the significance of photoperiod in bird reproduction was first identified (Rowan, 1931), numerous studies have explored how artificial lighting can enhance egg production in commercial operations.

Light stimuli trigger a complex neuroendocrine cascade in the hypothalamic–pituitary–gonadal axis, regulating the secretion of gonadotropin-releasing hormone. Gonadotropin-releasing hormone

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subsequently stimulates the pituitary secretion of gonadotropins, including luteinising hormone and follicle-stimulating hormone, which, in turn, regulate gonad development and function (Bédécarrats & Hanlon, 2017). The mechanisms underlying the activation of this axis in birds, as well as its composition and integration, have been described in a number of papers (Bédécarrats, 2015; Bédécarrats & Hanlon, 2017).

Chickens (*Gallus gallus*) have seven types of photoreceptor cells in their retinas, including one rod and six cones. Their colour vision is tetrachromatic, enabling the perception of violet, blue, green, and red. Double cones are thought to enhance the ability of birds to detect movement (Kram *et al.*, 2010). In addition to the light receptors in their retinas, fowl have other intracranial photoreceptors that respond only to long-wavelength light (Raziq *et al.*, 2020). Consequently, some colours may be more stimulating than others (England & Ruhnke, 2020).

Evidence suggests that anthropogenic genetic changes have reduced the visual capacity of chickens, compared with that of other birds and their wild ancestors (Kristensen *et al.*, 2007). However, chickens' vision is still superior to that of humans, and their eyes constitute a greater proportion of their cranial volume (Kamanli *et al.*, 2015; Seifert *et al.*, 2020). Hens perceive light with wavelengths between 320 nm and >700 nm. Hens also perceive ultraviolet (UV)-A radiation and use it to assess the fitness of cocks; therefore, breeder birds may not be able to evaluate each other in their preferred way in the absence of light of this wavelength (Prescott & Wathes, 1999). Supplemental UV light has consequently been found to reduce fear and stress in hens during the early lay period (Rana *et al.*, 2024). Lighting also controls sexual maturation, leading to an advance or delay, according to the photoperiod. However, hens must be photosensitive to respond appropriately to this stimulation. Research has confirmed that the red spectrum is the most potent stimulator of sexual maturation (Baxter *et al.*, 2014).

With the development of more energy-efficient lamps, such as light-emitting diodes (LEDs), several studies have evaluated the effects of using LED lights of various colours for lighting programmes (Huber-Eicher *et al.*, 2013; Hassan *et al.*, 2014; Su *et al.*, 2021; Wei *et al.*, 2022; Hanlon *et al.*, 2023; Osadcha *et al.*, 2023; Bahuti *et al.*, 2023; Barros *et al.*, 2024). While these studies have used varying light intensities, a recent study found that 5 lx (lumen/m^2) was sufficient to ensure that birds could access feeders and drinkers comfortably, thereby avoiding potential losses in egg production (Bahuti *et al.*, 2023).

Extending the production period of laying hens to over 72 weeks is a global goal. This could enhance profits, sustainability, and food security (Guo *et al.*, 2021; Koeleman, 2024). Although numerous studies have investigated the effects of different lighting programmes on younger hens, few have examined the impact of different light wavelengths on the laying performance of hens over 70 weeks of age. Thus, the objective of this study was to evaluate the effects of natural light supplementation with red and white LED lamps on the production and quality of eggs from commercial laying hens over 70 weeks of age.

Materials and methods

This study was approved by the Animal Use Ethics Committee of the State University of Northern Paraná (CEUA/UENP) under reference number 03/2021. The study was conducted on a commercial farm in Palmital, São Paulo State (22°47'14.86'' S, 50°14'4.39'' W) between April and July of 2022, during the autumn–winter season.

A total of 7680 70-week-old commercial laying hens of the Lohmann LSL line were used. The birds were housed in four California-type sheds equipped with nipple drinkers and trough feeders, all of which were under automatic control. Each shed consisted of four rows of 96 cages, with a capacity of five birds per cage (450 cm^2 per bird), totalling 1920 birds per shed. The sheds were spaced 5 m apart. The hens were randomly distributed in an experiment consisting of two treatments (white and red LED) with eight replicates each, and with each replicate comprising 96 cages containing 480 birds. The hens were allowed to adapt to the LED lighting systems for 10 days prior to data collection. Data were collected over three 28-day periods for each of the treatments.

Lighting systems consisting of white LED lamps (Empalux® model E27 - AL10762: 6500 K, 10 W; Empalux, 2025) or red LED lamps (Empalux® model AL10319: 10 W, 650 nm; Empalux, 2023) were used for the treatments, with both systems built using SMD 2835 LEDs (Ledestar, 2021). Both treatments consisted of 13 lamps distributed throughout the sheds (Figure 1), with a standardised light intensity of 15 lx, calculated according to the dimensions of the sheds and measured using a digital lux meter (Instrutemp® model ITLD 300; Instrutemp, 2023). Measurements were taken at the level of the hens' heads. Sunlight intensity was not measured inside the houses because California-type houses provide sufficient light intensity for the hens' needs during the day (Gongruttananun & Guntapa, 2012; Bahuti *et al.*, 2023).

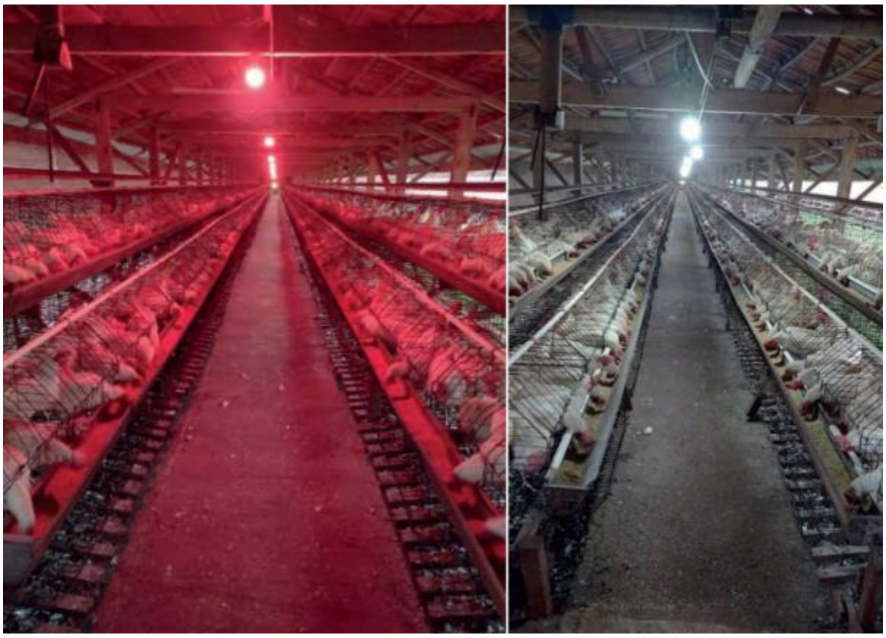

Figure 1 View of the experimental treatments in which laying hens were provided with red or white light-emitting diode-based lighting.

The artificial lighting system was connected to a timer and photocell to provide a continuous lighting programme of 16 hours, consisting of 10 hours of natural light and 6 hours of artificial light. The lights were turned on at 05:00 and switched off at sunrise, which occurred at around 07:00. The hens were then exposed to natural light until 17:00, after which the lights were turned on and kept on until 21:00. The luminous intensity of the sunlight inside the facilities was not measured in this study. Figure 2 shows the intensity of the sunlight in the sheds with the lamps turned off during the day.

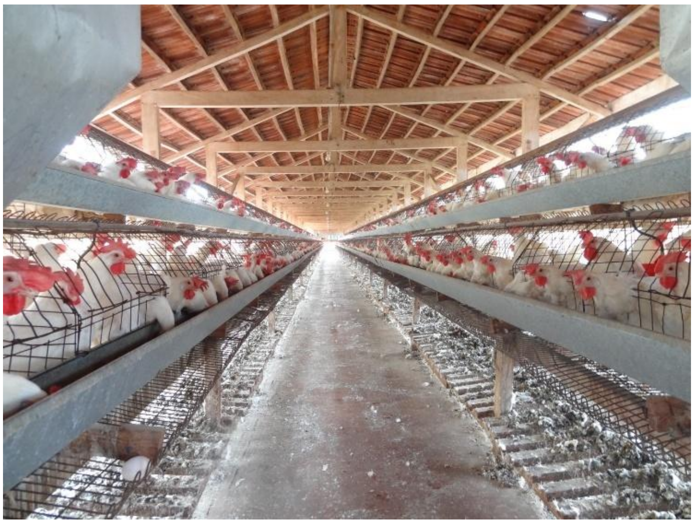

Figure 2 Visual luminosity of sunlight inside the sheds during the day, with the lamps turned off.

The birds were fed according to the nutritional requirements of their lineage, as shown in Table 1.

Table 1 Composition of the feed provided to the laying hens during the course of the study

Macro ingredients	Weight (kg)
Ground maize	221
Ground millet	500.18
Soybean meal	120
Coarse limestone (38% calcium)	60
Limestone (38% calcium)	47.75
Meat and bone meal	21
Wheat bran	20
Vitamin and mineral supplement[1]	4
Sodium chloride	3.2
DL-methionine 99%	0.5
L-lysine 98%	2.300
Betaine hydrochloride	0.035
Red pigment	0.035
Total weight	1000
Nutritional composition	
Metabolisable energy (kcal/kg)	2743.892
Crude protein (%)	15.627
Ether extract (%)	3.867
Crude fibre (%)	2.733
Calcium (%)	4.585
Total phosphorus (%)	0.565
Xanthophylls (mg/kg)	7.478

[1]Composition per kg of product: 26.67 g/kg zinc (min), 4 g/kg copper (min), 18.33 g/kg iron (min), 30.00 g/kg manganese (min), 400 mg/kg iodine (min), 100 mg/kg selenium (min), 39.25 g/kg choline (min), 497.60 mg/kg phosphatidylcholine (min), 150 mg/kg folic acid (min), 5.67 mg/kg biotin (min), 2233.34 mg/kg pantothenic acid (min), 2 833 321 IU/kg vitamin A (min), 366.68 mg/kg vitamin B_1 (min), 3500 µg/kg vitamin B_{12} (min), 1233.31 mg/kg vitamin B_2 (min), 366.68 mg/kg vitamin B_6 (min), 900 000 IU/kg vitamin D_3 (min), 2666.67 IU/kg vitamin E (min), 700.00 mg/kg vitamin K_3 (min), 7000 mg/kg niacin (min), 100 000 ftu/kg phytase (min), and 9333.3 mg/kg zinc bacitracin.

Laying performance and feed consumption data were collected daily during the three experimental periods. At the end of each period, 10 eggs from each replicate were randomly selected for quality analyses. Water and feed were provided *ad libitum* throughout the study. Leftover feed was collected, weighed, and deducted from the supply, and mortality was considered when calculating the daily feed consumption.

The feed conversion efficiency per egg mass was calculated by dividing the feed intake (in kg) by the egg mass (in kg). Egg mass was calculated by multiplying the egg production by the average egg weight in kilograms. The feed conversion efficiency per dozen was calculated by dividing the feed intake (in kg) by the number of dozens of eggs produced.

Egg quality was assessed using a Digital Egg Tester (DT6000, Nabel Co. Ltd., 2017). Analyses were performed to determine the albumen height, yolk colour (YolkFan™ colour scale; DSM-Firmenich, 2025), average egg weight (g), Haugh unit, shell thickness, and shell strength. For the shell percentage, the shells were washed and dried at room temperature for 48 hours and then weighed using a Scientech SA 210 analytical balance (Scientech, 2006). At the end of the experimental period, two hens with similar live weights were collected from each shed line and euthanised by cervical dislocation for necropsy to obtain the weights of the ovaries and oviducts.

The variables were initially subjected to the Shapiro-Wilk test to verify whether the data presented a normal distribution. An analysis of variance was performed to compare the mean results of the treatment groups. Variables with normal distributions are reported as arithmetic means and standard deviations. An independent samples t-test (P <0.05) was used to compare the different treatments.

Two tables summarising the laying performance data from several studies were created for comparison purposes. Table 3 compares laying age phases under white and red lights, and Table 4 considers the effects of other colours and wavelength combinations.

Results and discussion

Egg weight and laying performance did not differ between the lighting treatments: egg weight was 63.44 g for the white LED hens and 63.87 g for the red LED hens. These results are similar to those reported in the Lohmann LSL management guide (Lohmann Breeders, 2020), where the target value for egg weight for hens aged 70 to 85 weeks is 64.4 g, and the egg production ratio is 72.2% per housed bird. The average egg production values found for the treatments in this study were similar to those in the breed manual, with 87.52% for the white LED hens and 86.88% for the red LED hens (Table 2).

Table 2 Egg weights and laying performance (mean ± standard deviation) of hens exposed to white or red light-emitting diode (LED) lighting

	Lighting treatments				*P*-value
	White LED	**SEM**	**Red LED**	**SEM**	
Egg weight (g)	63.44 ± 5.09	0.3031	63.87 ± 6.09	0.3653	0.622
Laying performance (%)	87.52 ± 2.88		86.89 ± 1.74		0.363

Significance level: P <0.05. SEM: standard error of the mean.

Raziq *et al.* (2020) observed that Lohmann LSL-Lite hens maintained under red LED lighting had a higher egg number and overall egg production percentage (90.81%) than those maintained under white LED lighting (86.95%). However, hens aged 33 to 50 weeks and exposed to white LED light had significantly higher egg weights than those exposed to red LED light. Kim *et al.* (2010) found that hens exposed to red light initiated laying earlier and reached 50% egg production significantly sooner than those reared under other light colours. By 59 weeks of age, hens maintained under red LED lights produced the largest number of eggs per hen (271.62), when compared to those reared under white lights (259.98 eggs/hen) or incandescent lights (251.76 eggs/hen). Egg weight was significantly higher from 26 to 35 weeks of age under red lighting, but showed no significant difference from 16 to 25 weeks of age. Hassan *et al.* (2014) reported that monochromatic red light increased egg production (87.34%) in Hy-Line Brown hens, and that a combination of red and green light (R→G) resulted in even higher egg production (89.56%). However, from 22 to 48 weeks of age, egg weight was notably higher under blue and green light treatments than under monochromatic red light.

Huber-Eicher *et al.* (2013) demonstrated that red light significantly enhanced early laying performance, with hens under red lights achieving 70.66% laying performance at 22 weeks of age, compared to the 52.00% achieved by hens under white lights. Min *et al.* (2012) concluded that Hy-Line Brown pullets reared under red light matured significantly earlier, and subsequently exhibited higher egg production than those reared under incandescent or blue light. Tez & Akşit (2024) reported that Lohmann Brown hens reared under monochromatic red LED light reached sexual maturity and peak egg production five and four days earlier, respectively, than those reared under white light, and therefore produced 2.05% more eggs. Li *et al.* (2014) indicated that Chinese local mountainous laying hens reared under red light produced more eggs from the age of first egg to 42 weeks compared to other groups.

Reddy *et al.* (2012) asserted that red lighting improved the laying performance of hens over 72 weeks of age, based on a sample of 24 birds. However, these researchers reported that incandescent bulbs emit light at a wavelength of 450 nm, whereas incandescent bulbs have a range of emissions, between 300 nm and 1400 nm. Additionally, the light intensity was measured in watts per square meter (W/m^2), which complicates comparisons with other studies, which report light intensity in lumens (lux).

Conversely, some studies have found no significant differences in egg production when red light was directly compared with white or control light, as observed in this study. Svobodová *et al.* (2015) reported no significant differences in hen–day egg production or egg weight among ISA Brown hens exposed to blue, green, red, or yellow LED lights from 22 to 75 weeks of age. Er *et al.* (2007) reported no significant difference in overall egg production from 19 to 52 weeks of age between Hy-Line Brown hens under incandescent white lights (85.15%) and red lights (85.53%). However, for the later period of production (38–52 weeks), hens under red lights (87.47%) had significantly higher overall egg production than hens under blue and green lights, but this did not significantly differ from those under white lights. Poudel *et al.* (2022) observed no difference in hen–day egg production between Hy-Line W-36 hens under red (64.04%) and white (65.71%) LEDs (P = 0.775) during the laying phase (17–31 weeks). Borille *et al.* (2013) showed that egg production rates were significantly higher for hens under red LEDs (91.25%), white LEDs (91.95%), and incandescent lights (91.58%), compared to those under green and blue LEDs, but there were no significant differences among the red, white, and incandescent light sources for the ISA Brown layer hens. Additionally, Min *et al.* (2012) found no significant difference in egg production between red and white lights across all the tested periods.

It is clear that red light has a positive effect on the laying performance of hens. Nonetheless, some controversy still exists regarding whether these positive effects persist throughout all laying phases. Furthermore, it is essential to consider other factors, such as pre-exposure, nutrition, genetics, type of lamp, lighting intensity, photoperiod duration, and age of the birds, as these can also significantly influence the results. This complicates the comparison of findings in the literature because these variables differ between the studies. Furthermore, a recent study found that constant exposure to red light wavelengths led to lower egg-laying performance because of refractoriness (Hanlon *et al.*, 2023).

Er *et al.* (2007) evaluated three different laying periods of hens between 19 and 52 weeks of age and did not find significant differences in laying performance between red and white LED lights. In addition, Hassan *et al.* (2013) did not find significant differences in production between 22 and 57 weeks of age for hens under red and white LED lighting. In contrast, Soliman *et al.* (2023) and Huber-Eicher *et al.* (2013) found better results for laying performance between 25 and 40 weeks of age. Table 3 presents a comparison of the effects of red and white light according to the age of the hens during the study. Table 4 presents a more complete comparison of the laying performance of hens reared under different colours of light and wavelength combinations, as evaluated in several studies.

Table 3 Comparison of the laying performance (%) of hens reared under red or white lights across different studies and laying age phases

Source	Laying age period (weeks)	Red light (%)	White light (%)	*P*-value
Er *et al.* (2007)				
	19 to 52	85.53	85.15	>0.05
	19 to 37	83.58	87.31	>0.05
	38 to 52	87.47	84.66	>0.05
Hassan *et al.* (2013)				
	22 to 57	87.79	86.16	>0.05
Soliman *et al.* (2023)				
	Overall mean	74.94[a]	68.42[b]	≤0.001
	25th week	10.85[a]	3.95[b]	≤0.001
	30th week	85.63[a]	83.73[b]	≤0.05
	35th week	83.95[a]	79.73[b]	≤0.001
	40th week	78.88[a]	75.15[b]	≤0.001
Huber-Eicher *et al.* (2013)				
	22nd week	70.66[a]	52.00[b]	<0.001

[ab] Values with different superscripts are significantly different between treatments.

Table 4 Average laying performance (%), average egg units per hen (n), and daily egg production (n) per hen under different lighting treatments and at different hen ages, as evaluated in various studies

Author	Hens' age (weeks)	Lighting treatments												
		White LED	Red LED	Blue LED	Green LED	Yellow LED	Orange LED	Inc. bulb	G-R	R→G	R→B	R→G→B	R→B→G	*P*-value
Er *et al.*, 2007*	38–52	86.71^{ab}	87.47^{a}	84.66^{b}	84.78^{b}	N/A	N/A	NA	N/A	N/A	N/A	N/A	N/A	<0.05
Kim *et al.*, 2010[1]*	59	259.98^{ab}	271.62^{a}	249.09^{b}	249.82^{b}	249.78^{b}	NA	251.76^{b}	N/A	N/A	N/A	N/A	N/A	<0.05
Min *et al.*, 2012*	18–60	85.95^{ab}	87.96^{a}	80.92^{c}	NA	NA	NA	83.34^{bc}	N/A	N/A	N/A	N/A	N/A	<0.05
Reddy *et al.*, 2012[2]	72–82	N/A	67.78^{a}	N/A	N/A	N/A	N/A	47.76^{b}	N/A	N/A	N/A	N/A	N/A	<0.01
Huber-Eicher *et al.*, 2013	22	52.00^{b}	70.66^{a}	N/A	40.49^{b}	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	<0.05
Hassan *et al.*, 2013	22–57	86.16^{bc}	87.79^{ab}	84.28^{c}	85.82^{bc}	N/A	N/A	N/A	N/A	88.99^{a}	N/A	N/A	87.88^{ab}	0.004
Borille *et al.*,2013*	56–72	91.95^{a}	91.25^{a}	89.14^{b}	86.84^{c}	89.21^{b}		91.58^{a}	N/A	N/A	N/A	N/A	N/A	<0.05
Hassan *et al.*, 2014	40–48	89.86^{bc}	87.34^{ab}	83.75^{c}	85.26^{bc}	N/A	N/A	N/A	N/A	89.56^{a}	86.26^{b}	87.48^{ab}	86.76^{b}	0.002
Li *et al.*, 2014[3]	63	170.84	173.11	171.09	170.36	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	<0.05
Svobodová *et al.*, 2015	22–75	N/A	87.01	84.77	83.9	86.75	N/A	N/A	N/A	N/A	N/A	N/A	N/A	≤0.05
Raziq *et al.*, 2020	33–50	86.95^{b}	90.81^{a}	N/A	83.40^{c}	N/A	N/A	N/A	80.65^{c}	N/A	N/A	N/A	N/A	<0.0001
Poudel *et al.*, 2022[4]*	17–31	65.71	64.04	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	≤0.05
Soliman *et al.*, 2023	0–40	74.94^{a}	N/A	N/A	N/A	N/A	N/A	68.42^{b}	N/A	N/A	N/A	N/A	N/A	≤0.001
Osadcha *et al.*, 2023[5]	18–52	N/A	212.1^{d}	199.4^{a}	N/A	205.4^{b}	206.2^{c}	N/A	N/A	N/A	N/A	N/A	N/A	<0.05
Tez & Akşit, 2024	18–32	83.47^{a}	85.52^{b}	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.007

^{abc} Values with different superscripts are significantly different between treatments. [1] Number of eggs produced per hen (n). [2] Average (%) weekly egg production (72–82 weeks of age). [3] Total number of eggs at 63 weeks of age. [4] Daily egg production per hen. [5] Average egg-laying per hen. * Studies found no significant difference in egg production between the white and red lighting treatments at the mentioned age intervals. LED: light-emitting diode. Inc. bulb: incandescent bulb lamp. G-R: dichromatic lighting treatment with green and red light wavelengths. R→G: a lighting treatment that features red and green light wavelengths in that order of predominance. R→G→B: a lighting treatment that consists of red, green, and blue light wavelengths in that order of predominance. R→B→G: a lighting treatment that consists of red, blue, and green light wavelengths in that order of predominance. N/A: not applicable.

By analysing the comparative data from these two tables, it is evident that the egg-laying performance results depend on several factors, and that some studies have reported no significant differences between treatments with red and white light.

No differences between the treatments were observed in the feed consumption, feed conversion per egg mass, or feed conversion per dozen eggs (Table 4).

Table 5 Feed consumption, feed conversion per egg mass, and feed conversion per dozen eggs (mean ± standard deviation) of laying hens exposed to white or red light-emitting diode (LED) lights

	Lighting treatments		
	White LED	**Red LED**	***P*-value**
Feed consumption (g/bird/day)	107.90 ± 2.15	105.52 ± 4.32	0.622
Feed conversion (kg/kg eggs)	2.01 ± 0.11	1.98 ± 0.13	0.379
Feed conversion (kg/dz eggs)	1.55 ± 0.09	1.54 ± 0.11	0.646

Significance level: $P < 0.05$.

These results are similar to those of other studies in which no significant differences were found in feed consumption under different light colour conditions (Gongruttananun & Guntapa, 2012; Borille *et al.*, 2013; Raziq *et al.*, 2020). However, some studies have reported higher feed intakes in birds reared under red lights (Huber-Eicher *et al.*, 2013).

The feed conversion ratio seems to be more affected by the photophase duration, the type of lighting, and the production phase than by the colour of the lights used (Soliman *et al.*, 2023; Tez & Akşit, 2024). However, some studies have found more efficient feed conversion rates during the most productive phase when birds were reared under red lights (Min *et al.*, 2012; Raziq *et al.*, 2020; Tez & Akşit, 2024). Hassan *et al.* (2014) found that using combinations of red, green, and blue lights, as well as monochromatic red and green lights, improved the feed conversion efficiency. This concurred with the results of Barros *et al.* (2024), who found a better feed conversion ratio ($P = 0.0500$) when using a light treatment consisting of a dominant red band (43.7% 625–740 nm), indicating that having a higher intensity of red light than other light colours had a positive effect on feed conversion. Nonetheless, it should be noted that hens aged between 20 and 40 weeks were used in this study.

Table 6 reports the results of the egg quality parameters measured in this study, including the albumen height, Haugh unit, and yolk colour.

Table 6 Albumen heights, Haugh units, and yolk colours (mean ± standard deviation) of eggs produced by laying hens exposed to white or red light-emitting diode (LED) lights

	Lighting treatments		
	White LED	**Red LED**	***P*-value**
Albumen height (mm)	7.70 ± 1.04	7.60 ± 0.83	0.195
Haugh unit	86.57 ± 6.02	85.93 ± 5.67	0.196
Yolk colour[1]	5.92 ± 1.04	5.89 ± 1.08	0.780

Significance level: $P < 0.05$. [1] Yolk colour is a key factor in the consumer assessment of the internal quality of chicken eggs. Preferences for yolk colour intensity differ between countries; however, most consumers worldwide favour eggs with orange yolks (Saleh *et al.*, 2021).

These findings are consistent with those of other studies, indicating that different light colours do not influence egg quality parameters (Huber-Eicher *et al.*, 2013; Borille *et al.*, 2013; Hassan *et al.*, 2014; Raziq *et al.*, 2020; Su *et al.*, 2021). However, Poudel *et al.* (2022) found that the yolk percentage was higher ($P = 0.0435$) when hens were reared under red LED lights (23.37%) than when they were reared under white LED lights (22.49%), and that the albumen percentage was lower ($P = 0.015$) under red LED lights (67.05%) than under white LED lights (68.25%). Despite these varying results, it is clear that lighting and photoperiod are fundamental to egg quality (Bédécarrats & Hanlon, 2017).

Natural or artificial carotenoids in the diet influence the intensity of yolk colouration (Grashorn, 2016; Wang *et al.*, 2024); thus, diets with a higher carotenoid concentration result in eggs with more intense yolk colouration. In the present study, the feed formulation was not varied, and the tested lighting programme did not affect yolk colour. The eggshell quality indices and shell thickness values (Table 7) similarly did not differ between the treatments.

Table 7 Eggshell quality indices (mean ± standard deviation) of eggs produced by laying hens exposed to white or red light-emitting diode (LED) lights

	Lighting treatments		
	White LED	**Red LED**	***P*-value**
Shell strength (kgf)	3.73 ± 1.09	3.71 ± 0.97	0.821
Shell percentage (%)	9.59 ± 0.69	9.68 ± 0.97	0.231
Shell thickness (mm)	0.37 ± 0.03	0.37 ± 0.03	0.208

Significance level: $P < 0.05$.

Other studies have supported these findings, as they found no significant differences in shell parameters when hens were reared under different LED light colours (Gongruttananun & Guntapa, 2012; Raziq *et al.*, 2020; Poudel *et al.*, 2022). However, two studies have reported that the strongest and thickest eggshells were produced by hens reared under red LED lights (Kim *et al.*, 2010; Min *et al.*, 2012), and two other studies found that hens reared under green LED lights had better results (Er *et al.*, 2007; Hassan *et al.*, 2014).

The eggshell consists of approximately 95% calcium carbonate, and the diet provides 60%–70% of this essential mineral. However, because of an offset of calcium intake during the light period, a dark period is necessary for calcium fixation during eggshell production. The remaining 30%–40% of the calcium used to produce eggshells is mobilised from the bone, particularly from the medullary bone. This type of bone is produced at the onset of sexual maturity, and lighting programmes applied during this time could therefore affect eggshell quality parameters (Hervo *et al.*, 2022).

The body and reproductive system weights (ovaries and oviducts) of the hens exposed to red or white LED lights were also evaluated. No differences were observed in the body and oviduct weights (Table 8). However, there was a difference between the treatments in the ovary weight, with birds exposed to white LED lights having heavier ovaries than those exposed to red LED lights.

Table 8 Body, ovary, and oviduct weights (mean ± standard deviation) of laying hens over 72 weeks of age exposed to artificial lighting with white or red light-emitting diode (LED) lights

	Lighting treatments		
	White LED	**Red LED**	***P*-value**
Body weight (kg)	1.65 ± 0.04	1.65 ± 0.05	0.524
Ovary weight (g)	3.17^{a} ± 0.38	2.77^{b} ± 0.63	0.0369
Oviduct weight (g)	3.95 ± 0.36	3.82 ± 0.51	0.434

^{ab} Means followed by different letters in the same row differ significantly ($P < 0.05$).

Hassan *et al.* (2013) found that laying hens had heavier ovaries at 22 weeks of age when reared under red lights ($P = 0.002$). Another study similarly found that the ovaries of laying hens reared under red lights were heavier than those of hens reared under other colour lights between 16 and 20 weeks of age ($P < 0.05$) (Kim *et al.*, 2010). However, Gongruttananun & Guntapa (2012) did not find any significant differences in the ovary weights of 28-week-old Thai indigenous hens reared under red and other light-colour treatments. Min *et al.* (2012) reported that the ovary weights of laying pullets grew significantly at 16 weeks of age (P <0.05) when they were reared under white LED lights. However, there were no significant differences between the light treatments in ovary weight at 20 weeks of age. Red light thus seems to enhance ovary weight; however, its impact varies based on light intensity, exposure duration, and the age and breed of the hens. We suspect that the white LED lights used in this study emit a combination of wavelengths, which could affect ovarian weight. However, we cannot confirm this assumption because we did not measure reproductive hormone levels.

The main limitation of this study was that the experiments were performed in a commercial production system. Therefore, it was not possible to provide completely artificial lighting for all the birds, as they were housed in a California-type shed system. However, this approach allowed the effects of lighting supplements to be evaluated using large numbers of birds. An additional study is planned to investigate the effects of red lighting on the laying performance of hens over 72 weeks of age in a fully enclosed shed system with artificial lighting.

Conclusions

Despite previous studies finding that exposure to red light improved laying performance, this effect depended on the pre-exposure during sexual maturation and the age of the hens. Thus, the colour of the light used did not affect the laying performance and egg quality characteristics of commercial laying hens aged over 70 weeks in this study. Further studies using extended photophases and only artificial lighting are necessary to assess the impact of coloured LED lights on laying performance and egg quality in hens beyond 70 weeks of age. Additionally, it is essential to consider nutritional and genetic factors when evaluating the effects of red light on hens over a 72-week period. It can be concluded that under California-type shed conditions, either red or white lights can be utilised without negatively impacting the laying performance of hens.

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Authors' contributions

N.M.P. Monteiro collected the data for this study, and collaborated in the manuscript writing and the interpretation of results. D. Sato was involved in writing the manuscript, English revision, statistical revision, interpretation of the results, and communication of responsibilities. B.D.R. Bombem participated in writing the manuscript. J.E. De Moraes collaborated in the planning and execution of the experiment. D.R. Rodrigues and E.P. Porto conducted the statistical analyses. L.O. Silva and E.R. Duarte were involved in running the trial. M.A.A. Silva contributed to writing, statistical analysis, leadership, experimentation, and planning.

Conflict of interest declaration

The authors have no conflicts of interest to declare.

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