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Effects of lighting regimen on metabolic rate in broilers

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Abstract

Broilers were exposed to varying periods of light (L) and dark (D) within 4-h periods (0.5L to 1.5L and 3.5D to 2.5D). Effects of lighting regimen (LR) and trough position (open (F2) versus closed (F1)) during D-periods on heat production (H), activity-free (H_{acf}) and activity-related H (H_{ac}), and RQ were evaluated. At 0.5L and 0.67L, H_{ac} was less than in the longer L-periods. The longer the L-period, the less active animals were at the end of a L-period. In D-periods with F1, H and H_{acf} decreased more than with F2, while H_{ac} was similar. Therefore, after D-periods with F1, H and H_{acf} increased more than after D-periods with F2. This effect on H was greatest in short L-periods with F1. With 0.5L:3.5D and F1, animals did not have enough feeding time, because at the end of the L-period afterwards, H and RQ were lower than with the longer L-periods. Thus, broilers will consume feed in the dark and the length of L-period may not be crucial, because in practice, feed will remain available in the dark.

Keywords : broilers, lighting regimen, metabolic rate, physical activity, respiratory quotient

Introduction

Many investigators have studied the effects of lighting regimen (LR) on growth rate, feed intake and mortality of broilers (Buckland, 1975; Perry, 1981; Ketelaars et al., 1986; Scheele et al., 1987); however, the effects of LR on metabolic rate, respiratory quotient (RQ, volume of CO_2 produced divided by volume of O_2 consumed) and physical activity have not been well studied. Wenk & van Es (1976) and Scheele et al. (1987; literature review) showed that LR affects the physical activity of chickens. Scheele et al. (1987) concluded that physical activity is the most important component for losses of dietary energy. The RQ can be looked upon as a reflection of which kind of substrate is being oxidized (Brouwer, 1957); the RQ is lowered when there is no more energy available for direct assimilation. The length of the D-period could be established by knowing the moment that the RQ starts to decrease. As the average transit time of feed in young chickens is less than 3 h (Golian & Polin, 1984), one would expect a decrease of RQ after about 3 h of darkness. However, van Kampen (1989) found that the change in RQ between L- and D-periods (1L:3D) is very limited. Firstly, as van Kampen (1989) suggested, the occurrence of feed intake in the dark should be established. Furthermore, as Scheele (1988) suggested, the feed should contain no added fat in order to maximize a possible decrease in RQ during periods with no feed intake. Several authors (Buckland, 1975; Ketelaars et al., 1986) suggest that a LR with 0.5 to 1 h light (L) and 2 to 3 h dark (D), such as 1L:3D, is most suitable for broilers. The physiological basis for such a statement is unknown, but should involve a pattern of metabolic rate, RQ and/or physical activity during L- and D-periods. A hypothesis might be that in D-periods, without feed intake, metabolic rate and RQ will decrease. When a minimum level is reached, light should be provided to allow feed intake. The objective of the present experiment was, therefore, to investigate the occurrence and also the magnitude of a possible decrease in heat production and RQ during D-periods of several lengths. To determine if the birds consumed feed in the dark, the feed trough was closed during some D-periods. In addition, physical activity was measured to determine its contribution to metabolic rate in relation to LR.

Materials and methods

Animals, housing and feeding

Eighty neonatal male broilers were used, 40 from each of two selection lines (S1, selected on high growth rate; S2, selected on low feed:gain ratio; Leenstra, 1987). The S1 and S2 chickens were group housed in one of two identical climate respiration chambers with one selection line per chamber. Each chamber had a volume of 1.8 m^3 and a floor space of 0.8 m^2 (Verstegen et al., 1987). The experiment lasted for 43 d. Each week, a certain number of randomly selected birds was removed to maintain sufficient feeding and floor space for the remaining birds. At d 43, 6 S1 and 8 S2 birds remained. From d 1 to d 5, ambient temperature (T_a) was maintained at 32 °C. From d 6 to d 29, T_a was decreased stepwise by 1 °C every 2 or 3 d. From d 29 to d 43, T_a was maintained at 20 °C. Relative humidity was maintained at 65 to 70 % throughout the experiment. Feed and water were available ad libitum. Feed composition is shown in Table 1.

Lighting regimens

After 5 d of adaptation with continuous lighting, the animals were exposed to different LR's (Figure 1). Each day (0900 - 0900) was divided into six successive 4-h periods. Lighting was provided for 0.5 to 1.5 h at the start of each period (79 to 83 lux at animal level from 2 light bulbs of 25 W per chamber). For the remaining 2.5 to 3.5 h, lights were off. After 2 or 3 d (Figure 1), LR within each 4-h period was changed. After changing LR, a new 1 or 2 day acclimatization period started. The 1L:3D regimen was repeated every 7 d. The procedure from d 1 to 21 was identical to that from d 22 to 42.

Measurements

On the last d of each LR, heat production (H) and RQ were determined at successive 9-min intervals for 24 h (respiration days, R, Figure 1) using the exchange of oxygen and carbon dioxide as described by Verstegen et al. (1987), according to the formula of Romijn & Lokhorst (1961). Physical activity of the animals was measured during each R at 3-min intervals with an ultrasonic burglar device according to the method used by Wenk & van Es (1976). These 3-min activity measurements were combined into 9-min periods. The broilers were

Table 1. Composition and calculated feeding value of the experimental diet.

Feed components	Composition (% of feed)
Corn	54.0
Corn glutenfeed USA (23 % CP)	7.8
Soybean solvent extracted (49 % CP)	23.9
Herring meal, Danish (73 % CP)	2.0
Meat meal, high fat (58 % CP)	4.0
Soya oil	5.2
Dicalcium phosphate	0.45
Vitamins[1]	0.5
Minerals[2]	2.0
DL-Methionine (99 %)	0.1
Amprolium[3]	0.05
Total	100.0
ME_n, MJ[4]$\cdot kg^{-1}$ feed	13.18
Dry matter, %	91.08
Crude protein, %	22.1
Crude fibre, %	2.5
Lys (digestible), %	0.99
Met + Cys (digestible), %	0.71
Calcium, %	1.18
Magnesium, %	0.18
Phosphorus (available), %	0.52
Potassium, %	0.84
Sodium, %	0.18

[1]The vitamin premix supplied per kilogram of ration: vitamin A, 12 000 IU; vitamin B_1, 1 mg; vitamin B_2, 5 mg; nicotinic acid, 30 mg; pantothenic acid, 7.5 mg; vitamin B_6, 1 mg; vitamin B_{12}, 15 μg; folic acid, 1 mg; vitamin D_3, 2400 IU; vitamin E, 15 mg; vitamin K_3, 1.5 mg; choline chloride, 350 mg and ethoxyquin, 50 mg.
[2]The mineral premix supplied per kilogram of ration: dicalcium phosphate, 8 g, $CaCO_3$, 8.8 g; NaCl, 2.5 g; $CuSO_4 \cdot 5H_2O$, 0.04 g; $ZnSO_4$, 0.06 g; $MnSO_4$, 0.24 g; $FeSO_4$, 0.26 g; I, 0.77 mg; K, 0.23 mg and Se, 0.1 mg.
[3]Merck, Sharp and Dohme (MSD), Haarlem, the Netherlands.
[4]1 MJ = 0.239 Mcal.

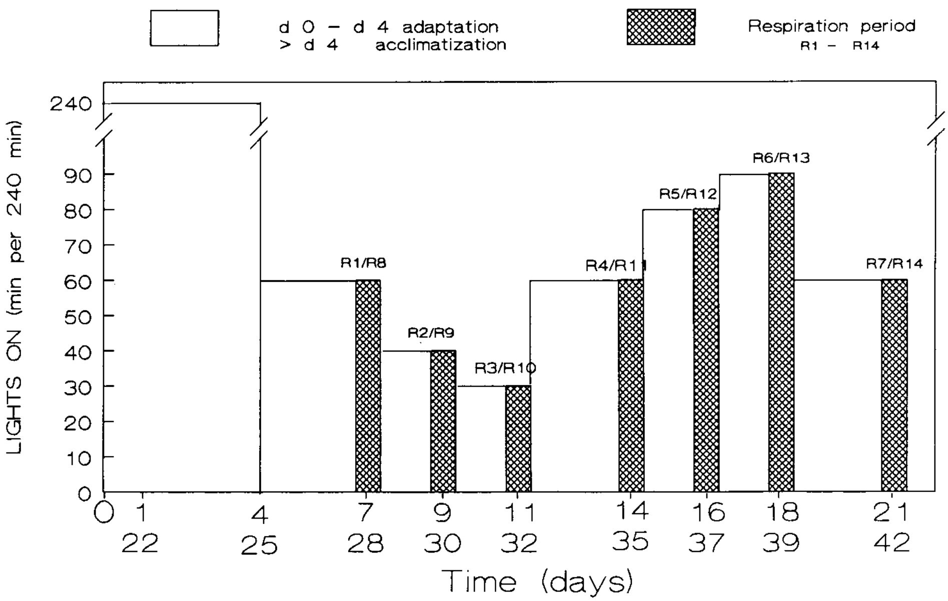

Fig. 1. Experimental design.

group-weighed after each respiration period. Also, individual body weight was determined each week, starting at d 1. Total feed intake per group over 43 d was determined by summation of intake as measured during 6 successive 7-d periods. To investigate whether feed intake occurred in the dark, the feed trough was closed during D-periods of the first two 4-h periods of each respiration day, except during d 14 (R4) and d 37 (R12) (Figure 1).

Statistical analysis

Individual body weights and growth rates (from animals still present at d 43) were analyzed for the effects of selection line (S) in a monofactorial model. Data on body weight and feed intake over 43 d were used to determine the effect of selection line on feed:gain ratio. From the data on H ($kJ \cdot kg^{-1} \cdot d^{-1}$) and activity, activity-related heat production (H_{ac}) was derived. In short, heat production was regressed on activity counts within each respiration day. Subsequently, H_{ac} was calculated by multiplying the regression coefficient by the total number of activity counts; then, activity-free heat production (H_{acf}) was calculated by subtracting H_{ac} from H. The relationship between the output of an activity meter and H within a day was considered linear because the correlation coefficients were 0.6 to 0.9 (Wenk & van Es, 1976; Verstegen et al., 1987). The 24-h means of H, H_{ac}, H_{acf} and RQ were analyzed in a model with selection line (S) and lighting regimen (LR) as factors. Only main factors were used because the interactions between S and LR were not significant ($P > 0.05$).

Differences in H, H_{acf}, H_{ac} and RQ between the last 20 min in L- and D-periods within each 4-h period were analyzed with the model:

$$Y_{ijk} = \mu + S_i + LR_j + F_k + e_{ijk}$$

with: Y = difference in H, H_{acf}, H_{ac} or RQ between L and D; μ = mean of the difference; S_i = effect of selection line (i = 1, 2); LR_j = effect of lighting regimen (j = 1, 5); F_k = effect of feed trough (k = 1, 2; closed or open); e_{ijk} = error term.

A 20-min time length was used because the shortest L-period was 30 min (0.5L:3.5D); thus, all periods contained two 9-min measurements. A model with only main factors was used, because the two- and three-way interactions were not significant ($P > 0.05$), except for the interaction between S and F for H_{acf} ($P < 0.05$). After a preliminary analysis, data from R1 were omitted, because the variation between 9-min data were large compared with that during other respiration days, probably due to still insufficient adaptation. Data from 11 respiration days were used for analyses of 24-h averages (R 2, 3, 5 to 11, 13, 14, Figure 1). Data from 13 respiration days were used for analyses of variation within days (R 2 to 14, Figure 1).

Results

Body weight, growth rate, feed intake and feed:gain ratio

Chickens from the line selected for high growth rate (S1) had higher daily gain than those from the line selected for low feed:gain ratio (S2) ($P < 0.001$) (Table 2). At 43 d of age, the difference in body weight between chickens of S1 and S2 lines was about 430 g. Chickens from the S1 line, although not statistically tested because of time-effect, had higher feed intake, higher daily gain and lower feed:gain ratio than those from the S2 line (Table 2).

Heat production (H), activity-free heat production (H_{acf}), activity-related heat production (H_{ac}) and respiratory quotient (RQ)

Daily averages. Average daily H, H_{acf} and RQ were not affected ($P > 0.05$) by selection line or lighting regimen (Table 3). Activity-related heat production, H_{ac}, differed ($P < 0.01$) between lines and also between lighting regimen. From d 14 onwards, S2 line chickens spent more energy on activity than the S1 line chickens (Figure 2). At 0.5L and 0.67L, less energy was spent on activity in comparison to longer L-periods (Table 3).

Variation within days. The differences in H, H_{acf}, H_{ac} ($P < 0.01$) and RQ ($P < 0.05$) between L- and D-periods differed between selection lines (Table 4). Heat production (H) and H_{ac} (Figure 3) as well as H_{acf} and RQ were higher during the last 20 min in L-periods than during the last 20 min in D-periods. At the end of D-periods, H, H_{acf}, H_{ac} and RQ were similar in the two selection lines (mean

Table 2. Body weight($g.an^{-1}$), growth rate($g.an^{-1}.d^{-1}$, feed intake ($g.an^{-1}.d^{-1}$) and feed:gain ratio of chickens from the two selection lines (S1, selected on high growth rate; S2, selected on low feed:gain ratio) during the 43 d experiment (Means ± SE; number of animals between brackets).

Parameter		Selection line				
		S1			S2	
body weight at	d 1	47 ± 1	(40)	***[1]	42 ± 1	(40)
	d 8	159 ± 2	(40)	***	124 ± 2	(39)
	d 15	380 ± 5	(33)	***	275 ± 6	(35)
	d 22	741 ± 22	(15)	***	516 ± 13	(20)
	d 29	1206 ± 49	(11)	***	853 ± 54	(13)
	d 36	1798 ± 48	(6)	***	1417 ± 36	(9)
	d 43	2374 ± 62	(6)	***	1947 ± 51	(8)
growth rate of remaining animals	d1-d43	55 ± 1.5	(6)	***	45 ± 1.2	(8)
feed intake[2]		92 ± 23	(6)	nt[3]	81 ± 22	(6)
average gain		55 ± 11	(6)	nt	45 ± 12	(6)
feed:gain ratio		1.58 ± 0.1	(6)	nt	1.67 ± 0.1	(6)

[1]Significant difference between selection lines ($P < 0.001$).
[2]Using data from 6 successive 7-d periods.
[3]nt - not statistically tested.

Table 3. Least square means (± SE) of 24 h heat production (H), activity-free heat production (H_{acf}), activity-related heat production (H_{ac}) and Respiratory Quotient (RQ) using a model with selection lines (S1, selected on high growth rate; S2, selected on low feed:gain ratio) and lighting regimens (LR, 0.5 to 1.5 h of light in each 4-h period) as main factors.

Source of variation		H ($kJ \cdot kg^{-1} \cdot d^{-1}$)	H_{acf} ($kJ \cdot kg^{-1} \cdot d^{-1}$)	H_{ac} ($kJ \cdot kg^{-1} \cdot d^{-1}$)	RQ (CO_2/O_2)
Line:	S1	830 ± 19	747 ± 17	83 ± 5^B	1.07 ± 0.01
	S2	867 ± 19	748 ± 17	119 ± 5^A	1.05 ± 0.01
LR:	0.5L:3.5D	855 ± 30	780 ± 27	75 ± 7^B	1.05 ± 0.02
	0.67L:3.33D	816 ± 30	733 ± 27	83 ± 7^B	1.07 ± 0.02
	1L:3D	870 ± 21	761 ± 19	109 ± 5^A	1.04 ± 0.01
	1.33L:2.67D	839 ± 42	720 ± 38	119 ± 10^A	1.10 ± 0.02
	1.5L:2.5D	863 ± 30	744 ± 27	119 ± 7^A	1.06 ± 0.02
MS model	(df = 5)	3085	1516	2683	0.0015
MS error	(df = 16)	3530	2866	211	0.0010
R^2		0.21	0.14	0.80	0.33

^{A,B}: values of classes within the same factor with different superscripts differ significantly ($P < 0.01$).
SE: standard error; MS: Mean Squares; df: degrees of freedom; R^2: coefficient of determination.

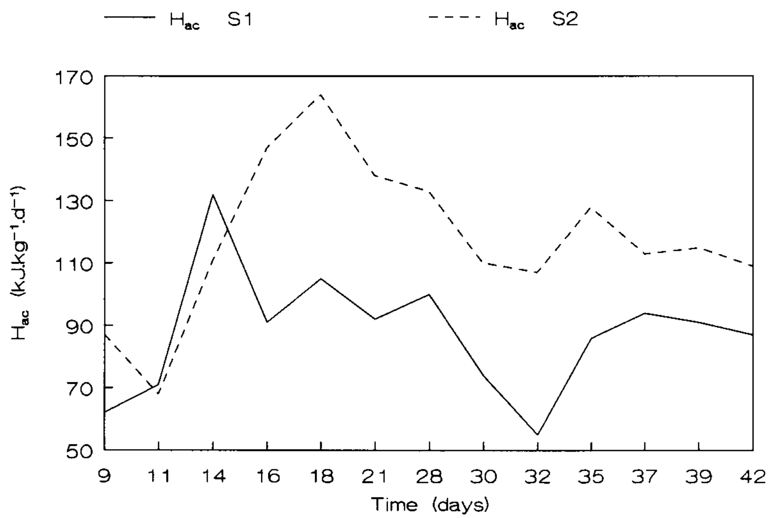

Fig. 2. Activity-related heat production (H_{ac}) of chickens selected on high growth rate (S1) and on low feed:gain ratio (S2) in relation to duration of the experiment.

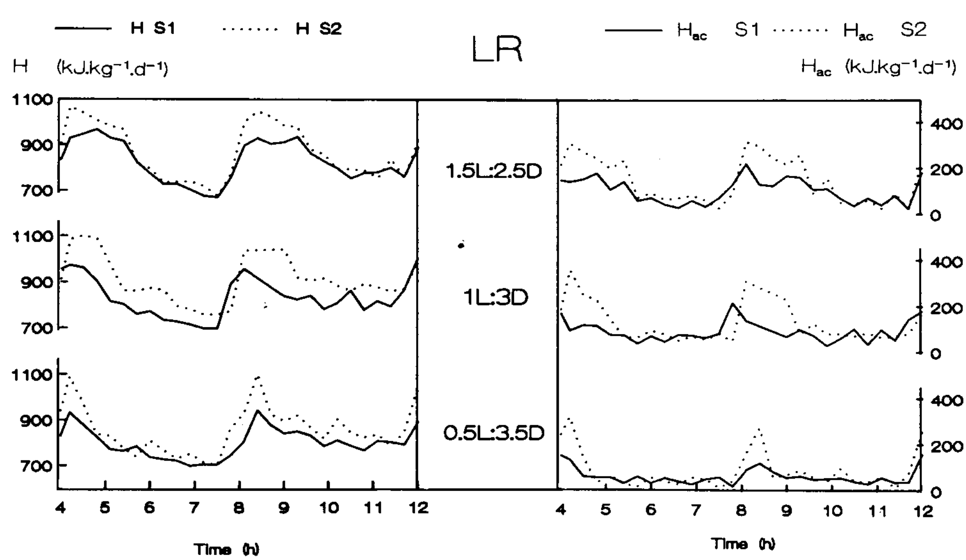

Fig. 3. Total heat production (H) and activity-related heat production (H_{ac}) within selection lines (S1, selected on growth rate; S2, selected on feed:gain ratio) and lighting regimens (LR, 0.5 to 1.5 h of light in each 4-h period) of 18-min averages (two 9-min intervals).

Table 4. Least square means (± SE) of differences between the last 20 min in the light and the last 20 min in the dark within a 4-h period of heat production (H), activity-free heat production (H_{acf}), activity-related heat production (H_{ac}) and Respiratory Quotient (RQ) using a model with selection lines (S1, selected on high growth rate; S2, selected on low feed:gain ratio), lighting regimens (LR, 0.5 to 1.5 h of light in each 4-h period) and feed restriction (F1, feed trough closed in the dark; F2, feeding trough open in the dark) as main factors.

Source of variation		H ($kJ \cdot kg^{-1} \cdot d^{-1}$)	H_{acf} ($kJ \cdot kg^{-1} \cdot d^{-1}$)	H_{ac} ($kJ \cdot kg^{-1} \cdot d^{-1}$)	RQ (CO_2/O_2)
Line:	S1	201 ± 10^B	113 ± 9^A	88 ± 9^B	0.04 ± 0.01^a
	S2	305 ± 10^A	80 ± 9^B	224 ± 9^A	0.02 ± 0.01^b
LR:	0.5L:3.5D	253 ± 16	53 ± 14^B	200 ± 14^A	0.00 ± 0.01
	0.67L:3.33D	282 ± 16	106 ± 14^A	176 ± 14^{AB}	0.01 ± 0.01
	1L:3D	255 ± 11	129 ± 10^A	126 ± 10^C	0.04 ± 0.01
	1.33L:2.67D	240 ± 24	90 ± 22^A	150 ± 22^{CB}	0.05 ± 0.02
	1.5L:2.5D	234 ± 16	104 ± 14^A	129 ± 14^C	0.04 ± 0.01
feed:	F1	312 ± 12^A	151 ± 11^A	161 ± 11	0.07 ± 0.01^A
	F2	193 ± 9^B	42 ± 8^B	151 ± 8	-0.01 ± 0.01^B
interaction:	S1 × F1		187 ± 15^a		
	S1 × F2	n.s.	48 ± 11^b	n.s.	n.s.
	S2 × F1		114 ± 15^c		
	S2 × F2		36 ± 11^d		
MS model	(df = 6)	132681	70869	123298	0.039
MS error	(df = 126)	5817	4456	4638	0.004
R^2		0.52	0.47	0.56	0.34

A,B,C: values of classes within the same factor with different superscripts differ significantly (P < 0.01).
a,b,c,d: values of classes within the same factor with different superscripts differ significantly (P < 0.05).
SE: Standard error; MS: Mean Squares; df: degrees of freedom; R^2: coefficient of determination; n.s.: not significant.

values: 732, 683, 49 $kJ \cdot kg^{-1} \cdot d^{-1}$ and 1.02, for the S1 and S2 lines, respectively). At the end of the L-periods, H of S1 and S2 chickens was 924 and 1031 $kJ \cdot kg^{-1} \cdot d^{-1}$, respectively, and H_{ac} was 138 and 264 $kJ \cdot kg^{-1} \cdot d^{-1}$, respectively; however, with respect to H_{acf} and RQ the differences were in the opposite direction. Thus, the H_{acf} and RQ of S1 chickens decreased significantly more between the L- to D-periods than those of S2 chickens.

Lighting regimen affected the difference in H_{acf} and in H_{ac} ($P < 0.01$) between the L- and D-periods. At 0.5L:3.5D, the difference in H_{acf} was smallest ($P < 0.01$) due to high value at the end of the D-period (718 $kJ \cdot kg^{-1} \cdot d^{-1}$). In the same LR, the difference in H_{ac} was highest due to high activity at the end of the L-period (247 $kJ \cdot kg^{-1} \cdot d^{-1}$). At 1L:3D, 1.33L:2.67D and 1.5L:2.5D, the difference in H_{ac} was lowest due to low activity at the end of the L-period (mean value: 181 $kJ \cdot kg^{-1} \cdot d^{-1}$).

Feed restriction in D-periods (F1) compared with open troughs (F2) caused ($P < 0.01$) differences in H and H_{acf} between L- and D-periods due to lower values at the end of D-periods (F1: 667 and 623, F2: 797 and 742 $kJ \cdot kg^{-1} \cdot d^{-1}$). In both

F1 and F2, the difference between L- and D-periods for H_{acf} was dependent on line. Feed restriction had a greater effect on this difference in H_{acf} for the S1 line. At F1, RQ decreased from L- to D-periods with 0.07 on average, from 1.05 to 0.98. At F2, an increase in RQ, from 1.06 (L) to 1.07 (D), was found.

Discussion

Results on body weight, gain and feed:gain ratio of S2 chickens were similar to those obtained in the original selection experiment (Leenstra, 1987, 1988); however, the body weights of S1 chickens at d 43 were high in comparison to the data of Leenstra (1987) (2374 vs. 2193 g). Also, the feed:gain ratio of the S1 chickens was lower in the present experiment than those of Leenstra (1987, 1988). Average gain of all the animals was similar to that of the remaining animals at the end of the experiment for both S1 and S2, which means that there was no effect of randomly taking out the animals.

Earlier experiments showed 1L:3D to be superior to 23L:1D with respect to broiler performance, which was ascribed partly to reduced activity (Ketelaars et al., 1986). In our experiment, activity-related heat production was affected by lighting regimen. In longer L-periods the chickens were more active (Table 3). However, this result was not the case within a L-period itself, because activity as measured at the end of a L-period became lower as the length of the L-period increased. Therefore, within a L-period, animals became less active after the initial increased activity when the lights were switched on; however, the birds continued to be more active than those placed in the dark after a short L-period (Figure 3).

Average daily H_{acf} did not differ between selection lines. Chickens from the line selected on low feed:gain ratio spent more energy on activity than the S1 chickens. Activity-related heat production of the S1 chickens, as measured in the present experiment, was similar to the value of 84 $kJ \cdot kg^{-1} \cdot d^{-1}$ reported by Wenk & van Es (1976) for ad libitum-fed chickens. It might be that selection for low feed:gain ratio results indirectly in excessive feeding behaviour, which results then in high activity-related heat production, because feed:gain ratio will be lower at higher levels of feed intake relative to maintenance.

Activity-related H during D-periods with open or with closed feed troughs were similar. It is possible that the broilers were adapted to eating in the dark (Cherry & Barwick, 1962) and, in their attempt to find feed when the trough was closed, remained similarly active as with open trough. Cherry & Barwick (1962) reported that birds on a restricted light regimen maintained intake similar to those illuminated continuously. Wenk & van Es (1976) found that activity-related energy costs, in terms of metabolizable energy (ME), increased from 15-20 % of maintenance at ad libitum (ME_m = 505 $kJ \cdot kg^{0.75} \cdot d^{-1}$ to 30 % of ME_m when broilers were given 75 % of voluntary intake. However, these authors applied a continuous restriction, while in our experiment the birds were only restricted in their feed intake in two out of six D-periods within 24 h. In starving birds, metabolic rate decreases rapidly after the light is turned off and increases rapidly after the light is switched on again (van Kampen, 1987). In the present experiment, H, H_{acf}, H_{ac} and RQ remained lower in a L-period following a D-period with closed compared to open troughs (differences: 43, 21, 22 $kJ \cdot kg^{-1} \cdot d^{-1}$ and 0.04, respectively).

Also, an effect of LR existed ($P < 0.01$) on differences in H and RQ in L-periods following D-periods with open compared to closed trough (H, 0.5L versus mean of 0.67+1+1.5L = 132 versus 40 $kJ \cdot kg^{-1} \cdot d^{-1}$; RQ, 0.12 versus 0.03; LR 1.33L:2.67D omitted due to missing values). Thus, at 0.5L:3.5D with closed troughs in the dark, birds did not have enough time to feed during the following L-period, because at the end of this L-period H and RQ were much lower than without feed restriction.

In each LR, H, H_{acf} and RQ decreased more in D-periods with closed compared to open troughs, while H_{ac} was similar. The subsequent increase in metabolic rate during the L-periods also depended on whether the feed trough in the previous D-period was open or closed. When closed, a L-period of 30 min is apparently too short for feed consumption and attaining normal metabolic rate. When open, differences between L- and D-period were much smaller. Because in practice feed troughs remain open in the dark, the length of L-periods may not be as crucial as thought, at least if there is enough feeding and drinking trough length available.

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