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Impact of light-emitting diode and compact fluorescent light source type and cage tier on layers reared in an enriched cage system
Part 1: Production performance and egg quality

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Abstract: This study's aim was to investigate the effects of age, light source type (light-emitting diode (LED), and compact fluorescent (FLO)), and cage tier on production performance and egg quality traits of layers reared in the enriched cage system. A total of 800 Nick Chick White layers were used in the study. A total of 800 eggs were used for egg quality traits at 25 and 45 weeks of age. The enriched cage tiers were coded as I, II, III, and IV from bottom to top. Layer age significantly affected egg mass, hen-day egg production rate, hen-house egg production rate, feed consumption, feed conversion ratio, damaged egg ratio ($P < 0.05$), egg weight, shape index, shell thickness, albumen weight, yolk weight, shell weight, yolk color index, albumen ratio, yolk ratio, and shell ratio ($P < 0.001$). The higher egg mass, egg weight, albumen weight, yolk weight, shell thickness ($P < 0.001$), dirty egg ratio ($P < 0.01$), and lower FCR, yolk color index ($P < 0.01$), shell ratio ($P < 0.01$) were found in the FLO group when compared to the LED group ($P < 0.05$). Highest body weight was found in cage tier I at 45 weeks of age ($P < 0.001$). Level of cage tier significantly affected 50% egg production age, egg mass, hen-day egg production rate, hen-house egg production rate, and dirty egg ratio ($P < 0.01$). Level of cage tier significantly affected 5% egg production age, FCR, and shape index ($P < 0.05$). It can be concluded that the hens in the FLO group were better than the LED group in terms of some production and egg quality traits.

Key words: LED, compact fluorescent, cage tier, age, production, egg quality traits

1. Introduction

Although poultry farming has grown tremendously in terms of egg yield and quality in recent years, it still contains many administrative factors that need to be investigated for optimum performance. Among various management tools, lighting management has great importance on egg yield and quality, especially with laying hens. With the artificial light used in poultry houses, laying age of hens can be regulatable, and the egg production and feed efficiency can be optimized [1]. Many different light sources and lighting programs are applied in order to obtain maximum efficiency of laying hens in commercial poultry production [2,3].

The LED lamps offer different wavelengths of monochromatic light and have many advantages over traditional light sources with features such as high energy efficiency, low maintenance costs, high reliability, and long life [4,5]. There are few studies about the effects of LED and Compact Fluorescent light on the egg production performance, egg quality, and various welfare parameters of layers [6,7,8]. In this respect, studies in this area are needed in terms of both the sector and the egg producers.

Today, conventional cage systems in commercial poultry farming has been replaced by alternative cage systems, such as furnished cages, modified cages, or enriched cages. For conventional cage systems which contain 3–7 hens in a cage unit, there are several studies about the effect of lighting. However, the number of studies on the effects of LED light on poultry species is quite limited for different rearing systems [2,3,6,9]. Moreover, it has been reported that the cage tier and cage position affect some yield characteristics of hens [10,11].

The perception of light for avians is different from that of humans and is quite advanced in many respects [12]. Poultry species can perceive the red and blue parts of the electromagnetic spectrum distinctly while humans cannot [13], and are sensitive to UV rays [14]. They can also detect flickering light at high frequencies [15] and have a shorter nerve path and therefore can react more rapidly to visual stimuli [16]. Although many studies show that there is a

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significant difference between the perceptions of light by poultry and human, this difference is often ignored in the lighting of the poultry houses [17]. In general, producers install light sources in poultry houses for lighting based on human visual requirements and visual perceptions of staff [18]. Thus, Prescott and Wathes [14] reported that most of the light sources concerted to the mode of human seeing might not meet the requirements of hens efficiently. In this respect, it is essential to determine the effects of light source types on the production and related parameters of the layers, and also to evaluate their effects on each cage tier. For this reason, in this study, the aim was to evaluate the effects of age, LED and FLO light source type, and cage tier on production and egg quality traits of layers reared in the enriched cage system.

2. Materials and methods

2.1. Animals and experimental design

This study was conducted in a commercial egg production enterprise. A total of 800 Nick Chick White layer at 16 weeks of age were used in the study. The study was continued until 45 weeks of age. All procedures related to the use of layers in this study were approved by the Animal Use and Ethical Committee of Bursa Uludağ University (Approval Number 2016-10/02).

The full automatic controlled poultry house was divided into two equal light-impermeable parts. One part of the poultry house was lighted by mini-compact fluorescent light and the other part by LED light type. In order to provide lighting to the house, the cool daylight color spectrum 6500 K, mini compact FLO lamp (Osram Duluxstar, Augsburg, Germany) and white color spectrum 6000 K- 6500 K, LED lamp (Rexus, Skopje, Macedonia) were used. Lamps were placed at 3 m height from the ground, and the distance between the lamps was 2.40 m. The 14L:10D photoperiod program was applied until the end of the experiment.

The hen house contained an eight-floor enriched cage system. All cages were separated at the fourth tier from the bottom where the walkway was mounted on the cage system. The lamps used in the experiment were mounted under this walkway. The layers used in the study were placed in the lower section of the eight-floor enriched cage system; thus, the bottom four cage tiers were used. The enriched cage unit measured 240 × 63 × 59 cm (L × W × H) and provided 756 cm^2 area per hen. Enriched cage tiers were coded as I, II, III, and IV from bottom to top.

In the experiment, a total of 40 cage compartments were used (20 for the FLO group and 20 for the LED group). In the experiment, a total of 800 layers were used; 20 layers were placed in each cage compartment, and 400 layers were used for each type of light source with 100 layers on each cage tier.

To determine the distribution of light intensity in different cage tiers, the light intensities in each cage tier were measured with a digital light meter (Extech Instruments, Light Meter LT300, Boston, Ms, USA) at three different points at the eye height of the layers (under the lamp, inside the feeder, and inside the cage). These values were averaged at the beginning of the trial. Light intensity measurements were repeated at 25 and 45 weeks of age.

The layers were fed with a standard layer diet (17.5% crude protein and 2770 kcal ME/kg between 17 and 20 weeks; 18.52% crude protein and 2799 kcal ME/kg between 20 and 28 weeks; 17.95% crude protein and 2779 kcal ME/kg between 28 and 35 weeks; 16.75% crude protein and 2717 kcal ME/kg between 35 and 45 weeks) in the study. The layers were supplied with ad libitum feed and water.

2.2. Determination of production performance

The layers were weighed individually and placed in cage compartments so that they were similar in terms of group means at 17 weeks of age (P > 0.05). The body weight of layers were also weighed at 25 and 45 weeks of age.

The number of eggs laid daily was recorded and 5% egg production age (sexual maturity age), 50% egg production age, and the peak egg production age were determined in each trial group. The hen-day and hen-house egg production, the number of damaged (cracked), shellless eggs, the number of dirty eggs and mortality were determined on a daily basis. The egg mass, feed consumption, and feed conversion ratio were determined on a weekly basis. The hen-day and hen-housed egg production, damaged egg ratio, shellless egg ratio, dirty egg ratio, feed consumption, egg mass, feed conversion ratio were calculated for each group.

2.3. Determination of egg quality

A total of 800 eggs were used for egg quality characteristics at 25 and 45 weeks of age. The eggs laid on the same day were collected and coded. They were kept in the egg storage room for 24 h, and each egg quality trait was measured. The egg shape index was determined with Rauch equipment. The egg weight, shell breaking strength, Haugh unit, and yolk color were determined by using a digital egg tester (Nabel, DET-6000 Digital Egg Tester, Kyoto, Japan). The egg yolk weight was weighed with a digital scale. The albumen weight was calculated by subtracting shell and yolk weight from the egg weight. The eggshell weight was determined as follows: eggshells were washed with water to remove the albumen and then dehydrated for 24 h in an oven (Memmert, UF55, Germany) at 105 °C, and then weighed with a digital scale. Shell thickness was determined at three points of the egg using a digital caliper, and the averages of these points were used. The egg yolk ratio, albumen ratio, and shell ratio were determined [19].

2.4. Statistical analysis
All statistical analyses were performed using SAS 9.4.M6 [20]. Continuous data were analyzed using PROC GLM procedure, percentage data were analyzed using PROC GLIMMIX procedure of SAS 9.4. The total mortality data was analyzed using chi-square test. The statistical model included age, light source type (LED or FLO), cage tier, and all interactions. In all cases, a probability of P < 0.05 was considered significant. Data are given as the means ± standard errors in the tables.

3. Results and discussion

3.1. Light intensity
The distribution of light intensity in different light source types and cage tiers were given in Table 1. There was no difference for light intensities of LED and FLO groups at the 17 and 25 weeks of age (P > 0.05). However, it was found to be higher in the FLO group at the 45 weeks of age (P < 0.01). There was a linear increase in the light intensity of cage tiers I to III, while there was a slight decrease in the IV cage tier. Slightly lower light intensity for cage tier IV was because of the light distribution angle from the light source which was not as effective as cage tier I–III.

3.2. Body weight
The effects of light source types and cage tier on the body weight, egg production performance, and mortality ratio were given in Table 2. Archer [9] reported that different light source types did not affect the body weight of hen with LED and compact fluorescent lamps. The findings obtained from the study supported these results and the body weight was found to be similar in the LED and FLO groups at 17 and 45 weeks of age (P > 0.05). The body weight was found to be similar between the cage tiers at the 17th week of age (P > 0.05). However, it was higher in cage tier I than the other cage tiers at 45 weeks of age of layers (P < 0.001). On the other hand, Durmuş and Kamanlı [21] reported that different cage tiers did not affect the body weight of layers.

Table 1. The distribution of light intensity during the study (mean ± SE).

Light Intensity, Lux	Weeks of age		
Light type	17	25	45
LED	12.67	11.96	11.25^{b}
FLO	15.94	15.53	15.66^{a}
SE	1.21	1.20	1.18
	NS	NS	**
Cage tier			
I	8.29^{c}	8.29^{b}	8.45^{b}
II	11.72^{bc}	11.87^{b}	11.73^{b}
III	20.87^{a}	20.43^{a}	19.37^{a}
IV	16.35^{ab}	14.40^{ab}	14.26^{ab}
SE	1.72	1.69	1.66
	**	**	**
L × C			
	NS	NS	NS

^{a,b,c}; Mean values within column with different superscripts are significantly different (P < 0.05).
*P < 0.05; ** P < 0.01; NS: Not significant
L: Light source type; C: Cage tier; LED: Light emitting diode, FLO: Compact Fluorescent;
I: 1st Tier (Bottom), II: 2nd Tier, III: 3rd Tier, IV: 4th Tier (Top)

Table 2. The effects of light source type and cage tier on body weight, egg production performance, and mortality of layers (mean ± SE).

	Light Type			Cage Tier							
Parameters	LED	FLO	SE	I	II	III	IV	SE	L	C	L × C
BW^{1}, g	1125.55	1121.85	1.87	1126.61	1123.30	1119.19	1125.70	2.64	NS	NS	NS
BW^{2}, g	1685.29	1687.72	6.78	1722.31^{a}	1680.35^{b}	1664.81^{b}	1678.57^{b}	9.58	NS	***	NS
5% Hen day egg production age, d	142.85	141.25	0.76	142.80^{ab}	139.80^{b}	144.90^{a}	140.70^{b}	1.08	NS	*	NS
50% Hen day egg production age, d	155.35	154.45	0.44	156.60^{a}	155.20^{a}	155.10^{a}	152.70^{b}	0.62	NS	**	NS
Peak Hen day egg production age, d	181.30	180.60	1.94	182.70	177.80	179.80	183.40	2.74	NS	NS	NS
17 – 45 wks of age Mortality, %	3.75	5.25	-	4.50	5.00	4.00	4.50	-	NS	NS	-

^{a,b}; Mean values within lines with different superscripts are significantly different (P < 0.05). *P < 0.05; ** P < 0.01; *** P < 0.001; NS: Not significant
L: Light source type; C: Cage tier; LED: Light emitting diode, FLO: Compact Fluorescent;
I: 1st Tier (Bottom), II: 2nd Tier, III: 3rd Tier, IV: 4th Tier (Top)
BW^{1}: 17th week of age body weight, BW^{2}: 45th week of age body weight

3.3. Egg production age

Light is very important for birds; it affects reproductive traits and also causes behavioral changes [22]. Red light increases the ovarian activity, which causes a significant effect on reproductive traits [23]. There are several light sources, such as LED, fluorescent, and incandescent lights which can all emit a certain amount of red light [8]. Thus, Liu et al. [8] reported that light source (LED and fluorescent) did not affect the time of sexual maturity and egg production level and they pointed out that there is a certain red color threshold level needed for necessary reproductive activity change in layers. This could support our results of 5%, 50%, and peak egg production age of layers between the LED and FLO groups, which were similar in this study ($P > 0.05$). In the present study, while layers at the cage tier II and IV reached 5% egg production age earlier ($P < 0.05$), layers at the cage tier IV reached 50% egg production age earlier than the layers in the other cage tiers ($P < 0.01$). On the other hand, there was no difference found between the cage tiers for peak egg production reach age ($P > 0.05$). Durmuş and Kamanlı [21] and Şekeroğlu et al. [24] reported that there were no significant effects of cage tier on 5% and 50% egg production age of layers in the three-tier conventional cage system. There was no light source type × cage tier interaction for the age of 5%, 50%, and peak egg production ($P > 0.05$).

3.4. Mortality

The light source type did not affect the mortality rate of layers reported in previous studies [2,7]. In the present study, the mortality rate was found to be similar in the LED and FLO groups ($P > 0.05$). However, a numerically higher mortality rate was observed in the FLO group than in the LED group ($P > 0.05$). Kjaer and Vestergaard [25] reported that high light intensity increased behavioral disorders, such as cannibalism, and in this case increased the mortality rate in conventional cage. Thus, Vits et al. [11] found that mortality was higher in the fourth cage tier than the other tiers of the furnished cage. However, Cook et al. [26] found that there was no difference for mortality ratio between the cage tiers in enriched colony cage system. Moreover, Şekeroğlu et al. [24] reported that there were no significant effects of cage tier on mortality of layers in three-tier conventional cage systems. In the present study, the mortality rate was found to be similar in different cage tiers ($P > 0.05$) which was lower compared to other studies [24]. There are several others reporting lower mortality rates in furnished cages when compared to the conventional cage systems [27,28] and in noncage systems [29,30].

3.5. Egg production

The effects of age, light source types, and cage tier on the egg production performance of layers were given in Table 3. As expected, the age of layers affected egg mass, hen-day egg production, hen-house egg production, feed consumption, and feed conversion ratio ($P < 0.001$). Age of layers also affected the damaged egg ratio ($P < 0.05$). The egg mass, hen-day egg production, hen-house egg production and feed consumption were increased with age ($P < 0.001$). The feed conversion ratio ($P < 0.001$) and damaged egg ratio decreased with the increase of age ($P < 0.05$). However, shellless egg ratio and dirty egg ratio were found to be similar in both age groups ($P > 0.05$). A similar result was reported by Yılmaz Dikmen et al. [31] in which they have found that the increase of age in layers affects production traits such as; hen-day egg production, feed intake, and egg mass were increased, but feed conversion ratio and damaged egg ratio were decreased. Şekeroğlu et al. [24] indicated that hen age affected feed efficiency, hen-house egg production rate, and hen-day egg production rate, and reported that laying performance increased until the age of 28 weeks.

In the present study, the effect of light source type on egg mass was found significant ($P < 0.05$). The egg mass was found to be higher in the FLO group than in the LED group ($P < 0.05$). The reason for higher results of egg mass between the light source groups in our study is the heavier egg weight result found in the FLO group which is taken into account in the formula while calculating the egg mass. However, Kamanlı et al. [7] reported that egg mass was similar in incandescent, FLO, and LED light source types in individual cages of the three tier battery cage system. In the present study, the effect of cage tier on egg mass was found significant, and highest egg mass was found at cage tier IV when compared to the other cage tiers ($P < 0.01$). Higher egg mass in cage tier IV was a result of higher egg production in this cage tier level, which is taken into account in the formula while calculating the egg mass. Yıldırım et al. [18] reported that the egg mass changed between cage tiers and the highest egg mass was laid by hens on the second and third cage tier in the conventional cage system.

Long et al. [2] reported that hens reared under fluorescent light had higher hen-house egg production than the LED ones; however, they found similar hen-day egg production ratio between LED and fluorescent light. In contrast to these results, Gallegos and Archer [6] reported that the hens reared under the LED light laid more eggs than the fluorescent light. In the present study, the effect of light source type on hen-day and hen-house egg production ratio was found similar ($P > 0.05$). In accordance with our findings, several researchers reported that there was no difference between the light source type for egg production [7,8,32]. Vits et al. [11] reported that hens at the bottom cage tier had a higher egg production than the other cage tiers. Similarly, Yıldırım et al. [18] reported that hen-day egg production was less in

Table 3. The effects of age, light source type, and cage tier on egg production performance of layers (mean ± SE).

	Egg mass, g	Hen-day egg production, %	Hen-house egg production, %	Feed consumption, g/hen	FCR, g feed/g egg	Damaged egg ratio, %	Shellless egg ratio, %	Dirty egg ratio, %
Age								
25 weeks	38.12^b	58.39^b	57.43^b	91.45^b	3.47^a	2.32^a	1.68	3.12
45 weeks	59.94^a	95.05^a	90.64^a	129.23^a	2.16^b	1.33^b	1.00	2.95
SE	0.41	0.65	0.55	1.15	0.07	0.34	0.30	0.16
Light type								
LED	48.40^b	75.80	73.44	109.82	2.95^a	2.03	1.52	2.70^b
FLO	49.67^a	77.64	74.63	110.87	2.67^b	1.62	1.16	3.37^a
SE	0.41	0.65	0.55	1.16	0.07	0.34	0.30	0.16
Cage tier								
I	47.77^b	74.85^b	72.06^c	110.24	3.00^a	2.04	0.98	3.67^a
II	48.48^{ab}	75.15^b	72.45^{bc}	109.92	2.77^{ab}	2.10	1.42	2.66^b
III	49.22^{ab}	77.82^{ab}	75.26^{ab}	110.84	2.96^a	1.94	1.89	2.68^b
IV	50.66^a	79.05^a	76.38^a	110.37	2.51^b	1.22	1.07	3.13^{ab}
SE	0.59	0.94	0.80	1.65	0.10	0.48	0.42	0.22
A	***	***	***	***	***	*	NS	NS
L	*	NS	NS	NS	*	NS	NS	**
C	**	**	**	NS	*	NS	NS	**
A × L	*	NS	**	NS	*	NS	NS	NS
A × C	NS	NS	*	NS	*	NS	NS	NS
L × C	NS	NS	NS	NS	NS	NS	NS	NS
A × L × C	NS	NS	NS	NS	NS	NS	NS	NS

a,b,c; Mean values within columns with different superscripts are significantly different ($P < 0.05$). *$P < 0.05$; ** $P < 0.01$; *** $P < 0.001$; NS: Not significant

A: Age; L: Light source type; C: Cage tier; LED: Light emitting diode, FLO: Compact Fluorescent;

I: 1st Tier (Bottom), II: 2nd Tier, III: 3rd Tier, IV: 4th Tier (Top)

the top cage tiers than in the other tiers. However, in the present study, the cage tier affects hen-day and hen-house egg production ratio ($P < 0.01$). The highest hen-day and hen-house egg production ratio were found at the cage tier III and IV when compared to other levels ($P < 0.01$). This difference might be a result of light intensity at these cage tier levels which was higher at these cage levels. Cook et al. [26] reported that percentage of eggs laid in top-tier nest boxes was higher compared to the bottom- and middle-tier nest boxes. However, they reported that cage tier did not affect egg production in enriched cages. On the other hand, several researchers reported that there was no difference between the cage tiers for egg production [21,24,33].

Some studies reported that different light source types did not affect feed consumption [9,34] and conversion ratio of hens [6, 7, 8]. Although in the present study the feed consumption was found to be similar in the LED and FLO groups ($P > 0.05$), the lower feed conversion ratio was found in the FLO group than in the LED group ($P < 0.05$). Thus, Long et al. [2] reported that hens under the fluorescent light had lower feed conversion than those under the LED light. However, they did not find any difference in their study between LED and fluorescent light for hen-day egg production, feed use, or mortality of hens for 20–70 weeks of age in commercial aviary hen houses. It was also reported that feed consumption of hens at different cage tiers was found to be similar [18,21,33]. In the present study, there was no difference for feed consumption of layers at different cage tiers ($P > 0.05$). However, feed conversion ratio was better in the cage tier IV and II than the other cage tiers ($P < 0.05$). Yıldırım et al. [18] reported that the light intensity increased with the increase of the cage tiers; 68.08, 41.68, 31.54, and 22.08 lux from top to bottom. In this study, feed conversion ratio was worse on top cage tiers when compared to the lower levels. Şekeroğlu et al. [24] reported that there was no significant effect of cage tier on feed conversion of layers. This result might be an impact of breed difference; thus, different genetic breeds of birds responded differently to light intensity, which results in changes in their feed conversion [35].

The integrity of the eggshell is essential for producers and consumers and is one of the factors that affect the profit of production [36]. In the present study, the damaged and shell-less egg ratio was found to be similar between the LED and FLO groups and also between the cage tiers (P > 0.05). In addition, in the present study, the effect of light source type and cage tier on shell breaking strength was found not significant (P > 0.05) (Table 4). In layers, differences in percentage of cracks were primarily due to differences in shell strength [37]. The different light sources usually have different spectral characteristics. When hens are reared under different light sources, their photoreceptors may be stimulated differently and this may have different impact on birds [35]. Thus, Yıldırım et al. [18] reported that the cage tier did not affect the rate of damaged eggs. However, Vits et al. [11] found a higher rate of cracked eggs in the fourth cage tier.

Contamination may occur in the shell for various reasons from the laying of eggs. Some of these reasons can be factors such as blood, hen feces, cracked or broken egg contents spread on the eggshells, especially in poorly managed hen houses fly stains on the eggshells, the increase

Table 4. The effects of age, light source type, and cage tier on egg quality traits of layers (mean ± SE).

	EW, g	SI, %	SBS, kgf	ST, mm	AW, gr	YW, gr	SW, gr	HU	YCI	AR, %	YR, %	SR, %
Age												
25 wks	56.68^{b}	76.86^{a}	5.494	0.449^{a}	37.52^{b}	13.25^{b}	5.91^{b}	84.26	11.29^{b}	66.16^{a}	23.40^{b}	10.44^{a}
45 wks	63.80^{a}	75.82^{b}	5.110	0.391^{b}	40.17^{a}	17.43^{a}	6.21^{a}	83.72	11.55^{a}	62.93^{b}	27.34^{a}	9.74^{b}
SE	0.20	0.11	0.17	0.00	0.16	0.07	0.03	0.66	0.05	0.11	0.11	0.04
Light type												
LED	59.90^{b}	76.23	5.22	0.415^{b}	36.60^{b}	15.23^{b}	6.07	84.51	11.52^{a}	64.52	25.33	10.16^{a}
FLO	60.59^{a}	76.45	5.38	0.425^{a}	39.09^{a}	15.44^{a}	6.06	83.46	11.32^{b}	64.57	25.41	10.02^{b}
SE	0.20	0.11	0.17	0.00	0.16	0.07	0.03	0.66	0.05	0.12	0.11	0.04
Cage tier												
I	60.62	76.55^{ab}	5.64	0.423	38.94	15.55	6.14	85.80	11.37	64.30	25.55	10.16
II	60.42	76.60^{a}	5.19	0.416	39.00	15.34	6.08	83.97	11.47	64.60	25.31	10.09
III	59.93	76.24^{ab}	5.12	0.421	38.61	15.29	6.03	82.94	11.38	64.47	25.44	10.09
IV	60.00	75.98^{b}	5.26	0.420	38.83	15.17	6.00	83.24	11.47	64.80	25.19	10.01
SE	0.29	0.16	0.24	0.00	0.23	0.10	0.04	0.94	0.07	0.16	0.15	0.05
A	***	***	NS	***	***	***	***	NS	***	***	***	***
L	*	NS	NS	***	*	*	NS	NS	**	NS	NS	**
C	NS	*	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
A × L	NS	*	NS	NS	NS	NS	NS	NS	NS	NS	NS	*
A × C	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	***
L × C	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
A × L × C	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	*

^{a,b}; Mean values within columns with different superscripts are significantly different (P < 0.05).
*P < 0.05; ** P < 0.01; *** P < 0.001; NS: Not significant
A: Age; L: Light source Type; C: Cage Tier; LED: Light emitting diode, FLO: Compact Fluorescent; I: 1st Tier (Bottom), II: 2nd Tier, III: 3rd Tier, IV: 4th Tier (Top)
EW: Egg Weight, SI: Shape Index, SBS: Shell Breaking Strength, ST: Shell Thickness, AW: Albumen Weight, YW: Yolk Weight, SW: Shell Weight, HU: Haugh Unit, YCI: Yolk Color Index, AR: Albumen Ratio, YR: Yolk Ratio, SR: Shell Ratio

of dust density in the hen house, and the formation of dust rings on eggshells [38]. In the present study, the higher dirty egg ratio was found in the FLO group than in the LED group ($P < 0.01$). The highest dirty egg ratio was found at cage tier I and IV when compared to the other cage tiers ($P < 0.01$). It is known that light intensity affects the activity level of birds [39]. It was thought that the light intensity in the FLO group was high, and layers were active in this group. Due to the intense movement of active layers, the layers' feces were transmitted to the materials in the cage floor; thus, it increased the dirty egg ratio.

In our study, the effect of light source type and cage tier interaction on egg production performance parameters were not significant ($P > 0.05$). In addition, the effect of age, light source type, and cage tier interaction on egg production performance parameters were found not significant ($P > 0.05$) (Table 3).

The statistically significant interactions on egg mass, hen-house egg production, and FCR were given in Table 5. The effect of age and light source type interaction on egg mass, hen house egg production ratio ($P < 0.01$) and feed conversion ratio were found significant ($P < 0.05$). The interaction of age and light source type resulted in heavier egg mass, higher hen-house egg production and lower FCR and this is mostly a result of age as expected. Egg mass and hen-house egg production were increased and FCR was decreased with the increase of age regardless of light source (Table 5). The effect of age and cage tier interaction on hen-house egg production ratio and feed conversion ratio were found significant ($P < 0.05$). The interaction of age and cage tier resulted in higher hen-house egg production with the increase of age but during the 25 weeks of age higher cage levels (Cage tier III and IV) had higher hen-house egg production and this difference was consistent in both light source type. Higher hen-house egg production during the early age of layer might be a result of light intensity provided to these cage tiers. Especially during the early ages of layer, the cage tier or proximity to light source have a significant effect on hen-house egg production level but this difference was not so prominent after the peak egg production or during the older age of layers. The age and cage tier interaction on FCR showed that there is a decrease with the increase of age. However, during the early ages (25 week) the layers in upper levels of cage had lower FCR, which was more prominent for cage tier IV (Table 5). The lower FCR results during these periods were a result of higher egg production.

3.6. Egg quality

It is well known that there is a significant effect of age on egg quality parameters [3,19,40]. The effect of age, light source type, and cage tier on egg quality traits were given in Table 4. In our study, egg weight, albumen weight, yolk weight, shell weight, yolk color index, and yolk ratio increased with age ($P < 0.001$). Thus, Long et al. [3] reported that egg weight, yolk weight, and yolk ratio increased with increased hen age. On the other hand, in the present study shape index, shell thickness, albumen ratio, and shell ratio decreased with the increase of age ($P < 0.001$). The shell breaking strength and Haugh unit were found to be similar in both age groups ($P > 0.05$). However, Long et al. [3] reported that shell breaking strength and Haugh unit decreased with increased hen age. This difference could be a result of breed which was used in their study [3].

The studies reported that different light types did not affect egg weight [1,7,8,34]. However, Long et al. [3] reported inconsistent results on the effect of light source type on egg weight; they reported that egg weight was higher in the LED group than in the FLO group at 27 weeks of age. However, they found that there was no difference between the light source groups at 40 weeks of age, whereas the FLO group had higher egg weight than LED group at 60 weeks of age. The different light sources usually have different spectral characteristics. When hens are reared under different light sources, their photoreceptors may be stimulated differently and this may have different impact on birds [35]. In the current study, the FLO group had heavier egg weight than in the LED group ($P < 0.05$). Poultry can detect ultraviolet rays, and these rays affect vitamin D, calcium and phosphorus metabolism, and bone formation and immune system of the hen [5]. The fluorescent lamps can produce 3%–4% UVA radiation but LED lights cannot produce the same amount of UVA [41]. Therefore, that might have resulted in higher egg weight in the FLO group when compared to the LED group. The effect of cage tier on egg weight was found similar ($P > 0.05$). Thus, there were several other studies with similar results, where it was reported that different cage tiers did not affect egg weight [21,24,33].

Kamanlı et al. [7] reported that the egg shape index was better in the LED group than in the fluorescent group. In the present study, there was no difference for egg shape index of both light source types ($P > 0.05$). There were studies reporting that the cage tier did not affect the egg shape index [2,18,24,33,40]. However, in the present study, cage tier affected egg shape index ($P < 0.05$). The lowest egg shape index was found at the cage tier IV ($P < 0.05$) but it was similar for cage tier I–III (Table 4). This difference might be a result of genotype difference; thus, there were several studies reporting that genotype effects egg shape index of hens but still the variance of shape index was in standard range for layers [42,43].

In poultry production, profit decreases when egg quality decreases [36]. The studies reported that different light sources did not affect eggshell breaking strength [3,7,34]. Thus, in the present study, the light source type did not affect eggshell breaking strength and shell weight

Table 5. The interactions on egg mass, hen house egg production ratio, FCR, shape index, and shell ratio. (mean ± SE).

Interactions	Egg mass, g	Hen-House egg production, %	FCR, g feed/g egg	SI, %	SR, %
Age × light type					
25 × LED	36.88^{c}	55.64^{c}	3.78^{a}	76.93^{a}	10.57^{a}
25 × FLO	39.36^{b}	59.23^{b}	3.15^{b}	76.79^{a}	10.31^{b}
45 × LED	59.91^{a}	91.25^{a}	2.13^{c}	75.54^{c}	9.75^{c}
45 × FLO	59.97^{a}	90.03^{a}	2.18^{c}	76.10^{b}	9.73^{c}
SE	0.58	0.78	0.11	0.14	0.05
	*	**	*	*	*
Age × cage tier					
25 × I	36.03	54.13^{c}	3.83^{a}	77.10	10.62^{a}
25 × II	37.12	54.78^{c}	3.37^{b}	77.12	10.49^{a}
25 × III	38.54	59.42^{b}	3.76^{ab}	76.53	10.47^{a}
25 × IV	40.82	61.40^{b}	2.89^{c}	76.68	10.18^{b}
45 × I	59.60	89.98^{a}	2.16^{d}	75.99	9.70^{c}
45 × II	59.71	90.11^{a}	2.16^{d}	76.08	9.69^{c}
45 × III	59.90	91.10^{a}	2.17^{d}	75.94	9.71^{c}
45 × IV	60.54	91.36^{a}	2.13^{d}	75.27	9.85^{c}
SE	0.94	1.13	0.15	0.20	0.07
	NS	*	*	NS	***
Age × light type × cage tier					
25 × LED × I	35.32	51.00	4.30	77.07	10.61^{ab}
25 × LED × II	35.39	55.58	3.54	77.00	10.62^{a}
25 × LED × III	37.00	56.87	4.10	76.43	10.64^{a}
25 × LED × IV	39.76	59.06	3.15	77.20	10.41^{ab}
25 × FLO × I	36.75	57.29	3.44	77.13	10.63^{a}
25 × FLO × II	38.85	54.06	3.15	77.23	10.37^{ab}
25 × FLO × III	40.08	61.89	3.28	76.63	10.30^{b}
25 × FLO × IV	41.88	63.73	2.78	76.17	9.95^{c}
45 × LED × I	60.19	90.36	2.16	75.54	9.77^{cd}
45 × LED × II	59.95	90.20	2.17	76.00	9.71^{cd}
45 × LED × III	59.32	92.31	2.12	75.82	9.76^{cd}
45 × LED × IV	60.15	92.11	2.11	74.80	9.75^{cd}
45 × FLO × I	59.01	89.57	2.19	76.44	9.63^{d}
45 × FLO × II	59.47	90.06	2.17	76.16	9.68^{cd}
45 × FLO × III	60.48	89.81	2.19	76.06	9.67^{cd}
45 × FLO × IV	60.92	90.66	2.16	75.74	9.94^{c}
SE	1.33	1.66	0.16	0.28	0.10
	NS	NS	NS	NS	*

^{a,b,c,d}; Mean values within columns with different superscripts are significantly different (P < 0.05).
*P < 0.05; ** P < 0.01; *** P < 0.001; NS: Not significant
LED: Light emitting diode, FLO: Compact Fluorescent; I: 1st Tier (Bottom), II: 2nd Tier, III: 3rd Tier, IV: 4th Tier (Top) FCR: Feed conversion ratio, SI: Shape Index, SR: Shell Ratio

(P > 0.05). Moreover, Liu et al. [8] reported that different light types did not affect the eggshell breaking strength at 23 and 32 weeks of age, but the FLO group had a higher eggshell breaking strength value than the LED group at 41 weeks of age. Yıldırım et al. [18] reported that the cage tier affected the eggshell breaking strength. However, Karaman et al. [33] and Şekeroğlu et al. [24] reported that the cage tiers did not affect the eggshell breaking strength and shell weight. In accordance with these reports, our results indicate that the cage tier did not affect eggshell breaking strength and shell weight (P > 0.05).

Gallegos and Archer [6], Kamanlı et al. [7], and Archer [32] reported that different light source types did not affect the eggshell thickness. Moreover, Long et al. [3,25] reported that their different light type did not affect the eggshell thickness at early age, but with advanced age, the LED group had a thicker eggshell than the FLO group. Contrary to this, Liu et al. [8] reported that different light type did not affect the eggshell thickness at 23 and 32 weeks of age, but FLO group had a thicker eggshell than the LED group at 41 weeks of age. Thus, in the present study, the eggshell was found to be thicker in the FLO group than the LED group (P < 0.001). Poultry can detect ultraviolet rays, and these rays affect vitamin D, calcium and phosphorus metabolism, bone formation, and immune system of the hen. Fluorescent lamps emit ultraviolet radiation [5,41]. Therefore, that might have resulted in the FLO group having a thicker eggshell than the LED group. In the present study, the effect of cage tier on eggshell thickness was found to be similar (P > 0.05). In accordance with our findings, Karaman et al. [33] and Şekeroğlu et al. [24] reported that cage tiers did not affect the eggshell thickness. However, Vits et al. [11] found that the eggshell density was lower in the fourth cage tier when compared to the other cage tiers. The egg shell found thicker and stronger in the bottom cages than top cages, with the decreased light intensity [44].

It has been reported that albumen weight and yolk weight were found to be similar in the LED and Fluorescent groups [3,8]. In our study, effect of cage tier on albumen and yolk weight was not significant (P > 0.05), but the light source was significant (P < 0.05). The albumen and yolk weight were found to be higher in the FLO when compared to the LED group (P < 0.05). The increase in egg weight also resulted in an increase in yolk weight and albumen weight [45]. However, increase in egg weight is not accompanied by a proportional increase in shell weight [46]. Thus, in the present study, shell weight was found to be similar in light source types and in different cage tiers (P > 0.05).

The Haugh unit is used for the evaluation of the freshness of eggs. In many studies, it has been reported that light type did not have an effect on the Haugh unit value [3,6,7, 8,32]. Thus, in the present study, the Haugh unit value was similar in both light type groups (P > 0.05). Karaman et al. [33], Yıldız et al. [44], and Şekeroğlu et al. [24] reported that the Haugh unit value was also similar between the cage tiers of conventional battery cage system. In accordance with their results, we have found that the effect of cage tiers on the Haugh unit value was found to be similar (P > 0.05).

The egg yolk color is a relative concept in commercial egg production and humans in various countries can make different choices in terms of egg yolk color. Long et al. [3] and Liu et al. [8] reported that egg yolk color was found to be similar in the LED and FLO light groups. However, in our study, lighter egg yolk color was found in the FLO group (P < 0.01). Egg yolk color principally depends on the intake of plant pigments with the diet [47]. Thus, in the present study, the effect of cage tier on the egg yolk color index was found not significant (P > 0.05). Our results were in accordance with previous studies on cage tier, where it was reported that there was no effect of cage tier on egg yolk color [24,33,40,44].

Long et al. [3] and Liu et al. [8] reported that different light sources did not affect egg yolk ratio. Thus, in the present study, the effects of different light source types on albumen and yolk ratio were similar (P > 0.05). However, higher eggshell ratio was found in the LED group than in the FLO group (P < 0.01). The effect of cage tier on albumen, yolk ratio, and shell ratio were found to be similar (P > 0.05).

The effect of light source type and cage tier interaction on all investigated egg quality traits were found not significant (P > 0.05). In addition, the effect of age, light source type and cage tier three way interaction on all investigated egg quality traits were not significant (P > 0.05), except for shell ratio (P < 0.05) (Table 3).

The statistically significant interactions on shape index and shell ratio were given in Table 5. The effects of age and light source type interaction on shape index and shell ratio were found significant (P < 0.05). The shape index was decreased with the increase of age but this decrease was more prominent for the LED group (Table 5). The interaction of age and light source type was a result of lowest shape index found in the LED group at 45 weeks of age. The interaction of age and light source type showed that there was a decrease in shell ratio with the increase of age (Table 5).

Akkuş [40] reported that there was a significant age and cage tier interaction on egg weight, shape index, shell thickness, shell breaking strength, albumin index, yolk index, yolk color, and the Haugh Unit of white and brown egg layers reared in five-cage-tier conventional cage system. In the present study, the effect of age and cage tier interaction on investigated egg quality parameters were not significant (P > 0.05), except for shell ratio (P < 0.001) (Table 3). The interaction of age and cage tier significantly changed the shell ratio in layers which shows a prominent decrease with the increase of age (Table 5).

The effect of age, light source type, and cage tier three way interaction on shell ratio was found significant (P < 0.05) (Table 5). Shell ratio was reduced with the increase of age in both light groups except the cage tier IV which was the lowest at 25 weeks of age but the highest at 45 weeks of age. However, shell ratio did not change with the increase of age in FLO group.

As a conclusion; during the trial period, the highest light intensity was found on the III cage tier. The hens are sensitive to ultraviolet light and light intensity is perceived differently by hens [48]. Thus, it was determined that the FLO group was better in terms of some egg production and quality parameters, and the IV cage tier was better in terms of some egg production parameters.

The appropriate light intensity and light duration provided by artificial lighting in laying hens stimulate the growth of chickens, sexual maturity, egg production, and quality characteristics by activating the pituitary gland. The light types and light intensity used in illumination of houses are essential in terms of height and continuity of egg production. The incandescent lamps used in the layer houses, and later, fluorescent lamps have been used because of their low operating cost and long life. In recent years, although the cost of installation of monochromatic LED lamps is high, they have been used because they are long-lasting and economical. In today's poultry sector, new cage systems have been developed instead of traditional cage systems. Especially in production, enriched cages have become widespread. To date, there is very little information on the effect of LED light in enriched or furnished colony cage systems. Recently, it has gained increasing attention from both scientific and commercial communities. For this reason, there is a need for further research on LED lighting and the responses of hens to this light type. In this respect, this research, which was conducted on commercial poultry house conditions, will be an important source of information especially for other producers.

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