Light demand characteristics, production performance, and changes in the feeding patterns of broilers

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Abstract: Poultry is a light-sensitive animal and the light environment has an important influence on the growth and development of these animals. Previous studies have mainly focused on the effects of the light environment on various physiological indicators of poultry but seldom explored the light demand characteristics of broilers under free selection. This experiment mainly studied the light demand characteristics of broilers under a yellow LED light environment and the influence of different breeding densities [low-density (2.5 broilers/m^2), high-density (7.5 broilers/m^2)] on the production performance and diet characteristics of broilers. Studies showed that the production performance indexes of low-density groups are higher than those of high-density groups. The feed and water consumption in the light area of the two experimental groups were significantly higher than those in the dark area, which means that the broilers showed a great preference for the light area. However, as the age of the broilers increased, the food and water consumption of the broilers decreased, indicating that broilers had a lower preference for light in the middle and late stages of growth. The statistical results for the residence frequency distribution characteristics showed that broiler chickens had different light requirements at different growth stages under the condition of active selection: 1) low-density breeding environment: 23.8L (light):0.2D (dark) for chicks and 22.3L:1.7D for adult broilers; 2) high-density breeding environment: 22.6L:1.4D for chicks and 15.0L:9.0D for adult broilers. This study will provide a reference for the optimization and control of light environment in broiler breeding

Keywords: broiler, light-demand characteristics, production performance, feeding pattern
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1 Introduction

Poultry is a light-sensitive animal with a highly developed visual system, and light stimulation has an important impact on the growth, behavior, and rhythm of these animals[1,2]. Therefore, controllable artificial light sources have become the main source of breeding light. Compared with traditional incandescent lamps and fluorescent lamps, light-emitting diode lights (LEDs) have very different spectral characteristics, including a narrow and special spectrum that can be formed by concentrating energy in a specific wavelength band. Due to the acute vision of poultry, optimizing the lighting environment according to the light demand characteristics of poultry can effectively improve the production performance of poultry[3,4].

Light intensity, light color, and photoperiod are three light environment factors and changes in these factors will have different effects on the growth of poultry[5,6]. Different light intensities have no significant effect on the performance of broiler chickens, although too high or too low light intensity often affects the welfare of poultry[7-11]. Light color is mainly determined by spectrum, which is also the focus of previous research. Relevant studies have found that blue light and green light have a significant advantage in promoting the performance of broiler chickens but previous research has also shown that short-wavelength light induces a broiler’s behavioral and physiological syndrome through a misaligned eating rhythm[12-15]. So, its practical application value remains to be further studied. Yellow light is spectrally similar to white light, and previous research has demonstrated its advantages in broiler breeding[16-18]. The photoperiod includes two aspects: the light duration and the light system. A recent study showed that night

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length can seriously affect the sleep of starlings[19], previous experiments have demonstrated that changes in the photoperiod will affect the feed conversion rate of poultry and the incidence of chicken diseases such as leg disease, and continuous light will inhibit the growth of broilers to a certain extent[20,21]. Overall, previous studies mainly focused on the effects of the light environment on various physiological indexes of poultry and did not take into account the light demand characteristics of poultry themselves.

Stocking density is an important parameter in broiler breeding[22], previous studies have indicated differences in the effects of strain and stocking density on male broiler conformation, performance, and welfare and highlight the importance of tailoring management practices to the strain of broiler-raised[23,24]. In this study, conventional high-density and low-density groups were designed, where the high-density group corresponds to conventional stocking densities, and the low-density group was designed to minimize the effect of crowding on free-choice light areas.

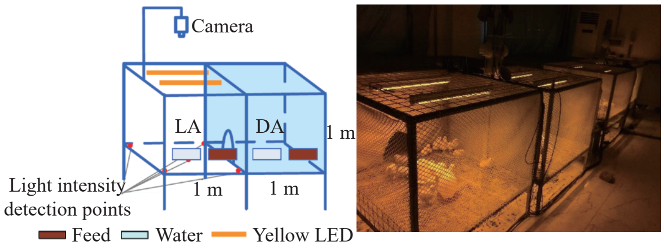
A yellow LED was selected for this work for previous work[17], and the ambient temperature was maintained at room temperature (26°C). In this research, we investigated the light demand characteristics of different growth stages and the influence of different breeding densities on broiler weight and diet characteristics, and we hope to provide references for further application to broiler breeding lighting.

2 Materials and methods

All procedures in this experiment were approved by the Laboratory Animal Center, Zhejiang University (Hangzhou, Zhejiang, China).

2.1 Animals and experimental treatments

61-day-old yellow-feathered chicks (Meihuang, Zhejiang Guangda Breeding Poultry Co., Ltd., Zhejiang, China) were used for the experiment. Due to the fragile nature of the newly hatched, the chicks were raised intensively to adapt to the environment in the first three days of the brooding period and then weighed and separated into three replicate experimental groups. Each experimental group included two independent chicken cages [2 m×1 m×1 m, length (L)×width (W)×height (H)] that included 5 and 15 chicks (low-density: 2.5 chicks/m^2 and high-density: 7.5 chicks/m^2) (Figure 1). The cages were equally divided into two connected areas named light area (LA) and dark area (DA) with arched holes (height: 30 cm, width: 20 cm) except which all other parts were shaded to prevent light from passing through. The broilers could pass through the holes to stay where they want. Cameras were installed on the top of the LA to record the activities of the broilers in real time. The manure receiving boards were placed 0.5 m below the chicken coop and cleaned once a day. Feeding and drinking devices of the cage were placed at specific positions, where the chicks could eat and drink freely, and the feed and drinking water were changed every day to prevent feed spoilage or odor production, which may affect the experimental results. During the experiment, the ambient temperature T_a was controlled at 26°C-28°C, and the relative humidity (RH) was controlled at 56%-70%. The vaccination procedures for broiler chickens were strictly in accordance with the vaccine standards for commercial broiler chickens of Zhejiang Qinqin Breeding Co., Ltd (Zhejiang, China), and epidemic prevention work was performed by the company's professional technicians. The feed for different growth stages of broilers was provided by the company, and the main ingredients were maize and soybean meal.



a. Structure diagram b. Photograph

Note: LA: Light area; DA: Dark area.

Figure 1 Structure diagram and photograph of the breeding area

2.2 Lighting environment

Straight yellow LED tubes were selected as the light source in the experiment. The LED tubes and light adjustment controllers were provided by Hangzhou LightTalk Biotechnology Co., Ltd. (Zhejiang, China). The main wavelength range of the LED tubes was 587.9-589.1 nm, and the tube power was 4.32 W. Each LED tube contained 108 lamp beads, and the length of the tube was 60 cm. In the formal experiment, two tubes were installed at the top of the LA and the lighting system of the LA was 24L:0D (24 h light: 0 h dark), while the DA was covered with shading cloth. The light intensity setting value of the LA was 15 lx, which is commonly used in the growing period in actual production. The five points were measured in the trapezoidal area with an illuminance meter (SMART SENSOR AR823+; Hong Kong SMART SENSOR Co., Ltd, China) and obtained the average value. The surface of the lamp was cleaned every week to reduce the influence of dust on the light intensity, thereby reducing the influence of light intensity on the experimental results. The windows and doors of the breeding area are sequentially covered by high white plastic nets and silver shading cloth to avoid the influence of external light on the breeding area.

2.3 Production performance and behavior observation

The consumption of feed and water (remaining amount and added amount) in the LA and DA was measured daily to calculate the chick's preference for eating behavior. To reduce the influence of too frequent manual weighing on the accuracy of the experiment, each chick was weighed once a week (4, 11, 18, 25, 32, 39, 46, and 53 d old). On the first day of grouping, all chicks were placed in the LA, and the chicks were placed in the area opposite the previous location after each weighing. The death of the chickens was recorded daily and the dead would be removed. At the end of the experiment, all broiler chickens were killed and various slaughter indicators were measured.

Behavior observations were carried out on the day before weighing to avoid the influence of manual weighing on the behavior of broilers. The video recording of the chick behavior was completed by a CCD (charge-coupled device) camera (DH-CA-D481/3; Hangzhou Dahua Technology Co., Ltd., China), and the shooting range could cover the entire breeding surface of the LA. Screenshots of the videos were taken at 5 min intervals and counted the number of chicks in both the LA and DA. The 15-min interval has been shown to cover 95% of the change interval in the total result[25]. When counting the numbers, the basis for judging an individual chick in a certain area was the eyeball location. If most of the body of the broiler is in the LA but its eyes are in the DA, then the broiler is still counted as being in the DA. To ensure the accuracy of the experimental results, counting was not performed in the videos at certain specific moments such as during the addition of feed and water or the removal of dust.

2.4 Statistical Analysis

During the experiment, some production performance indicators including body weight, relative growth rate (RGR), feed consumption, water consumption, feed conversion ratio (FCR), and mortality rate, were used. The relative growth rate is the percentage of poultry weight gain in a certain period. The formula is as follows:

$$\mathrm{RGR}=\frac{W_{t1}-W_{t0}}{W_{t0}} \tag{1}$$

where, RGR represents the relative growth rate, %; W_{t0} represents the weight of the broiler at the age of t_0, g; W_{t1} represents the weight of the broiler at the age of t_1, g.

The feed conversion ratio is an important index for characterizing production performance, and the feed-to-weight ratio is a kind of feed conversion rate. The equation is as follows:

$$\mathrm{FCR}_W=\frac{\sum_{i=1}^{d}E_i}{W_{t1}-W_{t0}} \tag{2}$$

where, FCR_W represents the feed-to-weight ratio, %; E_i represents the feed intake on day I; W_{t0} represents the weight of the broiler at the age of t_0, g; W_{t1} represents the weight of the broiler at the age of t_1, g.

The percentage of staying frequency directly reflected the broilers' preference for a certain area. The formulas are as follows:

$$F_{sl}=\frac{N_l}{N}\times 100\% \tag{3}$$

$$F_{sd}=1-F_{sl} \tag{4}$$

where, F_{sl} represents the percentage of staying in the LA frequency, %; N_{sl} represents the number of broilers staying in the LA at a certain moment; F_{sd} represents the percentage of staying in the DA frequency, %; N_{sd} represents the number of broilers staying in the DA at a certain moment; N represents the number of all broilers. All data such as body weight, feed consumption, water consumption, and regional residence time were analyzed by Excel (Microsoft Office 2013, Microsoft Corporation, the USA).

3 Results

3.1 Production performance

No broilers died in this experiment, and different breeding densities had significant effects on broiler body weight, weight gain rate, and other production performance indicators, but had no significant effect on the feed-to-weight ratio (Table 1). The final body weight, weight gain rate, and feed consumption of low-density broilers were significantly higher than those of high-density broilers. Although there was no significant difference in the body weight of the broiler chickens between the two groups in the early period of the experiment (4, 11, and 18 d of age), the final body weight of the broilers in the low-density group was significantly higher than that in the high-density group from the perspective of the later period and the whole period of the experiment (Figure 2).

Table 1 Effects of different rearing densities on the production performance of broilers

Group	Index				
	4-day-old weight/g	52-day-old weight/g	RGR	Feed consumption/g	FCR_W
Low-density	71.2±1.2	1766.3±156.3	2379.82±2.00	3914.2±552.1	2.31
High-density	68.9±1.3	1546.1±13.5*	2145.27±0.60*	3508.2±161.0*	2.37

Note: The values in the table are expressed as the mean ± SD. *p<0.05

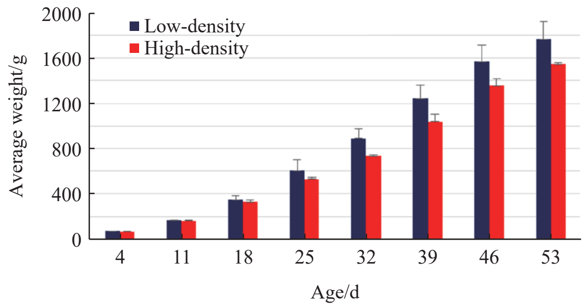


Figure 2 Average weight of broilers at different rearing densities

3.2 Feeding and drinking characteristics

The preference for eating and drinking was measured by the value of feed and water consumption of an average single broiler per day calculated in 7 d intervals. The daily feed intake and drinking water preference of broilers reflect the time the broilers stayed in the LA and DA to a certain extent, thus allowing the law of light demand for broilers to be detected.

The feed and water consumption of all test groups in the LA are much larger than those in the DA (Figure 3), and broilers with different densities have certain similarities. In the early stage of broiler growth, consumption increased with increasing age and then began to decrease in the later stage of growth. However, from a numerical point of view, the LA feed and water consumption of the low-density group was much higher than those of the high-density group.

For the low-density groups, the inflection points of feed and water consumption in the LA appeared in the 5-week-old, with consumption increasing along with age before this point, and consumption decreasing along with age after this point. For the entire experimental cycle, the consumption of the DA was maintained at a very low level but still improved to a certain extent in the later stage of growth.

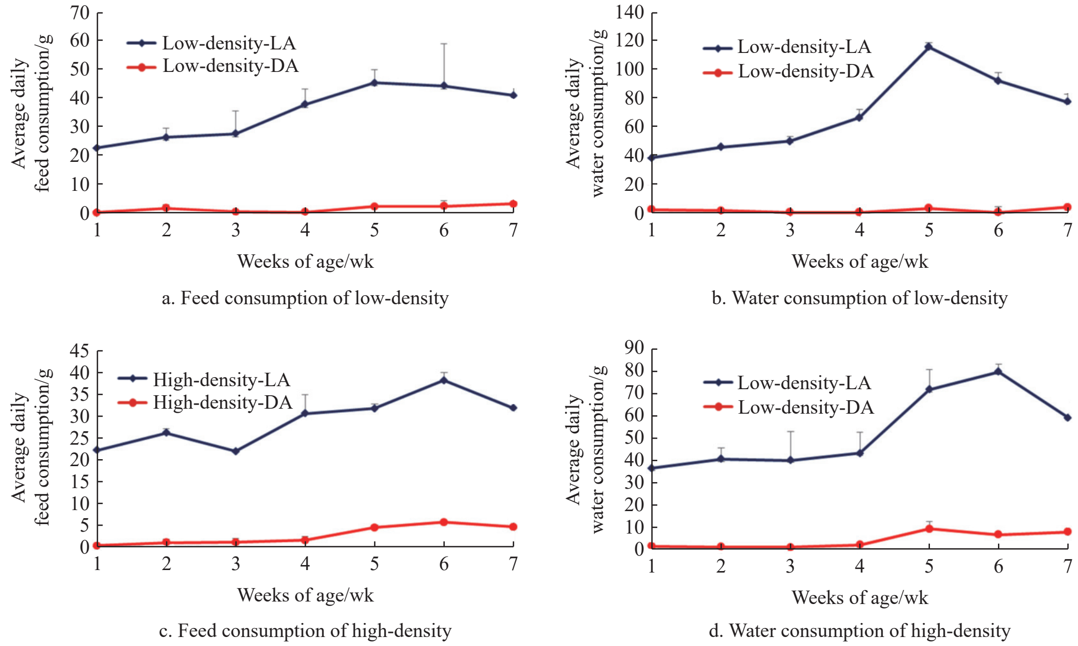
For the high-density groups, the inflection points of feed and water consumption in the LA appeared in the 6-week-old, although feed consumption declined and then increased in the third week. It was also found that the feed consumption in the LA increased slowly and decreased significantly at 7 weeks of age. Before 4 weeks of age, the water consumption of broilers in LA increased slightly and then greatly increased. The feed and water consumption of broilers in the DA was low, but it still increased to a certain extent in the late growth period.

A comparison of the groups with different densities showed that the LA feed and water consumption of the low-density group were significantly higher than those of the high-density group, indicating that even in the same light area, broilers in the low-density group had a stronger preference for the light area than those in the high-density group.

3.3 Staying distribution characteristics

The videos were processed of the broiler's activities in each area and the time of the broiler's stay was obtained in the LA and the DA. The residence frequency distribution of broilers in each zone can more intuitively reflect the change in light preference of broilers during the whole growth process compared with feed and water consumption, finally, the light demand of the broilers during the whole growth stage was obtained.

All groups of broilers had a significant difference in the staying frequency in the LA and DA (Figure 4). Starting at 4 days of age, the broiler's staying frequency in the LA always occupied an absolute advantage, and this advantage gradually weakened with increasing days of age. For low-density broilers, the staying frequency in the LA presented an absolute advantage during the whole process. Before 25 days of age, broilers of low density stayed in the LA with a frequency of almost 100%, and this frequency continued to decrease with age and eventually reached the lowest level of 78%. The DA showed an opposite trend relative to LA. The staying frequency of broilers in the high-density group had similar trends and decreased with increasing age. Until the age of 53 d, the staying frequency in the DA exceeded that of the LA. These results showed that broiler preference for the DA gradually increased, and the increase was slower in the early stage and faster in the middle and late stages.



Note: Low-density-LA and -DA refer to the light area and the dark area of the low-density experimental group; High-density-LA and -DA refer to the light area and the dark area of the high-density experimental group.

Figure 3 Average daily feed and water consumption at different rearing densities per week

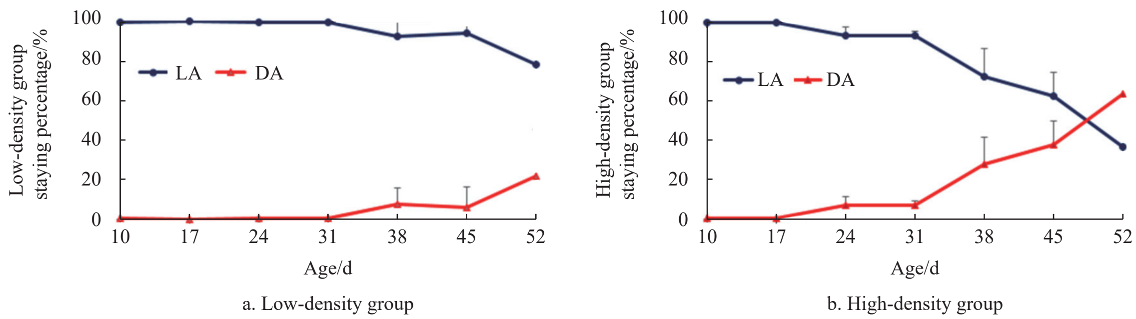


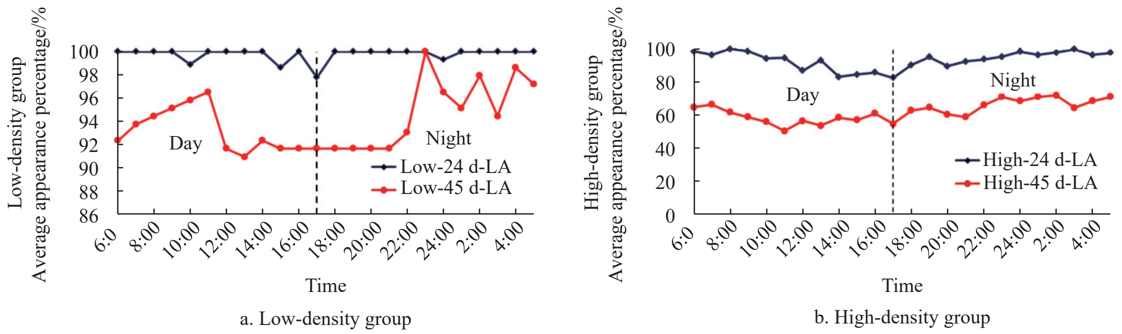
Figure 4 Distributions of broilers at different rearing densities

In addition, statistics on the percentage of broilers' staying frequency throughout the entire process showed that the average staying percentage of broilers in the LA of the low-density group was 94.82%, which was significantly higher than that of the high-density group of 79.51%. When the light and temperature are the same, broilers under different breeding densities also have a certain degree of difference in light demand, with the low-density group exhibiting a higher light demand.

We took two typical broilers at 24-day-old and 45-day-old as representatives of the early and late growth stages, respectively, and counted the changes in the staying frequency of the broilers at different densities throughout the day (Figure 5). The daily occurrence frequency of broilers in the LA was divided into two time periods: daytime (DT, 06:00-17:00) and nighttime (NT, 18:00-5:00). The demarcation line of day and night was determined by referring to the average sunrise time and sunset time of Hangzhou during the reference experiment, and the stay time of the broiler in the LA during the day and night was used for the calculation of the lighting system.

At 24-day and 45-day of age, the stay frequency was evenly distributed throughout the day. However, the 45-day-old broilers generally had a lower frequency in the LA than the 24-day-old broilers, indicating that young broilers had more light demand. The frequency of high-density broilers in the LA showed a certain regularity, that is, the activity pattern of broilers changed periodically with outside day and night changes. During the day, the frequency of broilers in the LA showed a certain downward trend over time, and during the night, the frequency of broilers in the DA showed a certain upward trend over time. However, this pattern was not obvious, and further investigation is needed. In addition, the effect of broiler age on the staying time in LA can be clearly observed from the figure. The young broilers stayed in the LA longer than the grown broilers.

After calculation, the light system under the active choice of broilers can be obtained. For the low-density groups, during the day and night, the 24-day-old broilers stayed in the LA for 11.9 and 11.9 h, respectively, and the 46-day-old broilers stayed in the LA for 10.9 and 11.4 h, respectively. For the high-density groups,



Note: Low-24 d-LA represents the light area of the low-density experimental group at the age of 24 d; Others can be deduced by analogy, and the water and feed were updated daily at 9:00 a.m.

Figure 5 Daily presence frequency in the LA at two ages (24 d and 45 d)

during the day and night, the 24-day-old broiler stayed in the LA for 11.2 h and 11.4 h, respectively, and the 45-day-old broiler stayed in the LA for 7.0 h and 8.0 h respectively. Further calculations and obtained two light systems were performed at different growth stages under the active selection of broilers: 1) low-density breeding environment: 23.8L:0.2D for chicks and 22.3L:1.7D for adult broilers; 2) high-density breeding environment: 22.6L:1.4D for chicks and 15.0L:9.0D for adult broilers. As an experimental result, the lighting system has a certain reference value for lighting system settings of chicken breeds in actual production, although further exploration is required before it is applied in practice.

4 Discussion

The high-density groups (7.5 chickens/m^2) were set to simulate the real breeding environment in which the stocking density is 7-10 broilers/m^2. Low-density groups were set up (2.5 chickens/m^2) to reduce the effect of high density on area selection. There was no significant difference in the body weight of broiler chickens between the two groups in the early stage of the experiment, although the difference was significant starting in the later stage of the experiment and over the whole process. These findings may be due to the increase in volume in the later stage of growth, which narrowed the growth space, resulting in limited feeding and drinking water, slow growth of broilers, and poor group uniformity. It is generally believed that an appropriate increase in the stocking density can increase the slaughter rate of broilers, the weight of the glandular stomach, and the weight of abdominal fat[26]. However, the results of this experiment were not consistent with the above results, which may be related to the generally low breeding density used in this experiment and the maximum breeding density of 7.5 broilers/m^2, which was insufficient to cause differences. Additionally, the light environment was different because the poultry grew under a nonuniform LED light environment and could freely shuttle between the LA and the DA in this experiment. Light duration and light cycle were determined by the broilers' independent choice. Therefore, the conclusions need further verification.

In the observation of the typical day-old broiler's single-day stay behavior, it was found that the broiler behavior did not have a significant correlation with the external time rhythm, which is inconsistent with previous studies. For example, Senaratna et al.[27] found that under the combined effects of time phase (morning, evening, night), light color, and age, the frequency of many behaviors (sleeping, lying down, and feeding behavior) of broiler chickens were significantly different, and other studies have reached similar conclusions[25]. The possible reason for these discrepancies is that the experiment started during the broiler brooding period, which had already destroyed the internal rhythm of the broilers themselves. The broilers formed a behavior pattern based on their comfort under a relatively constant light environment, which is the result of the broilers' active choice and response to many factors in the external environment. There was a significant difference in the demand for light between the high-density group and the low-density group in the later period. Mallory et al.[28] found that low-density rearing may exacerbate anxiety and fear in broilers to reduce welfare compared to birds housed at higher stocking densities. It may be that the fear level of broilers dominated late active selection and thus increased light requirements for broilers, which requires further research.

Photoperiod can impact broiler performances from embryo phase to marketing time[29]. Previous studies usually compare the differences in production performance and physiology of broilers under different light regimes to select an appropriate photoperiod[30-33]. Several commonly used lighting systems (12L:12D, 16L:8D, 20L:4D)[34] and the 16L:8D regiment are the most commonly used intermediate values[35]. This light regimen has been shown to improve poultry welfare, reduce animal psychological stress, and enhance immune effects[36]. The photoperiod optimized by the above methods ignored the endogenous rhythm-driven light selection of laying hens. In our experiment, broilers could choose their own light cycle according to their needs. The choice of LA and DA reflects their choice of light cycle. In the early stage of growth, the chicks chose close to 24 hours of light, which was possible because chicks were not sensitive to light immediately after hatching and needed to find food to survive. In the late growth period, broilers gradually adapted to the environment and started to choose a light cycle that suited them. Yang et al.[33] reported that constant light in early life induces fear-related behavior in chickens with suppressed melatonin secretion and disrupted hippocampal expression of clock- and BDNF-associated genes. The prolonged stay of the low-density groups in LA may further exacerbate the fear of the DA. Taking these into account, the status of the birds in each area should be further confirmed. So, the broiler's autonomous choice of photoperiod was more in line with the laws of nature[37], but whether this choice will have an impact on physiological functions and production performance needs further research.

5 Conclusions

Under the yellow LED light environment, the production performance indexes of chicks in the low-density group were better than those in the high-density group. The feed and water consumption in the LA of the three experimental groups were significantly higher than those in the DA. Therefore, the chicks showed a great preference for the LA. However, the feed and water consumption of the chicks in LA decreased in the middle and late stages, indicating that broilers had a lower preference for light in the middle and late stages of growth. A comparison of the different breeding density groups showed that the low-density group's LA feed and water consumption were significantly higher than that of the high-density group, indicating that even in the same light area, broilers in the low-density group had a stronger preference for the light area than the high-density group. The statistical results of the residence frequency distribution characteristics showed that chicks had different light requirements at different growth stages under the condition of active selection: 1) low-density breeding environment: 23.8L:0.2D for chicks and 22.3L: 1.7D for adult broilers; 2) high-density breeding environment: 22.6L:1.4D for chicks and 15.0L:9.0D for adult broilers. In addition, statistics on the frequency distribution of broilers' eating and drinking behaviors during one day did not show a significant rule, thus, follow-up studies are needed.

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