Effects of intermittent lighting on broiler growth performance, slaughter performance, serum biochemical parameters and tibia parameters

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Introduction

Environmental factors, such as light and temperature, are known to affect performance in broilers (Attia et al., 2011; Bovera et al., 2013). In many areas, broilers are commonly provided continuous or near continuous illumination. Buckland et al. (1976) were the first to report that birds grown under continuous lighting (CL) exhibited significantly more leg abnormalities than birds grown under durations of intermittent lighting (IL). During production, it is predicted that broiler chickens are exposed to a daily dark period of at least 4 hours; however, during the growth and rest periods, the needs of the birds may exceed this duration (Olanrewaju et al., 2006). Skrbic et al. (2015) reported that treatment with gradually increasing photoperiods was significantly superior to the 23 h lighting program for all periods, because it significantly reduced the incidence of leg abnormalities and mortality due to sudden death syndrome or other causes compared to the 23 h lighting program. In terms of health, increasing lighting programs were also reported to be superior to near CL for broiler chickens (Zheng et al., 2013). In addition, in view of welfare conditions, light regimes should be optimised (Meluzzi and Sirri, 2009). A large number of research studies have concentrated on the effects of IL on growth performance in broilers. The results of select studies have indicated that IL increases body weight and improves feed conversion (Petek et al., 2005), and that increasing photoperiods and dim light intensities improve broiler growth performance (Lien et al., 2009). At the same time, consecutive darkness for a fixed time each day aids in preventing abnormal eye development (Li et al., 2000). Birds fed intermittently also had significantly better feed efficiency than those fed ad libitum (Svilhus et al., 2010, 2013). As well, the incidence of tibial dyschondroplasia was lower at 42 d of age in birds reared under IL compared to CL treatment (Lewis et al., 2010). In addition, Zhang et al. (2010) reported that in adult chicks, 10% of total diets were digested and excreted after feeding two hours, 25% was digested and excreted after feeding four hours, and 25% was digested and excreted after feeding six hours. Further, another study indicated that body weight, feed consumption, and breast meat were generally reduced in birds exposed to 18L:6D (Lien et al., 2007).

Melatonin is a neurohormone secreted by the pineal gland during darkness in vertebrates. Apeldoorn et al. (1999) found that broilers exposed to CL were severely deficient in serum melatonin. Further, darkness can induce the secretion of pineal melatonin, which plays an important role in growth performance, immune function, and the reproductive system. Several researchers have focused on the effects of lighting regimens on immune system function, and the results of one investigation indicate that IL improves both cellular and humoral immune responses (Abbas et al., 2008). The results of Schwean-Lardner’s study indicated that entailed an examination of the impact of graded levels of day length (14, 17, 20, and 23 h) on causes of mortality, bird mobility, footpad health, and ocular size, suggests that 7 h per day is an appropriate length of darkness for maximizing broiler welfare based on the observed health parameters (Schwean-Lardner et al., 2013). Similarly, Zheng et al. (2013) found that the ILs scheme INL II, which entailed 17L:3D:1L:3D, yielded improved antioxidant status in broilers compared to INL I, which included 16L:2D:1L:2D:1L:2D. The two experimental groups were subjected to equivalent periods of total darkness, but the INL II group experienced longer dark periods.

Based on these research results, it is not dif-
ficult to conclude that IL is beneficial to broilers during growth and rest. A prominent hypothesis is that the addition of darkness to a photoperiod program would result in increased expression of behaviors associated with comfort, exploration, exercise, and nutrition. Thus, IL schedules consisting of light and dark cycles appear to be a suitable scheme. Accordingly, this experiment was conducted to examine the effects of different IL photoperiods on growth and slaughter performance, as well as serum biochemical and tibia parameters in broilers.

Materials and methods

Experimental design and diets

A group of 1-day-old Ross 308 broilers from Jiangsu Shengnong Poultry Development co., LTD (Huai’an, China) were used in the current study. Newly hatched chicks were separated by vent sexing, wing-banded, and reared under the same environmental conditions. All birds were provided a commercial broiler starter ration and water ad libitum from 1 to 7 d of age. At 7 d of age, 288 birds were selected and distributed among 18 pens with rubber mat flooring. Similar total bird weights were maintained in each pen. The pens were randomly divided into 3 treatment groups with 6 replicates per group and 16 broilers (8 male, 8 female) per replicate.

During the first 7 d, the lighting schedule provided CL that included 23 h light and 1 h dark. At 8 d of age, the CL schedule was maintained for one treatment group, whereas IL schedules consisting of 2L:2D cycles and 4L:4D cycles were initiated for the other two treatment groups. Each pen contained the same treatment groups, and each of the three pens was protected by black webbing to prevent light-spillage. Incandescent bulbs with an intensity of 20 lux were used for all treatments, and an automatic timer was used for IL. The chicks remained in their allocated light treatment from 8 d of age throughout the experimental period (8 to 42 d of age).

The birds had ad libitum access to feed during the experimental period, and were administered a 3-period feeding program consisting of a starter (0 to 10 d), grower (11 to 24 d) and finisher (25 to 42 d) period. A corn-soybean meal-based diet was prepared and formulated to meet the nutrient requirements of chickens recommended by the National Research Council (1994). The ingredient and calculated nutrient profile of the trial diets are shown in Table 1. The amount of feed consumed in each pen was recorded and birds were weighed individu-ually at 42 d of age for ADFI and FCR (kg of feed intake per kg of body weight gain) calculations. At 42 d of age, two birds (1 male, 1 female) were randomly selected from each replicate, blood (2 mL) was collected from the wing vein of each broiler for serum biochemical parameter analysis, and the birds were euthanized to determine slaughter performance. In addition, the left tibias of broilers were dissected for subsequent analysis.

The experiments were conducted at the experimental pasture of Yangzhou University, and all experimental procedures were approved by the Yangzhou University Animal Care and Use Committee.

Serum biochemical parameters

Blood tubes were placed at a slant at room temperature for 30 min, and then centrifuged at 3500 rpm for 10 min. Separated serum was stored at -20°C until the measurement of biochemical parameters. Serum total protein (TP), glucose (GLU), blood urea nitrogen (BUN), cholesterol (CHO), triglyceride (TG), high-density lipoprotein cholesterol (HDL-C), and low-density lipoprotein cholesterol (LDL-C) were determined using a Beckman Coulter UniCel DxC 800 automatic biochemical analyzer.

Tibia parameters

Tibias were stored with the flesh intact at -20°C until further analysis. Prior to analysis, the bones were cleaned of all tissue. The bone elastic modulus, bone breaking strength, and bone bending displacement were measured using an Instron universal testing machine with a 50 kg load range and a crosshead speed of 50 mm/min with the bone supported on a 3.00 cm span.

Statistical analyses

All data were subjected to repeated measures analysis, with each replicate mean as the experimental unit. All data were analyzed using SPSS software (SPSS 17.0 for Windows). One-way ANOVA followed by a Duncan’s multiple comparison test was used to separate different means among treatments. Data were assumed to be statistically significant when P<0.05.

Results

Growth performance

The different photoperiods affected boiler growth performance (Table 2). The body weight of broilers subjected to the 4L:4D photoperiodic lighting schedule significantly increased compared to broilers in the 2L:2D photoperiod at 42 d of age (P<0.05). The average daily feed intake (ADFI) in the 4L:4D photoperiod was the lowest, but ADFI was lower in both the 4L:4D and 2L:2D photoperiods compared to corresponding CL values (P<0.05). As well, the feed conversion ratio (FCR) of birds in the 4L:4D photoperiod was 6.30% more efficient than FCR of birds in CL (P<0.05).

Table 1. Ingredients and nutrient levels of the experimental diets.

| Ingredients, % | 0-10 d | 11-24 d | 25-42 d |
|---------------|--------|---------|--------|
| Corn          | 60.7   | 65.4    | 69.3   |
| Soybean meal  | 28.9   | 24.3    | 20.3   |
| Corn protein meal | 7     | 5       | 5      |
| Vitamin-mineral premix° | 1    | 1       | 1      |
| Calcium phosphate secondary | 0.4  | 0.4     | 0.4    |
| Limestone     | 2      | 1.9     | 1.8    |
| Soybean oil   | 0      | 2       | 2.2    |
| Total         | 100    | 100     | 100    |

| Nutrient levels° | 0-10 d | 11-24 d | 25-42 d |
|-----------------|--------|---------|--------|
| ME, MJ/kg       | 12.59  | 13.14   | 13.31  |
| Crude protein, %| 22.98  | 19.98   | 18.46  |
| Calcium, %      | 0.91   | 0.86    | 0.81   |
| Phosphorus, %   | 0.45   | 0.42    | 0.41   |
| Methionine, %   | 0.47   | 0.43    | 0.41   |
| Lysine, %       | 1.18   | 1.15    | 1.00   |

°Mineral premix provided the following per kg diet: Fe, 75 mg; Mn, 60 mg; Zn, 20 mg; Cu, 15 mg; I, 0.75 mg; Se, 0.3 mg; Vitamin premix provided the following per kg diet: vitamin A, 2.7 mg; vitamin D3, 0.14 mg; vitamin E, 66 mg; menadione, 9.0 mg; pyridoxine, 0.04 mg; riboflavin, 2.0 mg; Ca-pantothenate, 20.3 mg; biotin, 0.39 mg; thiamine, 3.75 mg; niacin, 75 mg; cobalamin, 0.03 mg; folic acid, 3.75 mg; ME, metabolisable energy.°Nutrient levels were all calculated values (Yang, 2000).

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Slaughter performance

As shown in Table 3, no significant differences in heart weight, liver weight, spleen weight, and/or intestinal tract weight were detected among the three treatments (P>0.05). However, a trend indicating that the intestinal tract weight of broilers exposed to IL was greater than corresponding weights in CL, and intestinal tract weight was greater in broilers in the 4L:4D photoperiod than in CL (P=0.090). Differences in slaughter performance were detected among the three photoperiod treatments (Table 4). The eviscerated yield with giblets of broilers in the 4L:4D photoperiod was the largest, and was significantly higher than corresponding weights in CL (P<0.05). The eviscerated carcass weight of broilers in the 4L:4D photoperiodic lighting was also higher than the eviscerated carcass weights in the 2L:2D photoperiod and in CL (P<0.05). However, no significant differences in the abdominal fat ratio, wing ratio, breast muscle ratio, or leg muscle ratio were detected among three treatments (P>0.05).

Serum biochemical parameters

Table 5 presents the serum biochemical parameters of broilers in the different photoperiods. The serum total protein content of broilers in the 4L:4D photoperiod was significantly higher than values in both the 2L:2D photoperiod and CL (P<0.05). Similarly, the serum cholesterol concentration of broilers in the 4L:4D photoperiod was significantly higher than the values detected in CL (P<0.05). No significant differences in the concentrations of GLU, BUN, TG, HDL-C or LDC-C were detected among the three photoperiod treatments (P>0.05).

Discussion

Growth performance

The results of the present study indicated that broiler growth performance (BW, feed intake, and FCR) was significantly affected by differences in photoperiod (Table 1), which was in accord with Buyse et al. (1996) who reported that IL caused reduced feed intake in birds, and resulted in superior broiler productivity compared to CL. The light schedule to which the broilers were subjected affected

Table 2. Effects of intermittent lighting on growth performance.

| Treatments | N  | Body weight at 8 d, g | Body weight at 42 d, g | Average daily feed intake, g | Feed conversion ratio |
|------------|----|-----------------------|------------------------|-----------------------------|----------------------|
| 2L:2D      | 6  | 181.4±1.2             | 2466±14d               | 150.2±1.0d                  | 2.30±0.02d           |
| 4L:4D      | 6  | 180.5±0.9             | 2351±20a               | 149.4±2.3b                  | 2.23±0.04b           |
| CL         | 6  | 184.2±2.4             | 2496±21d               | 156.8±1.2a                  | 2.36±0.02a           |

2L:2D, 2 hours of light: 2 hours of dark photoperiodic lighting cycle; 4L:4D, 4 hours of light: 4 hours of dark photoperiodic lighting cycle; CL, continuous lighting. Values are expressed as mean±standard deviation. a,bIn the same column, values with no superscript letters indicate no significant differences (P>0.05), whereas different lowercase superscript letters indicate significant differences (P<0.05).

Table 3. Effects of intermittent lighting on internal organs.

| Treatments | N  | Heart weight, g | Liver weight, g | Spleen weight, g | Intestinal tract weight, g |
|------------|----|-----------------|-----------------|------------------|----------------------------|
| 2L:2D      | 6  | 11.18±0.66      | 64.19±2.93      | 3.38±0.27        | 50.66±1.54                |
| 4L:4D      | 6  | 12.38±0.48      | 62.36±2.02      | 3.28±0.27        | 52.46±2.69                |
| CL         | 6  | 12.38±0.48      | 62.36±2.02      | 3.28±0.27        | 50.66±1.54                |

2L:2D, 2 hours of light: 2 hours of dark photoperiodic lighting cycle; 4L:4D, 4 hours of light: 4 hours of dark photoperiodic lighting cycle; CL, continuous lighting. Values are expressed as mean±standard deviation.

Table 4. Effects of intermittent lighting on slaughter performance.

| Treatments | N  | Eviscerated yield with giblet, g | Eviscerated carcass weight, g | Abdominal fat ratio, % | Wing ratio, % | Breast muscle ratio, % | Leg muscle ratio, % |
|------------|----|---------------------------------|-------------------------------|-----------------------|---------------|-----------------------|---------------------|
| 2L:2D      | 6  | 2045±18b                        | 1761±12c                      | 10.84±0.15            | 28.10±0.53    | 20.38±0.44            |
| 4L:4D      | 6  | 2124±17c                        | 1834±14a                      | 10.55±0.17            | 26.95±0.81    | 19.42±0.49            |
| CL         | 6  | 2033±20a                        | 1754±36b                      | 10.66±0.24            | 28.32±1.00    | 19.99±0.70            |

2L:2D, 2 hours of light: 2 hours of dark photoperiodic lighting cycle; 4L:4D, 4 hours of light: 4 hours of dark photoperiodic lighting cycle; CL, continuous lighting. Values are expressed as mean±standard deviation. a,bIn the same column, values with no superscript letters indicate no significant differences (P>0.05), whereas different lowercase superscript letters indicate significant differences (P<0.05).

Table 5. Effects of intermittent lighting on serum biochemical parameters.

| Treatments | N  | TP, g/L | GLU, mmol/L | BUN, mmol/L | CHO, mmol/L | TG, mmol/L | HDL-C, mmol/L | LDL-C, mmol/L |
|------------|----|---------|-------------|-------------|-------------|-------------|---------------|---------------|
| 2L:2D      | 6  | 34.62±0.28a | 12.98±0.30  | 0.525±0.036 | 4.00±0.07a  | 0.560±0.056 | 2.44±0.05     | 1.01±0.03     |
| 4L:4D      | 6  | 37.79±0.93a | 13.50±0.29  | 0.642±0.037 | 4.04±0.06a  | 0.603±0.045 | 2.41±0.06     | 1.00±0.02     |
| CL         | 6  | 35.63±0.92a | 13.12±0.28  | 0.575±0.061 | 3.81±0.09a  | 0.592±0.071 | 2.27±0.06     | 1.07±0.09     |

TP: total protein; GLU: glucose; BUN: blood urea nitrogen; CHO: cholesterol; TG: triacylglycerol; HDL-C: high-density lipoprotein cholesterol; LDL-C, low density lipoprotein cholesterol; 2L:2D, 2 hours of light: 2 hours of dark photoperiodic lighting cycle; 4L:4D, 4 hours of light: 4 hours of dark photoperiodic lighting cycle; CL, continuous lighting. Values are expressed as mean±standard deviation. a,bIn the same column, values with no superscript letters indicate no significant differences (P>0.05), whereas different lowercase superscript letters indicate significant differences (P<0.05).
their general activity level (Nielsen et al., 2003). As a matter of fact, the physical activity of broilers was very low during periods of darkness, and the energy expenditure was considerably lower in broilers reared in IL than birds raised in CL. In addition, without an extended dark period, broilers are likely to be disturbed during resting periods by the movements of other birds. Moreover, a bright environment is not conducive for sleep, and the birds might have experienced sleep deprivation (Duve et al., 2011). Different effects of varied photoperiods on growth in birds have been observed. Body weight was greater at 22 and 49 d following a 16L:2D:11L:2D photoperiod treatment than after a 16L:8D photoperiod treatment (Lewis et al., 2010). Specifically, birds grown under the 16L:8D photoperiod consumed less feed and grew less rapidly than birds under CL. In the current study, birds reared in the 4L:4D photoperiod grew faster than broilers exposed to the 2L:2D photoperiod. Blokhuis (1983) suggested poultry be provided an absolute minimum of 4 h of uninterrupted darkness, and advised that the requirements for sleep might be higher at certain points of the growing period. As well, provision of a dark period stimulates higher feeding rates during the light period (Maddock et al., 2001), and improves rest during the dark period (Malleau et al., 2007). Therefore, the dark period in the 2L:2D IL regimen might have been too short to exert an influence on the broilers in the current study.

Slaughter performance

In regards to abdominal fat content, only a limited number of reports exist on the effects of IL on carcass yield and quality. Zdenka et al. (2011) observed that an IL regime is justified from the standpoint of carcass quality improvement. In addition, Abreu et al. (2011) found that IL programme promoted the highest drumstick and thigh yields. Cave et al. (1985) reported that males raised under IL had higher abdominal fat content than female broilers; however, other report indicated that the abdominal fat pad contents of broilers reared under IL were significantly less than those of broilers exposed to CL (Buyse et al., 1996). In contrast, Abreu et al. (2011) did not observe differences in abdominal fat deposition between IL and CL programme. Based on these research results, it could be inferred that abdominal fat content might be affected by several factors, such as lighting time, photoperiod, sex, age, and breed. However, no significant differences in slaughter performance were detected among the three photoperiod treatments in the current study.

Table 6. Effects of intermittent lighting on tibia parameters.

| Treatments | N  | BEM, MPa | BBD, mm | BBS, kg |
|------------|----|----------|---------|---------|
| 2L:2D      | 6  | 1745±168 | 0.035±0.004 | 21.45±2.21 |
| 4L:4D      | 6  | 2191±160 | 0.031±0.002 | 25.76±2.22 |
| CL         | 6  | 1814±191 | 0.035±0.003 | 22.01±1.95 |

BEM, bone elastic modulus; BBS, bone breaking strength; BBD, bone bending displacement; 2L:2D, 2 hours of light: 2 hours of dark photoperiodic lighting cycle; 4L:4D, 4 hours of light: 4 hours of dark photoperiodic lighting cycle; CL, continuous lighting. Values are expressed as mean±standard deviation.

Serum biochemical parameters

Poor health is arguably the most obvious indication of reduced welfare (Dawkins et al., 2004). Several prior studies have compared the impact of lighting programs on health status in broiler flocks. Zheng et al. (2013) observed that IL significantly improved nonspecific immunity and serum melanin levels in broilers. However, Balog et al. (1997) found that clinical chemistries of birds were not affected by IL activity. In addition, energy restriction significantly decreased serum total cholesterol, high-density lipids and blood urea nitrogen (Chen et al., 2012). Serum glucose, urea levels were similar in all the groups whereas the levels of total cholesterol and triglyceride were found to be higher in the additive agent group (Rout et al., 2015). In the current experiment, the total serum protein content of broilers reared in the 4L:4D photoperiod was significantly higher than levels observed in birds exposed to the other two photoperiod treatments, which illustrated that the 4L:4D photoperiod might be optimal for broilers. Further, the results were in accord with Duve et al. (2011) who reported that splitting a long dark period into two shorter periods separated in time might reduce the negative implications of an extended dark period. As well, the 12L:12D IL schedule in particular might enhance immune function in broilers (Guo et al., 2010). It was apparent from the current study that dark does have an important impact on the health parameters measured, which could in turn alter broiler welfare and immune performance.

Tibia parameters

The endogenous melatonin rhythm modulates markers important to bone physiology (Witt-Endebery et al., 2012). Light could induce osteoclastogenesis and inhibit osteoblastogenesis in Multiple Myeloma bone disease, and it could synergically stimulated osteoclast formation with rankl through the phosphorylation of Akt, NF kappa B and JNK pathways, light inhibited the formation of CFU-F and CFU-OB as well as the expression of osteoblastic markers including collagen-I, osteocalcin and bone sialoprotein-II (Brunetti et al., 2014). The continuous selection of broilers for fast growth and higher breast yield in carcasses has resulted in the emergence of significant conformation changes including leg disorders (Reddish and Lilburn, 2004; Sherlock et al., 2010). At present, it is generally accepted that the application of CL schedules significantly reduces the incidence of leg disorders in both broilers and meat-type turkeys. To this end, Sanotra et al. (2002) demonstrated that light-dark programs reduced the duration of tibial dyschondroplasia compared with control birds exposed to 24 h CL. Further, Onba İlar et al. (2007) reported that chicks reared in IL had numerically lower tibial dyschondroplasia values. As well, prior reports indicated that tibial breaking strength was significantly affected by photoperiod and genotype, and that peak bone strength was achieved with a 7 h lighting period, with reductions in strength apparent following both shorter and longer photoperiods (Lewis et al., 2009). In the present experiment, no leg abnormalities were detected among the three experimental treatments; however, the bone elastic modulus of birds reared in the 4L:4D photoperiod was greater than the corresponding measurements obtained from birds in the other two photoperiod treatments, which indicated that the 4L:4D photoperiodic lighting perhaps favored tibial growth in broilers. The results were in agreement with Lewis et al. (2010). However, Das and Lacin (2014) reported that the photoperiod program and stocking density had no significant impact on tonic immobility or tibial dyschondroplasia values, which could be explained by the positive correlation between tibial dyschondroplasia and body weight, or perhaps by the differences in slaughter age.

Conclusions

Overall, IL significantly decreased the average daily feed intake and feed conversion ratio of broilers compared to CL. The 4L:4D photoperiod increased intestinal tract weight, the eviscerated yield with gibel and eviscerated carcass weights compared to CL. In addition, the
4L:4D photoperiod significantly increased body weight, serum total protein concentration and the bone elastic modulus of broilers compared to the 2L:2D photoperiod at 42 day of age. In conclusion, the 4L:4D photoperiodic lighting schedule improved growth performance, slaughter performance, serum biochemical parameter and tibia parameter compared to the 2L:2D photoperiod and CL in broiler production. Consequently, the 4L:4D photoperiodic lighting schedule seems to be a possible alternative to the conventional method.

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