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Effect of light-emitting diode (LED)-based colors on production performance and welfare of commercial layers

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Abstract: Artificial light, in terms of its intensity and color, is of significant importance for the performance of laying hens. In this study, the efforts were made to evaluate the effect of different light-emitting diode (LED)-based light colors on production performance, welfare, and egg quality attributes of Lohmann LSL lite hens in an open-sided house. For this, 200 commercial laying hens were distributed into 4 treatment groups, having 5 replicates of 10 birds each. The treatments included different LED colors, i.e. white, monochromatic green, monochromatic red, and dichromatic red–green. Green light significantly increased body weight as compared to other LED light colors. Egg number and overall egg production percentage were higher in birds maintained under red LED. Egg mass was better under white light as compared to the rest of the treatments. Feed conversion ratio per dozen eggs and kg egg mass were better in birds reared under red and white LED lights, respectively. Initially, footpad dermatitis and feather cleanliness scores were not influenced by the light color; however, significant effects were recorded at 50 weeks of age. Hormonal profiles of laying birds also revealed several differences at 50 weeks of age under different LED light colors. Keeping in view the overall production performance and considering the fitness of the bird, red LED light may best serve the purpose.

Key words: LED light colors, production performance, egg quality, hormonal profile, and welfare

1. Introduction

Artificial lighting is one of the most vital management tools for egg-type birds. It is considered to be responsible for beginning or delaying of laying, improving egg production, and optimizing feed efficiency. It also influences vision, growth, reproduction, and welfare [1] by modulating various behavioral and physiological pathways [2]. Light in the poultry house is aimed at feeding, maintenance of the thermal environment, and to regulate the production cycle in egg-type birds [3]. Light has four basic aspects that can affect birds including intensity, photoperiod (duration), spectral content (color), and source [4]. Avian species identify light through retinal and extraretinal photoreceptors [5]. Light perceived by these photoreceptors (pineal gland and hypothalamic gland) is responsible for sexual development and reproductive success of poultry [6]. However, the extraretinal photoreceptors can only be activated by long-wavelength radiation that can penetrate the skull and head tissues [7]. Therefore, artificial lights from the best available source, for a particular duration having a specific color must be applied to the laying house to achieve the expected production level of laying birds.

Nowadays, fluorescent and LED light sources are used in the poultry sector. Recent studies suggest that LED sources are more efficient in terms of overall production performance and consume less electricity. LED is also used worldwide because of its low energy consumption [8]. LED light sources are available in several colors and each color is responsible for different functions [9]. The effects of light color on poultry performance have been studied by various researchers [10]. However, these studies are too old and very few investigated the LED-based light colors regarding production performance, egg quality, and welfare of laying hens. Furthermore, these studies used older technologies with less control over the spectral output and used birds of different genetic makeup. Therefore, the present study intended to fill in the gap regarding LED-based lights colors' effects on the production performance, egg quality, welfare, and hormonal profiles of laying hens.

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2. Materials and methods

The current study was performed to determine the effect of different LED light colors on production performance, egg quality, hormonal profile, and welfare of commercial layers. The study was conducted at the Department of Poultry Production, University of Veterinary and Animal Sciences (UVAS), A-Block, Ravi Campus, Pattoki, Pakistan for 17 weeks (33–50 weeks). Pattoki is located at 31° 1′ 0N, and 73° 50′ 60E with an altitude of 186 m (610 ft). This city experiences normally hot and humid tropical climate with temperature ranging from 5 °C in winter to +45 °C in summer.

2.1. Ethical approval

The care and use of birds were performed following the laws and regulations of Pakistan and the study was approved by the Committee of Ethical Handling of Experimental Birds (No. DR/985), UVAS.

2.2. Population size

Thirty-three-week-old commercial layers of LSL lite strain (1273 ± 22 g) were distributed into 4 groups and assigned to four light colors (white LED, monochromatic red LED, monochromatic green LED, and dichromatic red–green LED) according to completely randomized design. Each group consisted of 5 replicates with 10 birds in each; hence, a total of 200 birds were subjected to the experimentation.

2.3. Birds' husbandry

The birds were maintained in an independent open-sided laying house with the east to west dimension measuring 6.10 × 6.10 m (37.21 m^2), equipped with two rows of 3-tiered laying cages measuring 5.18 × 1.52 m (47.42 m^2) with sloping wire floor to facilitate egg collection. Removable dropping trays were fitted under the mesh floor for the removal of fecal material. Feeding of the birds was done through removable individual trough feeders installed outside the cage and watering through with the automatic nipple drinker system fitted therein. The birds were fed with commercial laying ration with an allowance of 100 g / bird /day and availability of freshwater was ensured throughout the experimental period and routine management practices were carried out (Table 1).

2.4. Light intensity

In the rearing and growing period, natural day length and in the production phase, 40–50 lx light was provided [11]. When the age of maturity is reached, the photoperiod was increased by 30 min per week until a total of 16 h/day. Required light intensity was checked and evaluated by using a digital lux meter (at Poultry Production department, UVAS, Lahore-Pakistan) under the bulbs. Light intensity was checked at 33, 40, 45, and 50 weeks of age. Light intensity at bird level was maintained 20 lx throughout the experimental period. The bulbs were 12-W LED bulbs with a temperature of 5000 K and considered as cool light (Paramount LED BULB).

Table 1. The feed composition of experimental birds during the starter and grower phases.

Ingredients	Starter (g/100 g)	Grower (g/100 g)
Corn	55.65	58.37
Soybean meal 44%	30.72	27.24
Canola meal	10	6.00
Sunflower meal	0	1.60
Calcium carbonate	1.21	1.27
Monocalcium phosphate	0.56	0.61
*Premix	0.50	0.50
Vegetable oil	0.32	3.27
Lysine sulphate	0.30	0.33
DL Methionine	0.27	0.27
Salt	0.20	0.14
Soda bicarb	0.19	0.31
L-Threonine	0.07	0.08
Phytase 10000	0.01	0.01
Composition		
Crude protein (%)	22.48	20.05
Metabolizable energy kcal/kg	2800	3025

*Premix contained vitamin A: 9000 I.U; vitamin D3: 3250 I.U; vitamin E: 30 I.U; vitamin K3: 4 mg; thiamine: 3.5 mg; riboflavin: 8 mg; vitamin B6: 4.4 mg; vitamin B12: 1.5 mg; folic acid: 1 mg; vitamin B5 calcium-D-pantothionate: 12 mg; niacin: 55 mg; biotin: 5 mg; choline chloride: 700 mg; selenium: 50 mg; zinc: 110 mg; copper: 67.2 mg; iron: 394 mg; manganese: 172 mg; potassium iodide 0.8 mg; furazolidone 100 mg; maduramicin: 50 mg.

2.5. Parameters studied

2.5.1. Production performance

The effect of different light colors was determined on body weight gain from 33 to 50 weeks of age. Moreover, average daily feed intake, daily egg number, and egg weight were recorded to calculate egg production (%), feed conversion ration per dozen eggs (FCRdz), and per kg egg mass (FCRem) until 50 weeks of age.

2.5.2. Egg characteristics

The egg quality analysis was conducted at 33 and 50 weeks of age. For this purpose, 5 eggs per replicate were collected each time, respectively. First of all, egg geometry parameters were evaluated, egg length and egg width were recorded by using a Vernier caliper and these parameters were used to evaluate egg shape index (cm), surface area (cm^2), and volume (cm^3). The eggs were subjected to an estimation of egg specific gravity analysis using the protocol of Hempe et al. [12]. The eggshell thickness of each egg was measured using a micrometer screw gauge. Albumen height of each egg was measured using a Digital Haugh tester (ORKA Food Technology Ltd) and the measurement result was used to calculate the Haugh unit (HU) score using the formula $HU = 100 \times \log (H - 1.7 \times W^{0.37} + 7.6)$, where H is the height of albumen (mm) and W is the egg weight (g). Yolk index was measured as a ratio of yolk height to yolk width [13]. Eggshell breaking strength (N) was also measured by placing the eggs lengthwise and using an Egg Force Reader (ORKA Food Technology Ltd).

2.5.3. Bird welfare

Welfare was evaluated for every bird at the age of 33 and 50 weeks. Welfare-related aspects such as cannibalism, feather cleanliness score (FS), and footpad dermatitis (FPD) were studied. The feather cleanliness was scored on a scale of 0 to 3 by examining individual birds and noting how clean their breasts were. A score of 0 indicates clean, 1 indicates slightly dirty, 2 indicates very noticeably dirty, and 3 indicates almost completely dirty [14]. Footpad dermatitis was scored on a five-point scale from no lesion to severe lesions (0 = no lesions, 4 = severe lesions) according to the welfare assessment protocol of the Netherlands [15].

2.5.4. Physiological response

The physiological response of each bird was assessed at 33 and 50 weeks of age by measuring their respiration rate (RR), heartbeat rate (HR), and body temperature (BT). The respiratory rate was recorded by holding the birds in an inverted position and observing the abdominal movements for 1 min [16]. The heartbeat rate was measured using a stethoscope (3M™ Littman© Classic III, USA). The body temperature (°F) was recorded using Medicare digital translucent thermometer (MANA & Co, Pakistan).

2.5.5. Hormonal profiles

For this purpose, blood samples were collected from three females per replicate at 50 weeks of age (15 birds from each treatment; 30% of the total population) and serum was extracted for further analysis. The following test was performed by a local laboratory (Decent Hormone Lab), at Lahore, Pakistan using specific kits:

Triiodothyronine (T3) using Total T3 RIA Kit (Ref # IM199 & IM3287)

Thyroxin (T4) using Total T4 RIA Kit (Ref # IM1447 & IM3286)

Gonadotropin-releasing hormone (GnRH), using Elabscience (Lot No # E1TF7MCWQB)

Follicular stimulating hormone (FSH) using FSH IRMA Kit (Ref # IM2125 & IM3301)

Catalase following Hadwan and Abed [17].

Cortisol using CORTISOLRIA Kit (Ref # IM841)

Luteinizing hormone (LH) using LH IRMA Kit (Ref # IM1381 & IM3302).

2.6. Statistical analysis

Collected data were analyzed through one-way ANOVA in SAS software [18]. Significant treatment means were separated through DMR test considering the probability level of $P \leq 0.05$ assuming the following mathematical model:

$$Y_{ij} = \mu + \tau_i + \epsilon_{ij}$$

where

Y_{ij} = observation of dependent variable recorded on i^{th} treatment group

μ = population mean

τ_i = effect of i^{th} light colors (i = 1, 2, 3 and 4)

ϵ_{ij} = random error

3. Results and discussion

3.1. Production performance

Findings of the present study revealed that green LED light significantly increased the body weight gain, followed by white LED light, green–red LED, and red LED light, respectively. The increase in weight gain in birds treated with green LED light is within the optimum range in the laying phase.

Results of the current study indicated that feed intake (FI) was recorded the same in different experimental groups treated with different LED light colors throughout the study. Thus, a nonsignificant effect was recorded on FI for different LED light colors. FCR was recorded in terms of per dozen eggs and egg mass/weight, under different LED light colors. Significantly low and good FCR, (FCR/dz and FCR/em), was found in a group of birds that were placed under red LED and white LED, respectively as compared to other groups. Egg number was significantly affected by different LED colors throughout the trial. A significantly higher number of eggs were recorded in the experimental group treated with red LED light, followed by white LED, green LED, and green–red LED light, respectively. Similarly, egg mass was also significantly influenced by different LED colors; significantly higher egg mass was recorded under white LED light, followed by green LED, green–red LED, and red LED light, respectively. Egg production (%) was significantly influenced by the light color in laying hens. birds exposed to red light had the highest egg production (90.81%), those that received white light had the intermediate (86.95%) while a gradual decline in production was observed in birds exposed to green (83.40%) and a mixture of green and red light (80.65%) (Table 2).

FCR is the main parameter determining the farm profit/loss because feed comprises more than 70% of the production costs in all poultry enterprises [19]. Light color was found to have a profound influence on

Table 2. Production performance of commercial layers maintained under different LED colors (33 to 50 weeks).

Trait	Red LED	Green LED	White LED	Green–red LED	P-value
FI	100.00 ± 0.00	100.00 ± 0.00	100.00 ± 0.00	100.00 ± 0.00	NS
IBW	1246.00[c] ± 4.00	1298.00[a] ± 0.95	1278.00[b] ± 2.00	1270.40[b] ± 2.40	<0.0001
FBW	1438.00[d] ± 5.15	1636.00[a] ± 5.10	1589.00[b] ± 2.92	1545.00[c] ± 8.66	<0.0001
BWG	192.00[d] ± 3.74	338.00[a] ± 5.09	311.00[b] ± 2.92	275.40[c] ± 11.20	<0.0001
EN	114.42[a] ± 1.57	105.08[c] ± 1.82	109.56[b] ± 1.45	101.62[c] ± 0.88	<0.0001
EM	6243.01[d] ±15.97	6493.15[b] ±23.01	6657.97[a] ± 34.25	6351.76[c] ± 20.03	<0.0001
EP	90.81[a] ± 1.24	83.40[c] ± 1.45	86.95[b] ± 1.15	80.65[c] ± 0.70	<0.0001
FCRdz	1.32[c] ± 0.02	1.44[a] ± 0.03	1.38[b] ± 0.02	1.49[a] ± 0.01	<0.0001
FCRem	2.02[a] ± 0.01	1.94[c] ± 0.01	1.89[d] ± 0.01	1.98[b] ± 0.01	<0.0001

Means with different superscripts in the same row differ significantly (P ≤ 0.05); FI: Feed intake (g); IBW: Initial body weight (g) at 33 weeks of age; FBW: Final bodyweight at 50 weeks of age; BWG: Body weight gain (g); EM: Egg mass; EN: Egg number; EP (%): Egg production (%); FCRdz: Feed conversion ratio per dozen; FCRem: Feed conversion ratio per kg egg mass.

growth performance. Findings of the present study are supported by those of Blatchford et al. [20], who observed an increased feed intake (FI) in broilers reared under red LED light. This increased feed intake (FI) might be due to a longer red LED light wavelength which tends to increase its physical locomotory activities only. Our results are also in agreement with the findings of Halevy et al. [21], who noticed that muscle growth was accelerated in birds exposed to green light. This enhanced growth may be because of the plasma androgens elevation that increases protein synthesis and decreases destruction, consequently maintaining myofibrils and muscle growth [22]. Our results are supported by those of Takeshima et al. [23], who observed an increased egg production (%) in layers reared under red LED light compared to those reared in green LED light. Such an increased egg production (%) might be due to an increased E_2 (estradiol) concentration in the layer's plasma [24].

3.2. Egg quality

Different colors of LED light in housed hens considerably affected egg weight. Significantly higher egg weight was recorded in the group of birds that were treated with white LED light, followed by green LED, green–red LED, and red LED light, respectively. However, other egg quality parameters either external or internal, i.e. egg specific gravity, egg length, egg breadth, EBS, EST, ESW, YI, and HU, remained nonsignificant among different treatments (Table 3).

Islam et al. [25] stated that egg weight is one of the vital phenotypic traits which influence egg quality and reproductive fitness of the chicken parents. Er et al. [26] recorded a different light color influence on poultry egg quality. Berger [27] recorded a significant difference in egg breaking strength of layers reared under white light as compared to those reared under red LED light and recorded a higher Haugh unit under red as compared to white LED. Li et al. [28] recorded an increased egg breaking strength and eggshell thickness in layers reared under red LED light. This might be due to estradiol (an ovarian hormone which is responsible for vitamin D production and eggshell calcification (calcium metabolism)) [29]. Hassan et al. [30] observed a higher eggshell strength in layers reared under green LED. This improvement in layers' eggshell strength might be due to the growth hormones, which helps in calcium absorption in the small intestine [31]. Min et al. [32] observed that blue and green light is responsible for the improvement in hen egg weight, eggshell thickness, and breaking strength. This might be due to a light short wavelength. Elkomy et al. [33] recorded a higher pullet egg yolk index (%) and Haugh unit score in quails reared under white LED as compared to those reared in red and green LED. Our results are supported by those of Jácome et al. [34], who observed nonsignificant effect on layer egg specific gravity under various LED light colors, e.g., red, white, and blue.

3.3. Egg geometry

Egg geometry traits were evaluated in laying hens treated with different LED light colors. The egg geometry parameters [egg volume (EV), egg shape index (ESI), and egg surface area (ESA)] were not significantly altered by different colors of LED. LED light color did not influence hens' egg geometry in any productive phase, i.e. from 33 to 50 weeks) (Table **4**). However, significant differences were found on quail egg length and width. The highest egg volume (12.34 cm^3) was measured under white light as compared to other LED light colors. Yang et al. [35] recorded a nonsignificant effect in the egg shape index of layers grouped treated with different light colors. Chang et

Table 3. Egg quality of commercial layers maintained under different LED colors.

Trait	Red LED	Green LED	White LED	Green–red LED	P-value
Egg quality at 33 weeks of age (initial)					
EW (g)	56.29^{c} ± 0.26	59.36^{a} ± 0.32	59.91^{a} ± 0.43	58.02^{b} ± 0.17	<0.0001
EBS (N)	70.00 ± 0.71	70.80 ± 0.80	69.60 ± 0.51	69.00 ± 0.89	0.4031
ESW (g)	6.44 ± 0.22	6.48 ± 0.21	6.46 ± 0.20	6.46 ± 0.27	0.9995
EST (mm)	0.47± 0.02	0.50 ± 0.03	0.48 ± 0.02	0.50 ± 0.03	0.7621
HU	100.56 ± 0.50	99.46 ± 0.65	100.53 ± 0.37	100.77 ± 0.28	0.2348
EYI (%)	47.78 ± 0.85	48.72 ± 0.83	48.27± 0.56	47.84 ± 1.21	0.8659
ESG	1.09 ± 0.00	1.09 ± 0.00	1.09 ± 0.00	1.09 ± 0.00	0.6660
Egg quality at 50 weeks of age (final)					
EW (g)	62.44 ± 1.60	65.00 ± 1.58	63.40 ± 1.17	64.24 ± 0.56	0.5552
EBS (N)	59.21 ± 4.36	67.40 ± 2.68	63.24 ± 1.45	66.38 ± 1.09	0.1799
ESW (g)	8.40 ± 0.33	9.58 ± 0.04	8.96 ± 0.41	8.56 ± 0.34	0.0739
EST (mm)	0.31 ± 0.00	0.30 ± 0.01	0.32 ± 0.01	0.30 ± 0.02	0.6207
HU	87.40 ± 3.63	96.31 ± 2.48	90.47 ± 1.71	94.19 ± 5.08	0.3091
EYI (%)	63.04 ± 1.04	64.40 ± 0.51	63.40 ± 0.93	65.44 ± 0.23	0.1450
ESG	1.09 ± 0.00	1.09 ± 0.00	1.09 ± 0.00	1.09 ± 0.00	0.6706

Means with different superscripts in the same row differ significantly (P ≤ 0.05); EG: Egg weight (g); EBS: Egg breaking strength (Newton); ESW: Eggshell weight (g); EST: Eggshell thickness (mm); HU: Haugh unit; EYI: Egg yolk index (%), ESG: Egg specific gravity.

Table 4. Egg geometry of commercial layers maintained under different LED colors (at 33 and 50 weeks of age).

Trait	LED Red	LED Green	LED White	LED Green Red	*P*-value
Egg geometry at 33 weeks of age					
EV (cm^3)	45.73 ± 1.05	47.22 ± 1.21	46.11± 0.79	46.00 ± 1.05	0.7559
ESA (cm^2)	62.80 ± 0.96	64.16 ± 1.10	63.25 ± 0.84	63.16 ± 0.72	0.7564
ESI (cm)	74.06 ± 1.16	74.69 ± 0.26	74.04 ± 1.39	75.18 ± 0.43	0.7021
Egg geometry at 50 weeks of age					
EV (cm^3)	51.59 ± 2.78	55.83 ± 1.32	54.74 ± 1.00	54.18 ± 1.15	0.3785
ESA (cm^2)	74.43 ± 0.91	75.42 ± 1.19	70.75 ± 2.26	73.92 ± 1.05	0.1662
ESI (cm)	73.32 ± 0.95	75.68 ± 1.42	74.80 ± 2.58	77.20 ± 0.66	0.6265

Means with different superscripts in the same row differ significantly (P ≤ 0.05); EV: Egg volume (cm^3); ESA: Egg surface area (cm^2); ESI: Egg shape index (cm).

al. [36] observed a lower shape index of geese egg under monochromatic red and white as compared to blue LED light color. This lower ESI might be due to a red LED light longer wavelength.

3.4. Physiological response

The physiological response of laying hens reared under different lighting colors was evaluated through different aspects like respiration rate, heartbeat, and body temperature (BT). At both dates of collection, data revealed that there were no significant effects for respiration rate and heartbeat rate (HBR), while body temperature (BT) was significantly increased in birds that were reared under red LED light (Table 5).

In the current study, we recorded an increased body temperature in layers treated with red LED light as compared to other LED light colors. The reason might be that red LED has the longest wavelength and therefore increased stress, fairness, and discomfort in layers. Sultana et al. [37] reported a significant effect of light color on poultry physiological response. Physiological welfare parameters are most closely associated with stress physiology. Mohamed et al. [38] observed higher levels of physiological responses to stress in Mallard ducks reared under red LED and white LED light. This might be due to the longer wavelength. Zheng et al. [39] recorded that both color and source of light were responsible for the increase in birds' body temperature. Our results are supported by those of Morrill et al. [40], who observed the highest and lowest respiratory rates in broilers exposed to red and green LED light colors, respectively. This might be due to light wavelengths. Klandorf et al. [41] observed higher and lower heart rates in layers exposed to light and darkness, respectively. This elevated heart rate might be due to increased T3 levels in layer plasma. The highest heart rate was recorded in layers treated with red LED light as compared to those treated with other LED light colors. Our findings are supported by those of Wohlfarth and Sam [42], who recorded an increased heart rate under red LED light. This might be due to the correlation between longer wavelength and increased systolic pressure.

3.5. Welfare traits

Welfare effects of laying hens reared under different lighting colors were assessed through different parameters like footpad dermatitis (FPD) and feather scoring (FS). In the beginning, at 33 weeks of age, no positive effect of different light colors was recorded for FPD and FS in laying hens, while at 50 weeks, higher incidence of FPD was observed ($P \leq 0.05$) in birds that were reared under red LED light, followed by green, green–red, and white LED lights, respectively (Table 6).

Patel et al. [43] recorded the effects of different LED light colors on laying hens' behavior and reported a higher cannibalism rate in hens treated with red light as compared to those treated with blue LED light. The reason might be that the red LED light would reach the hypothalamus more rapidly as compared to blue light. Another trait that

Table 5. Physiological response of commercial layers maintained under different LED colors (at 33 and 50 weeks of age).

Trait	Red LED	Green LED	White LED	Green–red LED	P-value
Physiological response at 33 weeks of age					
BT	$105.25^{a} \pm 0.16$	$103.02^{ab} \pm 0.17$	$104.96^{ab} \pm 0.22$	$104.63^{b} \pm 0.14$	0.1421
HBR	311.60 ± 7.25	300.00 ± 7.07	308.00 ± 12.94	303.40 ± 6.90	0.7706
RR	22.20 ± 0.97	20.00 ± 1.10	21.40 ± 2.18	18.20 ± 1.16	0.2542
Physiological response at 50 weeks of age					
BT	$105.26^{a} \pm 0.18$	$104.70^{ab} \pm 0.13$	$103.91^{c} \pm 0.37$	$104.14^{bc} \pm 0.18$	0.0067
HBR	285.00 ± 5.00	275.20 ± 6.55	272.00 ± 3.54	275.00 ± 5.00	0.3412
RR	32.20 ± 3.73	30.80 ± 1.46	29.60 ± 1.63	28.00 ± 1.05	0.5225

Means with different superscripts in the same row differ significantly ($P \leq 0.05$); BT: Body temperature (°F); HBR: Heartbeat rate (beat/minute); RR; Respiratory rate (breath/minute).

Table 6. Welfare aspects of commercial layers are maintained under different colors of LED at 33 and 50 weeks of age.

Trait	Red LED	Green LED	White LED	Green–red LED	P-value
Welfare aspects at 33 weeks of age					
FPD	1.20 ± 0.20	1.20 ± 0.20	1.00 ± 0.00	1.00 ± 0.32	0.8275
FS	1.40 ± 0.24	1.40 ± 0.24	1.40 ± 0.24	1.40 ± 0.24	1.0000
Welfare aspects at 50 weeks of age					
FPD	$3.00^{a} \pm 0.32$	$2.60^{ab} \pm 0.24$	$2.20^{b} \pm 0.20$	$2.40^{ab} \pm 0.24$	0.1887
FS	$4.20^{a} \pm 0.37$	$2.80^{ab} \pm 0.37$	$2.60^{b} \pm 0.24$	$3.20^{ab} \pm 0.37$	0.0223

Means with different superscripts in the same row differ significantly ($P \leq 0.05$); FDP: Footpad dermatitis; FS: Feather scoring.

is directly related to hen welfare is the health of footpads because footpad dermatitis is a serious worldwide problem for commercial poultry including broilers, layers, broiler breeders as well as turkeys [44]. In contrast, Olanrewaju et al. [45] reported that lighting programs are responsible for footpad dermatitis. Our results are in agreement with those of Farghly and Mahrose [46], who stated that light has a significant influence on poultry plumage condition. Shi et al. [47] recorded better plumage condition in hens reared under red and green light as compared to those reared under white light. This might be due to the wavelength difference.

3.6. Hormonal profiles

The association among different LED light colors and reproductive and productive hormones was also investigated in this study. Green–red LED lighting schedule significantly increased the triiodothyronine (T3) as compared to that of other treatment groups, while the highest level of thyroxine (T4) was reported in birds that were reared under green LED light. A significant increase in GnRH, FSH, LH, and Cortisol was recorded in the group of birds maintained under red LED light in comparison with other treatment groups. Catalase was found at an increased level under red as compared to other LED light colors (Table 7).

Thyroid hormones play an important role in regulating the fat metabolism and plasma concentrations of these hormones and could be potential indicators of metabolic activity and physiological responses of birds at commercial poultry farming [48]. Findings of the current study revealed that serum T3 level was significantly increased in the green–red LED group; because this T3 concentration helps LH level boosting, LH is responsible for oviposition and ovulation in domestic goose ganders [49]. The increased T3 level in this group might be attributed to stimulatory effect of red and green color on thyroid epithelial cell which increased the secretion in blood [50]. Mahrous et al. [51] observed a low level of either T3 (under white LED light) or T4 (under yellow LED light) in poultry that might cause a positive nitrogen balance, which stimulates growth parameters. Light is responsible for the stimulation of gonadal development, which results in the onset of egg lay by stimulating hypothalamus through eye or by stimulating pineal gland to secrete GnRH [52]. Results of the current study reported significant increase in GnRH levels in egg-type birds that were reared under red LED light scheme. Our results are supported by those of Kuffman and Rissman [53], who recorded a higher concentration of poultry GnRH hormone level reared under red LED light. This might be due to the longer wavelength of red LED light which has more energy to penetrate through skull and brain tissue to produce GnRH. Data regarding the FSH revealed that LED red light program significantly increased the secretion of FSH and LH in laying birds. This might be because of red light impact on the area of the hypothalamus through the skull receptors, which acts to enhance the GnRH hormone synthesis and works to stimulate the master gland to produce the FSH [54]. Our current findings are in agreement with those of Hassan et al. [55], who noted that red LED light greatly increased the FSH levels in layers. This increase in FSH, LH, and estradiol (E_2) might be due to the longer wavelength of red LED light, which has the strongest penetration power of light through skull and hypothalamus [56]. Light, especially its color, plays a vital role in increasing birds' cortisol level [57]. In the present study, layers' serum cortisol levels were recorded highest. This increased serum cortisol levels in egg-type birds reared under red LED light could be attributed to longer wavelength which causes aggressiveness in birds. Sharma et al. [58] reported that catalase acts as an antioxidant enzyme which protects animals against oxidative stress. Our current results are

Table 7. Hormonal profiles of commercial layers maintained under different colors of LED (at 50 weeks).

Trait	Red LED	Green LED	White LED	Green–red LED	P-value
T_3 (nmol/L)	$1.05^b \pm 0.07$	$1.34^b \pm 0.08$	$1.10^b \pm 0.10$	$1.68^a \pm 0.12$	0.0008
T_4 (nmol/L)	$12.90^b \pm 0.58$	$19.98^a \pm 0.87$	$9.60^c \pm 0.53$	$13.22^b \pm 0.64$	<0.0001
GnRH(pg/ml)	$161.30^a \pm 35.06$	$69.84^c \pm 13.99$	$141.76^{ab} \pm 23.70$	$86.46^{bc} \pm 9.30$	0.0346
FSH (IU/L)	$0.28^a \pm 0.05$	$0.09^c \pm 0.02$	$0.18^b \pm 0.02$	$0.10^{bc} \pm 0.01$	0.0007
LH (IU/L)	$0.17^a \pm 0.01$	$0.05^b \pm 0.01$	$0.15^a \pm 0.02$	$0.05^b \pm 0.01$	<0.0001
Cort (Nm)	$15.42^a \pm 1.58$	$10.60^b \pm 0.47$	$11.84^b \pm 0.88$	$11.08^b \pm 0.95$	0.0203
Cata (kU/L)	2.63 ± 0.21	2.28 ± 0.11	2.33 ± 0.39	2.46 ± 0.28	0.6062

Means with different superscripts in the same row differ significantly ($P \leq 0.05$); T_3 = Triiodothyronine (nmol/L); T_4: Thyroxine (nmol/L); GnRH: Gonadotropin releasing hormone (pg/mL); Cata: Catalase (kU/L); FSH: Follicular stimulating hormone (IU/L); LH: Luteinizing hormone (IU/L); Cort: Cortisol (Nm).

supported by those of Tsybulin et al. [59], who observed an increased catalase enzyme activity in broilers reared under monochromatic red LED. This increased activity might be due to higher absorption power of catalase under longer-wavelength lights. This was further verified by Wu et al. [60], who observed significantly lower catalase activity in turbot larvae reared under blue light as compared to other light colors (green, red, and orange).

4. Conclusion

It is concluded from the above discussion that red LED light causes an improvement in the production efficiency of egg-laying-type birds. No alteration effects of different color light programs were recorded for egg geometry, welfare aspects, and physiological responses. Hormonal profiles of egg-type birds are significantly affected by red LED light program.

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