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Effect of light sources on productivity, welfare aspects, and economic evaluation of commercial layers

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Abstract: The present study was aimed to evaluate the influence of incandescent, fluorescent, and light emitting diode (LED) lights on the productive efficiency and economic aspects of laying hens. For this, 216 laying hens were distributed into three groups of light sources with six replicates each. Each replicate consisted of 12 birds. The data were analyzed in SAS 9.1 (SAS InstituteInc., Cary, NC, USA) by applying one-way ANOVA technique, and significant means were compared through least significant difference test. In the present study, LED light significantly improved the body weight, body weight gain, percentage of egg production, FCR per dozen and FCR per kg egg mass. All parameters for egg quality (excluding egg yolk index and Haugh unit) and egg geometry (including egg shape index, egg surface and volume) were affected by light sources at 24th week, while significant effects were recorded at egg quality (excluding egg Haugh unit and yolk index) and egg geometry (excluding egg volume) at 32nd weeks. Physiological norms (except heartbeat) and welfare aspects (except footpad score) were not affected by light sources; however, footpad score at 32nd week and heartbeat at 17th and 32nd week were significantly better in the pullets under LED lights. Reproductive hormones and metabolic enzymes (T3, T4, GnRH, LH, FSH, and cortisol including catalase enzyme) were significantly better in the birds kept under LED light at the 20th and 32nd weeks. The present findings suggested that productive parameters and reproductive traits, welfare aspects, hormonal profile as well as overall economics of layer production varied significantly based on light sources, and LEDs positively exceeded the fluorescent as well as incandescent light sources.

Key words: Light sources, productive performance, egg quality, hormonal profile, welfare aspects

1. Introduction

Increasing energy costs in poultry production facilities are compelling the producers to find ways of minimizing the cost of production without any compromise on performance and welfare of birds [1]. In developing countries like Pakistan, availability and cost per unit of electricity may create a real panic in many aspects. For example, light in poultry houses aimed at feeding, maintenance of the thermal environment, and regulation of production cycle in egg-type birds may contribute enough towards the total energy cost [2]. The vitality of light can be well understood from the fact that avian species need it before the birds' birth [3]. Birds perceive light through retinal and extra-retinal photoreceptors, which further transform photonic energy into biological signals by photosensitive pigments in the cones and rods of the retina in the eye and transmitted through neurons to the brain where the signals are assimilated in an image [4]. Light related factors involved in affecting the bird's performance are photoperiod, source, intensity, color, and wavelength [5]. Light sources can affect the physiological state by altering various hormones frequency [6]. Therefore, the addition of artificial lights must be applied to the laying house to achieve the expected production level of laying birds. Different lighting programs and light sources have been developed to optimize the health status, production and welfare of the laying birds in laying house [7]. Nowadays, efforts are being made to install fluorescent as well as light emitting diode (LED) instead of incandescent because incandescent light sources' energy consumption is high; they utilize only 5 % energy input for light generation, while rest 95% is wasted in the form of heat [8]. Kamanli et al. [9] stated that there are limited studies about the LED and compact fluorescent lights' effects on the egg production performance, egg quality, and various welfare parameters of layers [10]. Due to

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enormous shortage of energy sources and their progressive increasing costs all over the world, especially in Pakistan, it became essential to achieve efficient lighting for the least costs by applying efficient manipulations [11]. So, it is important to select the most adequate and economic lighting source for raising growing chicks, laying hens, and breeder stocks. Although incandescent and fluorescent bulbs are widely used in modern poultry houses, the use of LEDs is relatively new and it is more energy-efficient than incandescent and fluorescent light sources [12]. Kamanli et al. [9] observed that although LED lamp cost is greater than other sources, its energy consumption is low. LED has superiority over fluorescent and incandescent light sources and can potentially replace these conventional light resources [13]. Some researchers recorded economic benefits of LED [14]. LED light source produces little heat energy and exerts little or no stress on the farmed species. Hence, bird's productive efficiency may be high under LED lights [15]. This study is an effort to compare the egg production, egg quality, hormonal profile, welfare aspects of laying hens, and economics benefits of using conventional and LED light sources in hen houses.

2. Materials and methods

The current trial was performed to determine the effect of different LED light colors on productive performance, egg quality, hormonal profile, and welfare aspects of commercial layers. The study was conducted at the Department of Poultry Production, the University of Veterinary and Animal Sciences, Lahore (UVAS), A-Block, Ravi Campus, Pattoki, Pakistan for 16 weeks (17-32 weeks). Pattoki is located at 31°1'0" N, and 73°50'60" E 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 and +45 °C in summer.

2.1. Ethics

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

2.2. Population size

At the age of 16 weeks, commercial layers of LSL lite strain (1250 ± 22 g) were distributed into three groups and assigned to three light sources (incandescent, fluorescent, and LED) according to completely randomized design. Each group consisted of six replicates with 12 birds in each; hence, a total of 216 birds were subjected to the experimentation.

2.3. Bird's husbandry

Birds were maintained in an independent open-sided laying housed 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. The ventilation, humidity, and house temperature were controlled using ceiling fans, curtains, and other helpful manual techniques. Variations in daily temperature (°F) and humidity (%) were noted using a wet and dry bulb hygrometer (Mason's type, Zeal, England) and later an average of the temperature and humidity were derived on weekly basis (Figure 1). The removable dropping trays were fitted under the mesh floor for the removal of faecal material. Feeding of the birds was done through removable individual trough feeders installed outside the cage and watering through the automatic nipple drinker system fitted therein. Birds were offered a commercial laying ration (Table 1) at 06:00 AM with an allowance of 100 g / bird /day, and availability of fresh water was ensured with nipple drinking system throughout the experimental period.

2.4. Light intensity

During rearing and growing period, natural day length is used, while in production phase 40-50 lux light was provided [16]. Attaining the age of maturity, 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 at bird level was maintained 20 lux throughout the experimental period. The incandescent, fluorescent, and LED bulbs had 100, 26, and 12 W, respectively; they were brought from a local market, and LED bulb with a temperature of 5000 K is considered as cool light (Paramount LED BULB).

2.5. Parameters evaluated

2.5.1. Productive performance

The effect of different light sources was determined on body weight gain from 17 to 32 weeks of age. Moreover, cumulative 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) till 32 weeks of age.

2.5.2. Egg characteristics

The egg quality analysis was conducted at the 24th and 32nd 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 the help Vernier caliper, and these parameters were used to evaluated egg shape index (cm), surface area (cm^2), and volume (cm^3). These eggs were subjected to an estimation of egg specific gravity analysis using the protocol of [17]. The eggshell thickness of each egg was measured using a micrometer screw gauge. Albumen height of each egg was measured using

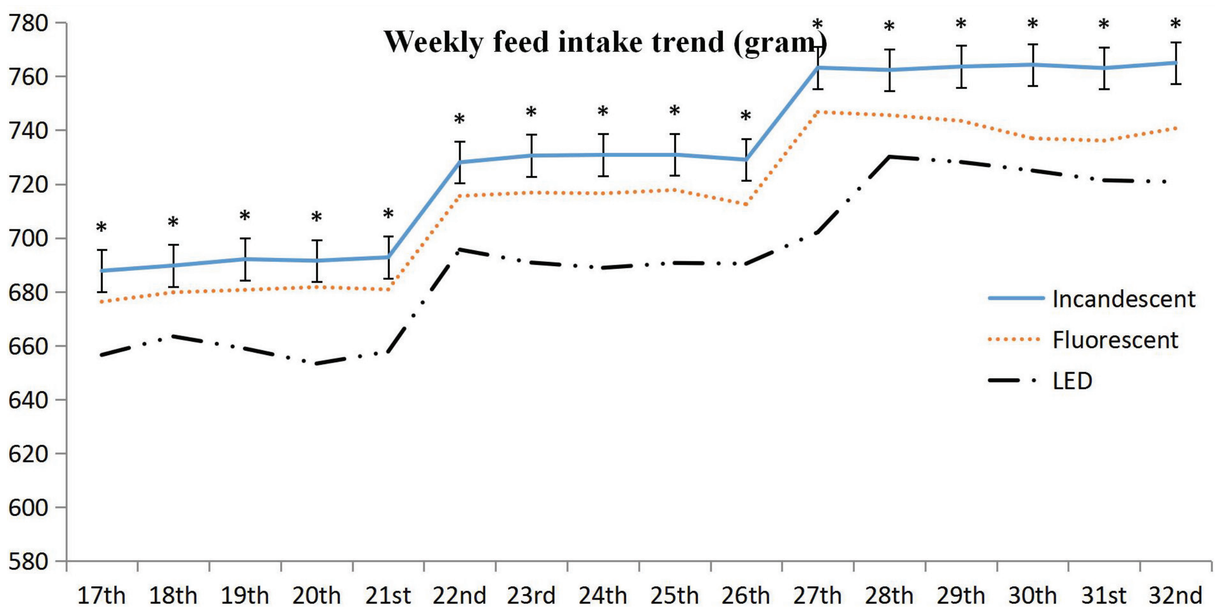

Figure 1. Variation in house temperature and humidity during the experimental period.

Digital Haugh tester (ORKA Food Technology Ltd) and the measurement was used to calculate 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 also measured as a ratio of yolk height to yolk width [18]. Eggshell breaking strength (N) was also measured by placing the eggs lengthwise and using egg force reader (ORKA Food Technology Ltd).

2.5.3. Bird welfare

Welfare traits were evaluated for every bird at the age of 17th and 32nd week. Regarding welfare-related traits: cannibalism, plumage cleanliness (PC) score, and footpad dermatitis (FPD) score were evaluated. The plumage cleanliness scoring involved examining individual birds and noting how clean their breasts were. The scoring was done on a scale of 0 to 3 where 0 indicates a clean bird, 1 indicates a bird with a slightly dirty feather, 2 indicates a very noticeably dirty, and 3 indicates an almost completely dirty bird [19]. 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 Netherland [20]. Cannibalism was also aimed to record by observing the any incidence of prolapsed vagina and pecked vents.

2.5.4. Physiological response

The physiological response of each bird was assessed at the 17th and 32nd week of age by measuring their respiration rate (RR), heartbeat rate (HR), and rectal temperature (RT). The respiratory rate was recorded by holding the birds in an inverted position and observing the abdominal movements for 1 min [21]. The heartbeat rate was

Table 1. Composition of the ration offered to the experimental laying hens.

Ingredient	Inclusion rate (g/100g)
Corn	62.30
Guar meal	3.00
Raw rice bran	4.00
Soybean meal 44 %	1.31
Rape seed meal	2.00
DL-Methionine	0.23
L-threonine	0.08
Calcium carbonate	8.29
Salt	0.11
Corn gluten	1.00
Canola meal	8.00
Cotton Seed meal	4.00
Lysine sulphate	0.36
Premix	0.30
L-Tryptophan	0.01
Fish meal 47 %	1.00
Feather meal 54 %	4.00
Quantum 600FTU	0.01
Total	100.00
Crude protein %	16.5%
Metabolizable energy	2902 Kcal/kg

measured using a stethoscope (3M Littman Classic III, USA). The rectal temperature (°F) was recorded using Medicare digital translucent thermometer with an alarm signal (Product # 693966390034, MANA & Co, Pakistan).

2.5.5. Hormonal profile

For this purpose, blood samples were collected from three birds per replicate at the 20th and 32nd week of age, and serum was extracted for further analysis. The following test was performed by a local laboratory (Decent Hormone Lab. 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)

Cortisol using CORTISOLRIA Kit (Ref # IM841)

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

Catalase following the protocol adopted by Hadwan and Abed [22].

2.6. Statistical analysis

Collected data were tested for normality and after confirming the normal distribution of the data, parametric statistics were applied through one-way ANOVA in SAS software (SAS InstituteInc.) [23]. Significant treatment means were separated through Fisher's least significant difference test considering the probability level of ($P \leq 0.05$) assuming following mathematical model:

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

where: Y_{ij} = observation of dependent variable documented on ith treatment

μ = population mean, t_i = effect of ith treatment i.e., light source (i = 1, 2, 3) for this experiment

ϵ_{ij} = r

esidual outcome of jth observation in ith treatment NID ~ 0, σ^2

3. Results and discussion

3.1. Productive performance

The present findings revealed that LED light source significantly increased the body weight gain in laying hens as compared to other light sources. Trend of weekly feed intake, egg weight, egg production percent, FCR per kg egg mass, and per dozen eggs are expressed in graphs (Figures 2, 3, 4, 5, 6). The increase in bird's weight gain kept under LED light source is within optimum range at laying phase. Cumulative feed intake (FI) per bird was observed significantly different in the experimental groups throughout the trial. Significantly higher FI per bird was observed in the group maintained under incandescent light sources ($P \leq 0.05$). Hen day egg production % (HDEP) and hen housed egg production % (HHEP) were significantly affected by different light sources. Significantly higher

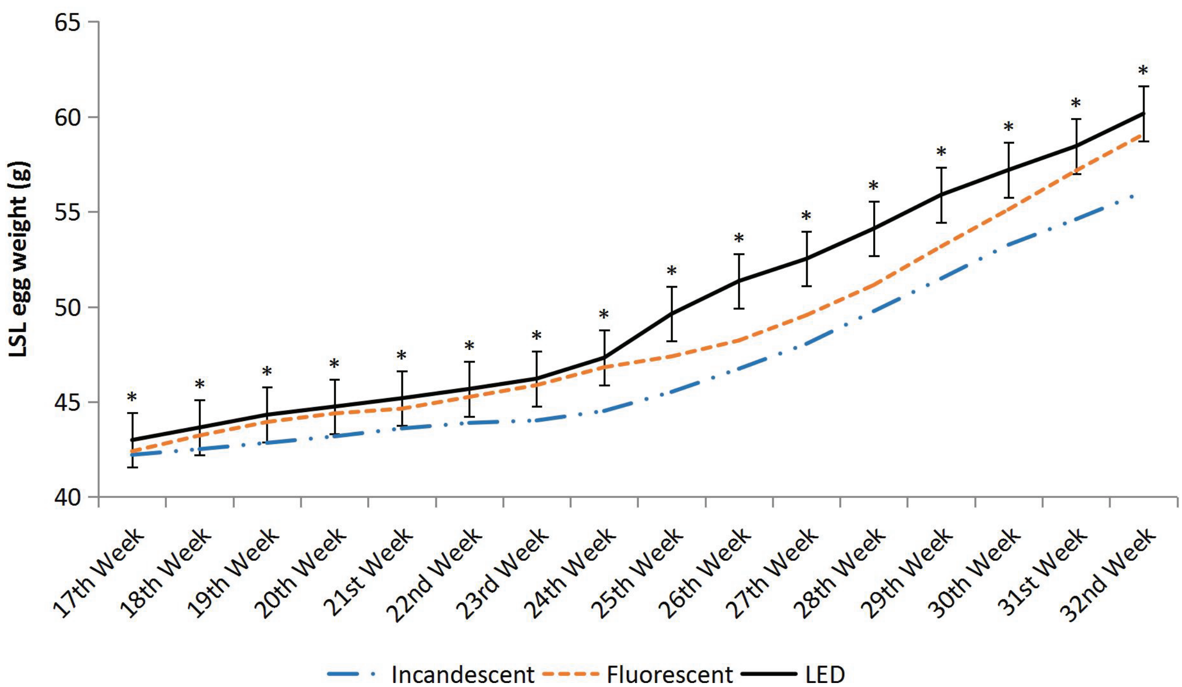

Figure 2. Trend of weekly feed intake (g) on per bird basis (17-32 weeks) maintained under different light sources.

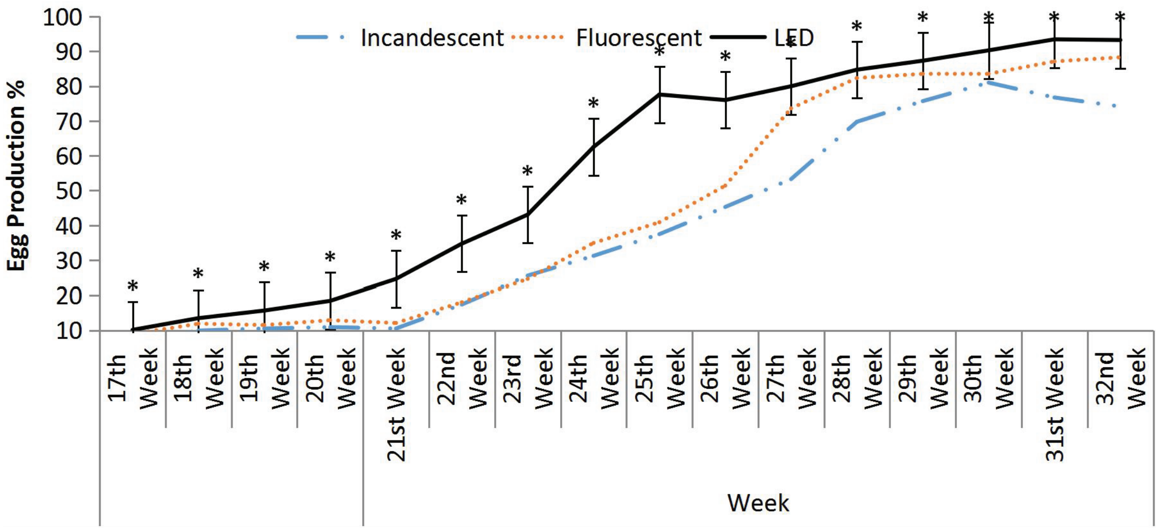

Figure 3. Weekly egg weight (g) trend of birds maintained under different light sources (17-32 weeks).

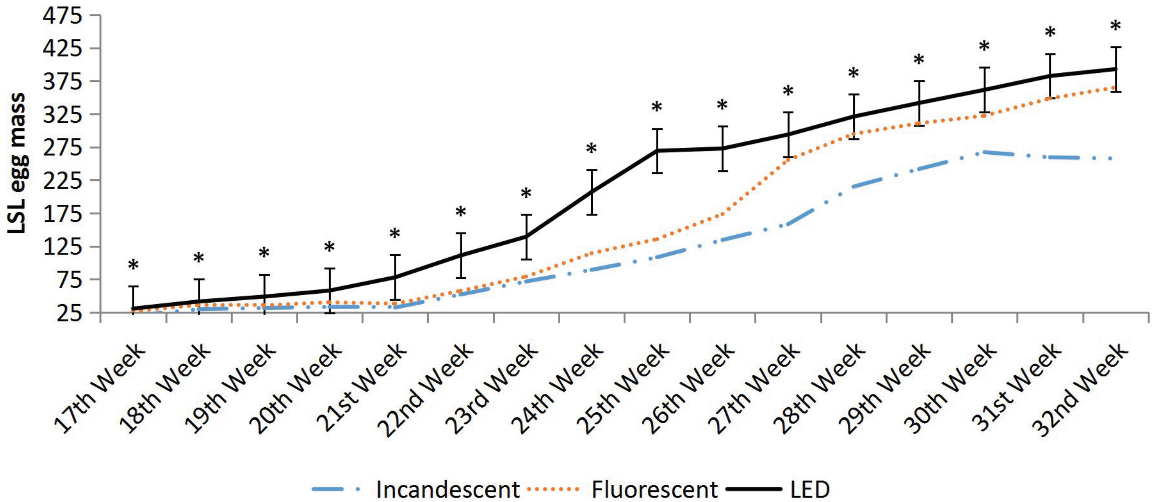

Figure 4. Weekly egg production (%) trend of birds maintained under different light sources (17-32 weeks).

($P \leq 0.05$) hen egg day production % (HDEP) and hen housed egg production % (HHEP) were recorded in light-emitting diodes treated group versus other light sources. Age at sexual maturity (ASM) (days) was recorded to be significantly affected by the light sources in the current trial ($P \leq 0.05$). Feed conversion ratio (FCR) was recorded in terms of a dozen/eggs and per kg egg mass basis. Significantly better FCR per dozen egg and per kg egg mass were recorded in the group of birds that were placed under the light-emitting diodes. Poor FCR values were recorded for the incandescent light source (Table 2). Light is considered as a powerful exogenous factor which helps in the regulation of many physiological processes in birds. In laying birds, light influences many factors like, maturity age, egg formation, feeding behavior, and overall egg production. In the current study, different light sources were evaluated for their effects on different productive parameters of commercial egg-laying hens. The findings of the present study revealed that LED light significantly increased the body weight (BW) and body weight gain (BWG) in laying hens as compared to other sources of light. Our current trial, the results are supported by Olanrewaju et al. [24] who noted improved BW and BWG in pullets exposed to LED compared to those under the fluorescent light source. Hence, it was suggested by them that this may be a result of decreased stress under the LED lighting, which in turn, decreases energy waste and ultimately increases the amount of energy put towards muscle growth, thereby improving conversion of feed into muscle. An increased broiler's cumulative feed consumption is recorded in birds grouped under the incandescent light, because incandescent light source

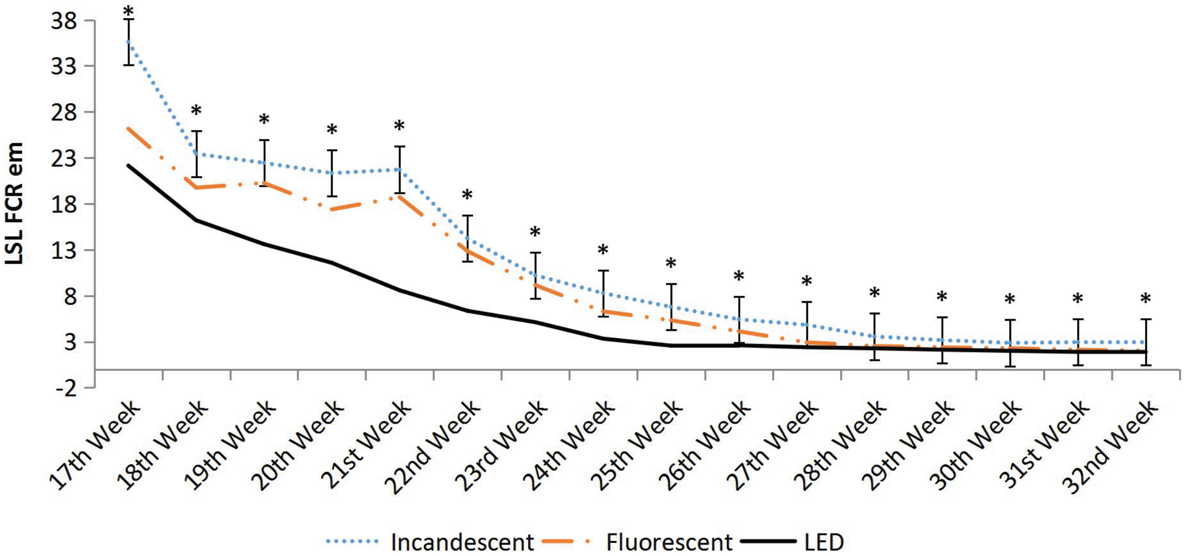

Figure 5. Weekly trend of FCR per kg egg mass of birds maintained under different light sources (17-32 weeks).

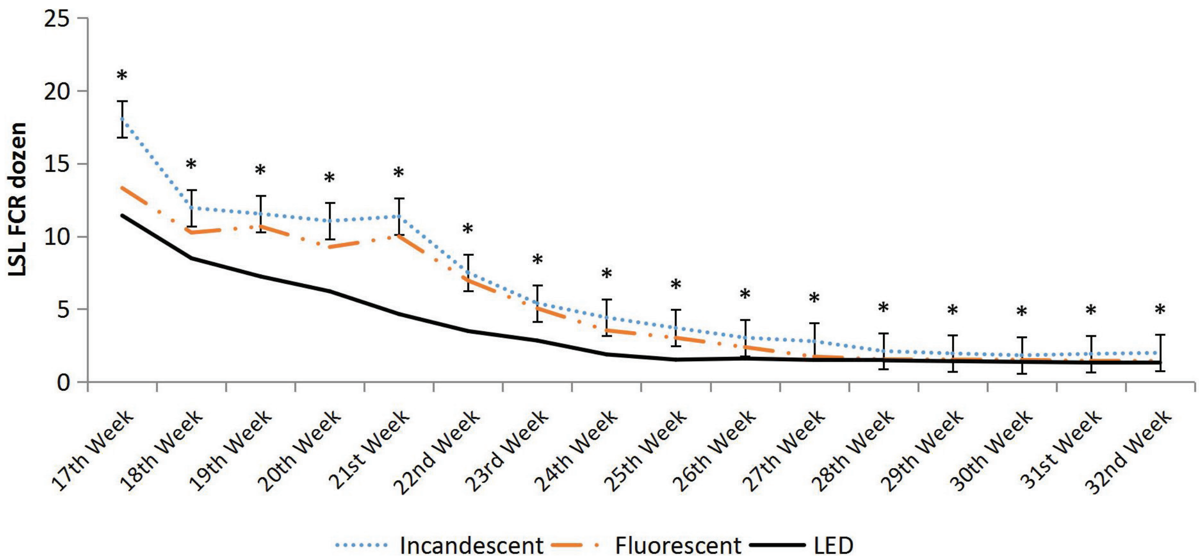

Figure 6. Weekly FCR per dozen eggs of bird maintained under different light sources (17-32 weeks).

emits long-wavelength light (towards yellow to the red end of the spectrum). Therefore, more long-wavelength light would have reached the hypothalamus making the birds more active, hence increasing the feed consumption [25]. Regarding the weight at maturity, the results of the current study (Figure 7) are supported by Bobadilla-Mendez et al. [26] who recorded an increased body weight at maturity in female quails reared under incandescent light as compared to the fluorescent light. Similarly, regarding the age of sexual maturity (ASM), our current trial results (Figure 8) are supported by Liu et al. [10] who recorded an early ASM in layers grouped under LED versus to fluorescent light source. This earlier age of sexual maturity (ASM) might be due to a steroid hormone estradiol (E_2) that is responsible for early maturity and ovulation that may be released at a higher concentration under LED as compared to other light sources [27]. Hen day egg production percentage and hen housed egg production percentage were significantly affected by different light sources. Significantly higher HDEP and HHEP were recorded in LED light treated group versus other groups. The significance of LED regarding improvement might be due to light intensity (brightness) of the LED light.

3.2. Egg quality

Significant effects were recorded on egg weight at both ages (24th and 32nd weeks) (Table 3). The hens reared under LED lights produced eggs with significantly higher

Table 2. Productive performance of birds reared under different light sources (17 to 32 weeks).

Parameters	Incandescent	Fluorescent	LED	P-value
BW 17th week	1100.83[c] ± 2.79	1193.00[b] ± 2.55	1250.00[a] ± 3.65	<0.0001
BW 32nd week	1446.67[c] ± 6.01	1560.00[b] ± 3.54	1639.17[a] ± 2.71	<0.0001
BWG (g)	345.83[c] ± 5.61	367.00[b] ± 5.39	389.17[a] ± 2.39	<0.0001
CFI (g) per bird	11684.86[a] ± 5.13	11428.04[b] ± 6.67	11073.94[c] ± 7.82	<0.0001
Egg number per bird	40.13[c] ± 0.52	50.79[b] ± 0.47	63.36[a] ± 1.36	<0.0001
HDEP %	39.75[c] ± 1.05	45.35[b] ± 0.42	56.57[a] ± 1.21	<0.0001
HHEP %	35.83[c] ± 0.46	45.35[b] ± 0.42	56.57[a] ± 1.21	<0.0001
FCR per dozen eggs	3.50[c] ± 0.05	2.70[b] ± 0.03	2.10[a] ± 0.05	<0.0001
FCR per kg egg mass	5.85[c] ± 0.09	4.34[b] ± 0.05	3.31[a] ± 0.07	<0.0001

Superscripts on means within row differ significantly (P ≤ 0.05); BW = Body weight (g); BWG: Body weight gain (g); CFI = Cumulative feed intake (g); EN = Egg number; HDEP: Hen day egg production (%); HHEP: Hen housed egg production (%).

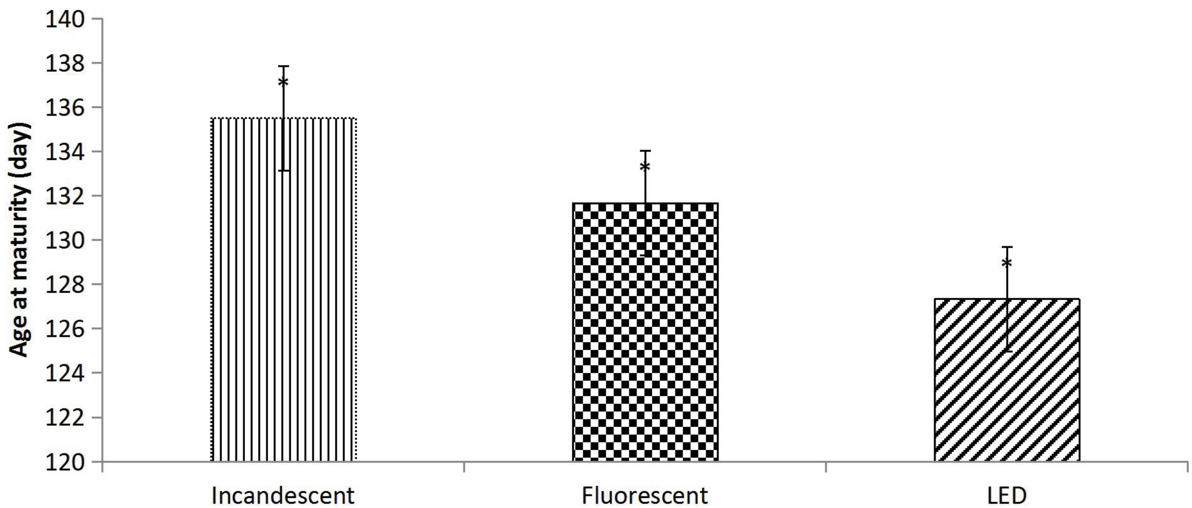

Figure 7. Age at sexual maturity of birds among different treatment groups affected by different light sources.

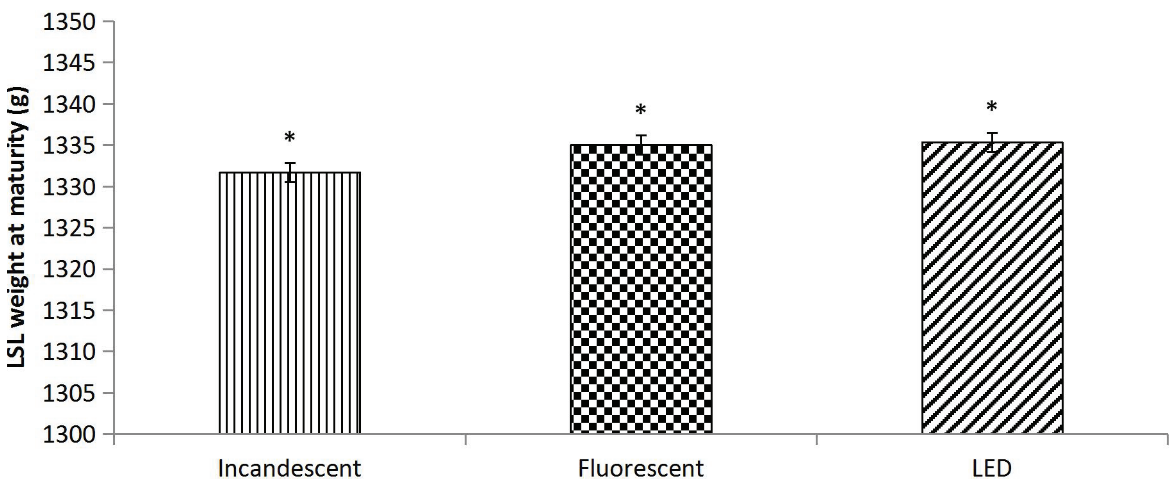

Figure 8. Weight at sexual maturity (g) in birds subjected to different light sources.

Table 3. Egg quality characteristics at 24h and 32nd week grouped under different light sources.

Parameters	Incandescent	Fluorescent	LED	P-value
Egg quality at 24th week				
EW (g)	$50.90^{c} \pm 0.23$	$51.80^{b} \pm 0.29$	$52.80^{a} \pm 0.20$	<0.0001
ESG	1.08 ± 0.00	1.07 ± 0.00	1.04 ± 0.00	0.2700
EBS (N)	$52.00^{b} \pm 0.21$	$52.45^{ab} \pm 0.02$	$52.90^{a} \pm 0.18$	0.0058
EST (mm)	0.37 ± 0.01	0.37 ± 0.01	0.38 ± 0.00	0.0896
HU	95.02 ± 1.18	93.90 ±0.24	94.26 ± 0.32	0.5496
EYI	47.04 ± 1.34	48.76 ± 0.19	49.08 ± 0.20	0.1870
ESW(g)	$7.12^{c\pm}$ 0.04	$7.32^{b} \pm 0.02$	$7.42^{a} \pm 0.02$	<0.0001
Egg quality at 32nd week				
EW (g)	$60.72^{c} \pm 0.37$	$63.46^{b} \pm 0.10$	$66.00^{a} \pm 0.45$	<0.0001
ESG	$1.05^{c} \pm 0.00$	$1.08^{b} \pm 0.00$	$1.09^{a} \pm 0.00$	<0.0001
EBS (N)	$52.22^{b} \pm 0.10$	$52.66^{a} \pm 0.02$	$52.78^{a} \pm 0.04$	0.0001
EST (mm)	$0.38^{b} \pm 0.01$	$0.39^{b} \pm 0.00$	$0.40^{a} \pm 0.00$	0.0097
HU	89.60 ± 0.24	90.00 ± 0.55	89.20 ± 0.37	0.4104
EYI	47.00 ± 1.30	49.18 ± 0.21	49.18 ± 0.23	0.1117
ESW(g)	$7.24^{c} \pm 0.02$	$7.46^{b} \pm 0.02$	$7.56^{a} \pm 0.02$	<0.0001

Superscripts on means within row differ significantly (P ≤ 0.05); EW = Egg weight (g); ESG: Egg specific gravity; EBS: Egg breaking strength (Newton); Egg shell thickness (mm); HU: Haugh Unit; EYI: Egg yolk index; ESW: Egg shell weight (g).

weight (52.80 ± 0.20 g) than those under fluorescent (51.80 ± 0.29) and incandescent bulbs (50.90 ± 0.23). Eggshell breaking strength and eggshell weight were also significantly different at these two recording times (24th and 32nd week of age) with better values from the groups of LED light. However, no difference was noted in experimental groups of laying hens for egg specific gravity, eggshell thickness, Haugh unit\ and egg yolk index at 24 weeks of age (P > 0.05). At the 32nd week of age, all the egg quality parameters were significantly better in the eggs of hens from LED than fluorescent and incandescent illuminated groups. Our findings are favored by Long et al. [7] who recorded that birds maintained under LED light had significantly improved egg weight versus fluorescent lighting at 27th week of age. The variation might be due to wavelengths because short-wavelength lights (LED) significantly improved the egg weight in pullets versus the long-wavelength lights [28]. House et al. [29] stated that 3%-4% of ultraviolet (UV) radioactivity is produced by LED and fluorescent, while the incandescent source is unable to produce such radiations. Such UV activity might have resulted in higher avian egg weight under LED and fluorescent as compared to the incandescent light source. Similar to our results at 32nd week, Tůmová and Gous [30] recorded a reduced egg specific gravity of the eggs from laying hens under incandescent as compared to fluorescent and LED light sources. This variation might be due to the stress produced by the incandescent light [8].

In the present study, significantly higher egg breaking strength was observed in LED treated group versus other groups at 24th and 32nd week. However, Kai [31] reported that laying hens reared under the LED and fluorescent lights did not show any significant variation regarding egg breaking strength. Significantly higher eggshell thickness and eggshell weight under LED light might be due to UV radiations, while the incandescent light source is unable to produce UV radiation [29]. These UV radiations are responsible for vitamin D production and enhanced shell calcification [29, 32]. Regarding the Haugh unit and yolk index of eggs from hens grouped under different light sources, our findings are in accordance with the previous reports from Liu et al. [9] who explained that white leghorn egg quality parameters like egg yolk index, and Haugh unit are not affected by the light source.

3.3. Egg geometry

In the present study, egg geometry traits (egg shape index, egg surface are and egg volume) were nonsignificantly different (P > 0.05) at the both ages, i.e 24th and 32nd weeks except the egg shape index and egg surface area at 32nd week (Table 4). An increased egg shape index (%) was recorded in eggs from hens under LED followed by

Table 4. Egg geometry at 24[th] and 32[nd] weeks under different light sources.

Parameters	Incandescent	Fluorescent	LED	P-value
Egg geometry at 24th week				
ESI (%)	75.08 ± 0.08	75.22 ± 0.35	74.66 ± 0.73	0.6888
ESA (cm^2)	63.44 ± 0.66	64.01 ± 0.42	64.59 ± 0.21	0.2700
EV (cm^3)	46.38 ± 0.67	46.88 ± 0.35	47.29 ± 0.34	0.4247
Egg geometry at 32nd week				
ESI (%)	75.10[b] ± 0.36	75.62[b] ± 0.19	76.84[a] ± 0.28	0.0031
ESA (cm^2)	63.49[b] ± 0.32	64.60[a] ± 0.51	65.20[a] ± 0.20	0.0042
EV (cm^3)	46.73 ± 0.68	47.60 ± 0.24	48.00 ± 0.32	0.1761

Superscripts on means within row differ significantly ($P \leq 0.05$); ESI: Egg shape index; ESA: Egg surface area (cm^2); EV: Egg volume (cm^3).

fluorescent light, and the least value of egg shape index was noted in the eggs from hens under incandescent light. These results are supported by Gülsüm and Bilgehan [33] who observed a significant effect of light on poultry egg shape index (ESI) in egg laying chickens kept under LED as compared to fluorescent and incandescent light sources. This variation might be due to light wavelengths. A significant effect of light source was also noticeable on the egg surface area. The eggs from the hens of LED group presented higher surface area compared to those of fluorescent and incandescent light. This variation might be due to egg weight.

3.4. Physiological response

The physiological response of laying hens reared under different lighting sources were evaluated through different aspects like respiratory rate, heartbeat, and body temperature. At both the stages, data revealed no significant variation for the rectal temperature of the hens. Respiration rate at an early age (17th week) was not affected by the light source; however, at 32nd week of the age, significant differences ($P \leq 0.05$) were observed in the respiration rate of the hens reared under a different light source. The hens under the incandescent light presented highest respiration rate followed by those under fluorescent bulbs. The least respiratory frequency was counted in the hens under LED lights. Similarly, at both recording ages (17th and 32nd week of the hens' age) heartbeat was significantly higher in birds that were reared under the incandescent light source followed by those under fluorescent while the hens under LED lights presented the lowest count of heartbeat (Table 5).

Raap et al. [34] reported that poultry physiological responses are highly influenced by artificial light. Sultana et al. [35] reported a significant effect of light sources on the poultry physiological responses. The increase in respiration and heartbeat rates in the current study might be due to more heat production and the difference in wavelengths of experimental lights [8] in incandescent groups compared to others. This is further supported by El-Hammady and Abdel-Kareem [36] who observed a higher respiratory rate in rabbits exposed to incandescent as compared to a fluorescent light source.

3.5. Welfare traits

Welfare aspects of laying hens reared under different lighting systems were evaluated through different parameters like cannibalism, footpad dermatitis (FPD) and plumage cleanliness (PC) scores (Table 6). Not a single incidence of cannibalism was observed in any of the treatment group throughout the experimental period. FPD was also a similar amount the groups of laying hens when compared at 17th week of age ($P > 0.05$). However, at 32nd weeks of age, FPD score was significantly ($P \leq 0.05$) higher in the hens exposed to the incandescent and fluorescent lights sources than those under LED lights. Feather conditions of the experimental laying hens were not affected ($P > 0.05$) by light sources at both ages (Table 6). Lighting programs can modulate many aspects of avian physiology, welfare, behavior, and other factors, including blood chemistry, and behavioral rhythms [37]. Today, the poultry industry is believed to produce perpetual and instant animal proteins in intensive production systems; however, such systems need to be evaluated continuously from birds' welfare point of view [38]. Mohammed [39] reported that plumage score, foot condition, and growth traits of layers are affected by light colors and sources due to the presence of many types of retinal regional specializations. James et al. [40] reported that qualities of the light environment have significant importance for overall welfare in several species. Gongruttananun [41] recorded a higher layer's activity, aggression, and

Table 5. Physiological norms of birds under different light sources during 17th and 32nd week of age

Parameters	Incandescent	Fluorescent	LED	P-value
Physiological response at 17th week				
RR	23.50 ± 0.43	20.50 ± 1.06	21.50 ± 1.43	0.1583
HBR	305.83^a ± 3.52	277.83^b ± 2.24	255.00^c ± 3.65	<0.0001
RT	104.98 ± 0.46	105.70 ± 0.37	105.68 ± 0.21	0.3058
Physiological response at 32nd week				
RR	24.50^a ± 1.15	20.50^b ± 2.92	15.00^c ± 0.37	0.0077
HBR	292.00^a ± 3.31	262.50^b ± 3.82	239.33^c ± 6.39	<0.0001
RT	106.03 ± 0.40	105.77 ± 0.20	105.15 ± 0.11	0.0888

Superscripts on means within row differ significantly ($P \leq 0.05$); RR: Respiratory rate (breath/minute); HBR: Heartbeat rate (beat/minute); RT: Rectal temperature (°F).

Table 6. Average scores of welfare traits in laying hens grouped under different light sources.

Parameters	Incandescent	Fluorescent	LED	P-value
Welfare aspects at 17th week				
FPD	0.50 ± 0.34	0.67 ± 0.49	0.50 ± 0.34	0.9437
PC	1.50 ± 0.22	1.33 ± 0.21	1.50 ± 0.22	0.8271
Welfare aspects at 32th week				
FPD	3.50^a ± 0.22	3.17^a ± 0.17	2.33^b ± 0.21	0.0029
PC	3.17 ± 0 .31	3.00 ± 0.26	2.67 ± 0.21	0.4103

Superscripts on means within row differ significantly ($P \leq 0.05$); FPD: Footpad Dermatitis; PC: Plumage cleanliness.

cannibalism grouped under fluorescent as compared to the LED light source. This variation might be due to wavelengths. In contrast, Mohammed et al. [42] recorded a lower cannibalism intensity in laying hens grouped under fluorescent as compared to the incandescent light. Another trait that is directly related to the hens' welfare is the health of footpad dermatitis because it is a serious worldwide problem for commercial poultry including broilers, layers, broiler breeders and turkeys [43]. Our current trial's findings are opposed by Campbell et al. [44] who observed a nonsignificant effect on Pekin duck's footpad dermatitis reared under different light color or light source. However, results of the present trial are allied by Huth and Archer [45] who reported better results for broiler's footpad condition reared under LED as compared to the fluorescent light source. This variation might be due to wavelengths.

3.6. Hormonal profile

Results of the present study revealed that productive/metabolic hormones (Triiodothyronine and Thyroxine) and enzyme including catalase and reproductive hormones (Gonadotropin-releasing hormone, follicular stimulating hormone and luteinizing hormone) were significantly higher in layers maintained under the LED lights followed by fluorescent lights, excluding a stress hormone (cortisol) that was found to be higher in birds maintained under incandescent light source (Table 7). Hormonal profile of poultry is highly influenced by artificial light [6, 34, 46]. Our results are supported by Hanafy and Hegab [47] who reported an increased plasma T3 level in chicks exposed to fluorescent as compared to incandescent light source during incubation. This higher T3 level can be attributed to the light source's impact on various physiological and metabolic processes. However, Olanrewaju et al. [48] disagreed and reported no effect of light sources (incandescent, fluorescent, and LED) on T_3 and T_4 levels in chickens. Involving the catalase enzyme, similar findings were described by Kumar [49] who recorded higher catalase level in broilers reared under LED as compared to incandescent light source. This might be attributed to

Table 7. Hormonal profiles of birds under different light sources.

Parameters	Incandescent	Fluorescent	LED	P-value
Hormonal profile at 20th week				
T_3	$2.51^c \pm 0.09$	$2.93^b \pm 0.03$	$3.16^a \pm 0.06$	0.0002
T_4	$16.51^c \pm 0.40$	$20.26^b \pm 0.41$	$25.05^a \pm 0.70$	<0.0001
CAT	$1.80^a \pm 0.09$	$2.26^b \pm 0.04$	$2.55^a \pm 0.06$	<0.0001
GnRH	$39.67^c \pm 0.35$	$81.92^b \pm 4.28$	$145.94^a \pm 6.44$	<0.0001
Cort	$46.60^a \pm 1.55$	$35.38^b \pm 1.37$	$26.92^c \pm 0.67$	<0.0001
FSH	$0.14^c \pm 0.00$	$0.23^b \pm 0.02$	$0.33^a \pm 0.01$	<0.0001
LH	$2.22^c \pm 0.01$	$2.31^b \pm 0.01$	$3.07^a \pm 0.03$	<0.0001
Hormonal profile at 32nd week				
T_3	$2.80^c \pm 0.07$	$3.20^b \pm 0.03$	$3.68^a \pm 0.08$	<0.0001
T_4	$18.80^c \pm 0.34$	$23.10^b \pm 0.32$	$28.75^a \pm 0.32$	<0.0001
CAT	$1.80^c \pm 0.09$	$2.26^b \pm 0.04$	$2.55^a \pm 0.06$	<0.0001
GnRH	$44.34^c \pm 1.04$	$88.18^b \pm 5.39$	$159.28^a \pm 4.22$	<0.0001
Cort	$47.94^a \pm 1.43$	$36.33^b \pm 1.21$	$28.17^c \pm 0.79$	<0.0001
FSH	$0.18^c \pm 0.01$	$0.26^{b} \pm 0.01$	$0.36^{a} \pm 0.01$	<0.0001
LH	$2.25^c \pm 0.01$	$2.36^{b} \pm 0.02$	$3.33^{a} \pm 0.08$	<0.0001

Superscripts on means within row differ significantly ($P \leq 0.05$); T_3: Triiodythyronine (ng/dL), $T_{4:}$ Thyroxine (ng/dL); CAT: Catalase (KU/mL); GnRH:Gonadotropin Releasing Hormone (pg/mL); Cort: Cortisol (nmol/L); FSH: Follicular stimulating hormone (IU/L); LH: Luteinizing hormone (IU/L).

relatively lower stress level in broilers reared under LED as compared to incandescent light source [13, 45]. Profile picture of reproductive hormones showed revealed that FSH and LH were significantly higher in birds maintained under LED light followed by fluorescent light. However, earlier to this, El-Fiky et al. [50] observed that the LH concentration in bird's serum in the period before 25 weeks of age increased significantly when using incandescent versus fluorescent or UV illumination. Further, Baxter et al. [51] did not observe any effect of the light source on pullet's GnRH, FSH, and LH.

3.7. Light source economics evaluation

In the poultry production chain, electricity cost is one of the largest expenses, second only to feed. For managing electricity cost, light management is one of the biggest challenges for the poultry industry [52]. Proper lightning management may be used as a tool towards ensuring improved economics on an overall basis. In the current experiment, most of the costs of different input segments such as total feed cost, the total number of bulbs, and total hours of the light provision were same in all three groups (Table 8). However, the difference was evident in terms of electricity consumption and its cost. Incandescent bulbs consumed the highest electric units followed by fluorescent and the least numbers of electric units were consumed by LED light bulbs. This probably had led to a difference in the electricity costs that were 69.168, 17.981, and 8.298 US dollars for incandescent, fluorescent and LED bulbs. Lightening programs and light source, both influence the electricity consumption. Incandescent bulbs are one of the oldest and most commonly used in poultry farms all around the globe. However, it consumes too much electricity and produces much heat [53]. Considering the electricity expenses in a broiler house, its demand can be reduced by 90.62% if incandescent bulbs are replaced with a fluorescent source of light [54]. In the current experiment, total profit was higher in LED lights (0.807 US dollar per bird), whereas the incandescent and fluorescent bulbs were not profitable, rather the groups under these two light sources encountered losses (-1.708 and -0.174 US dollars per bird, respectively). Jácome et al. [55] also supported to prefer the fluorescent rather than incandescent lightning to lower down the demand for electrical energy. However, fluorescent bulbs containing Mercury dust and vapor can be harmful to both humans and the environment when disposed of inappropriately [56]. Son et al. [12] reported that the LED is much more efficient from the energy use perspective than other types of lamp, and therefore are

Table 8. Economic appraisal of layers subjected to different light sources.

Description	Incandescent	Fluorescent	LED
Number of birds	72	72	72
Cumulative feed intake per bird (Kg)	11.6848	12	12
Total Feed Intake by a group of birds	841.3056	841	841
Total Feed Cost @ 0.31 per group (US $)	261.275	261.273	261.273
Electricity Consumed			
Bulbs Wattage	100	26	12
Number of bulbs used	4	4	4
Light hours per bulb (17 -32 weeks)	1740	1740	1740
Total light hours per group	6960	6960	6960
Electricity consumed (watts per group)	696000	180960	83520
Total electric units consumed following the thumb rule that one-watt bulb lighted for 1000 hours uses one unit of electricity	696	181	84
Electricity cost @ 0.099 per unit (US $)	69.168	17.981	8.298
Purchase price of one bulb of each source (US Dollar)	0.311	0.932	1.863
Total purchase price of bulbs (total 13 bulbs of incandescent, 04 fluorescent and 04 LEDs) US $	4.037	3.726	7.453
Total cost of electricity in terms of providing light to the birds of a group	73.205	21.708	15.752
Miscellaneous expenses (US $)	3.106	3.106	3.106
Total expenses (US $)	337.584	286.093	280.137
Number of egg produced per bird	40	51	63
Total Salable eggs produced per experimental group @ 72 birds per group	2880	3672	4536
Total return @ 0.074 US $ per egg	214.658	273.689	338.087
Profit/Loss per group (US $)	-122.925	-12.404	57.950
Profit /Loss per bird (US $)	-1.708	-0.174	0.807

US $ is United STATE dollar; original Prices in local currency were converted into US dollar and currency prices were obtained on 21 November 2020 from Pakistan Open Market Forex Rates, available at: http://www.forex.com.pk/.

more affordable to consumers. Similar to our findings, Benson et al. [57] described that LED is more energy-efficient than fluorescent and incandescent lights. Baxter and Bédécarrats [27] observed lower energy consumption in LED-bulbs versus incandescent and fluorescent light sources and reported a reduced production cost in pullets. Hence, on an overall basis, LED lights can be considered an economical and animal-friendly source of light for egg-laying poultry.

4. Conclusion

Based upon the findings and current discussion, it can be concluded that LED bulbs are an economical and animal-friendly source of light in commercial laying hens as it improved the body weight gain and productive performance, a physiological response, and welfare aspects in laying hens. Major improvements were seen in the HDEP (%), HHEP (%), egg weight, (g) egg number, FCR per dozen, and per kg egg mass. Hence, LED lights can be used in egg-laying poultry especially the commercial layer setups.

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