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Choice between LED and Fluorescent Lights by Pullets and Laying Hens

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ABSTRACT. *Light plays a key role in the development, production performance, health, and well-being of poultry. Yet there are no standards regarding light type, spectrum, intensity and diurnal photoperiod for poultry production. Thus, it is of socio-economic as well as scientific values to assess light needs of pullets and laying hens, especially considering the emergence of LED lights intended for poultry production. This study assessed the choice between a commercial dim-to-red LED light (LED, correlated color temperature or CCT = 2000K) and a typical compact fluorescent light (CFL, CCT = 2700K) by Hy-Line W-36 pullets and laying hens using free-choice preference test. Three categories of birds with different prior lighting experiences were evaluated, including pullets (14-16 weeks of age) reared in incandescent light (IP), layers (44-50 weeks of age) reared and kept in LED (LL), and layers reared and kept in CFL (CL). Each bird category consisted of 12 groups (replicates), three birds per group. A 6-day preference test was performed for each group, where the birds could move freely between two inter-connected compartments that contained LED or CFL. Feed intake and time spent of birds in each light were determined using load-cell scales and automated computer vision, respectively. Behavior parameters were analyzed with generalized linear mixed models. Evaluation of the light preference was accomplished by testing the null hypothesis that the proportions of feed intake or time spent in each light under concern equaled 50%. Results showed that the birds spent significantly higher proportion of light-period time in the CFL (P = 0.011, 0.030, and 0.001 for IP, LL, and CL, respectively), regardless of their prior lighting experience (P = 0.422). Birds in all three categories had comparable proportions of daily feed intake in the LED and CFL (P = 0.419, 0.566, and 0.749 for IP, LL, and CL, respectively). The study reveals that the CFL was preferred over the LED by the pullets and layers in terms of time spent regardless of their prior lighting experience; but no distinct effect of one light vs. the other was observed on feed use.*

Keywords. *LED light, Preference assessment, Pullet and laying hen, Computer vision, Behavior and welfare*

Introduction

Light plays an important role in behavior, development, production performance, health, and well-being of poultry (Manser, 1996; Lewis & Morris, 2000; Olanrewaju et al., 2006; Rajchard, 2009; Lewis, 2010). As such, extensive research on poultry lighting has been conducted over the past eight decades, leading to establishment of general guidelines on photoperiod and light intensity for improved animal performance and energy efficiency. However, some aspects remain to be further investigated and understood, such as lack of standards or recommendations on light type and the corresponding spectral characteristics that better mesh the animal's biological or behavioral needs.

Poultry have a different light spectral sensitivity as compared to humans (Prescott and Wathes, 1999; Prescott et al., 2003; Saunders et al., 2008). In particular, poultry have five types of retinal cone photoreceptors that are sensitive to ultraviolet (UV), short-, medium-, and long-wavelength lights (Osorio and Vorobyev, 2008), and can perceive light not only through their retinal cone photoreceptors in the eyes, but via extra-retinal photoreceptors in the brain (e.g., pineal gland and hypothalamic gland) (Mobarkey et al., 2010). It has been demonstrated that retinal cone photoreceptors produce the perception of light colors by receiving lights at the peak sensitivities about 415, 450, 550, and 700 nm, and are more related to poultry activities (e.g., feeding, drinking, and locomotion) and growth. However, the extra-retinal photoreceptors can only be activated by the long-wavelength lights (e.g., yellow-red and red) which can penetrate the skull and deep tissue of poultry, and are more related to the sexual development and maturity (Lewis and Morris, 2000). As different lighting sources (e.g., incandescent, high pressure sodium or HPS, fluorescent, and light-emitting diode or LED lights) usually have different spectral characteristics, retinal and extra-retinal photoreceptors of birds may be stimulated differently when exposed to different lighting sources, thus causing different impacts on the animals. For example, research found that the spectra of red lights were associated with sexual development and maturity of pullets (Harrison et al., 1969; Gongruttananun, 2011; Min et al., 2012; Baxter & Joseph, 2014), while the spectra of blue lights were associated with improving broiler growth, calming the birds (though the underlying mechanism was not delineated), and enhancing the immune response (Prayitno et al.1997; Rozenboim et al., 2004; Cao et al., 2008; Xie et al., 2008; Sultana et al., 2013)

A lighting study on broilers reported that LED lights resulted in better well-being (better plumage and hock conditions) and improved production (increased feed conversion) when compared to CFL lights (Huth & Archer, 2015), although once again no information was provided regarding the underlying mechanism. However, another study reported no differences in growth, feed intake, feed conversion or mortality of broilers reared under two types of LED lights and a CFL light (Olanrewaju et al., 2016). Similarly, when applying a commercial LED light and a typical CFL light in commercial aviary hen houses, no differences were detected in egg weight, egg production, feed use, mortality rate or egg quality parameters of DeKalb white hens between the two light regimens (Long et al., 2016a; 2016b). These inconsistent results, along with the emerging lights intended for poultry production and increasing attention toward animal well-being, make it necessary to further investigate the responses of poultry to lighting conditions. Performance-based studies, such as those reported in the literature, although important and necessary, can be subject to the influence of other factors, such as thermal conditions, nutrition density, feeding practices, space allowance, and indoor air quality. On the other hand, behavior-based assessment on the animal responses to light conditions under otherwise uniform environment may provide insight into the lighting needs of the animal.

Preference test investigates instantaneous behavioral responses of animals to various environmental stimulus rather than the long-term physiological impacts, thus can offer better assessment on animal needs (Ma et al., 2016). As a result, preference test has been used extensively in poultry studies assessing different environmental conditions, including floor type (Hughes, 1976), nest box (Appleby et al., 1984; Millam, 1987), perch height and shape (Struelens et al., 2008; Lambe & Scott, 1998), ammonia level (Green, 2008; Kashiha et al., 2014), and various light regimens. Broilers were shown to have no behavioral sign of preference between white and yellow LED lights (Mendes et al., 2013). Turkeys preferred fluorescent light with supplementary UV radiation (Moinard & Sherwin, 1999), and spent significantly longer time under 25 lux of light when given free choice among <1, 5, 10, and 25 lux (Sherwin, 1998). Laying hens preferred CFL light over incandescent light in that they spent on average 73.2% of time under CFL and only 26.8% under incandescent (Widowski et al., 1992), but did not have a preference for high or low flicker frequency of CFL lights (Widowski & Duncan, 1996), and had no preference for HPS or incandescent light (Vandenbert & Widowski, 2000). In addition, preference studies on pullets reared in incandescent light or natural daylight revealed that the early lighting experience of pullets would affect their later preference for lights in that birds reared in incandescent light showed a preference for incandescent light as compared to birds reared in natural daylight (Gunnarsson et al., 2008; 2009). Nowadays more energy-efficient, readily-dimmable and long-lasting LED lights are increasingly finding applications in poultry production. There is anecdotal evidence about the advantages of some commercial LED lights (e.g., dim-to-red LED) on performance and behavior of poultry over the traditional CFL lights; however, concrete research data are lacking. Thus it is of socio-economic as well as scientific values to evaluate behavioral responses of poultry to various lighting sources through preference test.

The objectives of this study were a) to assess light preference of pullets and layers between a commercial dim-to-red LED light (**LED**) and a typical compact fluorescent light (**CFL**); and b) to evaluate the influence of prior lighting experience on the subsequent preference of lights. The results are expected to contribute to improvement of current lighting guidelines and establishment of lighting standards for pullet rearing and laying-hen production.

Materials and methods

The study was conducted in an environment-controlled animal research laboratory located at Iowa State University, Ames, Iowa, USA. The experimental protocol was approved by the Iowa State University Institutional Animal Care and Use Committee (IACUC # 3-15-7982-G).

Experimental Animal and Husbandry

Hy-Line W-36 breed birds were used in the study. A total of 36 pullets and 72 layers in two flocks were tested for light preference. All the birds were not beak-trimmed and were individually identified with wing-bands. The pullets were reared in litter-floor rooms that only used incandescent light, and were randomly selected for the preference test at the age of 14 to 16 weeks. The layers, transferred from litter-floor rooms as pullets at 16 weeks of age, were kept in conventional cages that used LED or CFL, and were randomly selected at the age of 44 to 50 weeks. Half of the layers (36 layers) had been kept under LED (dim-to-blue in the pullet phase on litter floor and dim-to-red in the layer phase in conventional cages), and the other half had been kept under CFL solely (including the pullet phase). Consequently, the birds were divided into three categories based on the prior lighting experience and age, i.e., pullets reared in incandescent light (IP), layers reared and kept in LED (LL), and layers reared and kept in CFL (CL). Each category consisted of 12 groups or replicates, three birds per group.

A light preference test tunnel and an acclimation chamber were used for the study. The tunnel was modified from an existing system, consisting of five identical compartments, with each compartment measuring 61 cm W x 91 cm D x 198 cm H and containing a 60 cm W x 60 cm D x 90 cm H cage. The acclimation chamber (216 cm W x 91 cm D x 150 cm H) was used to house two inter-connected cages, with each cage measuring 74 cm W x 64 cm D x 46 cm H. Detailed specifications of the test tunnel and the acclimation chamber could be found in a previously published article (Ma et al., 2016), including construction materials and dimensions of the ventilation system (air duct, inlet and exhaust fans), egg and manure collection, and feeding and watering systems.

For the modified test tunnel (fig. 1), two pairs of light preference test compartments (LPTC) were formed by grouping the two adjacent compartments from both ends of the tunnel, with the middle compartment used as a separation space between the two pairs. A rectangular passageway (20 cm W x 25 cm H) was located at the lower portion (floor to 20 cm high) of the partition wall within each pair of LPTC, allowing birds to move freely between the two inter-connected cages (one bird a time). As such, two groups of birds could be tested simultaneously in the test tunnel. The test tunnel was equipped with mechanical ventilation so that all the compartments were maintained at essentially identical constant temperature of 21ºC throughout the experiment. A linear feeder (50 cm long) and two nipple drinkers (35 cm high) were installed in each compartment, located outside the front wall and on the back wall of the cage, respectively. A light bulb, either LED or CFL, was installed above the perforated ceiling in each compartment to provide uniformly distributed light intensity within the cage area. A service window on the front wall of each compartment allowed caretakers to refill feeder and collect eggs with minimum disturbance to the birds. Free accesses to feed and water were allowed in all cages. The same amount of feed was added to each feeder before assigning the birds, and refilled daily during the dark period. Eggs were also collected daily during the dark period. At the end of each trial, euthanasia procedures were performed on the test birds according to the IACUC protocol, and manures on the cage floor and manure belt were removed. The test system was disinfected before the start of the next trial.

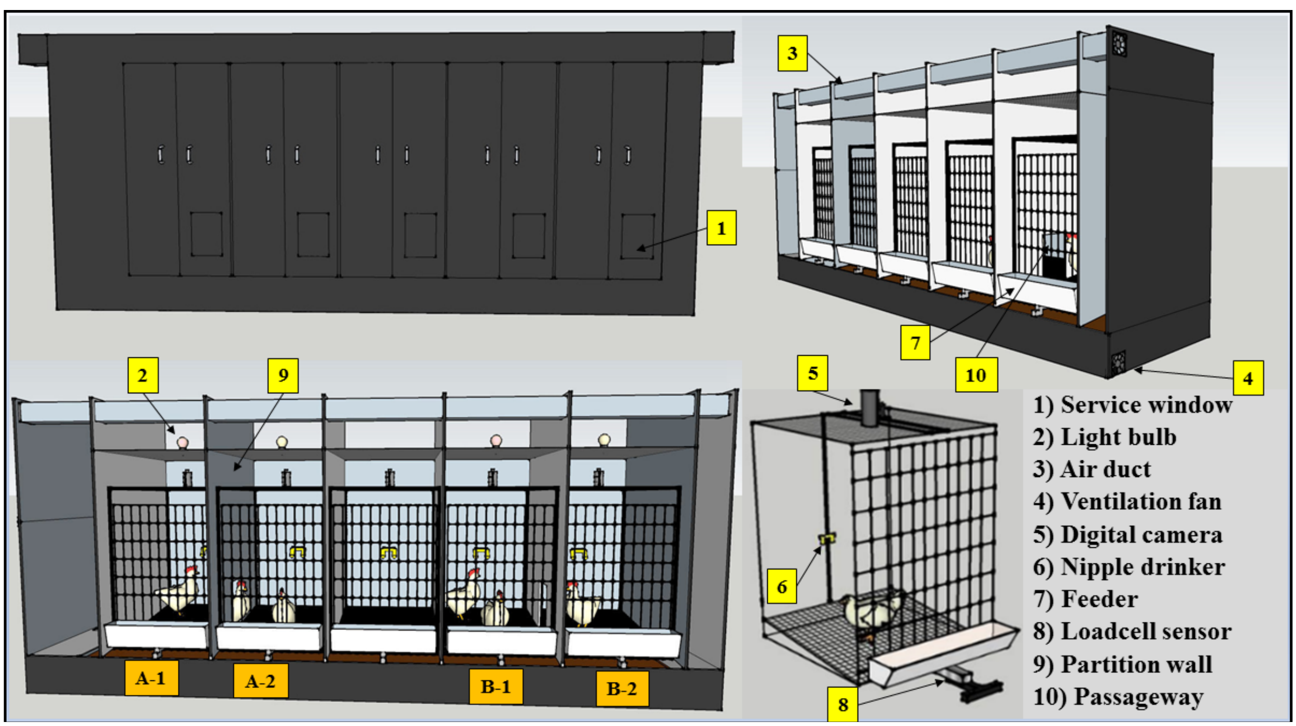

Figure 1. A schematic representation of the light preference test system.

Lighting Regimens

Artificial light was the only light source throughout the entire experiment. The spectral characteristics of the incandescent light (correlated color temperature or CCT = 2550K), CFL (Cold Cathode CFL, 8W, soft white, CCT = 2700K, Litetronics, Alsip, IL, USA[1]), dim-to-blue LED (Agrishift MLB LED, 12W, dim-to-blue, CCT = 4500K, Once, Inc., Plymouth, MN, USA), and dim-to-red LED (Agrishift, JLL LED, 8 Watt, dim-to-red, CCT = 2000K, Once, Inc.) used in the pullet-rearing and layer-production phases are shown in figure 2. These lights had different spectral profiles as measured using a spectral meter (GL Spectis 1.0 Touch, GL Optic Inc., Germany). Specifically, incandescent light increasingly emits long-wavelength lights with increase of wavelength. The two types of LED had relatively even spectral distributions as compared with the CFL. The relatively elevated spectral peaks for both LED occurred at 450 and 630 nm; whereas spectral spikes for the CFL occurred at 545 and 610 nm. In addition, the dim-to-red LED had a predominant spectral output at 610-640 nm (long-wavelength lights, e.g., red), whereas the dim-to-blue LED had a predominant spectral output at 430-460 nm (short-wavelength lights, e.g., blue).

The preference or choice of lights was tested between the dim-to-red LED and the CFL. Light intensity was determined using spectral meter coupled with a software for measuring poultry-perceived (p-lux) light intensity (SpectraShift 2.0, Once, Inc.). Arrangement of the lights was made according to the experimental design as described below. In the acclimation chamber, light intensity varied from 18 to 30 p-lux, depending on the distance from the floor to the lights. In the LPTC, light intensities were adjusted to similar levels (i.e., 25 p-lux on the floor and 20 p-lux at the feeder) and maintained constant throughout the testing period. Constant photoperiods for pullets and layers were also used, i.e., 10L:14D for pullets at 14-16 weeks of age and 16L:8D for layers at 44-50 weeks of age.

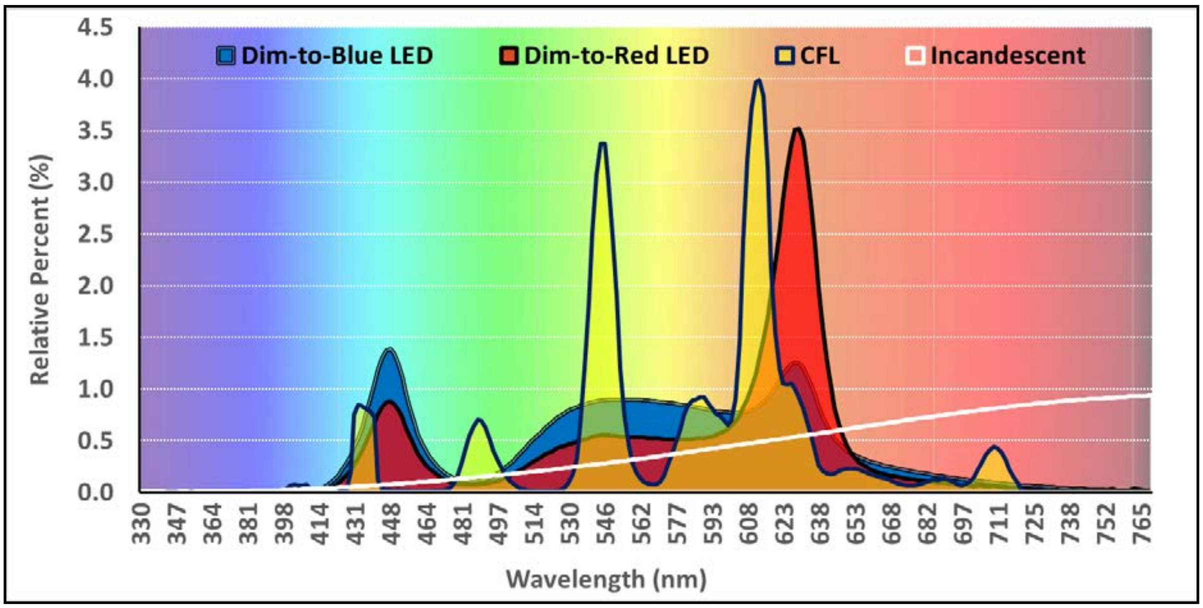

Figure 2. Spectral characteristics of the incandescent light (2550K), CFL (2700K), dim-to-blue LED (4500K) and dim-to-red LED (2000K) used in this study. Number in the parentheses is the correlated color temperature of the light.

Experiment Procedures

A total of 36 groups of birds (12 groups for each LP, LL, and CL category) were tested in 18 trials to evaluate light preference or choice by the birds. For each trial, six birds in two groups of the same category were tested simultaneously. The six test birds first underwent a 7-day acclimation period together in the acclimation chamber (1578 cm^2 $bird^{-1}$ space allowance), during which they got used to passing through the passageway between the inter-connected cages. The acclimation chamber was alternately lit by the LED (dim-to-red) and the CFL from one day to the next, thus allowing birds to experience both test lights before assigned to LPTC. After the acclimation period, these two groups of birds were randomly assigned to the two pairs of LPTC (2400 cm^2 $bird^{-1}$) for a 6-day testing period. During this 6-day testing period, the LED and the CFL were randomly assigned to the compartments, and alternated daily (during the dark period) between the compartments to avoid potential compartment effect (e.g., location preference). The first two days in LPTC were used as acclimation period for birds, thus results were analyzed based on data collected in the last four days.

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[1] Mention of product or company name is for presentation clarity and does not imply endorsement by the authors or Iowa State University, nor exclusion of other suitable products.

Data Collection

A real-time sensor-based monitoring system was built by incorporating five load-cell scales (RL1040-N5, Rice Lake Weighing Systems, Rice Lake, WI, USA), six thermocouples (±0.5ºC, Type-T, OMEGA Engineering Inc., Stamford, CT, USA), and a relative humidity (RH) sensor (HMT100, Vaisala, Inc., Woburn, MA, USA) with a LabVIEW-based data acquisition system (version 7.1, National Instrument Corporation, Austin, TX, USA). This system consisted of a compact FieldPoint controller (NI cFP-2020, National Instrument Corporation) and multiple thermocouple input modules (NI cFP-TC-120, National Instrument Corporation), and collected data at 1 Hz sampling rate. Real-time temperature in each compartment, RH near the exhasting fan, and each feeder weight were monitored. Temperature was used for adjusting ventilation rate to maintain consistent temperature among the compartments. Feeder weight was used for determining daily feed consumption in each compartment by calculating the weight difference between the beginning and the end of the day. Average daily feed intake per bird (g $bird^{-1}$ d^{-1}) was then calculated.

A real-time vison system was built by incorporting six infrared video camers (GS831SM/B, Gadspot Inc. Corp., Tainan city, Taiwan, China) and a PC-based video capture card (GV-600B-16-X, Geovision Inc., Taipei, Taiwan, China) with a surveillance system software (Version 8.5, GeoVision Inc.). This vision system could record images from all compartments simultaneously at 1 frame per second. With the recording of real-time images throughout the testing period, distributions of the birds in LPTC were analyzed using an automated image processing program in MATLAB (R2014b, MathWorks Inc., Torrance, CA, USA) and an Excel VBA program (Microsoft Office 2016, Redmond, WA, USA).

Determination of Time-Series Distributions of Birds

The algorithm for determining dristributions of birds in LPTC mainly consisted of three procedures, including 1) extracting pixels of birds and converting into binary image (fig. 3a-e); 2) counting number of blobs detected in the binary image and determining the centroid and area of each blob (fig. 3f); and 3) determining number of birds in each cage. The images were analyzed separatedly for each cage of LPTC; thus a bird passing through the passageway would be identified as two blobs, one blob in each cage. In addition, a blob could be a single bird or multiple contacting birds. In the current study, contacting birds were not individually segmented. Instead of implementing a computation-intensive segmention procedure, a simple enumeration method was applied as described below. Consequently, with only three birds in LPTC, there were four possible numbers for the total detected blobs, i.e., one, two, three, and four blobs. All the possible distributions of birds, 10 scenarios in total, are illustrated in figure 4, based on the number of detected blobs. To determine the number of birds in each cage, an automated VBA program was implemented as illustrated in the flowchart (fig. 5). The number of birds in each cage was determined based on the number of blobs detected and the respective area of each blob. With the knowledge of distributions of the birds, the following behavioral responses could be determined or derived with the VBA program: time spent in each light (min $bird^{-1}$), moving frequency between lights (times $bird^{-1}$ h^{-1}), and duration with no bird, one bird, two birds, or three birds staying together in each light (min) during a specific time period (e.g., light period, dark peirod or 24-h day). In this study, birds were not individually identified with the vision system, thus all the behavior parameters were presented as group average.

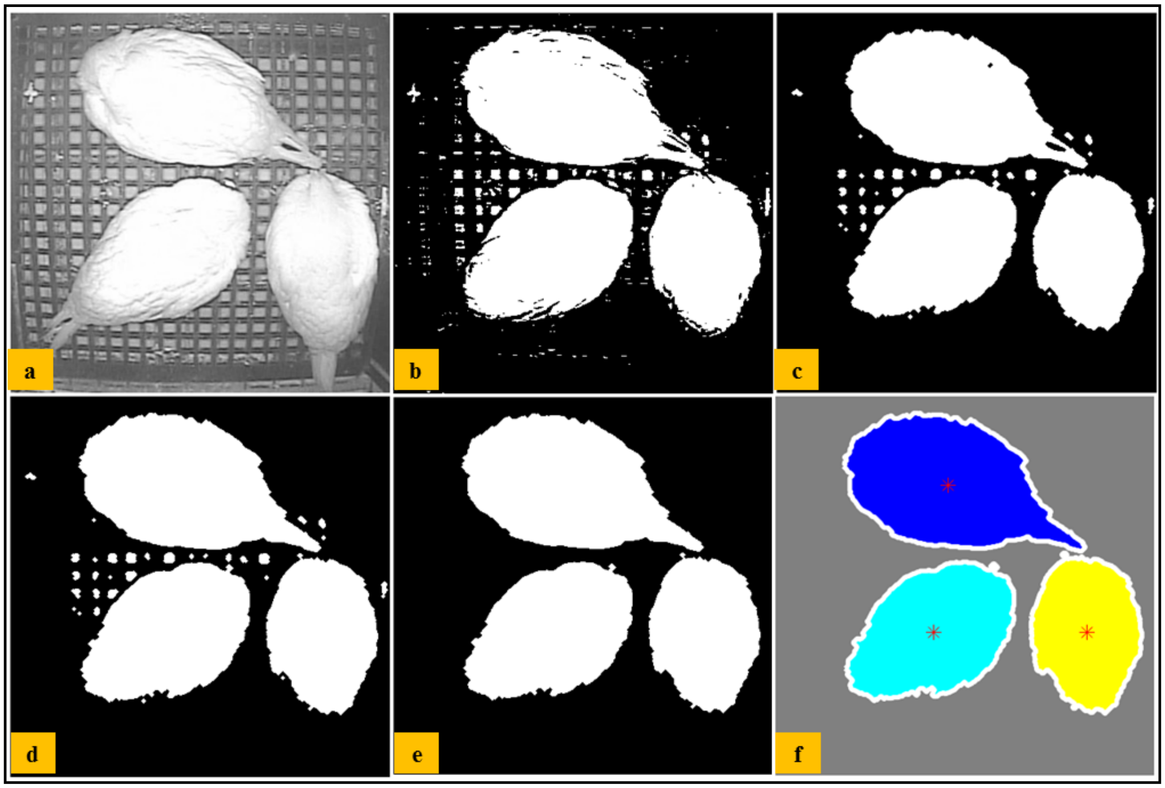
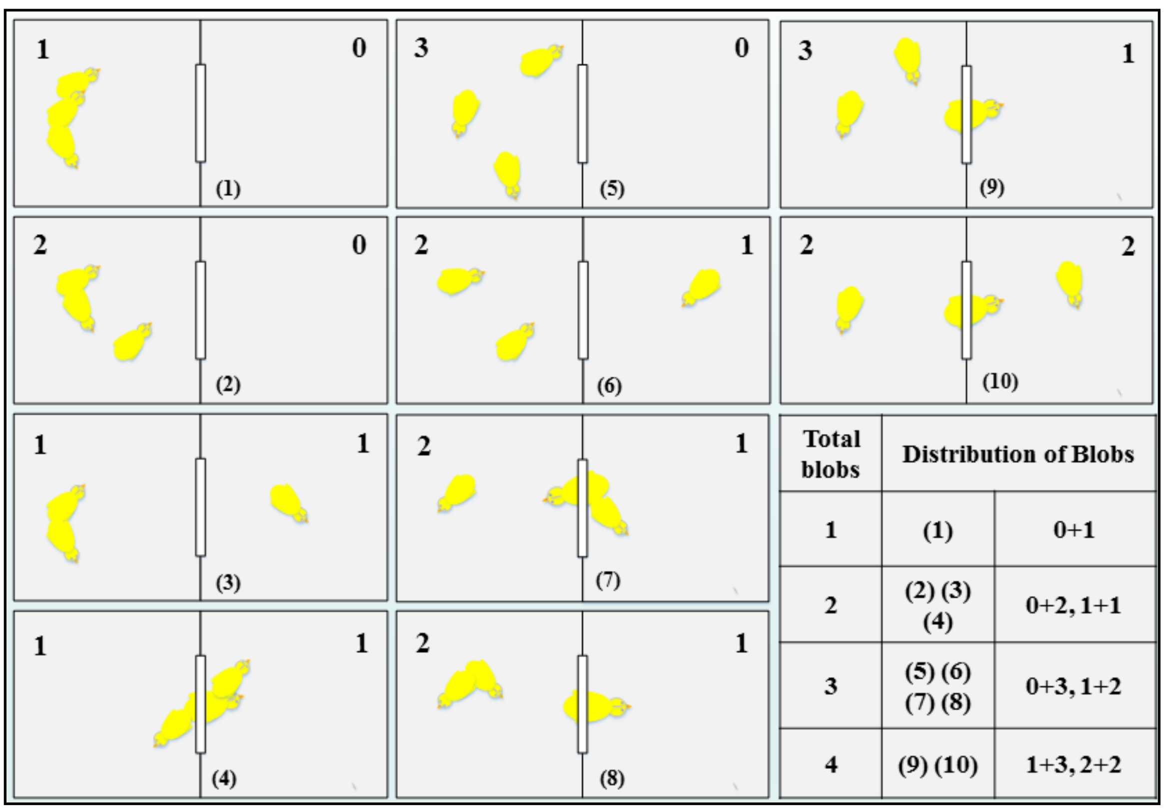


Figure 3. Image processing procedures. (a) RGB image with birds, (b) binary image of birds without enhancement, (c) binary image of birds with morphological opening operation, (d) binary image of birds with morphological closing operation, (e) binary image of birds with small objects removed, and (f) detected blobs in the binary image.



Total blobs	Distribution of Blobs	
1	(1)	0+1
2	(2) (3) (4)	0+2, 1+1
3	(5) (6) (7) (8)	0+3, 1+2
4	(9) (10)	1+3, 2+2

Figure 4. Distributions of birds based on the number of detected blobs in light preference test compartments. The small rectangular in the center represents the passageway between the inter-connected cages. The number in each corner represents the number of blobs detected in that cage. The number in parentheses is the scenario ID.

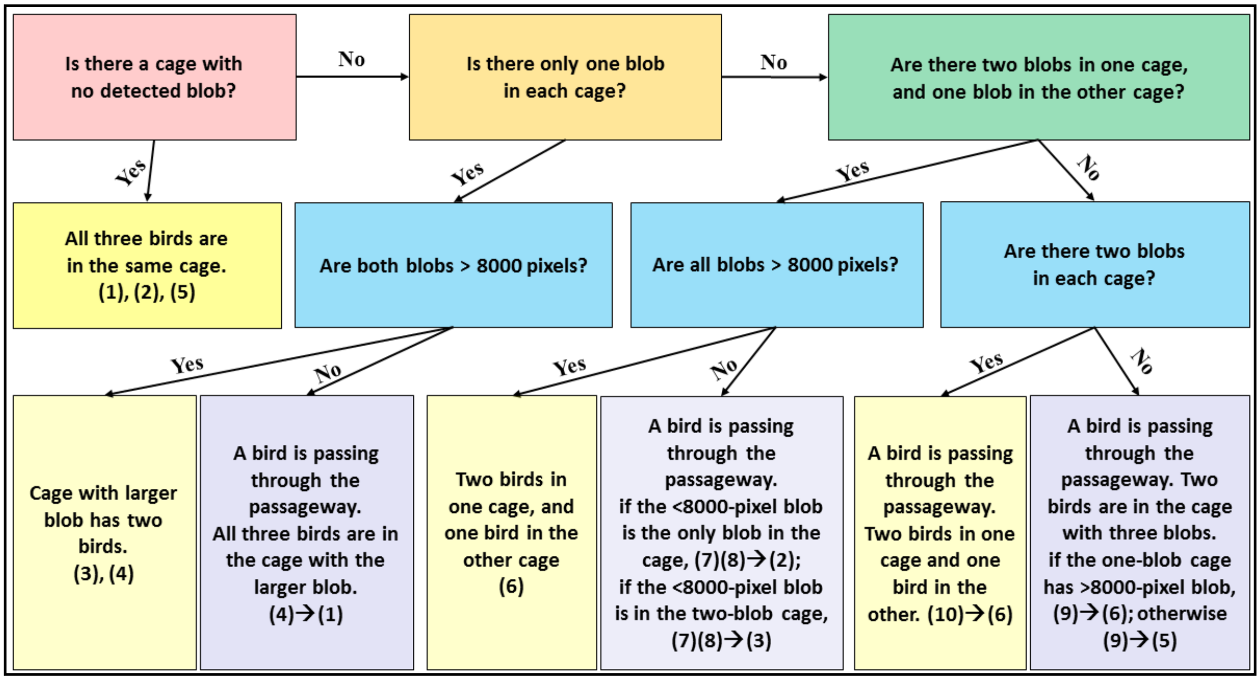


Figure 5. Flowchart for determining the distributions of birds in light preference test compartments. The threshold (8000 pixels) in this chart was applied for detection of layers. In the case of pullets, the threshold was set at 5000 pixels. The number in parentheses is the scenario ID as indicated in figure 4.

Table 1. Nomenclature of bird behavior parameters measured during the preference test

Abbreviation	Description
LMF	Light-period moving frequency; times bird^{-1} h^{-1}
DFI	Daily feed intake; g bird^{-1} d^{-1}
PDFI	Proportion of daily feed intake in the LED or CFL; %
PLTS	Proportion of light-period time spent in the LED or CFL; %
L3C0	Proportion of the light period with all three birds in the LED; %
L2C1	Proportion of the light period with two birds in the LED and one bird in the CFL; %
L1C2	Proportion of the light period with one bird in the LED and two birds in the CFL; %
L0C3	Proportion of the light period with all three birds in the CFL; %

Statistical Analysis

Statistical analyses were performed using SAS Studio 3.5 (SAS Institute, Inc., Cary, NC, USA). Behavior parameters measured in the preference test, including LMF, DFI, PDFI, PLTS, L3C0, L2C1, L1C2, and L0C3 (table 1), were analyzed to compare the behavioral differences among the three categories of birds (LP, LL, and CL) and to determine their light preference/choice. In the current study, group of birds was the experimental unit, and each category of bird had 12 replicates. LMF, DFI and all the proportion data (PDFI, PLTS, L3C0, L2C1, L1C2 and L0C3) were analyzed with generalized linear mixed models by implementing PROC GLIMMIX procedure. A Gaussian distribution was specified for the analyses of LMP and DFI; a beta distribution was specified for the analyses of PDFI, PLTS, L3C0, L2C1, L1C2, and L0C3. All the models could be expressed as:

$$Y_{ijkd} = \mu + B_i + P_j + (BP)_{ij} + G(BP)_{ijk} + D(BPG)_{ijkd} + e_{ijkd}$$

Where Y_{ijkd} denotes the independent observation on day d for group k in LPTC$_j$ of bird category i; μ is the overall mean; B_i is the bird category effect (fixed); P_j is the LPTC effect (fixed); $(BP)_{ij}$ is the interaction effect (fixed) of bird category and LPTC; $G(BP)_{ijk}$ is the group effect (random) tested within each LPTC for each bird category, $D(BPG)_{ijkd}$ is the day effect (random) for each group, adjusted with first-order autoregressive or AR (1) covariance structure; and e_{ijkd} is the random error with $N \sim (0, \sigma^2)$.

Evaluation of the light preference was accomplished by testing the null hypothesis that the proportion under concern (PDFI and PLTS) equaled 0.5. Namely, in the case of no preference, 50% of the daily feed intake or light-period time spent would be in either LED or CFL. As the beta distribution used a logit link function, the evalaution was actually to test whether the intercept equaled zero (logit(0.5) = 0). In addition, Tukey-Kramer tests were used for pairwise comparisons among bird catogries for all the behavior variables. Effects were considered significant at $P<0.05$. Normality and homogeneity of variance of data were examined by residual diagnostics. Unless otherwise specified, data are presented as least squares means along with SEM.

Results and Discussions

Light-Period Time Spent of Birds

As shown in figure 6, the CFL was preferred over the LED by all the three categories of birds in terms of light-period time spent (P = 0.011, 0.030 and 0.001 for IP, LL, and CL, respectively), and such preference was not affected by the prior lighting experience (P = 0.422). Specifically, PLTS in the CFL was 58.0 ± 2.9%, 53.7 ± 1.6%, and 54.2 ± 1.2% for IP, LL, and CL, respectively. Correspondingly, PLTS in the LED was 42.0 ± 2.9%, 46.3 ± 1.6%, and 45.8 ± 1.2% for IP, LL, and CL, respectively. The results of the current study are similar to the findings from an earlier study in that laying hens preferred CFL over incandescent light by spending on average 73.2% of time in CFL and only 26.8% of time in incandescent light (Widowski et al., 1992). However, there was no clear information to explain why birds preferred CFL than the other light in the cited study. Laying hens showed no preference for HPS or incandescent lights (Vandenbert & Widowski, 2000). Broilers showed no behavioral sign of preference between white and yellow LED (Mendes et al., 2013). However, turkeys were found to prefer fluorescent light with supplementary UV radiation compared to without UV radiation (Moinard & Sherwin, 1999). Research has demonstrated that poultry have a fourth retinal cone photoreceptor that allows them to see in the UVA wavelength (315-400 nm) (Prescott & Wathes, 1999; Cuthill et al., 2000), and may use UVA perception to modify various behavioral functions such as feeding, peer recognition, mate selection, and social encounters (Lewis & Gous, 2009). With UVA radiation forming 3-4% of fluorescent light, but almost totally absent in incandescent light and most of newly emerging LED lights (Lewis & Gous, 2009), attraction of the bird to the CFL as observed in the current study may be another reflection of the UVA light effect. Therefore, further investigation of bird preference for UVA light is warranted.

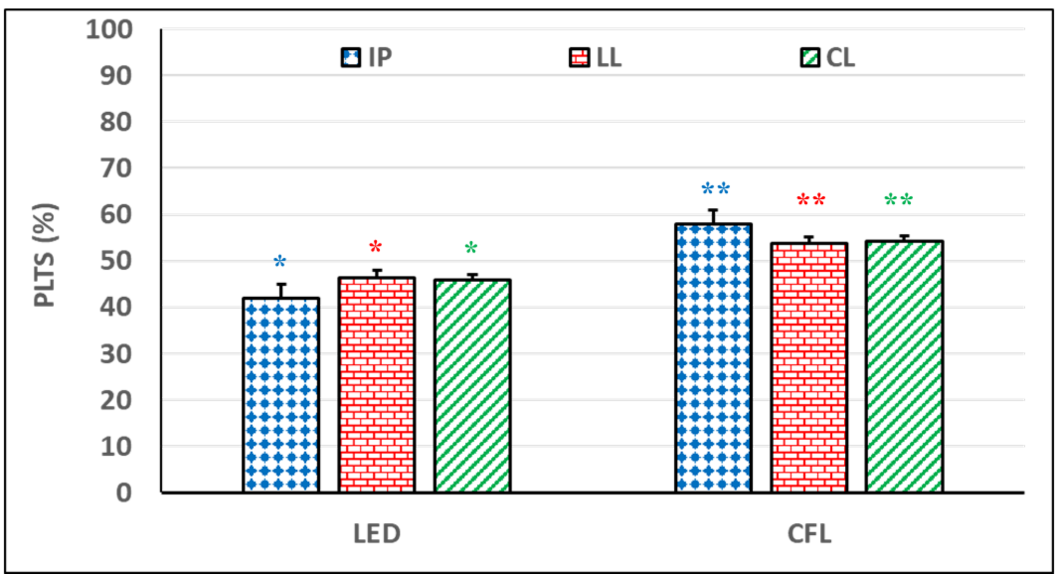


Figure 6. Proportions of light-period time spent in the LED and CFL. IP = pullets reared in incandescent light; LL = layers reared and kept in LED; CL = layers reared and kept in CFL. PLTS (%) = proportion of light-period time spent in the LED or CFL. Data bars with single asterisk (*) are significantly lower than 50% at P<0.05; data bars with double asterisks (**) are significantly higher than 50% at P<0.05; data bars without asterisk are not significantly different from 50%. For LED or CFL, bars with different superscript letters are significantly different at P<0.05.

Light-Period Distributions of Birds

Light-period distributions of birds in the two light types provide more detailed illustration on their choices (fig.7). In general, birds in all three categories spent significantly higher proportions of time splitting into the two cages than staying together in one cage, with a tendency of choosing CFL when more birds stayed together. Specifically, L1C2 (40.7 ± 2.4%) and L2C1 (33.6 ± 2.5%) for IP were significantly higher than L0C3 (18.9 ± 2.6%, P = 0.001 and 0.021, respectively) and L3C0 (6.8 ± 0.8%, P < 0.001 and P < 0.001, respectively). L1C2 (31.6 ± 1.4%) for LL was significantly higher than L0C3

(22.6 ± 1.7%, P=0.031) and L3C0 (15.3 ± 1.5%, P < 0.001), and L2C1 (30.5 ± 1.6%) for LL was also significantly higher than L3C0 (P < 0.001). Likewise, L1C2 (33.6 ± 1.2%) and L2C1 (31.6 ± 1.4%) for CL were significantly higher than L0C3 (20.6 ± 1.7%, P = 0.005 and P <0.001, respectively) and L3C0 (14.2 ± 1.2%, P < 0.001 and P < 0.001, respectively). Such distribution patterns of birds were not consistent with the findings of a previous study in that laying hens spent about 60% of time during the light period in three to four hens in the same cage when housed four hens in five inter-connected cages (Ma et al., 2016).

As mentioned earlier, laying hens spent on average 73.2% of time in CFL and only 26.8% of time in incandescent light (Widowski et al., 1992), whereas the degree of preference was lower in the current study as reflected by the time spent of birds (about 55% vs. 45%). To a large extent, as reflected by the distribution patterns of birds in the current study, the lower degree of preference might be explained by the subordinate bird(s) escaping from being pecked by the dominate one(s). Birds are social animals and usually have a specific dominance relationship when they are in small groups. The establishment of dominance hierarchies in pullets and laying hens housed in small groups usually start as early as the first encounter and maintain relatively consistent in the subsequent lives. Due to the existence of the dominance hierarchies, the subordinate birds usually benefit from avoiding costly contests in their encounters (Pagel & Dawkins, 1997; D'Eath & Keeling, 2003). In the current study, floor space, feeder space, and nipple drinkers provided in each cage were considered sufficient for all the birds, which might have weakened the significance of the hierarchies. However, aggressive pecking had been observed among the test pullets and layers during the early rearing period and seemed to continue after assigned to the test environment.

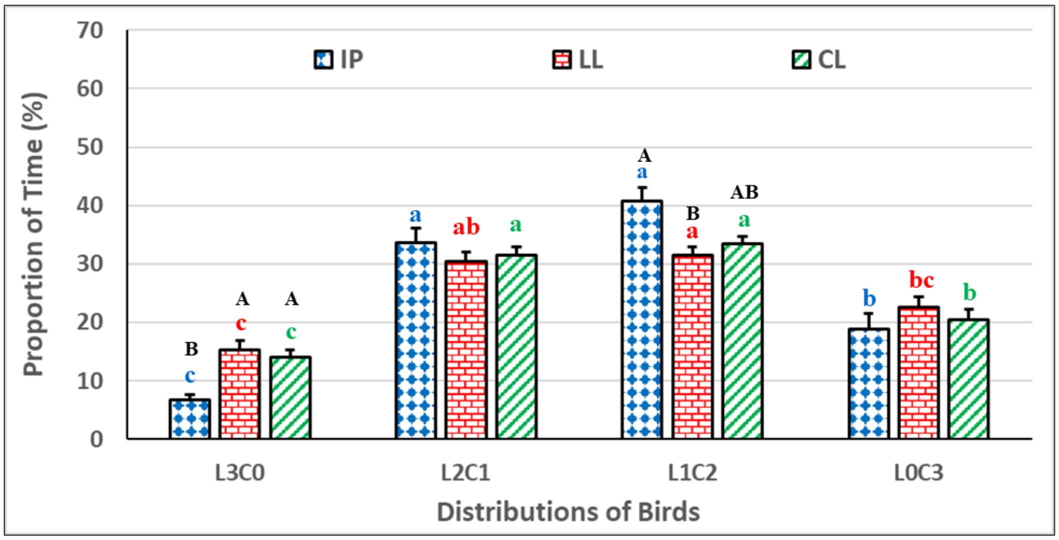


Figure 7. Light-period distributions of birds in the LED and CFL. IP = pullets reared in incandescent light; LL = layers reared and kept in LED; CL = layers reared and kept in CFL; L3C0 = proportion of the light period with all three birds in LED; L2C1 = proportion of the light period with two birds in LED and one in CFL; L1C2: proportion of the light period with one bird in LED and two in CFL; L0C3 = proportion of the light period with all three birds in CFL. For each distribution of birds, bars with different uppercase superscripts differ significantly at P<0.05. For each category of birds, bars with different lowercase superscripts differ significantly at P<0.05.

Light-Period Moving Frequency of Birds

Birds were observed to move frequently between the inter-connected cages for feeding, drinking, resting, foraging, and nest-seeking during the light period. LMF of IP, LL, and CL averaged 19.8 ± 1.0, 31.9 ± 2.4, and 29.9 ± 1.9 times $bird^{-1}$ h^{-1}, respectively (fig. 8). LL and CL had significantly higher LMF than IP (P < 0.001 and P < 0.001, respectively), while LMF of LL and CL was highly comparable (P = 0.804). The higher LMF of layers than that of pullets as observed in the current study probably stemmed from the intensive nest-seeking behavior of hens, because nest box was not available in the current study. Hens were highly motivated to gain access to nest box prior to oviposition and displayed frustration when nest was not available (Cooper & Appleby, 1996), and appeared to be more willing to aggressively compete to lay their eggs in the curtained nest area when housed in small cages (Hunniford et al., 2014). But it was not a behavior requirement for the 14-16-week-old pullets. In an earlier study, a significant negative correlation was found between the degree of preference that a bird had for a particular light and its movement between lights (Widowski et al., 1992) in that birds having a stronger preference for a particular light moved less frequently between lights. However, this finding may be not applicable to explaining what was observed in the current study, as all the three categories of birds performed similar degrees of preference for CFL light during the light period.

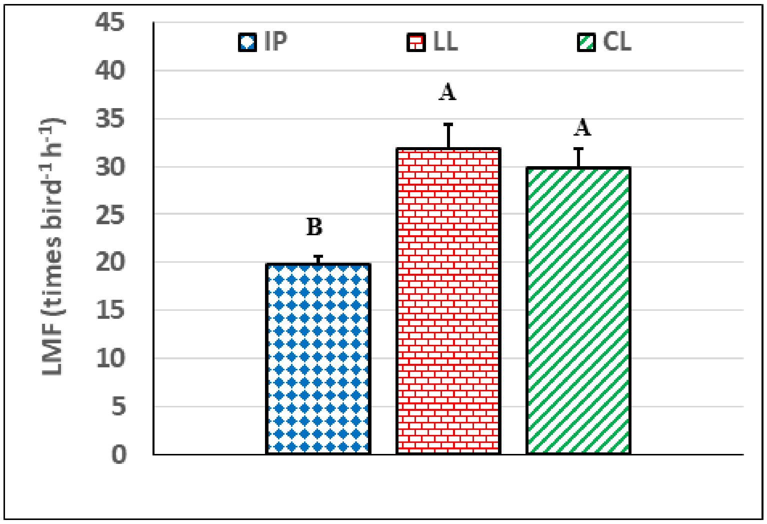


Figure 8. Light-period moving frequency (LMF). IP = pullets reared in incandescent light; LL = layers reared and kept in LED; CL = layers reared and kept in CFL. Bars with different superscripts differ significantly at P<0.05.

Daily Feed Intake

All the three categories of birds showed no light preference for feeding in terms of PDFI (P = 0.419, 0.566, and 0.749 for IP, LL, and CL, respectively, fig. 9). Specifically, 51.8 ± 2.3%, 51.2 ± 2.0%, and 49.6 ± 1.4% of the DFI occurred in the LED for IP, LL, and CL, respectively. Correspondingly, 48.2 ± 2.3%, 48.8 ± 2.0%, and 50.4 ± 1.4% of DFI happened in the CFL for IP, LL, and CL, respectively. The result of no light preference for feeding was not consistent with the findings of some earlier studies. Shaver hens in fluorescent light were found to perform more ingestion behaviors (feeding, drinking, and ground pecking) than in incandescent light (Widowski et al., 1992). Broilers were found to eat substantially more feed in chambers equipped with white LED than with yellow LED (Mendes et al., 2013). However, the preferences for light types was confounded by light intensities in these studies as the bird-perceived light intensities were not equal when lights applied to the cages or chambers were adjusted using human light meters (Prescott and Wathes, 1999; Prescott et al., 2003; Saunders et al., 2008). Indeed, feed intake of birds seemed to be more associated with light intensity than with light type or spectrum. ISA Brown hens were observed to eat the most time in the brightest (200 lux) and least time in the dimmest (<1 lux) light intensity when given free choice among <1, 6, 20 or 200 lux (Prescott & Wathes, 2002). On the other hand, W-36 laying hens were found to have highest feed intake at 5 lux (32.5%) and lowest at 100 lux (6.7%) when given free choice among <1, 5, 15, 30 or 100 lux (Ma et al., 2016).

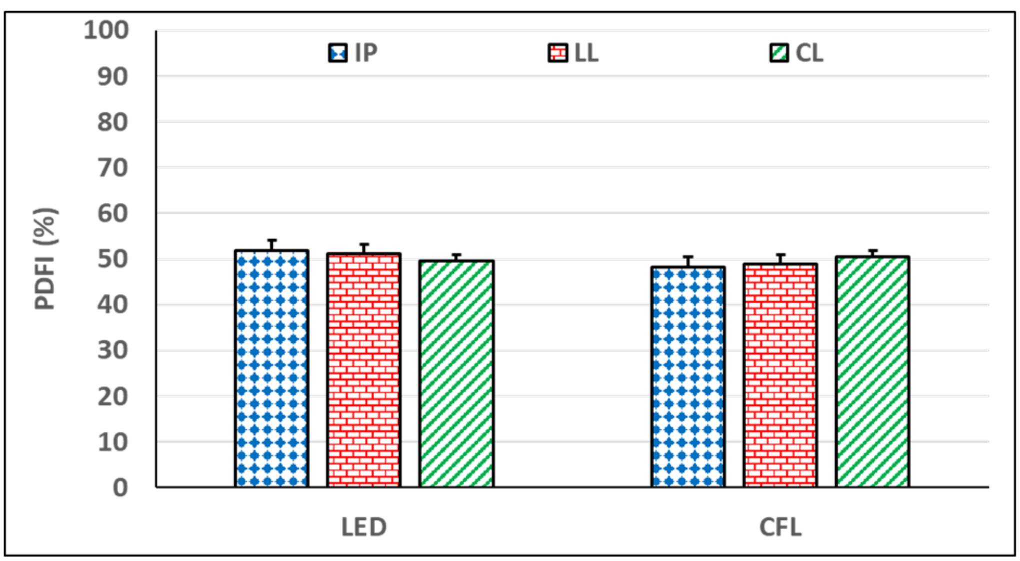


Figure 9. Proportions of daily feed intake in the LED and CFL. IP = pullets reared in incandescent light; LL = layers reared and kept in LED; CL = layers reared and kept in CFL. PDFI (%) = proportion of daily feed intake in the LED or CFL. Data bars with single asterisk (*) are significantly lower than 50% at P<0.05; data bars with double asterisks (**) are significantly higher than 50% at P<0.05; data bars without asterisk are not significantly different from 50%. For LED or CFL, bars with different superscript letters are significantly different at P<0.05.

Although birds showed no light preference for feeding, the three categories of birds had significantly different DFI (P <0.001, fig. 10). Specifically, DFI averaged 48.7 ± 0.9, 104.7 ± 0.9, and 101.3 ± 1.0 g bird^{-1} d^{-1} for IP, LL, and CL, respectively. As expected, LL and CL had significantly greater DFIs than IP (P < 0.001 and P < 0.001, respectively) due to the difference in age and body weight. While it is interesting that LL had significantly higher DFI than CL (P = 0.046), the exact cause for this difference was unclear to the authors. Early lighting experience of the LED might have played a role, as feed intake of LL during the early production period in conventional cages tended to be higher than that of CL (unpublished data). However, without additional supporting data (production rate and activity levels were not monitored in the study), it is difficult to make any solid conclusion.

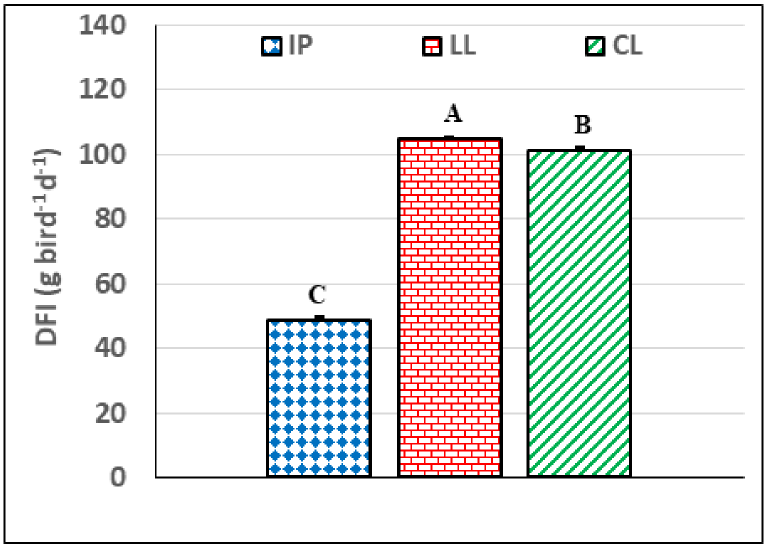


Figure 10. Daily feed intake (DFI) of birds. IP = pullets reared in incandescent light; LL = layers reared and kept in LED; CL = layers reared and kept in CFL. Bars with different superscripts differ significantly at P<0.05.

Conclusions

In this study, light preference of Hy-Line W-36 pullets and laying hens between a commercial dim-to-red LED light (LED) and a typical compact florescent light (CFL) was assessed in free-choice light preference test compartments. Three categories of birds each with different prior lighting experiences were tested, including pullets reared in incandescent light (IP), layers reared and kept in LED (LL), and layers reared and kept in CFL (CL). Each category consisted of 12 groups (replicates), three birds per group. The following conclusions were drawn.

- The pullets and layers spent significantly higher proportion of time in the CFL and significantly lower proportion of time in the LED during light period, regardless of their prior lighting experience.
- The pullets and layers had comparable proportions of daily feed intake in the LED and CFL conditions, regardless of their prior lighting experience.

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