ABSTRACT: This study aimed to establish response curves between broiler chicken growth parameters and artificial light periods, as opposed to optimizing a lighting regimen for broiler production. Medium-growing broiler chickens were illuminated for periods of 12, 14, 16, 18, 20, 22, or 24 h each day. The BW of the broilers were significantly influenced by light periods (P < 0.05). Moreover, BW responded to light periods in a linear fashion, suggesting that long light periods result in greater BW. In addition, a linear relationship was found between feed intake and light periods. However, the relationship between shank length and light period was quadratic. When the light period was too short (12 h) or too long (24 h), the light stimulus did not enhance shank growth in the broiler chickens (P < 0.05). In addition, a quadratic relationship between the quantity of abdominal adipose tissue and light period suggested that the quantity of abdominal adipose decreases when the period of the light stimulus was too short or too long (P < 0.05). Moreover, a broken-stick analysis suggested that the triiodothyronine (T3) concentration in the blood was minimally affected beyond 18 h (P = 0.267), although a quadratic relationship was found between the period (from 18 to 24 h) and T3 concentrations in the blood. The response curves established in the present study will be valuable for designing future lighting regimes for medium-growing broiler strains.

Key words: artificial light period, broiler, growth response

INTRODUCTION

The period of light influences weight gain by affecting the balance between food intake and digestion (Charles et al., 1992). In an open experimental house, the rate of BW gain in birds in the tropics was 23% lower than the rate in birds inhabiting temperate areas (Ricklefs, 1976). This difference in weight gain rate could be explained by a difference in the light duration between the 2 latitudes, as the light period determines when birds gather food.

Earlier studies showed that birds continuously exposed to light had the greatest BW gain in controlled conditions (Renden et al., 1993; Ingram et al., 2000), whereas shorter light periods were associated with slower growth (Li et al., 1995). If given a choice, chickens preferred to eat during exposure to light (Simmons, 1982). Later reports indicated that darkness was also important for the growth and health of broilers (Classen et al., 1991). Exposing birds continuously to light can lead to potential welfare concerns such as greater prevalence of leg weakness (Brickett et al., 2007) and skeletal disorders (Sanotra et al., 2001, 2002) and incidence of ascites (Brickett et al., 2007). Therefore, the inclusion of a dark period has been incorporated into management strategies for production (Olanrewaju et al., 2006).

However, previous studies have primarily focused on comparing particular lighting regimes rather than on experimental approaches for predicting growth responses to different light periods. Moreover, previous
studies have examined no more than 4 treatments; this number of treatments has been insufficient to construct comprehensive growth responses to varying light periods. Furthermore, these studies have largely focused on limited indicators, including BW and feed intake. Therefore, this study was conducted to clarify the effects of light periods on comprehensive growth indicators and to establish growth response curves that can be used for growth enhancement.

MATERIALS AND METHODS

The Animal Care and Use Committee of Zhejiang University approved the experimental and animal care protocols.

Animals and Experimental Design

A total of 210 native Chinese female broiler chickens (Meihuang; age 0 d; mean BW 30.5 g) were purchased from a commercial hatchery (Guangda Breeding Co. Ltd., Hangzhou, China) and used in this study. This broiler strain is very genetically stable and is certified by the Chinese Agricultural Ministry as 1 of the 2 national gene pools of native broilers. On Day 0, all broilers were randomly housed in 7 light-controlled rooms, with 30 birds per light treatment. Each room was divided into 2 equal-sized replicate pens, with 15 birds per pen. Each pen had its own independent light system (Fig. 1) and was covered with fluorescent fabrics to avoid light pollution from other sources. Each group of treated broilers was exposed to 12, 14, 16, 18, 20, 22, or 24 h of light exposure from the time they were 1 d old until the termination of the experiment at 80 d. Each of the light-treated birds had similar initial BW: 30.6 ± 0.2 (12 h), 30.4 ± 0.3 (14 h), 30.7 ± 0.4 (16 h), 30.6 ± 0.2 (18 h), 30.6 ± 0.1 (20 h), 30.2 ± 0.4 (22 h), and 30.4 ± 0.3 g (24 h). When the brooding period ended (Day 21), all broilers were weighed individually, and the average BW for each light treatment was immediately calculated. To maintain uniformity without creating a deviation in the original BW, the 2 heaviest birds, the 2 lightest birds, and 1 lame bird were removed from the study. Illumination was provided using yellow light-emitting diode lamps (Langtuo Biological Technology Co. Ltd., Hangzhou, China). Each group of lamps was placed 75 cm above the broilers using plastic ties that were attached to the ceiling. The pulse width modulation (PWM) method is popular for controlling the light intensity of LED (Loo et al., 2009). Pulse width modulation uses a driving current that is determined from the peak current, period of repetition, and pulse duty. The pulse duty is the ratio of on time to the period that controls the average light intensity. Therefore, in this study, we used the PWM method to precisely control the light intensity and a radiometer (AR823; Digital Lux Meter Co. Ltd., Hangzhou, China) to measure the intensity. In addition, the intensity was measured in each pen at 5 locations (the 4 corners and the center of the floor) to maintain a uniform intensity that was the same in each room. Typically, 15 lux is sufficient for the normal growth of chickens (Rozenboim et al., 1999). However, young chickens exposed to brighter light can more easily adapt to environments and find food and water. Therefore, during the first 3 d (Day 0 to 3), the light intensity was maintained at a relatively brighter level (30 lux) in all rooms. Following this period, the light intensity was reduced to 15 lux (Day 4 to 80) to save energy. The dry-bulb temperature and relative humidity were measured once each day using data loggers (TH602F; Anymetre Co. Ltd., Hangzhou, China) to ensure that the temperature and relative humidity were similar in all rooms (Fig. 2). These conditions were maintained via an electric thermostat and a ventilator throughout the period of the experiment. The experimental layout is shown in Fig. 1. The broilers had ad libitum access to feed and water. All broilers were fed with the same starter diet (13.4 MJ ME/kg and 220 g/kg CP) when they were between 1 and 21 d old followed by
Responses of broilers to light periods

a grower diet (13.6 MJ ME/kg and 200 g/kg CP) for the remainder of the experiment (80 d old).

Measurement of Growth Parameters

Body weights (g) were recorded individually at 35, 49, 63, and 80 d of age. Daily feed consumption (g) was also measured. At the end of the trial (80 d of age), after fasting for 12 h, 3 broilers were randomly selected from each replicate pen (n = 3 × 2 × 7 = 42) so that each replicate pen was equally represented. A specific body structure measurement (shank length) for broilers from each replicate was made with a vinyl metric measuring tape. Shank length (mm) was measured on the back of the left shank, from the top of the back toe to the top of the shank. The broilers were killed by cervical dislocation to collect blood samples and were eviscerated to measure abdominal adipose tissue weight. A 5-mL sample of blood was obtained from each bird. The blood samples were centrifuged at 4°C for 30 min at 3,000 × g to separate the serum. The serum was transferred into polypropylene microcentrifuge tubes and stored at –70°C for subsequent use. The blood levels of triiodothyronine (T3) were determined using an Automatic Biochemistry Analyzer (AU5400; Olympus Co. Ltd., Tokyo, Japan). Nonstressful conditions were provided on the slaughter line, and the birds were slaughtered using a slaughter funnel to prevent wing flapping and stress during slaughter (Karakaya et al., 2009).

Statistical Analyses

Data were analyzed using SPSS Statistical software (version 20; International Business Machines Corporation, Armonk, NY). The data were analyzed in a factorial design by rooms and light. The rooms were not significant for all of the treated variables, and the results were retested by 1-way ANOVA to analyze the effects of light period on the growth parameters of the broilers. The homogeneity of the variance was checked for each set of data, and no transformations were applied. When appropriate, post hoc comparisons were performed by using least significant differences. The data are presented as means ± SEM. In every case, differences between groups were considered statistically significant if \( P < 0.05 \). The dependent variables (growth parameters) were also analyzed via regression analysis; linear, broken-stick, and quadratic regression models were applied, using SPSS software (Pallant, 2010).

RESULTS

Body Weight

The BW (g) of the broilers exposed to different periods artificial light is shown in Table 1. An ANOVA indicated that the BW was significantly influenced by the light period \((F(6,553) = 60.874, P = 0.016; \text{Table 1})\). Relative to a light period of ≤16 h, a significant increase in BW was observed in the chicks that were exposed to light periods of ≥20 h when they were as young as 35 d old \((F(6,133) = 6.795, P = 0.012)\). This trend continued until the chicks were 49 d old. At this age and older, no significant differences were observed between the chicks reared under 18 h of daylight relative to those reared under ≥20 or ≤16 h of daylight \((F(6,133) = 1.939, P = 0.165 \text{ and } P = 0.230, \text{ respectively})\). However, between 63 and 80 d, the broilers raised under light periods of 22 and 24 h were significantly heavier than the broilers raised under light periods of ≤20 h \((F(6,133) = 5.179, P = 0.032, \text{ and } F(6,133) = 7.061, P = 0.003, \text{ respectively})\). Moreover, regression analysis confirmed that the BW responded to light periods in a linear fashion at 35, 49, 63, and 80 d of age (Table 1), which

<table>
<thead>
<tr>
<th>Duration, h</th>
<th>35 d</th>
<th>49 d</th>
<th>63 d</th>
<th>80 d</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>517.7 ± 2.7 (d)</td>
<td>816.2 ± 8.6 (b)</td>
<td>1,120.5 ± 4.1 (b)</td>
<td>1,405.3 ± 8.0 (b)</td>
</tr>
<tr>
<td>14</td>
<td>525.6 ± 9.7 (d)</td>
<td>821.1 ± 15.7 (b)</td>
<td>1,113.9 ± 1.6 (b)</td>
<td>1,427.8 ± 20.8 (b)</td>
</tr>
<tr>
<td>16</td>
<td>528.7 ± 13.4 (abcd)</td>
<td>816.6 ± 13.6 (b)</td>
<td>1,108.4 ± 19.8 (b)</td>
<td>1,398.2 ± 44.2 (b)</td>
</tr>
<tr>
<td>18</td>
<td>540.5 ± 0.7 (abcd)</td>
<td>831.7 ± 6.5 (b)</td>
<td>1,146.6 ± 20.3 (b)</td>
<td>1,438.3 ± 20.6 (b)</td>
</tr>
<tr>
<td>20</td>
<td>546.4 ± 4.8 (abc)</td>
<td>843.6 ± 3.7 (b)</td>
<td>1,131.2 ± 2.3 (b)</td>
<td>1,449.2 ± 33.8 (b)</td>
</tr>
<tr>
<td>22</td>
<td>553.2 ± 1.1 (ab)</td>
<td>866.2 ± 6.5 (a)</td>
<td>1,192.7 ± 15.6 (a)</td>
<td>1,528.0 ± 23.3 (a)</td>
</tr>
<tr>
<td>24</td>
<td>564.3 ± 6.5 (a)</td>
<td>873.6 ± 5.7 (a)</td>
<td>1,193.1 ± 11.3 (a)</td>
<td>1,527.5 ± 17.3 (a)</td>
</tr>
</tbody>
</table>

Regression: \(y = 3.8x + 471.1\)

Fitness: 0.9874

Fitness: 0.8926

Fitness: 0.7375

Fitness: 0.7876

\(P\)-value

1.0001

0.0001

0.0001

0.0001

\(a\)–\(d\) Means within a column with different superscripts differ significantly \((P < 0.05)\).

1. The fitness of the regression models is specified here.

2. The regression model was considered significant if \(P < 0.05\).
suggested that long periods of light resulted in a greater BW. In addition, the increased BW was age related. Therefore, the BW increased by approximately 3.8, 5.2, 7.1, and 11.0 g for each 1 h increase in period when the chickens were 35, 49, 63, and 80 d old, respectively (Fig. 3). However, light period had less impact on BW gain during any specific period (Table 2). Among all groups, there was no difference in BW gain between Days 35 and 49 and between Days 49 and 60, except for the light periods of 22 and 24 h.

Table 2. Effects of light period (h) on BW gain (g) in broilers for specific light periods

<table>
<thead>
<tr>
<th>Age, d</th>
<th>Duration, h</th>
</tr>
</thead>
<tbody>
<tr>
<td>35–49</td>
<td>12 14 16 18 20 22 24</td>
</tr>
<tr>
<td>35–49</td>
<td>298.5b 295.5b 287.9b 291.2b 297.2b 313a 309.3a</td>
</tr>
<tr>
<td>49–63</td>
<td>304.3b 292.8b 291.8b 314.9b 287.6b 326.5a 319.5a</td>
</tr>
</tbody>
</table>

Means within a column with different superscripts differ significantly ($P < 0.05$).

Feed Intake

The cumulative feed intake per broiler (g) in response to light period is shown in Table 3. An ANOVA indicated that broilers consumed a similar amount of feed in all treatments at 35 d of age ($F(6, 14) = 2.562$, $P = 0.081$; Table 3). However, when broilers reached 49, 63, and 80 d of age, broilers raised with ≤20 h of light ate significantly more than broilers raised with ≤14 h of light ($F(6, 14) = 5.651$, $P = 0.041$). Moreover, regression analysis confirmed that the feed intake response to light period was linear at 35, 49, 63, and 80 d of age (Table 3), indicating that long light periods resulted in greater feed intake. Regression analysis indicated that the cumulative feed intake increased linearly by approximately 8.4, 17.5, 27.4, and 47.1 g for each 1 h increase in light period at 35, 49, 63, and 80 d of age, respectively (Fig. 4), which indicated that the increased rate of feed intake was also age related. In addition, correlation analysis revealed that feed intake was positively related to final BW ($R^2 = 0.9781$, $P = 0.0001$; Fig. 5), confirming that increased feed intake contributed to BW gain. Therefore, there was a positive interrelationship between feed intake and BW ($P = 0.001$).
Specific Structure Measurement

Shank length was significantly longer on broilers raised with 18 h of light compared with 12 or 24 h, indicating that too short or too long a light period was not beneficial to skeletal growth in broiler chickens ($F(6, 35) = 6.234, P = 0.02$; Fig. 6). Regression analysis indicated that the shank length ($y$) was quadratically correlated with light period ($x$; $y = -0.19x^2 + 6.95x + 26.5; R^2 = 0.7713$), which indicated that the maximum shank length occurred when a light period of 18 h was used and that similar shank lengths occurred with light periods of 12 and 24 h, 14 and 22 h, and 16 and 20 h. Correlation analysis also revealed that shank length was positively associated with final BW ($R^2 = 0.7183, P = 0.001$; Fig. 7).

Abdominal Adipose Tissue

Broilers raised with 18, 20, and 22 h of light had more abdominal adipose tissue than did broilers raised with 12 h of light ($F(6, 35) = 10.568, P = 0.0001$; Fig. 8). Moreover, abdominal adipose tissue ($y$) exhibited a quadratic response to light period ($y = -0.31x^2 + 12.4x - 83.3; R^2 = 0.9702$). The quadratic equation demonstrated that the maximum abdominal adipose tissue was observed in broilers raised with 20 h of light, indicating that shorter and longer light periods decreased abdominal adipose tissue. Correlation analysis also revealed that abdominal adipose tissue was positively related to final BW ($R^2 = 0.6844, P = 0.001$; Fig. 9).

Metabolic Indicators

The T3 concentrations did not differ significantly with light period. A broken-stick analysis suggested that T3 concentrations would be similar for light periods $\leq 18$ h ($F(6, 35) = 1.852, P = 0.267$; Fig. 10). Although no significant differences were found among broilers raised with light periods of 18 to 24 h, a quadratic relation was found between light period (from 18 to 24 h) and blood T3 concentrations that suggested relatively higher T3 concentrations with 20 or 22 h of light than with 18 or 24 h of light.

DISCUSSION

Previous studies examined no more than 4 light treatments, which prevented the construction of comprehensive growth responses to light period. In addition, previous studies have primarily focused on a small number of indicators, such as BW and feed intake. The present study examined the effect of light period on comprehensive growth parameters in native Chinese broiler chickens. Growth response models as a function of different periods of artificial light were constructed, and the linear relationship between BW and light period indicated that longer light periods resulted in heavier broiler BW. A similar relationship was found between feed intake and light period; feed intake increased linearly with light period. However, the relationship between shank length and light period was quadratic and suggested that neither too short nor too long a light period was beneficial to shank growth in broiler chickens. Similarly, a quadratic relationship between abdominal adipose tissue and light period suggested that too short or too long a light period could decrease the amount of abdominal adipose tissue. A
broken-stick analysis suggested that T3 concentration was minimally affected beyond 18 h, although a quadratic relationship was observed between light period (from 18 to 24 h) and T3 blood concentrations.

Growth response curves were established in the present study. A previous study compared broilers raised to 6 wk of age with either 23 or 12 h of light and found that the birds were heavier at 6 wk with the longer light period (Ingram et al., 2000). Another study examined the effects of light periods of 12, 16, and 20 h on the performance of broiler chickens from the time of hatching to the end of processing. The results showed that broiler growth was reduced with the shorter periods of light (Classen, 2004). Similarly, when broilers were exposed to 8, 16, 21, or 23 h of light per day, longer light periods resulted in larger birds at 35 d (Sorensen et al., 1999). In the present study, we found that BW and feed intake increased with increasing light period; in addition, we found that the relationships between shank length, abdominal adipose tissue, and metabolic indicators and light period could be described by quadratic regression models.

An early study showed that light is not essential for feeding in broilers (Beane et al., 1962). However, the current findings did not support this conclusion. In general, long light exposures provide constant visual access to feed; therefore, long periods of light should maximize feed consumption and growth. This trend was confirmed in this study based on the positive relationship between BW and feed intake ($R^2 = 0.9781, P = 0.0001$; Fig. 6). A recent study examined the effects of providing light at night on body mass in male mice (Fonken et al., 2010). In this study, mice that were exposed to light at night had significantly greater body masses and reduced glucose tolerance relative to the mice that were exposed to cycles with 16 h of light and 8 h of dark, despite equivalent caloric intake levels and total daily activity levels. Furthermore, the timing of food consumption in mice exposed to light at night differed from that in mice on a 16:8 h light:dark cycle; mice exposed to light at night
Responses of broilers to light periods

Responses of broilers to light periods typically ate substantially more food at night. However, restricting food consumption in mice exposed to light at night prevented body mass gain, and this finding suggested that light at night disrupted the timing of food intake and other metabolic signals (Fonken et al., 2010). When broilers were exposed to 12 or 14 h of daylight, they did not eat at night (Buyse et al., 1993). Therefore, constant exposure to light, which provided constant visual access to feed, contributed to the constant BW gain observed in broilers in the present study. However, the feeding behaviors of broilers that are exposed to different periods of artificial light were not recorded in this experiment. Therefore, it would be useful to conduct further studies to observe the feeding rhythms of broilers and to investigate how their behavior could be adjusted to respond optimally to changes in light period.

The aim of the present study was to compare the effects of increasing light periods on broiler performance rather than to conduct a direct comparison of specific lighting regimes. Therefore, we did not aim to demonstrate that long light duration was beneficial to broiler production. In fact, sufficient darkness is needed to reduce the incidence of several health problems, such as leg problems, as well as sudden death syndrome and mortality in broilers (Apeldoorn et al., 1999; Moore and Siopes, 2000). Darkness allows broilers to maintain good health by allowing normal physiological processes associated with darkness to occur. Darkness causes melatonin synthesis in the pineal gland and retina of birds, which establishes circadian rhythms of body temperature, essential metabolic functions that influence feed intake, water intake, and digestion, and the secretion of several lymphokines that are integral to normal immune function (Binkley et al., 1973; Bernard et al., 1997; Apeldoorn et al., 1999). In contrast, a lack of darkness contributes to sleep deprivation in birds. Although little is known about sleep patterns in chickens, sleep is thought to be important for many aspects of life. Sleep deprivation has negative effects on digestion efficiency and on the absorption and metabolism of nutrients (Spiegel et al., 1999; Everson and Crowley, 2004; Hipolide et al., 2006; Van Cauter et al., 2007). In addition, sleep deprivation has been reported to disrupt hypothalamic function and the production of growth hormone and insulin-like growth factor (Everson and Crowley, 2004). However, no obvious health problems were found in broilers that were exposed to long light periods in this study. The disrupted physiological functions previously found may have resulted from health problems, including leg problems, and mortality, both of which are often associated with broilers with rapid growth rates. However, the broilers in this experiment are a type of native Chinese chicken that has a medium growth rate.

Furthermore, in this study, we found that increases in the rate of BW gain were age related. Older broilers gained more weight when the light period was increased by 1 h than did younger broilers. A similar age-dependent effect was found for feed intake. The metabolic indicator T3 acts on different target tissues and stimulates oxygen utilization and heat production in the cells of the body. Overall, these hormones increase the basal metabolic rate to make more glucose available to cells to stimulate protein synthesis, increase lipid metabolism, and simulate cardiac and neural functions (Todini et al., 2007). Moreover, plasma thyroid hormone concentrations are correlated with feed intake in ruminant species (Ryg and Langvatn, 1982; Chunchin and Brown, 1984; Timisjärvi et al., 1994). In another study, correlations

Table 3. The feed intake and linear regression models of feed intake (g) as a function of light period (h) for broilers exposed to 12, 14, 16, 18, 20, 22, and 24 h of light per day from hatching until termination of the experiment at 80 d of age

<table>
<thead>
<tr>
<th>Duration, h</th>
<th>35 d</th>
<th>49 d</th>
<th>63 d</th>
<th>80 d</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>577.8 ± 3.0</td>
<td>1,473.3 ± 39.4&lt;sup&gt;b&lt;/sup&gt;</td>
<td>2,585.5 ± 75.6&lt;sup&gt;b&lt;/sup&gt;</td>
<td>4,227.4 ± 74.5&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>14</td>
<td>589.5 ± 1.9</td>
<td>1,477.8 ± 6.0&lt;sup&gt;b&lt;/sup&gt;</td>
<td>2,545.9 ± 48.1&lt;sup&gt;b&lt;/sup&gt;</td>
<td>4,203.3 ± 44.8&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>16</td>
<td>615.0 ± 15.1</td>
<td>1,514.7 ± 29.8&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>2,765.0 ± 53.3&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>4,438.0 ± 72.2&lt;sup&gt;ab&lt;/sup&gt;</td>
</tr>
<tr>
<td>18</td>
<td>625.4 ± 2.7</td>
<td>1,542.5 ± 10.8&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>2,706.9 ± 47.6&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>4,383.0 ± 47.3&lt;sup&gt;ab&lt;/sup&gt;</td>
</tr>
<tr>
<td>20</td>
<td>469.6 ± 9.1</td>
<td>1,637.4 ± 2.0&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2,765.1 ± 36.6&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>4,549.4 ± 37.3&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>22</td>
<td>667.6 ± 7.7</td>
<td>1,652.9 ± 22.3&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2,911.1 ± 37.8&lt;sup&gt;a&lt;/sup&gt;</td>
<td>4,728.3 ± 59.4&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>24</td>
<td>671.6 ± 4.8</td>
<td>1,642.1 ± 26.0&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2,853.6 ± 48.6&lt;sup&gt;a&lt;/sup&gt;</td>
<td>4,719.0 ± 52.0&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Regression</td>
<td>y = 8.4x + 476.3</td>
<td>y = 17.5x + 248.2</td>
<td>y = 27.4x + 2,240</td>
<td>y = 47.1x + 3,616.7</td>
</tr>
<tr>
<td>Fitness&lt;sup&gt;1&lt;/sup&gt;</td>
<td>0.9815</td>
<td>0.9029</td>
<td>0.7955</td>
<td>0.908</td>
</tr>
<tr>
<td>P-value&lt;sup&gt;2&lt;/sup&gt;</td>
<td>0.0001</td>
<td>0.0001</td>
<td>0.0001</td>
<td>0.0001</td>
</tr>
</tbody>
</table>

<sup>a</sup> Means within a column with different superscripts differ significantly (P < 0.05).
<sup>1</sup> The fitness of the regression models is specified here.
<sup>2</sup> The regression model was considered significant if P < 0.05.
were found between plasma T3 and both feed intake and weight gain in broilers and turkeys that were exposed to different ambient temperatures (Yahav et al., 1996; Yahav, 1999). In the present study, a quadratic relationship was found between light period (from 18 to 24 h) and blood T3 concentrations, which indicated that T3 concentrations were relatively greater with 20 or 22 h of light per day than with 18 or 24 h of light. This finding was in agreement with the effects of light period on BW or feed intake because the broilers were significantly heavier and ate more when raised with long light periods (≤22 and 20 h) rather than shorter light periods.

Shank length is generally regarded as a good indicator of skeletal development, which is related to the amount of weight a broiler chicken can support. Indeed, in this study, we observed that the shank length was positively correlated with the final BW ($r = 0.7183$, $P = 0.001$). The shank length was significantly smaller in broilers exposed to 12 h of light compared with broilers exposed to 18 h of light. A similar result was reported in a previous study, which found that shank length in a group exposed to 12 h of light per day was significantly shorter than that in a control group exposed to 23 h (Ingram et al., 2000). In addition, a quadratic relationship was found between shank length and light period in the present study, which demonstrates that too short or too long a light period was not beneficial to skeletal growth in broiler chickens.

No significant differences in the quantity of abdominal adipose tissue were observed among broilers that were subjected to 18, 20, and 22 h of light per day, in agreement with a previous study that found that 16 and 23 h of light exposure had no effect on abdominal adipose deposition in broilers (Renden et al., 1996). However, Renden et al. (1996) did not examine the effect of light period below 16 h on abdominal adipose deposition. In the present study, we found that broilers exposed to long light periods (18, 20, and 22 h) had greater amounts of abdominal adipose tissue than did broilers that were treated with a shorter light duration (12 h). It has been reported that daily melatonin administration suppressed abdominal fat deposition and plasma leptin levels (Rasmussen et al., 1999; Wolden-Hanson et al., 2000). Blunted nighttime melatonin rhythms caused by constant light have been shown to increase visceral adiposity in rats as well (Wideman and Murphy, 2009). These studies may explain the greater extent of abdominal adipose deposition observed in broilers raised with long light periods in this study. In addition, the quantity of abdominal adipose tissue was positively related to the final BW ($r = 0.6844$, $P = 0.001$). A similar result was reported in mice that were exposed to light at night; the increased BW observed in these mice reflected an increase in adipose tissue ($R^2 = 0.5236$, $P = 0.0036$; Fonken et al., 2010).

In conclusion, light period can influence weight gain by affecting the balance between food intake and digestion (Charles et al., 1992). However, this factor has rarely been considered when designing lighting regimes for broilers. In contrast with previous studies that focused primarily on comparisons between particular lighting regimes, the primary aim of the present study was to use an experimental approach to predict growth response in broilers to different periods of artificial light. Therefore, a variety of quantitative growth response curves were established in this study. These growth response curves, which describe growth responses to varying light periods in medium-growing broiler strains, may aid in the design of future broiler lighting regimes.

**LITERATURE CITED**


