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Effect of photoperiod length and light intensity on some welfare criteria, carcass, and meat quality characteristics in broilers

Evrim Dereli Fidan[1*], Ahmet Nazlıgül[1], Mehmet Kenan Türkyılmaz[1], Serap Ünübol Aypak[2], Figen Sevil Kilimci[3], Solmaz Karaarslan[1], Mehmet Kaya[1]

[1] Adnan Menderes University, Faculty of Veterinary Medicine, Department of Animal Science, Aydin, Turkey.
[2] Adnan Menderes University, Faculty of Veterinary Medicine, Department of Biochemistry, Aydin, Turkey.
[3] Adnan Menderes University, Faculty of Veterinary Medicine, Department of Anatomy, Aydin, Turkey.

ABSTRACT - The objective of this study was to investigate the effects of photoperiod length and light intensity on leg and eye health, tonic immobility, some blood parameters, carcass, and meat quality characteristics in broilers. A total of 272 one-day-old male broiler chicks (Ross 308) were randomly assigned to four treatment groups based on the photoperiod length (23L:1D or increasing duration of light) and light intensity (20 lux vs. dim light) with four replicates. In this study, photoperiod lenght had no effect on incidence of foot pad and hock burn. On the other hand, the effect of photoperiod lenght had significant influence on the gait score. The incidences of gait score (3 + 4 + 5) in bright and dim light groups was found as 21.4 and 41.0% in broilers, respectively. In addition, the effect of light intensity had statistical significance on gait score. The tonic immobility duration in 20 lux and dim light groups were 271.53 and 226.78 s, respectively, and tonic immobility duration was unaffected by light intensity. All the blood parameters, except for triglyceride, were not affected by light intensity. The dim light had a negative effect on broiler welfare as demonstrated by increased eye weight and dimensions. Cold carcass yield and whole breast and wing yields were lower in the dim light group than in 20 lux light intensity. The broilers kept with dim light had lower breast meat ultimate pH (6.19) and L* values (54.30) than those reared with 20 lux. These findings have a lot of implications on the use of increasing photoperiod and bright light to improve leg an eye health benefits for the broiler welfare in broilers.

Key Words: carcass quality, corticosterone, eye and leg health, lighting

Introduction

Light duration and intensity play an important part in the regulation and control of production, reproduction, behavior, and welfare of poultry (Deep et al., 2010; Schwean-Lardner et al., 2013). In modern poultry production systems, continuous or near-continuous lighting programs have found common use in increasing the live weight gain and growth rate. However, the many skeletal, respiratory disorder, and cardiovascular system problems in broilers, turkeys, and ducks have been related to rapid gain in body weight, particularly during the early growing period in broilers (Velleman, 2000), and therefore more frequent in male broilers. Also, a study indicated that continuous lighting programs might result in inadequate sleep and, as a result of sleep deprivation, physiological stress responses increased (Campo and Davila, 2002). The effect of light intensity on health and welfare is less studied in broilers. Deep et al. (2010) reported that dim light (<10 lux) has been shown to negatively affect broiler production and welfare as indicated by a reduced carcass and tender yield, increased incidence of skeletal disorders, foot and leg health, and eye defects. Amid these conflicting results, EU (2007) has established guidelines on behalf of poultry welfare on light intensities and amounts and durations of darkness that must be provided to broilers daily. On this contex, the use of photoperiods longer than 20 h and intensities less than 21.52 lux were restricted. EU (2007) restricts the use of low intensities, which are still commonly used in many countries. In addition, recent studies have focused on limited lighting programs (such as increasing photoperiod), as an alternative to the continuous lighting program, to provide welfare of the broiler.

The response to stress is generally estimated by blood variables such as corticosterone, glucose, triglyceride, cholesterol, total protein, lactate dehydrogenase, and

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***Corresponding author:** derelievrim@hotmail.com
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aspartate aminotransferase levels (Bedanova et al. 2007; Onbasilar et al. 2007), and broiler welfare has been assessed from leg and eye health, tonic immobility, and carcass characteristics (Onbasilar et al. 2007). It has been reported that the hypothalamic-pituitary-adrenocortical axis is activated by stress and increases plasma corticosterone concentration in poultry (Jones et al., 1988). Tonic immobility reaction has been widely described as a reliable predictor of the level of fearfulness in birds (Jones, 1986). Meat quality of poultry is potentially affected by photoperiod length (Coban et al., 2014).

The objective of this study was to evaluate the effects of photoperiod length and light intensity on tonic immobility, foot pad dermatitis, hock burn, gait score, some blood parameters (corticosterone, glucose, triglyceride, cholesterol, total protein, and lactate dehydrogenase and aspartate aminotransferase levels), carcass parts yields, meat quality traits (breast meat pH_{15}, pH_{24}, color, cooking loss, and water holding capacity), and eye dimensions.

Material and Methods

Two hundred seventy two day-old male ROSS 308 broiler chicks were obtained from a commercial hatchery. One-day-old birds were wing-banded, initially weighed individually so that the pens had similar initial weight and weight distribution, and randomly assigned to four experimental groups, with four replicates of 17 chicks each. From the first day, chicks were housed in floor pens with clean pine shavings-based litter at approximately 8 cm deep. Each pen was supplied with hanging feeders and nipple drinkers to ensure *ad libitum* access to feed and water throughout the study. Birds were fed a starter diet from 1 to 21 d of age (3060 kcal metabolizable energy (ME)/kg, 23% crude protein) and a grower diet from 22 to 42 days of age (3200 kcal ME/kg, 21.5% crude protein). Two 40-W incandescent bulbs, controlled by a rheostat and automatic timer, were used for lighting. The lights were attached at 1.90 m above the floor. Light intensity was monitored at chick-head level using a digital illuminometer (Datalogging light meter, Extech HD 450, Extech Instruments, USA) thrice weekly**.** Walls and ceilings in the rooms were painted white color to ensure light intensity was permanent. The ambient barn temperature was maintained at 33±1 °C for the first three days and then gradually reduced by 2-3 °C per week to final temperature of 23±1 °C. Birds were hold the relative humidity of 50-60% in rooms.

This study was approved by Animal Experiments Local Ethic Council (case no.: 64583101/2013/088). A 2 × 2 experimental design was used with two categories of photoperiod length and light intensity experimental groups, for which there were four replicates for each photoperiod-light intensity combination. Photoperiod length groups were either near-continuous photoperiod length (CPL) (23L:1D from 1 to 42 d) or increasing photoperiod length group (IPL) (23L:1D from 1 to 8 d, 14L:10D from 9 to 15 d, 16L:18D from 16 to 22 d, 18L:6D from 23 to 29 d, 20L:4D from 30 to 36 d, followed by 23L:1D from 37 to 42 d). It should be noted that 23L was applied for the last 6 days before slaughter in the increasing photoperiod group because of recent EU guidelines (EU, 2007). Light intensity groups were either bright light (BLI) or dim light (DLI). Broilers in the bright light group were exposed to 20 lux from 1 to 42 d while those in dim light group were exposed to 5 lux from d 1 to 8, 2.5 lux from 9 to 15, and 1.25 lux from d 16 to 42.

At 41 days of age, seven broilers from each pen (28 birds per group), a total of 112 broilers, were randomly selected for foot pad dermatitis and hock burn, and gait score. The foot pad dermatitis was assigned to 1 of 3 scores: 0 = foot pads with no visible lesions, 1 = foot pads with mild superficial lesions, 2 = foot pads with severe ulcerative lesions (Ekstrand et al., 1998). Hock burn mild superficial lesions (score 1) were judged to not be a trouble or disorder and they were combined with category 0 (not affected). The ulcerative lesions (score 2) were assigned as a painful condition (Kjaer et al., 2006). Right and left feet were scored separately because different feet often displayed lesions of different severity for foot pad dermatitis and hock burn. Categories were later averaged to attain one score per bird for statistical analysis. Gait score was determined by using the 0-to-5 scale (0: excellent gait and 5: deficiency stand) (Garner et al., 2002). Fear level in poultry is simply measured by tonic immobility test (Benoff and Siegel, 1976). On day 41, five broilers from each pen (20 birds per group), a total of 80 broilers, were randomly selected for tonic immobility measurements. On day 42, blood samples from a total of 160 birds that were randomly selected, 40 birds per group (10 birds for each replication), were used for blood parameters. Blood samples were taken from the *vena basilica* of broilers in each photoperiod length and light intensity group. The blood serum was separated and stored at −20 °C for later analyses. Selected serum biochemical parameters were measured by an autoanalyzer (Ray Chemray 120) using commercial test kits (Archer Diagnostic Ind. Ltd.). The corticosterone concentration was determined using an ELISA kit (catalog no. ADI-900-097; Enzo Life Sciences).

Eight broilers from each pen, a total of 128 broilers, were slaughtered to determine some carcass and meat

quality characteristics at the age of 42 days after 12 h of feed withdrawal. Slaughtering was conducted by cutting the jugular veins and carotid arteries. The hot carcasses were stored at 4 ºC during 24 h. Cold carcass yields were expressed as percentage of slaughter weight. The carcasses were deboned to obtain skinless, boneless breast fillets (*pectoralis major muscles*), breast tenders (*pectoralis minor muscles*), whole breast meat, wings, legs, and abdominal fat pads. The yield of carcass parts was expressed as a percentage of cold carcass weight. Breast muscles were used to assign meat quality traits.

The breast meat pH was measured 15 min postmortem (initial pH, pH_{15}) and 24 h post slaughter (ultimate pH, pH_u) using a digital pH meter (Hanna Instrument HI 9124) equipped with a penetration electrode (Hanna FC-200). Muscle color was measured on the cranial portion on left breast muscle 24 h after slaughter. Color measurement was performed using a Minolta CR 400 chroma-meter (Konica Minolta Sensing, Inc., Osaka, Japan) in the CIELAB color space using a D65 illuminant. Values of L^*, a^*, and b^* indicate lightness, redness, and yellowness, respectively. Cooking loss was determined in meat samples placed inside polyethylene bags in a water bath. Samples were heated until an internal temperature of 75 °C and cooled for 15 min under running tap water. They were out of the bags, dried with filter paper, and weighed. Cooking loss was expressed as the percentage of loss related to the initial weight (Honikel, 1998). Water holding capacity was evaluated 24 h after slaughter, using the methodology described by Barton-Gade et al. (1993). The post-mortem samples were collected from the cranial side of the breast fillets and were cut into 5-g cubes. The samples were first carefully placed between two filter papers and then left under a 2250-g weight for 5 min. The samples were weighed and water holding capacity was determined by the exudated water weight through the following formula: 100 – [(initial weight – final weight)/(initial weight)].

The right eye was collected from 40 birds (10 birds for each replication) per group at 42 days of age and eye dimensions (eye weight, corneal diameter, mediolateral diameter, dorsoventral diameter, and anterioposterior size) were noted immediately after extirpation, using a digital caliper (Deep et al., 2010).

Statistical analyses were performed using software package Statistical Package for the Social Sciences for Windows (SPSS) 22.0 (SPSS Inc, Chicago, IL. USA). For all variables tested, normality was checked using a Shapiro-Wilk test (Zar, 1999). The data were subjected to ANOVA using the GLM procedure of SPSS 22.0 package program to test the effects of photoperiod length and light intensity, their interaction on the blood parameters, tonic immobility duration, carcass, and meat quality characteristics. Duncan test was used to determine differences among experimental groups (Duncan, 1955). Foot pad dermatitis score was classified into three scales: scores less than 1 or equal to 0, good; scores less than 2 or equal to 1, fair; and scores equal to 2, poor. Hock burn data were classified into two scales: scores less than or equal to 1, good and scores greater than 1, poor (Ventura et al., 2010). The χ^2 test was used to determine the effect of photoperiod and light intensity groups on foot pad dermatitis, hock burn, and gait score data.

Results

There were no significant differences between photoperiod length groups in terms of foot pad dermatitis rate in broilers ($\chi^2 = 4.353$, df = 2) (P = 0.113), such that scores cataloged as good (96.4%) were more frequent in the CPL group, whereas a higher proportion of poor scores (3.6%) was found in IPL group. Light intensity had statistically no significant effect on foot pad dermatitis ($\chi^2 = 2.157$, df = 2) (P = 0.340). Hock burn lesion scores cataloged as good were more frequent in the IPL group (92.9%), whereas a higher proportion of poor scores was detected in broilers maintained in CPL group (12.5%). However, the proportion of birds non affected by hock burn lesions was associated with photoperiod length treatment ($\chi^2 = 0.907$, P = 0.341) (Table 1). Gait score value was statistically significant between photoperiod groups (P<0.001).

Photoperiod and light intensity had a statistically nonsignificant effect on TI duration (Table 2). Serum triglyceride level was 70.70 and 77.75 mg/dL in broilers reared in bright and dim light groups, respectively (P<0.05).

The preslaughter live weight was found as 2930.00, 2955.61, 2947.14, and 2938.47 g for CPL, IPL, bright light, and dim light groups, respectively. In addition, photoperiod length and light intensity had no significant effects on final live weight. Light intensity significantly affected the yields of cold carcass, whole breast, and whole leg (P<0.05) (Table 3).

The pH_u value of breast meat of broilers in dim light group was lower compared with those in bright light group (P<0.01). The light intensity had a statistically significant effect on pH_{15}, pH_u, and L* values (Table 4).

Eye weight was determined to be lowest (1.98 g) in the IPL group and highest (2.45 g) in the CPL group (Table 5).

Table 1 - Effect of photoperiod length and light intensity on the incidence of foot pad dermatitis and hock burn lesions and gait scores in broilers

Factor	Incidence of foot pad dermitiitis (%)						χ^2	P-value
	n	Good	n	Fair	n	Poor		
Photoperiod length								
CPL	54	96.4	2	3.6	0	0.0	4.353	0.113
IPL	48	82.1	6	14.3	2	3.6		
Light intensity								
Bright light	49	83.9	6	14.3	1	1.8	2.157	0.340
Dim light	53	94.6	2	3.6	1	1.8		

Factor	Incidence of hock burn (%)				χ^2	P-value
	n	Good	n	Poor		
Photoeriod length						
CPL	49	87.5	7	12.5	0.907	0.341
IPL	52	92.9	4	7.1		
Light intensity						
Bright light	48	85.7	8	14.3	2.520	0.112
Dim light	53	94.6	3	5.4		

Factor	Gait score (%)													χ^2	P-value
	n	Score 0	n	Score 1	n	Score 2	n	Score 3	n	Score 4	n	Score 5	n	Score 3+4+5	
Photoperiod length															
CPL	2	3.6	11	19.6	21	37.5	18	32.1	4	7.1	0	0.0	22	39.2	13.404	<0.001
IPL	10	17.9	25	44.6	8	14.3	12	21.4	1	1.8	0	0.0	13	23.2		
Light intensity																
Bright light	9	16.1	21	37.5	14	25.0	11	19.6	1	1.8	0	0.0	12	21.4	7.781	0.005
Dim light	3	5.4	15	26.8	15	26.8	19	33.9	4	7.1	0	0.0	23	41.0		

CPL - near-continuous photoperiod length; IPL - increasing photoperiod length.

Table 2 - Least square means for tonic immobility duration and some blood parameters in treatment groups

Item	Tonic immobility duration	Corticosterone (pg/mL)	Glucose (mg/dL)	Triglyceride (mg/dL)	Cholesterol (mg/dL)	Total protein (mg/dL)	Lactate dehydrogenase (U/L)	Aspartate aminotransferase (U/L)
Photoperiod treatment								
CPL	248.55	2300.33	224.57	75.35	139.13	3.36	918.02	252.89
IPL	249.75	2245.95	236.27	73.11	136.59	3.29	915.34	240.33
Light intensity treatment								
Bright light (BLI)	271.53	2317.68	220.96	70.70a	134.73	3.29	866.38	240.13
Dim light (DLI)	226.78	2228.60	239.87	77.75b	140.99	3.36	966.98	253.09
SEM[1]	20.08	26.76	5.16	1.44	2.10	0.03	30.36	5.87
Photoperiod × light intensity treatment[2]								
CPL-BLI	291.90	2323.91	213.47	71.25	131.28b	3.17b	859.82	239.45
IPL-BLI	251.15	2311.46	228.45	70.15	138.19ab	3.41a	872.94	240.80
CPL-DLI	205.20	2276.75	235.66	79.45	146.98a	3.55a	976.22	266.33
IPL-DLI	248.35	2180.44	244.08	76.06	135.00ab	3.18b	957.74	239.85
SEM[3]	40.15	52.79	9.91	2.87	4.20	0.05	60.69	11.73
Effect	P-value							
Photoperiod	0.976	0.313	0.258	0.436	0.547	0.193	0.965	0.286
Light intensity	0.269	0.100	0.069	0.015	0.138	0.149	0.100	0.271
Photoperiod × light intensity	0.269	0.436	0.751	0.690	0.026	<0.001	0.795	0.238

CPL - near-continuous photoperiod length; IPL - increasing photoperiod length.
Means with different letters in the same column differ (P<0.05).
[1] Pooled standard error of the mean for main effects.
[2] Photoperiod × by light intensity interaction.
[3] Pooled standard error of the mean for interaction effect.

Table 3 - Effect of photoperiod length and light intensity on broiler carcass characteristics[1] (% of live weight)

Item	Live weight (g)	Cold carcass	Whole breast	Fillets	Tenders	Whole leg	Wings	Abdominal fat pad	Breast skin	Remaining carcass
Photoperiod treatment										
CPL	2930.00	76.45	31.81	26.64	5.17	37.53	8.17	1.89	2.67	17.93
IPL	2955.61	76.11	31.27	26.10	5.17	37.80	7.97	2.01	2.74	18.22
Light-intensity treatment										
Bright light (BLI)	2947.14	76.59a	31.96a	26.69	5.26	37.24b	8.11	1.96	2.67	18.07
Dim light (DLI)	2938.47	75.97b	31.13b	26.05	5.08	38.09a	8.04	1.93	2.73	18.08
SEM[2]	25.17	0.15	0.21	0.19	0.05	0.18	0.06	0.05	0.05	0.31
Photoperiod × light-intensity treatment[3]										
CPL-BLI	2966.28	77.29a	32.55	27.32	5.22	36.61b	8.14	1.83	2.69	18.18
IPL-BLI	2928.00	75.90b	31.08	25.96	5.13	37.87ab	8.08	2.10	2.66	17.95
CPL-DLI	2893.72	75.60b	31.37	26.06	5.30	38.44a	8.21	1.95	2.64	17.68
IPL-DLI	2983.22	76.33ab	31.18	26.14	5.04	37.73ab	7.86	1.92	2.82	18.49
SEM[4]	50.13	0.29	0.42	0.38	0.92	0.35	0.11	0.11	0.09	0.61
Effect					P-value					
Photoperiod	0.612	0.255	0.201	0.161	0.987	0.440	0.069	0.261	0.454	0.636
Light intensity	0.863	0.032	0.049	0.094	0.064	0.018	0.498	0.790	0.550	0.974
Photoperiod × light intensity	0.207	<0.001	0.126	0.059	0.374	0.006	0.199	0.140	0.276	0.389

Whole breast - combined yield of right and left pectoralis major and minor; fillet - combined yield of right and left pectoralis major; tender - combined yield of right and left pectoralis minor; whole leg - combined yield of right and left thigh and combined yield of right and left drum; left thigh - left thigh meat, skin, and bone; right thigh - right thigh meat, skin, and bone; left drum - left drum meat, skin, and bone; right drum - right drum meat, skin and bone.
CPL - near-continuous photoperiod length; IPL - increasing photoperiod length.
Means with different letters in the same column differ (P<0.05).
[1] Data presented as the least square means.
[2] Pooled standard error of the mean for main effects.
[3] Photoperiod × by light intensity interaction.
[4] Pooled standard error of the mean for interaction effect.

Table 4 - Least square means for some meat quality traits in broilers

Item	Meat quality trait						
	pH_{15}	pH_u	L*	a*	b*	CL (%)	WHC (%)
Photoperiod treatment							
CPL	6.72	6.22	53.34	1.04	10.94	24.75	8.46
IPL	6.70	6.22	53.57	1.26	10.39	26.06	8.77
Light-intensity treatment							
Bright light (BLI)	6.68b	6.25a	52.61b	1.06	10.92	25.43	8.34
Dim light (DLI)	6.74a	6.19b	54.30a	1.23	10.40	25.38	8.88
SEM[1]	0.02	0.01	0.42	0.07	0.24	0.57	0.24
Photoperiod × light-intensity treatment[2]							
CPL-BLI	6.62b	6.24	51.73	1.14b	10.99	24.38	8.27
IPL-BLI	6.73ab	6.25	53.48	0.99b	10.85	26.47	8.42
CPL-DLI	6.81a	6.19	54.94	0.93b	10.88	25.11	8.65
IPL-DLI	6.66b	6.18	53.66	1.54a	9.92	25.65	9.12
SEM[3]	0.29	0.02	0.83	0.13	0.48	1.12	0.48
Effect				P-value			
Photoperiod	0.459	0.936	0.783	0.091	0.260	0.246	0.525
Light intensity	0.045	0.005	0.046	0.193	0.284	0.969	0.268
Photoperiod × light intensity	<0.001	0.600	0.074	0.005	0.399	0.494	0.752

CPL - near-continuous photoperiod length; IPL - increasing photoperiod length; pH_{15} - initial pH value measured 15 min post mortem; pH_u - pH value measured 24 h post mortem; L*- lightness; a*- redness; b*- yellowness; CL - cooking loss; WHC - water holding capacity.
Means with different letters in the same column differ (P<0.05).
[1] Pooled standard error of the mean for main effects.
[2] Photoperiod × by light intensity interaction.
[3] Pooled standard error of the mean for interaction effect.

Table 5 - Least square means for eye dimensions in treatment groups

Item	Eye weight (g)	Corneal diameter (mm)	Mediolateral diameter (mm)	Dorsoventral diameter (mm)	Anterioposterior size (mm)
Photoperiod treatment					
CPL	2.45a	7.86	18.36a	18.84a	12.22a
IPL	1.98b	7.94	17.60b	17.73b	11.30b
Light intensity treatment					
Bright light (BLI)	2.15b	7.85	17.82b	18.17	11.50b
Dim light (DLI)	2.28a	7.95	18.14a	17.41	12.03a
SEM[1]	0.02	0.04	0.07	0.06	0.06
Photoperiod × light intensity treatment[2]					
CPL-BLI	2.39	7.80	18.35a	18.93a	11.91
IPL-BLI	1.92	7.90	17.28b	17.40c	11.08
CPL-DLI	2.51	7.91	18.36a	18.75a	12.53
IPL-DLI	2.04	7.98	17.91a	18.06b	11.52
SEM[3]	0.04	0.07	0.13	0.13	0.13
Effect			P-value		
Photoperiod	<0.001	0.235	<0.001	<0.001	<0.001
Light intensity	0.003	0.175	0.017	0.056	<0.001
Photoperiod × light intensity	0.952	0.833	0.020	<0.001	0.504

CPL - near-continuous photoperiod length; IPL - increasing photoperiod length.
Means with different letters in the same column differ (P<0.05).
[1] Pooled standard error of the mean for main effects.
[2] Photoperiod × by light intensity interaction.
[3] Pooled standard error of the mean for interaction effect.

Discussion

Research has shown that photoperiod programs have an unstable effect on the development of foot pad dermatitis. Sorensen et al. (1999) reported less severe foot pad dermatitis lesions on extended light duration. However, Sirri et al. (2007) compared broilers on 16L:8D with those on 23L:1D photoperiod and found no differences for this condition. Similarly, it was reported that the near-continuous photoperiod resulted in descreased severity of foot pad dermatitis, while there was no statistical significance among photoperiod groups. Photoperiod length did not have significant effect on hock burn. Accordingly, Sorensen et al. (1999) reported that the photoperiod length has no statistically significant effect on the incidence of hock burn lesions. Foot pad dermatitis has been associated with the prevalence of hock burn lesions. Deep et al. (2010) found an increased incidence of foot pad dermatitis and hock burn lesions with dim light. However, Olanrewaju et al. (2015) found that broilers exposed to the light intensity from 0.5 to 5 and 10 lux have a similar incidence of foot pad dermatitis. In addition, in another study, Sherlock et al. (2010) used 10 or 200 lux light intensities and found that the hock burn lesion was unaffected by light. Likewise, it was determined that light intensity has no effects on the incidence of the both lesions. The genotype and gender of broilers, severity of light intensity, and light intensity in combination with some environmental factors can be responsible for the differences in some studies regarding the effect of light intensity on foot pad dermatitis and hock burn lesions. In this study, it was determined that gait score was observed at a higher rate in the group subjected to CPL. Although a study is available, which suggested that continuous lighting program decreases gait disorders (Sorensen et al., 1999), there are also other studies which are in agreement with this study and indicate that constant lighting increases gait disorders (Sanotra et al., 2001; Schwean-Lardner et al., 2012). It can be said that increased darkness duration reduces the incidence of leg weakness. In this study, dim light is not suitable regarding leg health. Parallel to this study, Blatchford et al. (2012) found that birds kept under bright light had better overall leg health than broilers reared under dim light. Similarly, Newberry et al. (1988) and Ferrante et al. (2006) have shown that increasing broiler activity due to brighter light intensity resulted in a lower occurrence of foot and leg disorders. It can be said that bright light would increase broiler activity and hereby physical exercise, and that the increased exercise would improve leg health. Deep et al. (2010) reported that leg health was unaffected by light intensity. This finding can be derived from the differences in light intensity and light sources used in these studies.

In this study, it was suggested that the increasing lighting treatment involved no changes in fearfulness and did not affect broiler welfare. The tonic immobility duration was similar in the light intensity groups. Parallel to the study, Olanrewaju et al. (2015) reported that the light intensity (0.5, 5, and 10 lux) has no statistically significant effect on tonic immobility duration. Corticosterone

concentration is an important indicator of stress. In this study, photoperiod length had no significant effect on corticosterone concentration. This result confirms the findings of Olanrewaju et al. (2013), in which the serum glucose and corticosterone concentrations were not affected by lighting program. In this study, light intensity had no significant affect, except for triglyceride level, on all blood parameters. Similarly, Olanrewaju et al. (2013) found no influence of light intensity groups on glucose, total protein, and corticosterone concentrations. As a stress parameter, the triglyceride level was increased in the dim light group. Increasing triglyceride levels are described as an indicator of stress condition (Odihambo Mumma et al., 2006). There was an interaction between photoperiod length and light intensity for cholesterol level. The continuous photoperiod length and dim light increased cholesterol level. Therefore, we assume that broilers in continuous photoperiod length and dim light conditions were more stressed than continuous photoperiod length and bright light groups. An interaction effect resulted in the CPL-DLI and IPL-BLI groups having greater total protein level than the other two treatments, which were similar.

The results showed that cold carcass yield and part yields were not significantly affected by photoperiod. Similarly, several authors reported that there were no significant differences in cold carcass yield (Downs et al., 2006; Lien et al., 2007) and whole breast, legs, and wing yields (Downs et al., 2006; Çoban et al., 2014) among photoperiod groups. Also, Downs et al. (2006) observed a decrease in breast yield and increase in leg yield due to increasing photoperiod programs. Parallel to our study, in a study it was reported that the extension of the light period from 18 h to 23 h resulted in statistically greater percentage of whole breast (Lien et al., 2007). The cold carcass yield of broilers reared in bright light was higher (76.59%) than that of the broilers in dim light (75.97%) ($P<0.05$). This result was in agreement with Lien et al. (2007), who reported higher cold carcass yield of broilers of bright light group (10.76 lux) than of broilers exposed to dim light (1.08 lux) ($P<0.05$). In this study, it was determined that bright light resulted in increased cold carcass and whole breast yields. It was thought that the bright light treatment did promote greater growth, as well as greater cold carcass and breast meat yields. Likewise, Downs et al. (2006) and Lien et al. (2007) indicated that there was an increase in breast yield due to bright light in broilers. This study revealed that fillets, tenders, wings, abdominal fat pad, breast skin, and remaining carcass yields were not affected by light intensity. Similarly, Deep et al. (2010) reported broilers exposed to 1, 10, 20, and 40 lux light intensities with no influence on fillets, tenders, abdominal fat pad, and breast skin yields. In this study, the leg yield was increased by the dim light ($P<0.05$). Although whole leg and abdominal fat pad yields were not influenced by light intensity, an increase of leg yield in broilers exposed to low-light intensity has been indicated by other studies (Downs et al., 2006; Lien et al., 2008). An interaction effect resulted in the CPL-BLI treatment having greater cold carcass yield (average + 2.0%) than IPL-BLI and CPL-DLI treatments, which were similar. An interaction among photoperiod length and light intensity was observed for the whole leg yield. However, interaction effects among photoperiods and intensities were not observed in previous reports, which compared near continuous and increasing photoperiods of either 21.52 and 2.7 lux (Downs et al., 2006), or 10.76 and 1.08 lux (Lien et al., 2007).

It was determined that photoperiod has no effect on meat quality traits. The effect of photoperiod on meat quality traits is little studied in broilers. Our results were in agreement with the studies in which the effect of photoperiod on breast meat L* and a* color (Çoban et al., 2014), at 24 h pH_u value (Erdem et al., 2015) was statistically non-significant. Pale, soft, and exudative meat occurs due to postmortem rapid glycolysis associated with a quick pH drop while the carcass is still hot. This relationship between low pH and high temperature causes meat protein denaturation, impairing the functional properties of the protein and giving rise to meat surface exudates (Olivo et al., 2001). The higher pH_u level (6.25) in broilers grown under bright light demonstrated a higher glycogen content in the muscles. That can be explained by a lower influence of stress in those birds during growing time due to a bright light. It has been reported that stress accelerates post mortem metabolism and biochemical changes in the muscle, which produces a lower ultimate pH in broiler meat (Owens and Sams, 2000). Meat color is an important quality factor which determines the preference of the consumer. Qiao et al. (2001) suggested the value of L* higher than 53 to identify paler-than-standard broiler breast meat color (between 48 and 53). It was reported that the highest L* value (54.30) was determined in the dim light group, the lowest L* value (52.61) was found in bright light group ($P<0.05$). Thus, it is concluded that dim light led to rapid postmortem glycolysis with decreased pH values and increased L* value. An interaction effect resulted in the CPL-DLI group having greater pH_{15} value (6.81) than the CPL-BLI (6.62) and IPL-DLI (6.66) groups. In addition, an interaction effect on breast meat a* value resulted in a* value of the IPL-DLI treatment increase of relative to the CPL-BLI, IPL-BLI and CPL-DLI treatments. The eye weight was greater in the

CPL group than in the IPL. Similarly, Ashton et al. (1973) and Olanrewaju et al. (2015) reported that continuous photoperiod increased the weight of eye in birds. Ashton et al. (1973) indicated that 70% of turkey poults reared in 24L:OD light developed eye abnormalities (larger and heavier eyes, loss of corneal convexity, buphthalmos, and in some cases, retinal detachment). According to Morrison et al. (2005), larger eye had a pressure influence on the optic nerve and this pressure could induce nerve damage. It can be said that increased eye weight, and especially eye dimensions along with inflammatory changes, as evidenced in the several studies, may result in a painful condition for broilers kept under a near-continuous light, thus resulting in decreased broiler welfare. The use of dim light caused a change in the weight and dimensions of the eyes of broilers. Parallel to the study, several authors reported that there were significant differences in the anatomical structure of the eyes of birds among light intensity groups (Thompson and Forbes, 1999; Deep et al., 2010). It can be said that these welfare indicators can be positively affected by the 20 lux light intensity used. This positive effect can be attributed to the impairement of the vision of the birds and increase in the animal welfare. An interaction between photoperiod length and light intensity was observed for the eye mediolateral and dorsoventral diameters. This revealed that only the birds at 20 lux light intensity had smaller mediolateral and dorsoventral diameters when increasing photoperiod was provided.

Conclusions

The increasing photoperiod and bright light decreases leg and eye health problems and consequently improves welfare in broilers. Also, the bright light positively affects cold carcass, whole breast meat, and wing yields compared with dim light. The dim light has a detrimental effect on meat quality traits, as attested by reduced pH_u and increased L* values.

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