Effect of day length on cause of mortality, leg health, and ocular health in broilers

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ABSTRACT An experiment was conducted to study the effect of day length, sex, and genotype (Ross × Ross 308 and 708) on mortality causes, bird mobility, footpad health, and ocular size, with 4 trials within the experiment. Four graded day lengths were chosen to allow the study of relationship between day length and health parameters, including 14L:10D, 17L:7D, 20L:4D, and 23L:1D. The primary statistical tools used to assess the day length relationships were regression analysis (Proc Reg and RSReg of SAS). Data were also analyzed as a 4 (lighting program) × 2 (sex) × 2 (genotype) factorial arrangement. Total mortality, as well as mortality due to metabolic and skeletal disease, decreased linearly with increasing inclusion of darkness (7- to 32-, 7- to 38-, and 7- to 48-d periods). Infectious disorders were quadratically related to day length (7- to 48-d period only), with birds under 20L having the highest level. Day length was linearly or quadratically related to average gait score in a positive fashion, and the incidence of birds falling in painful gait score categories increased linearly with increasing day length. Average footpad lesion scores increased with increasing day length (28 and 35 d). The 23L photoperiod resulted in heavier eye weights than other lighting programs. Males had a higher mortality and morbidity rate and a higher average gait score than females. Average footpad score was lower for males than females (28 and 35 d). Overall mortality was higher for 308 than 708 broilers; hence, levels of specific mortality causes were higher. Average gait scores were lower for 308 than 708 birds in 2 of the 3 time periods measured and footpad lesions were higher. To conclude, many aspects of broiler health improve with decreasing day length.

Key words: day length, mortality, gait score, footpad, welfare

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INTRODUCTION

There are many indicators of welfare in agricultural animals, but one of the most obvious is health. Therefore, a clear understanding of the impact of management practices such as lighting programs on bird health is an important aspect of welfare assessment. Photoperiod length or its reciprocal scotoperiod length have previously been shown to affect the incidence of broiler mortality and culling, with increasing broiler exposure to darkness reducing the incidence (Shah and Petersen, 2001; Abbas et al., 2008; Lewis et al., 2009, 2010). Although this effect on mortality has been predominant, the effect has not been consistent with some studies not finding a day length effect (Ingram et al., 2000; Lewis and Gous, 2007). If an effect of lighting program on mortality is shown, the incidence of growth-associated causes such as sudden death syndrome (Manser, 1996; Brickett et al., 2007; Lewis et al., 2010), ascites (Lott et al., 1996), and skeletal disorders (Riddell and Classen, 1992; Renden et al., 1996; Knowles et al., 2008) are often most affected. Evidence of an impact of lighting program on infectious disease is also suggested by positive effects of darkness and melatonin on immune function (Abbas et al., 2008), but the actual impact on infectious-caused mortality is not well defined.

Other indicators of health are bird mobility, foot pad lesions, and ocular characteristics. It has been demonstrated that adding darkness to a lighting program can improve walking ability in broiler flocks (Robbins et al., 1984; Classen and Riddell, 1989; Classen et al., 1991; Sanotra et al., 2002) and this corresponds well with the impact on mortality and culling due to skeletal disease noted above. The effect on foot pad lesions has not been commonly monitored in lighting research, but the limited data on this topic suggest that increasing darkness increases foot pad lesions, presumably because of increased contact of the foot pad with litter during the

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scotophase (Sørensen et al., 1999; Ferrante et al., 2006). An increase in eye size has been associated with long day lengths (Lewis and Gous, 2009) and the most probable explanation is the reduction or elimination in the circadian rhythm of eye growth (Li and Howland, 2003; Lewis and Gous, 2009).

The reasons for the reduced mortality and improved bird mobility associated with shorter day lengths have not been precisely defined, but several mechanisms have been proposed. The introduction of darkness in a broiler flock has been shown to reduce growth rate at least temporarily and this is thought to reduce the growth-associated diseases mentioned above. The reduction in growth that is most effective in improving health is during the early life of broilers (Robinson et al., 1992). This is supported by research showing that broilers given shorter day lengths (14 and 17 h) grew more slowly to 31 d of age then those given 23 h of light, but were equal or heavier at later ages while having significantly less overall death loss (Schwean-Lardner et al., 2012b). Another potential benefit of darkness is the change in bird metabolism that occurs during the dark period and the consequential rejuvenation of tissue (Lewis and Perry, 1986; Classen and Riddell, 1989; Classen and Riddell, 1990; Brickett et al., 2007). Increased exercise that is associated with darkness addition may also positively influence skeletal health (Reiter and Bessei, 2009; Schwean-Lardner et al., 2012a). Recently, research has demonstrated that despite being mostly inactive during the scotophase, birds raised on lighting programs with 14 and 17 h day lengths were more active over the 24 h day/night than those birds given 23 h of day length (Schwean-Lardner et al., 2012a). The latter authors also suggested that the quality and quantity of sleep could be a contributing factor in production, behavior, and health responses seen in birds given near-constant light. This hypothesis is based on finding that broilers given near-constant light were lethargic, had reduced behavioral expression, and did not demonstrate synchronized flock rhythms in behavioral activity and melatonin output (Schwean-Lardner et al., 2010) found in birds exposed to longer dark periods.

Although research has been conducted on the comparison of specific lighting programs to constant or near-constant light, little research has studied cause of broiler mortality and other health criteria in response to varying day length. Therefore, the objective of this work was to examine the impact of graded levels of day length (14, 17, 20, and 23 h) on these criteria. Use of these graded levels of day length allows the health criteria to be examined in a dose-response format. Aspects of this work have been published previously, including production (Schwean-Lardner et al., 2012b) and behavioral (Schwean-Lardner et al., 2012a) responses. This paper presents the cause of mortality and culls, gait score, foot pad health, and eye size data from this research.

MATERIALS AND METHODS

Permission has been granted for all experimental work by the University of Saskatchewan Animal Care Committee, with all procedures following the recommendations of the Canadian Council on Animal Care (1993) as listed in the Guide to the Care and Use of Experimental Animals.

One experiment, which included 4 trial repetitions (trials), was conducted to study the impact of day length, bird sex, and genotype on health parameters of broilers. Specific details of the experiment, including housing and management of birds, are included in Schwean-Lardner et al. (2012b).

Lighting programs were initiated at 7 d of age. Prior to this time, birds were housed under 23L:1D with a light intensity of 20 lx. Experimental lighting programs were 14L:10D, 17L:7D, 20L:4D, and 23L:1D, with light provided by incandescent bulbs at an intensity of 10 lx. Darkness was provided in one section per day. Lighting programs remained in place until the end of the time period under study [31 or 32 d of age (d 32), 38 or 39 d of age (d 38), or 48 of age (d 48); Table 1].

In each of 4 trials included in the experiment, a total of 8 rooms were randomly allocated to 1 of the 4 lighting programs described above, allowing 2 room replications per lighting program per trial, and 8 room replications for the entire experiment. Within each of the rooms, genotypes (Ross × Ross 308 and Ross × Ross 708) and bird sexes were housed in small replicate pens.

Table 1. Experimental details

Trial	No. of birds	Market age (d)	Lighting treatment[1] replications (room)	Genotype × sex replications within each room	Age at data collection (d): Gait score[2]	Foot pad dermatitis[3]	Eye size[4]
1	5,040	31, 38	2	3	35	35	—
2	4,464	32, 39, 48	2	3	35, 45	35, 45	—
3	3,712	31, 38	2	2	—	—	31
4	2,912	31, 38, 48	2	2	28, 45	28, 45	46
Total	16,128						

[1]Day length: 14, 17, 20, and 23 h.

[2]Garner et al. (2002): 10 birds per replicate pen for each measurement.

[3]Ekstrand et al. (1998): 10 birds per replicate pen for each measurement.

[4]Number of birds examined: 5 birds per genotype × sex × room (160 total/age).

Removable penning within each of the rooms allowed 12 individual pens per room (2.3 × 2.0 m). Within trials 1 and 2, 12 pens were used, allowing for 3 replications of sex × genotype within each room. Within trials 3 and 4, only 8 pens were used, providing 2 replicate pens per sex × genotype. The remaining 4 pens were not used in the production research for trials 3 and 4. Because room was the experimental unit for lighting program, a total of 8 replications (4 trials with 2 rooms per lighting program per trial) were included.

Wheat straw was used as bedding and was placed within the pens to a depth of approximately 7.5 to 10 cm. Trials 1 and 2 were performed in a clean litter environment, where the barn was emptied of previous litter, washed, and a disinfectant was used before new straw was placed. Trial 3 was performed with chicks being placed on the litter from the previous trial (second flock on litter or reused 1 time), whereas trial 4 included litter reused 2 times (third flock on litter).

Data Collection

Mortality and Culls. Dead and cull birds were recorded to assess the impact of day length, sex, and genotype (308 and 708) on cause of morbidity and mortality. Birds were monitored by barn staff twice per day, and birds that appeared ill (physical or behavioral symptoms) were culled. Although the decision for culling an ill bird was subjective, the primary reasons for culling were inability to move and loss of BW. Birds were killed by cervical dislocation by trained staff members. All mortality and culled birds were necropsied for cause of death or morbidity by an independent laboratory (Prairie Diagnostics Services, Western College of Veterinary Medicine, University of Saskatchewan). The data were then categorized into 1 of 5 groupings based on etiology. These were grouped according to ages, based on the market age of the flock. These included 7 d to 31 or 32 d of age (32 d; 4 trials providing 8 replicate rooms per lighting treatment, 7 d to 38 or 39 d of age (38 d; 4 trials providing 8 replicate rooms per lighting treatment, or 7 to 48 d of age (48 d; 2 trials providing 4 replicate rooms per lighting treatment). The categories included infectious disorders (arthritis, polyserositis, peritonitis, osteomyelitis), metabolic disorders (sudden death syndrome, ascites), skeletal disorders (valgus-varus, tibial dyschondroplasia, rotated tibia, spondylolisthesis), unknown causes, and a final other category, in which individual numbers were minor (pendulous crop, twisted gastrointestinal tract, accidental deaths).

Gait Score. Bird mobility was assessed subjectively by the same 2 observers using the technique published by Garner et al. (2002). Data were collected in trial 1 at 35 d of age, trial 2 at 35 and 45 d, and trial 4 at 28 and 45 d. For all data collection times, 10 birds per replication pen (genotype × sex replication) were gait scored. Details on replication are given in Table 1. Each time, individual birds were randomly selected, separated from their pen-mates, walked down a straw-covered pathway, and scored by 2 gait score (**GS**) testers. Once a consensus was reached by the GS testers, the score was recorded. The technique consists of a 6-point system, where 0 represents no abnormality in gait, and 5 represents a complete loss of mobility. The data were expressed as an average GS, and as a percentage of birds falling within each category. Based on work by Danbury et al. (2000), in which it was determined that pain was felt in the upper GS categories of 3 and over, the percentages falling in these categories were combined.

Footpad Dermatitis. The same birds tested for GS were also examined for footpad dermatitis using the technique of Ekstrand et al. (1998). The footpad of the left foot was examined. A score of 0 represents a healthy footpad with no demarcation, whereas a score of 2 represents a severe lesion. The data were expressed as an average footpad score and as a percentage of birds falling within each score category.

Eye Size. Eye weight was obtained from a sample of birds within trial 3 (31 d) and 4 (46 d). Ten birds per lighting program × sex × genotype at each collection were weighed and then killed via cervical dislocation. The eyes were removed, adhering tissue was trimmed, and the 2 eyes were then weighed. The data were expressed as a total weight (g) and as a percentage of live weight.

Statistical Analyses

Statistics were performed using rooms as replicate units for lighting programs, and pens within rooms for genotype and sex analysis. Details on data collection and number of replications are listed in Table 1. All percentage data were transformed to (log + 1) before analysis. As graded levels of light were chosen specifically to study relationships between the variables measured and day length, the primary statistical technique used was regression analysis [PROC REG (regression) and PROC RSREG (response surface regression) of SAS (SAS Institute Inc., Cary, NC]. For GS and foot pad lesion data, each age was tested independently because these data were not measured in all trials. Differences were considered significant when the probability of difference was less than or equal to 0.05.

Main effects of day length, sex and genotype, as well as interactions between sex, genotype and lighting, were analyzed using PROC GLM (General Linear Model) of SAS (SAS 9.1) as a 2 × 2 factorial nested within 4 lighting programs. When specific data were measured at the same age in more than one trial, trial was also used as a trial within the model.

RESULTS

Causes of Mortality and Morbidity

Day length had significant linear or quadratic (depending on age) effects on many of the causes of mortality and morbidity (Table 2). Over the 7- to 32-d period, a positive linear relationship with day length was noted for total mortality ($P = 0.0006$), and for metabolic ($P = 0.0084$) and skeletal ($P = 0.0238$) classifications. Extending the grow-out period (7 to 38 d) resulted in a similar positive linear response for total mortality ($P = 0.0026$) as well as metabolic ($P = 0.0002$), skeletal ($P = 0.0041$), and other ($P = 0.0089$) etiology. When the growth period is extended even further (7 to 48 d), day length affected all etiologies with the exception of the other category. Total mortality ($P = 0.0008$) and metabolic ($P = 0.0242$) and skeletal ($P = 0.0065$) categories were once again influenced in a linear fashion, with the highest mortality found in flocks exposed to the longest day length. Quadratic responses were noted for infectious mortality (highest level occurring in flocks raised with 20L, $P = 0.0315$) and for unknown causes ($P = 0.0020$), where the highest level was found with the use of a 14L lighting program, followed by 23L, suggesting the relationship was not strong or predictive.

GS

Gait scoring was used to assess bird mobility. The summarized data are shown in Table 3, and a strong similarity was noted at all ages. The percentage of birds falling in 0 category follow either a linear (28 d, $P = 0.0001$; 45 d, $P = 0.0002$) or quadratic (35 d, $P = 0.0030$) trend with the highest percentage of birds with no noted abnormality (scoring 0) found under shorter day lengths. Relationships were also linear or quadratic in the 1, 2, and 3 categories with the exception of 45-d birds in category 1, with the highest percentage occurring under long day lengths. The percent of birds falling into the upper GS categories of 3+4+5 were affected in a linear (28 d, $P = 0.0301$; 35 d, $P = 0.0001$; 45 d, $P = 0.0005$) fashion regardless of the age, with the poorest mobility noted under 23L. Average GS was also affected with either linear (28 and 45 d, $P = 0.0001$) or quadratic (35 d, $P = 0.0009$) relationships.

Footpad Lesion Scores

The percentage of birds falling in the footpad lesion scores of 0, 1, 2, and the average score are shown in Table 4. When measured at 28 d ($P = 0.0374$) and 35 d ($P = 0.0409$) of age, the average footpad score increased linearly with day length, At 35 d, a linear relationship was noted in the percentage of birds with no footpad lesions (score 0), with birds raised under the 14L lighting program having the highest percentage of 0-scored birds ($P = 0.0494$). No relationship was noted at 45 d.

Ocular Weight

The relationship between eye weight and day length is shown in Table 5. At 31 ($P = 0.0001$) and 46 d ($P = 0.0033$), eye weight increased in a quadratic fashion with day length. Closer examination of the data indicates that values are similar under 14, 17, and 20L,

Table 2. Effect of day length on cause of mortality and culls (% of birds placed) from light program initiation to 32, 38, and 48 d of age

	Day length (h of light per d)						
Item	14	17	20	23	SEM[1]	P-value[2]	Equation
7 to 32 d of age							
Total	2.30	2.34	3.10	3.59	0.143	0.0006	$Y = -0.06395 + (0.15672x)$
Metabolic[3]	1.23	1.20	1.82	1.73	0.106	0.0084	$Y = 0.15630 + (0.072507x)$
Skeletal[4]	0.38	0.25	0.50	0.71	0.060	0.0238	$Y = 0.35240 + (0.10970x)$
Infectious[5]	0.48	0.59	0.62	0.63	0.066	NS	—
Unknown cause	0.14	0.23	0.08	0.39	0.035	NS	—
Other[6]	0.07	0.07	0.08	0.13	0.024	NS	—
7 to 38 d of age							
Total	3.03	2.97	3.98	5.04	0.218	0.0026	$Y = -0.59077 + (0.23493x)$
Metabolic[3]	1.42	1.35	2.00	2.36	0.148	0.0002	$Y = -0.35999 + (0.11591x)$
Skeletal[4]	0.77	0.40	0.86	1.11	0.105	0.0041	$Y = -0.12492 + (0.04914x)$
Infectious[5]	0.67	0.83	0.91	0.87	0.097	NS	—
Unknown cause	0.09	0.35	0.12	0.58	0.052	NS	—
Other[6]	0.07	0.04	0.09	0.12	0.029	0.0089	$Y = -0.03708 + 0.00646x$
7 to 48 d of age							
Total	3.64	3.88	7.13	6.56	0.424	0.0008	$Y = -0.35913 + 0.13082x$
Metabolic[3]	1.91	1.54	2.96	2.99	0.286	0.0242	$Y = -0.33000 + 0.07116x$
Skeletal[4]	0.36	0.73	1.71	1.48	0.196	0.0065	$Y = -0.68623 + 0.06353x$
Infectious[5]	0.65	1.44	2.01	1.30	0.185	0.0315	$Y = -13.96811 + 1.62228x - 0.04157x^2$
Unknown cause	0.63	0	0.18	0.54	0.081	0.0020	$Y = -9.46728 - 1.01641x + 0.02737x^2$
Other[6]	0.09	0.17	0.27	0.26	0.069	NS	—

[1]Values listed for lighting program means and for SEM and regression equation calculation based on actual data.

[2]Values for the P (probability of regression) based on log-transformed values.

[3]Metabolic disease: sudden death syndrome, ascites.

[4]Skeletal: valgus-varus, tibial dyschondroplasia, rotated tibia, spondylolisthesis.

[5]Infectious: arthritis, polyserositis, peritonitis, osteomyelitis.

[6]Other: pendulous crop, twisted gastrointestinal tract, accidental death.

Table 3. The effect of day length on the mean gait score, percentage of birds falling in gait score categories (as described by Garner et al., 2002), and the total of categories 3+4+5

Item	Day length (h of light per day)				Pooled SEM[1]	P-value[2]	Equation
	14	17	20	23			
28 d of age							
0	47.78	32.81	23.44	15.63	2.156	0.0001	Y = 95.18229 – 3.52803x
1	42.84	55.47	63.28	60.04	2.381	0.0044	Y = 18.77232 + 1.98041x
2	9.38	9.38	10.94	19.64	1.538	0.0174	Y = −7.62649 + 1.07887x
3	0	2.34	1.56	2.34	0.653	0.0207	Y = −4.03646 + 0.26042x
4	0	0	0.78	2.34	0.381	NS	—
5	0	0	0	0	0	NS	—
3+4+5	0.000	2.34	2.34	4.69	0.730	0.0301	Y = −6.32813 + 0.46875x
Mean	0.62	0.81	0.93	1.16	0.041	0.0001	Y = −0.19501 + 0.05805x
35 d of age							
0	72.81	70.00	67.50	45.33	1.836	0.0030	$Y = -2.822476 + 0.784522x - 0.024727x^2$
1	25.94	27.81	27.50	44.67	1.742	0.0214	$Y = 6.328488 - 0.636578x + 0.019520x^2$
2	1.25	1.56	2.50	5.67	0.457	0.0005	Y = −5.92116 + 0.46773x
3	0	0.63	2.50	3.67	0.386	0.0002	Y = −6.23775 + 0.42892x
4	0	0	0	0.67	0.112	NS	—
5	0	0	0	0	0	NS	—
3+4+5	0	0.63	2.50	4.33	0.413	0.0001	Y = −7.28350 + 0.11611x
Mean	0.28	0.33	0.40	0.70	0.023	0.0009	$Y = 1.940695 - 0.215711x + 0.007007x^2$
45 d of age							
0	28.82	22.05	10.40	11.51	1.945	0.0002	Y = 57.47576 – 2.12599x
1	49.77	49.28	50.64	40.76	1.835	NS	—
2	16.75	19.42	30.25	31.47	2.221	0.0051	Y = −9.48638 + 1.83725x
3	2.81	7.20	7.87	15.13	1.006	0.0001	Y = −14.91306 + 1.25090x
4	0.46	1.60	0.40	0.67	0.356	NS	—
5	1.39	0.46	0.44	0.46	0.273	NS	—
3+4+5	4.66	9.26	8.72	16.26	1.117	0.0005	Y = −11.35435 + 1.13791x
Mean	1.00	1.18	1.39	1.54	0.047	0.0001	Y = 0.16304 + 0.06033x

[1]Values listed for lighting program means and for SEM and regression equation calculation based on actual data.

[2]Values for the P (probability of regression) and R^2 values based on log-transformed values.

but that eye weight in birds raised with a 23L lighting program were significantly heavier.

Sex and Genotype

Differences in the causes of mortality were affected by sex and genotype (Table 6). Regardless of the period examined, males were more susceptible to death from metabolic and skeletal diseases and had higher mortality overall than females. Females in the 7- to 32-d and 7- to 48-d periods had a higher level of mortality from diseases included in the other category than males. Overall mortality and mortality due to infection for all age groups were higher for the 308 than the 708 genotype. The proportion of birds classified as unknown (7 to 32 d, 7 to 38 d), other (7 to 32 d), and metabolic (7 to 48 d) mortality were also higher for the 308 genotype. Only one interaction between strain

Table 4. The effect of day length on the percentage of birds falling in footpad lesion score categories of 0, 1, or 2 (as described by Ekstrand et al., 1998)

Item	Day length (h of light per day)				Pooled SEM[1]	P-value[2]	Equation
	14	17	20	23			
28 d of age							
0	75.26	70.31	62.50	60.60	3.020	NS	—
1	21.70	23.44	32.03	30.69	2.630	NS	—
2	3.04	6.25	5.47	8.71	1.042	NS	—
Mean	0.28	0.36	0.43	0.48	0.036	0.0374	Y = −0.03420 + 0.02267x
35 d of age							
0	52.50	50.94	40.94	44.67	1.924	0.0494	Y = 68.173 – 1.13256x
1	47.50	48.13	58.44	54.33	1.880	NS	—
2	0	0.94	0.63	1.00	0.245	NS	—
Mean	0.48	0.50	0.60	0.56	0.020	0.0409	Y = 0.30806 + 0.01222x
45 d of age							
0	64.41	64.55	62.22	65.02	2.789	NS	—
1	22.74	19.20	19.35	18.49	1.843	NS	—
2	12.85	16.25	18.43	16.49	1.956	NS	—
Mean	0.48	0.52	0.56	0.51	0.045	NS	—

[1]Values listed for lighting program means and for SEM and regression equation calculation based on actual data.

[2]Values for the P (probability of regression) and R^2 values based on log-transformed values.

Table 5. The effect of day length on the percentage of ocular weight compared with live weight

Age	Day length (h of light per day) 14	17	20	23	Pooled SEM[1]	P-value[2]	Equation
31 d of age							
Ocular weight (g)	4.02^{B}	3.87^{B}	3.99^{B}	4.66^{A}	0.048	0.0001	$Y = -0.775x + 0.023x^2 + 10.423$
% of live weight	0.20^{B}	0.19^{B}	0.19^{B}	0.23^{A}	0.002	0.0001	$Y = -0.042x + 0.001x^2 = 0.535$
46 d of age							
Ocular weight (g)	4.80	4.85	4.77	5.39	0.050	0.0033	$Y = 0.253x + 0.315x^2 + 4.777$
% of live weight	0.154	0.159	0.157	0.178	0.002	0.0039	$Y = -0.016x + 0.0005x^2 + 0.278$

[A,B]Means with common letters do not differ significantly ($P < 0.05$).

[1]For percentage of live data, values listed for lighting program means and for SEM and regression equation calculation based on actual data.

[2]Values for the P (probability of regression) and R^2 values based on log-transformed values for percentage data only.

and sex was noted, and only in one period (7- to 48-d period), where more male 708 broilers died from diseases in the other category causes than their male 308 counterpart (0.99 versus 0%). The reverse was seen for females (708, 0.09%; 308, 0.59%). The incidence in all cases was less than 1%, so this may have been a chance occurrence rather than a true effect.

Sex resulted in differences in mobility with females being more mobile than males (Table 7). Mobility was affected by genotype sporadically, but differences were not found for all ages (Table 7).

Only few interactions were noted between day length and other main effects. At 28 d of age, the percentage of birds falling into category 4 and those into 3+4+5 demonstrated a light × sex interaction (Table 7), but similar interactions were not found at other ages. Similarly, day length resulted in increasing numbers of males in the 3+4+5 category (0, 1.56, 4.69, and 9.38% for 14, 17, 20, and 23L), whereas little impact was seen in the females (0, 3.13, 0, and 0% for 14, 17, 20, and 23L). At 35 d, genotypes reacted differently to lighting programs. In both cases, the significance results from a difference in magnitude only rather than a change in ranking. The frequency of birds falling in GS 2 was higher under long day lengths, but more so in the 708 birds (308: 1.88, 1.88, 1.88, and 3.33% for 14, 17, 20, and 23L; 708: 0.63, 1.25, 3.13, and 8.00% for 14, 17, 20, and 23L). Again higher percentages falling in the 3+4+5 category were noted in the long day length groups, but in this case, a higher level was found for the 308 (0, 0.63, 3.75, and 7.33% for 14, 17, 20, and 23L) in comparison with the 708 broilers (0, 0.63, 1.25, and

Table 6. Effect of sex and genotype on cause of mortality and culls (% of birds placed) from light program initiation to 32, 38, and 48 d of age

Item	Sex Male	Female	Genotype 308	708	Light × sex	Light × genotype	Sex × genotype	Light × sex × genotype
7 to 32 d								
Metabolic[1]	2.30^{A}	0.70^{B}	1.63	1.36	NS	NS	NS	NS
Skeletal[2]	0.65^{A}	0.27^{B}	0.48	0.44	NS	NS	NS	NS
Infectious[3]	0.56	0.59	0.77^{a}	0.38^{b}	NS	NS	NS	NS
Unknown	0.16	0.26	0.29^{a}	0.13^{b}	NS	NS	NS	NS
Other[4]	0.04^{B}	0.14^{A}	0.15^{a}	0.03^{b}	NS	NS	NS	NS
Total	3.71^{A}	1.96^{B}	3.33^{a}	2.34^{b}	NS	NS	NS	NS
7 to 38 d								
Metabolic	2.82^{A}	0.75^{B}	1.81	1.76	NS	NS	NS	NS
Skeletal	1.07^{A}	0.50^{B}	0.77	0.80	NS	NS	NS	NS
Infectious	1.02^{A}	0.62^{B}	1.00	0.64	NS	NS	NS	NS
Unknown	0.23	0.34	0.39	0.18	NS	NS	NS	NS
Other	0.05	0.12	0.10^{a}	0.07^{b}	NS	NS	NS	NS
Total	5.18^{A}	2.33^{B}	4.06	3.45	NS	NS	NS	NS
7 to 48 d								
Metabolic	3.64^{A}	1.05^{B}	3.14^{a}	1.55^{b}	NS	NS	NS	NS
Skeletal	1.47^{A}	0.67^{B}	1.11	1.03	NS	NS	NS	NS
Infectious	1.43	1.27	2.88^{a}	0.82^{b}	NS	NS	NS	NS
Unknown	0.30	0.38	0.36	0.32	NS	NS	NS	NS
Other	0.05^{B}	0.34^{A}	0.30	0.09	NS	NS	0.0284	NS
Total	6.89^{A}	3.71^{B}	6.80^{a}	3.81^{b}	NS	NS	NS	NS

[A,B]Means within sex with common letters do not differ significantly ($P < 0.05$).

[a,b]Means within genotype with common letters do not differ significantly ($P < 0.05$).

[1]Metabolic disease: sudden death syndrome, ascites.

[2]Skeletal: valgus-varus, tibial dyschondroplasia, rotated tibia, spondylolisthesis.

[3]Infectious: arthritis, polyserositis, peritonitis, osteomyelitis.

[4]Other: pendulous crop, twisted gastrointestinal tract, accidental death.

Table 7. Effect of sex and genotype on birds falling in gait score categories of 0, 1, 2, 3, 4, and 5 and the combination of 3, 4, and 5

	Sex		Genotype					
Item	Male	Female	308	708	Light × sex	Light × genotype	Sex × genotype	Light × sex × genotype
% in category: 28 d								
0	25.00^{B}	34.83^{A}	33.48	26.35	NS	NS	NS	NS
1	55.08	55.74	55.97	54.85	NS	NS	NS	NS
2	16.02^{A}	8.65^{B}	9.77	14.90	NS	NS	NS	NS
3	2.34	0.78	0^{b}	3.13^{a}	NS	NS	NS	NS
4	1.56^{A}	0^{B}	0.78	0.78	0.0438	NS	NS	NS
5	0	0	0	0	NS	NS	NS	NS
3+4+5	3.91^{A}	0.78^{B}	0.78^{b}	3.91^{a}	0.0094	NS	NS	NS
Mean	1.00^{A}	0.75^{B}	0.79^{b}	0.97^{a}	NS	NS	NS	NS
% in category: 35 d								
0	60.31^{B}	68.23^{A}	62.86	65.56	NS	NS	NS	NS
1	33.75	28.71	32.06	30.48	NS	NS	NS	NS
2	3.59^{A}	1.77^{B}	2.22	3.17	NS	0.0362	NS	NS
3	2.03	1.29	2.54^{a}	0.79^{b}	NS	NS	NS	NS
4	0.31	0	0	0	NS	NS	NS	NS
5	0	0	0	0	NS	NS	NS	NS
3+4+5	2.34	1.29	2.86^{a}	0.79^{b}	NS	0.0150	NS	NS
Mean	0.48^{A}	0.36^{B}	0.45^{a}	0.39^{b}	NS	NS	NS	NS
% in category: 45 d								
0	12.89^{A}	23.44^{B}	19.84	16.35	NS	NS	NS	NS
1	47.30	47.99	48.94	46.32	NS	NS	NS	NS
2	26.32	22.71	21.54^{b}	27.59^{a}	NS	NS	NS	NS
3	11.60^{A}	4.83^{B}	7.89	8.61	NS	NS	NS	NS
4	0.99	0.57	0.89	0.67	NS	NS	NS	NS
5	0.91	0.46	0.91	0.46	NS	NS	NS	NS
3+4+5	13.49^{A}	5.87^{B}	9.68	9.74	NS	NS	NS	NS
Mean	1.43^{A}	1.12^{B}	1.24	1.32	NS	NS	0.0159	NS

^{A,B}Means within sex with common letters do not differ significantly ($P < 0.05$).

^{a,b}Means within genotype with common letters do not differ significantly ($P < 0.05$).

1.33% for 14, 17, 20, and 23L, respectively). Finally at 42 d, the average GS indicated that the sexes reacted differently within genotypes. The percentage of birds falling in the GS categories of 3+4+5 was higher for male 708 than for male 308 broilers (12.83 and 14.19% for 308 and 708, respectively), but in the females the ranking was opposite (6.41 and 5.30% for 308 and 708, respectively).

The effect of sex and genotype on the incidence of foot pad lesions is shown in Table 8. At 28 and 35 d of age, males had a lower mean score than did females, indicating less severe lesions. Although the trend was similar at 45 d, no significance was noted. Genotype differences were noted at all ages, with higher values for 308 than 708 broilers. At 28 d of age, an interaction was noted between sex and day length. The percentage of male birds falling into the most severe footpad lesion score of 2 increased in a linear fashion with day length (1.56, 3.13, 6.25, and 12.50% for 14, 17, 20, and 23L, respectively). Females did not show a consistent effect due to lighting program, and the highest percentage was found under 17L (4.52, 9.38, 4.69, and 4.92% for 14, 17, 20, and 23L, respectively).

Males had heavier eyes than females at both ages, but when corrected for BW there was no effect (Table 9). Percentage eye weight was higher for 708 than 308 birds, but absolute weights did not differ. A significant interaction between day length and genotype was noted for the 31-d proportional data. The data show that eye weight is similar for the 2 genotypes under 14L, 17L, and 20L, but that the 708 birds had heavier eyes under 23L (308: 0.20, 0.18, 0.18, and 0.21 for 14, 17, 20, and 23L, respectively; 708: 0.20, 0.20, 0.20, and 0.25% for 14, 17, 20, and 23L, respectively). An interaction was also found for light × genotype in absolute eye weight at 46 d of age, but a lack of clear trend in the data suggest that this is due to chance variation.

DISCUSSION

Poor health is likely the most obvious signal of reduced welfare (Dawkins et al., 2004). Although there have been many studies in the past comparing the impact of lighting programs on health status in broiler flocks, few have attempted to understand how much darkness is required to maximize health in a flock. Two such works were conducted by Gordon (1997) and Lewis et al. (2009). Gordon (1997) discussed the relationship between mortality and day length, but neither materials and methods nor actual data were included in the literature review, and therefore critical review is not possible. The report included a comparison of birds exposed to 8, 12, 16, or 20 h of light, and birds responded to liveability in a curvilinear manner, with long dark periods having the lowest mortality. Lewis et al. (2009), using 1 lighting treatment room replication (200 broilers per genotype per room), compared a range of day lengths including 2, 4, 6, 8, 10 (in trial 1 only), 12, 15, 18, 21, and 24 h in each of 2 trials. The results indicated that mortality increased with photoperiod

Table 8. Effect of sex and genotype on birds falling in footpad score categories of 0, 1, and 2

	Sex		Genotype					
Item	Male	Female	308	708	Light × sex	Light × genotype	Sex × genotype	Light × sex × genotype
% in category: 28 d								
0	72.66^{A}	61.68^{B}	55.86^{b}	78.48^{a}	NS	NS	NS	NS
1	21.48^{B}	32.45^{A}	34.77^{a}	19.17^{b}	NS	NS	NS	NS
2	5.86	5.87	9.38^{a}	2.36^{b}	0.0008	NS	NS	NS
Mean	0.33^{B}	0.44^{A}	0.54^{a}	0.24^{b}	NS	NS	NS	NS
% in category: 35 d								
0	53.13^{A}	41.29^{B}	42.38^{b}	52.22^{a}	NS	NS	NS	NS
1	58.55^{A}	45.78^{B}	56.83^{a}	47.30^{b}	NS	NS	NS	NS
2	1.09^{A}	0.16^{B}	0.79	0.48	NS	NS	NS	NS
Mean	0.48^{B}	0.59^{A}	0.58^{a}	0.48^{b}	NS	NS	NS	NS
% in category: 45 d								
0	68.71	59.19	55.50^{b}	72.80^{a}	NS	NS	NS	NS
1	17.21	22.75	22.45	17.34	NS	NS	NS	NS
2	14.08	18.06	22.04^{a}	9.85^{b}	NS	NS	NS	NS
Mean	0.45	0.59	0.66^{a}	0.37^{b}	NS	NS	NS	NS

[A,B]Means within sex with common letters do not differ significantly ($P < 0.05$).

[a,b]Means within genotype with common letters do not differ significantly ($P < 0.05$).

length above 12 h, but no differences were found below 12 h of light per day. Relatively small bird numbers per group and low replication may have made differences difficult to find in measurements that typically have high variability between replicates.

It is apparent from the current study that day length does have an important impact on the health parameters measured, which in turn alters broiler welfare. The use of graded day length treatments and appropriate replication in this work adds definition to the interpretation of these responses. In this work, the provision of darkness to broiler chickens improved overall liveability in a linear fashion. The largest impact was on incidence of metabolic disease [acute (sudden death syndrome) and chronic (ascites) heart failure with the former of predominant importance] and on skeletal health, which is in agreement with previous research (Robbins et al., 1984; Classen and Riddell, 1989; Classen et al., 1991). Day length also affected incidence of infectious disease in older birds, and this may relate to the beneficial effects of darkness on immune function (Kliger et al., 2000). Because of the low incidence of mortality falling in the unknown or other category, it is not possible to determine if day length has an impact.

Day length affected broiler mobility, with ability to move decreasing with increasing day length. A reduced ability to move as defined by GS can indicate a pathological or physiological condition that, depending on severity, can be a welfare concern. Danbury et al. (2000) fed analgesics to lame broilers in an attempt to determine if lameness caused pain, and found that birds in the GS categories of 3 or higher were in pain, and therefore a welfare concern. Regardless of the age measured, a positive linear relationship existed between day length and the percentage of birds in categories above 2. These results substantiate previous research, which has indicated that shorter day length (increased darkness) reduces the incidence of leg weakness (Classen and Riddell, 1989; Sanotra et al., 2002). This finding is in close agreement with the response of observed mortality due to skeletal disease to changing day length. The similarity of these trends suggests that GS techniques, despite their subjective nature, accurately define leg weakness in broilers.

Rapid broiler growth rate associated with long day lengths is often implicated as the cause of increased mortality, particularly with regards to metabolic and skeletal disease. Data from the present research show that growth rate is not the only factor involved. Birds raised on 20L:4D were the heaviest at 32 d of age (Schwean-Lardner et al., 2012b), yet mortality was higher and mobility poorer in birds raised under 23L:1D. This in-

Table 9. Effect of sex and genotype on the percentage of ocular weight compared with live weight

	Sex		Genotype					
Item	Male	Female	308	708	Light × sex	Light × genotype	Sex × genotype	Light × sex × genotype
31 d of age								
Ocular weight (g)	4.42^{A}	3.85^{B}	4.13	4.14	NS	NS	NS	NS
% of live weight	0.20	0.20	0.19^{b}	0.21^{a}	NS	0.0322	NS	NS
46 d of age								
Ocular weight (g)	5.36^{A}	4.54^{B}	4.96	4.94	NS	0.0001	NS	NS
% of live weight	0.16	0.16	0.16^{b}	0.17^{a}	NS	NS	NS	NS

[A,B]Means within sex with common letters do not differ significantly ($P < 0.05$).

[a,b]Means within genotype with common letters do not differ significantly ($P < 0.05$).

dicates that lack of darkness itself affects these health-associated factors rather than absolute growth rate always dictating the incidence levels and reducing welfare. At older ages, when birds appeared to better adapt to longer dark periods, market BW of birds exposed to 7 or even 10 h of darkness were as heavy or heavier than those of birds raised under 23L:1D, but again mortality rates were higher and bird mobility poorer under near-continuous light. These data support the concept that the timing of the rapid growth is important, with less detrimental impacts if rapid growth occurs later in life after a strong skeletal foundation has been established during early life. The shifts in broiler growth patterns associated with day length were described previously (Schwean-Lardner et al., 2012b).

Exercise is often cited as a reason why shorter day length and longer dark periods affect the incidence of broiler leg weakness and associated mortality. Data from an associated study (Schwean-Lardner et al., 2012a) used scan sampling techniques every 10 min over a 24-h period to accurately define behavioral differences associated with graded hour of day length. Exposure to darkness increased bird exercise (walking and standing) linearly when measured at 27 to 28 d, with little activity occurring under near-constant light. As birds aged, long day lengths still resulted in a reduction in bird exercise, but a quadratic relationship determined that behavior of birds under 7 and 10 h of darkness was similar. In all cases, 20 h of light produced intermediate results. Other behaviors followed similar trends, including time at the feeder, preening, dustbathing, and stretching.

In this work, the response pattern of mortality rates and incidence of leg weaknesses are similar to that seen in behavior, with mortality due to skeletal disease and percentage of birds falling in GS categories of 3+4+5 increasing linearly with day length over all time periods. Common trends observed support an exercise-based mechanism for improved health in broilers given increased darkness exposure. However, it is not clear how much exercise is required to reduce leg weakness, and an increase in total activity (exercise) over a 24-h period of time with shorter day length does not prove a cause-and-effect relationship. It is known that exercise can improve bone health (Goktepe et al., 2008), but research on the impact of exercise on mortality and leg weakness in poultry has been conflicting. As an example, Balog et al. (1997) used ramps, toys, or both to increase exercise in 2 separate trials. Cumulative mortality was reduced by ramps leading to feeders in their second trial, but no impact was found in the first trial. In apparent contradiction, bone-breaking strength was increased in birds with ramps in trial 1 but not in trial 2, further demonstrating the inconsistency in results. Because skeletal health has a multifactorial basis, it is probable that exercise is only one of several factors capable of improving health and reducing leg weakness as a result of darkness exposure in broiler chickens.

Near-constant light caused birds to have heavier eyes than was found in birds raised with any other lighting program. The eye grows in a circadian fashion in response to fluctuation in melatonin production, with growth during the light period, and cessation during the dark (Rada and Wiechmann, 2006). When exposed to long periods of day length, this rhythm is disturbed and consequently results in heavier and distorted eyes (Li et al., 1995). Our results are in agreement with research with turkey poults where exposure to both 24L:0D or 23L:1D resulted in heavier eyes than did exposure to photoperiods that included substantial dark periods. An accumulation of fluid in the eye results in the heavier weights, and could possibly increase intraocular pressure (Smith et al., 1969). Long-term changes in eye weight can lead to thickening of the cornea, damage to the retina and other components of the eye, and cataract development (Li et al., 1995). The potential for reduced vision and pain from increased ocular pressure would reduce bird welfare. A lack of a melatonin rhythm when birds are exposed to near-continuous light (Schwean-Lardner et al., 2010) supports the potential for increased eye weight of birds not given darkness exposure because of the disruption of eye growth rhythms. Our finding that birds given 4, 7, or 10 h darkness had identical eye weights suggests that as little as 4 h of darkness is enough to trigger the circadian eye growth pattern.

Footpad dermatitis is a skin lesion that occurs on the bottom of the foot. These lesions can result in bird discomfort and pain (Bradshaw et al., 2002) and are a welfare consideration. Research has shown that lighting programs have an inconsistent impact on the development of these lesions. Petek et al. (2010) compared birds on intermittent light with those on continuous light, and found no differences. Sørensen et al. (1999) compared birds raised on 8 to 16 h of light in one trial, and 16 to 21 h of light in another trial, and found footpad lesions to be less severe on long photoperiods when corrected for BW. In contrast, a linear increase in average lesion severity was seen with increasing day lengths in the current research.

Footpad dermatitis is affected by a variety of management factors, and light may only play a small role. Activity, for example, may improve litter quality as a result of more frequent turn-over, which in turn, reduces lesions (Kristensen et al., 2004). There may also be less continuous contact of skin with litter when activity levels are higher, again resulting in a reduction in lesion severity. Although activity levels were not reported in the other research mentioned, another segment of this work (Schwean-Lardner et al., 2012a) did show a linear decline in activity with increasing daylight. Studies in rats suggest that skin integrity, specifically thickness, is affected by melatonin production (Eşrefoğlu et al., 2005). If this is the case in poultry, litter irritation would cause more severe burns in thin-skinned birds compared with those with thicker skin as a result of increased melatonin secretion. To the authors' knowledge, this association has not been made in poultry. Schwean-Lardner et al. (2010) showed that the expected pattern of melatonin production is eliminated by long day lengths. Therefore, it could be that a combination of litter quality and skin integrity effects due to day length in this work resulted in the noted impact on lesions.

Sleep deprivation (**SD**) can have a large impact on health. For example, SD in rats as a result of repeated awakenings caused a variety of physical problems, including muscular weakness, foot pad lesions, a reduction in brain function, and a wide range of pathological diseases found on necropsy. In some cases, SD led to death (Rechtschaffen et al., 1983). Evidence exists to link melatonin production and SD, and a lack of a melatonin rhythm can suppress sleep (Yamada et al., 1988); hence, the 2 are likely intertwined. Therefore, the impact on sleep and its patterns is a concern when discussing lighting programs (Blokhuis, 1983), particularly in relationship to day and night rhythms. The degree of darkness required to provide adequate sleep is difficult to determine. Results from the present study suggest that birds exposed to 20L are achieving some degree of sleep, but not enough. This is indicated by only intermediate behavioral expression (Schwean-Lardner et al., 2012a), a shorter and weaker melatonin rhythm (Schwean-Lardner et al., 2010), and poorer health for birds exposed to 4 h darkness compared with those with longer dark periods.

Sex

Males had a higher incidence of mortality and were less mobile than females in this study. This is in agreement with previous research and is likely related to the growth-associated higher demands on skeletal (Sørensen et al., 1999) and metabolic systems (Peacock et al., 1990) in males than females. This is supported by an associated study that found that males grew faster and were heavier than females (Schwean-Lardner et al., 2012b). Day length affected the causes of death in both sexes similarly. Males exhibited poorer mobility in general and had a higher percentage of birds falling in upper GS categories at 28 d. Males have stronger skin than females (Kafri et al., 1986), and this could be reflected in less severe average footpad lesions.

Genotype

The 2 genotypes used in this work are quite diverse, with the 308 genotype growing quickly in contrast to the 708, which grows more slowly and has greater breast meat deposition. The faster-growing 308 birds had either significantly or numerically higher mortality levels overall, attributed to metabolic and infectious causes particularly over the 7- to 48-d period. It is important to note that both genotypes responded to the changes in day length in a similar manner. Average GS under the score of 1 for both strains at all time periods indicate good leg health and may be reflective of selection pressures placed on the genotypes by the primary breeder.

In conclusion, day length has a significant impact on many aspects of broiler health. By reducing the day length, the economics of broiler production can be improved, as mobile birds are better able to reach feeders and waterers, more birds are marketed, and condemnations and downgrading are reduced. Day length also affected pain due to leg weakness and liveability, with more darkness reducing the percentage of birds feeling pain. Therefore, the use of lighting programs with significant darkness will improve broiler welfare. Although the welfare implications are not fully understood, larger eye weight in birds raised under near-constant light is a concern. The data in the current study indicate that constant or near-constant lighting programs should not be used for broiler production. Although statistics show a linear nature in the response of the data in this work, it is interesting to note that mortality is similar or even higher under 14L than 17L, and this suggests that an appropriate length of darkness for maximizing broiler welfare based on health parameters alone approximates 7 h per day.

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REFERENCES

Abbas, A. O., A. K. Alm Ed-Dein, A. A. Desoky, and M. A. A. Galal. 2008. The effects of photoperiod programs on broiler chicken performance and immune response. Int. J. Poult. Sci. 7:665–671.

Balog, J. M., G. R. Bayyari, N. C. Rath, W. E. Huff, and N. B. Anthony. 1997. Effect of intermittent activity on broiler production parameters. Poult. Sci. 76:6–12.

Blokhuis, H. J. 1983. Sleep in poultry. World's Poult. Sci. J. 39:33–37.

Bradshaw, R. H., R. D. Kirkden, and D. M. Broom. 2002. A review of the aetiology and pathology of leg weakness in broilers in relation to welfare. Avian Poult. Biol. Rev. 13:45–103.

Brickett, K. E., J. P. Dahiya, H. L. Classen, C. B. Annett, and S. Gomis. 2007. The impact of nutrient density, feed form, and photoperiod on the walking ability and skeletal quality of broiler chickens. Poult. Sci. 86:2117–2125.

Canadian Council on Animal Care. 1993. Guide to the care and use of experimental animals. Vol. 1. 2nd ed. E. D. Olfert, B. M. Cross, and A. A. McWilliam, ed. Canadian Council on Animal Care. Ottawa, ON, Canada.

Classen, H. L., and C. Riddell. 1989. Photoperiod effects on performance and leg abnormalities in broiler chickens. Poult. Sci. 68:873–879.

Classen, H. L., and C. Riddell. 1990. Early growth rate and lighting effects on broiler skeletal disease. Poult. Sci. 69(Suppl. 1):35.

Classen, H. L., C. Riddell, and F. E. Robinson. 1991. Effect of increasing photoperiod length on performance and health of broiler chickens. Br. Poult. Sci. 32:21–29.

Danbury, T. C., C. A. Weeks, J. P. Chambers, A. E. Waterman-Pearson, and S. C. Kestin. 2000. Self-selection of the analgesic drug carprofen by lame broiler chickens. Vet. Rec. 146:307–311.

Dawkins, M. S., C. A. Donnelly, and T. A. Jones. 2004. Chicken welfare is influenced more by housing conditions than by stocking density. Nature 427:342–344.

Ekstrand, C., T. E. Carpenter, I. Andersson, and B. Algers. 1998. Prevalence and control of foot-pad dermatitis in broilers in Sweden. Br. Poult. Sci. 39:318–324.

Eşrefoğlu, M., M. Seyhan, M. Gül, H. Parlakpinar, K. Batçioğlu, and B. Uyumlu. 2005. Potent therapeutic effect of melatonin on aging skin in pinealectomized rats. J. Pineal Res. 39:231–237.

Ferrante, V., S. Lolli, S. Marelli, G. Vezzoli, F. Sirri, and L. G. Cavalchini. 2006. Effect of light programmes, bird densities and litter types on broilers welfare. XII European Poultry Conference, Verona, Italy.

Garner, J. P., C. Falcone, P. Wakenell, M. Martin, and J. A. Mench. 2002. Reliability and validity of a modified gait scoring system and its use in assessing tibial dyschondroplasia in broilers. Br. Poult. Sci. 43:355–363.

Goktepe, A. S., I. Tugcu, B. Yilmaz, R. Alaca, and S. Gunduz. 2008. Does standing protect bone density in patients with chronic spinal cord injury? J. Spinal Cord Med. 31:197–201.

Gordon, S. H. 1997. Effect of light programmes on broiler mortality with reference to ascites. World's Poult. Sci. J. 53:68–70.

Ingram, D. R., L. F. Hatten III, and B. N. McPherson. 2000. Effects of light restriction on broiler performance and specific body structure measurements. J. Appl. Poult. Res. 9:501–502.

Kafri, I., B. S. Jortner, and J. A. Cherry. 1986. Skin breaking strength in broilers: Relationship with skin thickness. Poult. Sci. 65:971–978.

Kliger, C. A., A. E. Gehad, R. M. Julet, W. B. Roush, H. S. Lillehoj, and M. M. Mashaly. 2000. Effects of photoperiod and melatonin on lymphocyte activities in male broiler chickens. Poult. Sci. 79:18–25.

Knowles, T. G., S. C. Kestin, S. M. Haslam, S. N. Brown, L. E. Green, A. Butterworth, S. J. Pope, D. Pfeiffer, and C. J. Nicol. 2008. Leg disorders in broiler chickens: Prevalence, risk factors and prevention. PLoS ONE 2:e1545. http://www.plosone.org/article/info%3Adoi%2F10.1371%2Fjournal.pone.0001545.

Kristensen, H. H., J. M. Aerts, T. Leroy, D. Berckmans, and C. M. Wathes. 2004. Using light to control activity in broiler chickens. Br. Poult. Sci. 45:S30–S31. (Abstr.)

Lewis, P. D., R. Danisman, and R. M. Gous. 2009. Photoperiodic responses of broilers. 1. Growth, feeding behaviour, breast meat yield and testicular growth. Br. Poult. Sci. 50:657–666.

Lewis, P. D., R. Danisman, and R. M. Gous. 2010. Welfare-compliant lighting regimens for broilers. Arch. Gerflügelk. 74:265–268.

Lewis, P. D., and R. M. Gous. 2007. Broilers perform better on short or step-up photoperiods. S. Afr. J. Anim. Sci. 37:90–96.

Lewis, P. D., and R. M. Gous. 2009. Photoperiodic responses of broilers. II. Ocular development. Br. Poult. Sci. 50:667–672.

Lewis, P. D., and G. C. Perry. 1986. Effects of interrupted lighting regimes on the feeding activity of the laying fowl. Poult. Sci. 27:661–669.

Li, T., and H. C. Howland. 2003. The effects of constant and diurnal illumination of the pineal gland and the eyes on ocular growth in chicks. Invest. Ophthalmol. Vis. Sci. 44:3692–3697.

Li, T., D. Troilo, A. Glasser, and H. C. Howland. 1995. Constant light produces severe corneal flattening and hyperopia in chickens. Vision Res. 35:1203–1209.

Lott, B. D., S. L. Branton, and J. D. May. 1996. The effect of photoperiod and nutrition on ascites incidence in broilers. Avian Dis. 40:788–791.

Manser, C. E. 1996. Effects of lighting on the welfare of domestic poultry. A review. Anim. Welf. 5:341–360.

Peacock, A. J., C. K. Picket, K. M. Morris, and J. T. Reeves. 1990. Spontaneous hypoxemia and right ventricular hypertrophy in fast growing broiler chickens reared at sea level. Comp. Biochem. Physiol. 97A:537–541.

Petek, M., R. Cibik, H. Yildiz, F. Ak Sonat, S. Sule, G. Abdülkadir Orman, and C. Aydin. 2010. The influence of different lighting programs, stocking densities and litter amounts on the welfare and productivity traits of a commercial broiler line. Vet. Med. Zoot. 51:36–43.

Rada, J. A., and A. F. Wiechmann. 2006. Melatonin receptors in chick ocular tissues: Implications for a role of melatonin in ocular growth regulation. Invest. Ophthalmol. Vis. Sci. 47:25–33.

Rechtschaffen, A., M. A. Gilliland, B. M. Bergmann, and J. B. Winter. 1983. Physiological correlates of prolonged sleep deprivation in rats. Science 221:182–184.

Reiter, K., and W. Bessei. 2009. Effect of locomotor activity on leg disorder in fattening chicken. Berl. Munch. Tierarztl. Wochenschr. 122:264–270.

Renden, J. A., E. T. Moran Jr., and S. A. Kincaid. 1996. Lighting programs for broilers that reduce leg problems without loss of performance or yield. Poult. Sci. 75:1345–1350.

Riddell, C., and H. L. Classen. 1992. Effects of increasing photoperiod length and anticoccidials on performance and health of roaster chickens. Avian Dis. 36:491–498.

Robbins, K. R., A. A. Adekunmisi, and H. V. Shirley. 1984. The effect of light regime on growth and pattern of body fat accretion of broiler chickens. Growth 48:269–277.

Robinson, F. E., H. L. Classen, J. A. Hanson, and D. K. Onderka. 1992. Growth performance, feed efficiency and the incidence of skeletal and metabolic disease in full-fed and feed restricted broiler and roaster chickens. J. Appl. Poult. Res. 1:33–41.

Sanotra, G. S., J. Damkjer, and K. S. Vestergaard. 2002. Influence of light-dark schedules and stocking density on behaviour, risk of leg problems and occurrence of chronic fear in broilers. Br. Poult. Sci. 43:344–354.

Schwean-Lardner, K., B. I. Fancher, and H. L. Classen. 2010. Effect of daylength on physiological and behavioural rhythms in broilers. Poult. Sci. 89(Suppl. 1):521.

Schwean-Lardner, K., B. I. Fancher, and H. L. Classen. 2012a. Impact of daylength on behavioural output in commercial broilers. AABS 137:43–52.

Schwean-Lardner, K., B. I. Fancher, and H. L. Classen. 2012b. Impact of daylength on the productivity of two commercial broiler strains. Br. Poult. Sci. 53:7–18.

Shah, S. B. A., and J. Petersen. 2001. Influence of variable lengths of darkness in the lighting programme on development of performance traits in broilers. Arch. Gerflügelk. 65:82–87.

Smith, M. E., B. Becker, and S. Podos. 1969. Light-induced angle-closure glaucoma in the domestic fowl. Invest. Ophthalmol. Vis. Sci. 8:213–221.

Sørensen, P., G. Su, and S. C. Kestin. 1999. The effect of photoperiod:scotoperiod on leg weakness in broiler chickens. Poult. Sci. 78:336–342.

Yamada, H., I. Oshima, K. Sato, and S. Ebihara. 1988. Loss of the circadian rhythms of locomotor activity, food intake and plasma melatonin concentration induced by constant bright light in the pigeon (*Columba livia*). J. Comp. Physiol. A Neuroethol. Sens. Neural Behav. Physiol. 163:459–463.