EFFECTS OF LIGHT AND DARKNESS ON HEAT AND MOISTURE PRODUCTION OF BROILERS

H. Xin, J. L. Sell, D. U. Ahn

ABSTRACT. Heat and moisture production rates of ad-libitum fed Ross x Ross broilers (averaging 6.5 weeks of age and 3.0 kg of body mass) subjected to a lighting cycle of 8 h light and 4 h darkness were measured by using indirect calorimeters. The experimental broilers were kept in groups of 24 birds on litter floors with a stocking density of 0.1 m²/bird. Air temperature and relative humidity inside the calorimeter chambers were 24 ± 0.25°C and 52 ± 5%, respectively. After a two-day acclimation period, moisture production (MP), sensible heat production (SHP), and total heat production (THP) rates of the broilers were measured at 30-min intervals for four consecutive days. MP, SHP, and THP during the lighting period averaged 6.1 g H₂O/(kg-h), 4.3 W/kg, and 8.4 W/kg, respectively, for the present study, as compared to the literature values of 6.5 g H₂O/(kg-h), 4.0 W/kg, and 8.5 W/kg, respectively, for 2 kg broilers at 16°C air temperature. MP, SHP, and THP during the dark period, not available in the literature, were reduced to 74%-76% of those for the lighting period and averaged 4.7 g H₂O/(kg-h), 3.1 W/kg, and 6.3 W/kg, respectively (P < 0.01). The result of reduced heat and moisture production for the broilers in the dark coincided with the literature report for pullets and layers, although the magnitudes were different. The substantial differences in broiler heat and moisture production between lighting and dark periods should be considered when designing heating and cooling schemes for broiler houses. For instance, variable water application rates would be more effective than a constant application rate in cooling broilers by surface wetting under intermittent lighting conditions. Keywords. Heat production, Moisture production, Broilers, Environmental control, Photoperiod.

The heat and moisture production data of broilers measured by Reece and Lott (1982) have been widely used as the design references for heating, cooling, and ventilation of broiler houses (ASAE Standards, 1994). Although these data were developed under continuous lighting condition (typical of broiler production practice in the past), intermittent lighting has become more attractive to both broiler researchers and producers because of its improved feed conversion, reduced growth abnormalities (i.e., leg problems and sudden death syndromes), and lower electricity cost (Buckland et al., 1973; Classen and Riddell, 1989; Andrews and Zimmerman, 1989; Renden et al., 1991; Blair et al., 1993). Light and darkness have been shown to have significant impacts on the heat and moisture production of layers (Riskowski et al., 1978) and pullets (Zulovich et al., 1987). Namely, birds in the darkness have much lower heat and moisture production than birds in the light. These light-dependent responses should be considered when sizing heating and cooling devices or developing environmental control schemes. However, no literature data were found on heat and moisture production of broilers as influenced by lighting conditions. Thus, the objective of this article was to compare the heat and moisture production rates of growing broilers during the light and dark periods of an intermittent lighting cycle of 8 h of light and 4 h of darkness (8L:4D).

MATERIALS AND METHODS

EXPERIMENTAL BROILERS AND LIGHTING REGIME

Ninety-six Ross x Ross broilers at 6 weeks of age and an initial body mass of 2.88 kg were delivered from the Iowa State University Poultry Farm to the Agricultural and Biosystems Engineering Livestock Environment and Physiology (LEAP) Research Laboratory. Upon arrival, the broilers were weighed and randomly assigned to four indirect calorimeter chambers, 24 broilers per chamber with approximately 0.1 m² of net floor area per bird. The broilers were fed ad-libitum with a round feeder and a fount waterer. The feed ration contained 3,100 kcal/kg of metabolizable energy, 20.2% protein (by analysis), 0.72% total sulfur amino acids, 0.40% methionine, 1.12 lysine, 0.90% calcium, and 0.40% nonphytate phosphorus. The wire-mesh floors of the chambers were covered with an artificial turf topped with 10 cm woodshavings. A standard intermittent fluorescent lighting cycle of 8-h light and 4-h dark (8L:4D) at 26 lux intensity was implemented with programmable electronic timers. A constant, thermoneutral air temperature of 24 ± 0.25°C with a relative humidity of 52 ± 5% was maintained inside the calorimeter chambers.

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throughout the experiment. The broilers were subjected to the experimental conditions for six days with the first two days being the acclimation period.

**INDIRECT CALORIMETERS AND MEASUREMENT OF BROILER HEAT AND MOISTURE PRODUCTION**

The Iowa State University open-circuit, indirect calorimeter system (Fig. 1) was used for this study. The four individually controlled calorimeter chambers each had a floor dimension of 1.52 × 1.83 m. The fresh air supply was heated to the desired temperature of the chamber by two electric heater/fan units located in the plenum space of the air inlet and the porous ceiling of the chamber. An air distribution duct was located along the perimeter of the chamber near the bird level to enhance uniform mixing of the outgoing air. Electric heating cords were used to prevent moisture condensation inside the air sample lines. Sequential air sampling was accomplished with solenoid valves controlled by the data acquisition system. Specifically, air sampling was performed at 6-min intervals, with the first 5 min used for system purging and stabilization. During the last (sixth) minute, the response variables were measured every two seconds and stored as 30-point averages into the datalogger. The O₂ (model 755A) and CO₂ (model 880A) gas analyzers (Rosemount Analytical Inc., La Habra, Calif.) were checked by combustion of pure ethanol at the beginning of the experiment and calibrated with primary standard calibration gases twice daily throughout the experimental period. Furthermore, an error analysis of the measurement system indicated a maximum error of ±0.26 W for heat production per chamber. Because the heat production rate for the present study was greater than 450 W/chamber, the measurement error should have negligible effects on the results. Detailed description of the system features and operation has been presented elsewhere (Xin et al., 1996).

The equations used in calculating the energetic responses of the broiler chickens are presented in the “Appendix”. Body mass of the broilers was assumed to change linearly over the six-day trial period. Heat and moisture production rates of the birds were converted to a unit-body-mass basis. Analysis of variance was performed to determine the effects of light and dark period on the energetic responses of the broilers.

<table>
<thead>
<tr>
<th>Period</th>
<th>MP</th>
<th>S.D.</th>
<th>SHP</th>
<th>S.D.</th>
<th>THP</th>
<th>S.D.</th>
<th>RQ</th>
<th>S.D.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall</td>
<td>5.6</td>
<td>0.6</td>
<td>3.9</td>
<td>0.2</td>
<td>7.7</td>
<td>0.5</td>
<td>0.88</td>
<td>0.02</td>
</tr>
<tr>
<td>Light (L)</td>
<td>6.1a</td>
<td>0.6</td>
<td>4.3a</td>
<td>0.3</td>
<td>8.4a</td>
<td>0.6</td>
<td>0.88a</td>
<td>0.03</td>
</tr>
<tr>
<td>Darkness (D)</td>
<td>4.7b</td>
<td>0.7</td>
<td>3.1b</td>
<td>0.6</td>
<td>6.3b</td>
<td>0.6</td>
<td>0.90a</td>
<td>0.04</td>
</tr>
<tr>
<td>D/L Ratio</td>
<td>0.75</td>
<td>—</td>
<td>0.74</td>
<td>—</td>
<td>0.74</td>
<td>—</td>
<td>1.03</td>
<td>—</td>
</tr>
</tbody>
</table>

Note: S.D. represents the standard deviation of four replicates. Column means with different letters are significantly different (P < 0.01).

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**Figure 1**—Schematic representation of the Iowa State University indirect calorimeter system.
RESULTS AND DISCUSSION

The average energetic responses of the broilers to light and dark conditions are summarized in Table 1. The dynamic profiles of the responses, averaged over the last four-day testing period, are shown in Figure 2. No residual acclimation effects on the energetic responses appeared to exist during the subsequent four-day trial period. During the lighting period, THP of the present study, 8.4 W/kg, was in good agreement with the literature value of 8.5 W/kg for the 2 kg broilers exposed to continuous lighting and 16°C temperature reported by Reece and Lott (1982). However, MP, 6.3 g \text{H}_2\text{O/(kg-h)}, and SHP, 4.2 W/kg, of the present study were respectively lower and higher than the values of Reece and Lott’s study, 6.5 g \text{H}_2\text{O/(kg-h)} and 4.0 W/kg, respectively, even though air temperature of the present study (24°C) was much higher than that (16°C) used by Reece and Lott (1982). Substituting the air temperature and bird age (45 days on average) of the present study into the empirical equations of Gates et al. (1996) yielded a higher MP of 7.5 g \text{H}_2\text{O/(kg-h)} and a lower SHP of 3.3 W/kg. The exact causes of such discrepancies in MP and SHP partition were unclear, but it was speculated that they resulted from differences in litter moisture conditions and bird genetics. The fraction of SHP as the percentage of THP (\(f_s\)) for this study, however, was quite similar to what the CIGR (1992) model would have predicted, i.e., 50% vs. 45%, which uses the relationships of

\[ f_s = F [0.8 - 1.85 \times 10^{-7} (t + 10)^4] \]

\[ F = 4 \times 10^{-5} (20 - t)^3 + 1 \]

where \(t\) is the air temperature (°C) and \(F\) is the correction factor for THP.

During the dark period, MP, SHP, and THP of the broilers all decreased by 25%–26% when compared with those during the lighting period. By comparison, Zulovich et al. (1987) reported that SHP and MP of 7-week-old pullets (0.52 kg) subjected to a 10L:14D lighting regime were 45% and 18%, respectively, lower in the darkness than in the light. Riskowski et al. (1978) showed a 22% reduction in THP during dark period for White Leghorn layers when subjected to a 14L:10D lighting regime, and smaller reduction of the heat production as the light hours decreased. The authors however did not present MP or SHP of the layers according to light and dark period. It seems that the experimental broilers shared similar heat reduction response as the layers, but quite different responses as compared to the pullets. The reduced MP and SHP in the darkness observed in the present study amount to 56 kg/h of water and 48 kw (163,822 BTU/h) of sensible heat for a broiler house with 20,000, two-kilogram broilers. Practically, these reductions translate to reduced minimum ventilation for moisture removal during cold weather and reduced cooling needs during hot weather when keeping birds in the dark. For instance, cooling broilers by surface wetting (Berry et al., 1990) in this case would require 71 kg/h less water for the reduced SHP during the dark period than during the light period. Thus, a constant water application rate that is based on SHP of broilers under continuous lighting would be more likely to result in wet litters than a light-dependent, variable water application rate. Similarly, significant fuel savings may be achieved during cold weather by reducing the minimum ventilation rate during the dark period.

The present study also showed circadian heat and moisture production patterns of broilers under lighting conditions (fig. 2). In particular, SHP and THP during the daytime lighting period (4.6 W/kg, 9.0W/kg) were 24% and 13%, respectively, higher than SHP and THP during the nighttime lighting period (3.7 W/kg, 8.0 W/kg). Substantial difference in the respiratory quotient (RQ) was also noted between the daytime light period (0.77) and the nighttime light period (0.97). Although the exact reason was unclear, it was speculated that the higher RQ at night might have been associated with a greater energy retention (lower THP) and thus tissue deposition during this period.

CONCLUSION

Heat and moisture production rates of broilers are greatly influenced by lighting conditions. A 25 to 26% reduction in moisture, sensible, and total heat production rates (MP, SHP, and THP) can be expected when switching from light to darkness. Specifically, MP, SHP, and THP of 3 kg broilers under 24°C and 52% relative humidity were 6.1 g \text{H}_2\text{O/(kg-h)}, 4.3 W/kg, and 8.4 W/kg, respectively, during the 8-h lighting period, and 4.7 g \text{H}_2\text{O/(kg-h)}, 3.1 W/kg, and 6.3 W/kg, respectively, during the 4 h dark period. Design and operation of broiler environmental control systems may need to consider the dynamic nature of these responses to maximize the control performance.

REFERENCES


**APPENDIX — CALCULATIONS OF HEAT AND MOISTURE PRODUCTION RATES**

**TOTAL HEAT PRODUCTION RATE (THP, W/kg)**

\[
\text{THP} = 16.18 \text{O}_2 + 5.02 \text{CO}_2 \quad \text{(Brouwer, 1965)} \quad (1)
\]

where \(\text{O}_2\) represents the oxygen consumption rate of the chicks, (mL·s\(^{-1}\)·kg\(^{-1}\)), STPD; and \(\text{CO}_2\) is the carbon dioxide production rate of the chicks, (mL·s\(^{-1}\)·kg\(^{-1}\)), STPD.

\[
\text{O}_2 = V_i (X_i - \alpha X_o) \cdot 10^{-6} \quad (2)
\]

\[
\text{CO}_2 = V_i (Y_o - \alpha Y_i) \cdot 10^{-6} \quad (3)
\]

where \(V_i\) = inlet air flow rate (mL·s\(^{-1}\)·kg\(^{-1}\)), STPD

\(X_i, X_o\) = oxygen concentration of the inlet and outlet air, respectively (ppm)

\(Y_i, Y_o\) = carbon dioxide concentration of the inlet and outlet air, respectively (ppm)

\(\alpha\) = correction factor for the outlet air flow rate

\[
\alpha = \frac{V_o}{V_i} = \frac{1 - (X_i + Y_i) \cdot 10^{-6}}{1 - (X_o + Y_o) \cdot 10^{-6}} \quad (4)
\]

**MOISTURE PRODUCTION RATE (MP, g H\(_2\)O/[h·kg])**

\[
\text{MP} = V_i p (\alpha W_o - W_i) \cdot \frac{3600}{1000} \quad (5)
\]

where \(p\) is the density of air, 1.293 g·L\(^{-1}\), and \(W_i, W_o\) represent the humidity ratio of the inlet and outlet air, respectively, gH\(_2\)O·gDA\(^{-1}\).

\[
W = 0.62198 \left( \frac{P_w}{P - P_w} \right) \quad \text{(Weiss, 1977)} \quad (6)
\]

where \(P\) is the barometric pressure of ambient air (kPa), and \(P_w\) is the partial vapor pressure of the inlet or outlet air (kPa) calculated as:

\[
P_w = 0.61078 e^{\left( \frac{17.2693882 \cdot t_{dp}}{u_p + 237.30} \right)} \quad \text{(Weiss, 1977)} \quad (7)
\]

where \(t_{dp}\) represents the dew point temperature of the inlet or outlet air (°C).

**SENSIBLE HEAT PRODUCTION (SHP, W/kg)**

\[
\text{SHP} = \text{THP} - \text{MP} \cdot h_{fg} \cdot 3600^{-1} \quad (8)
\]

where \(h_{fg}\) is the latent heat of water vaporization, 2450 J·(K·g\(^{-1}\)).

**RESPIRATORY QUOTIENT (RQ)**

\[
\text{RQ} = \frac{\text{CO}_2}{\text{O}_2} \quad (9)
\]