RESEARCH ARTICLE

J Anim Sci Technol 2022;64(5):985-996
https://doi.org/10.5187/jast.2022.e47

JAST
Journal of Animal Science and Technology
pISSN 2672-0191 eISSN 2055-0391

Effects of light intensity on growth performance, blood components, carcass characteristics, and welfare of broilers

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Check for updates

Received: Apr 25, 2022
Revised: Jun 7, 2022
Accepted: Jun 8, 2022

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Abstract
This study investigated the effects of light intensity on growth performance, blood components, eye condition, and carcass characteristics of broiler chickens. Three hundred and fifty-two 1-day-old male chicks were assigned to one of four treatments (four repetitions per treatment, 22 birds per repetition) and reared in a floor pen for 5 weeks. From the second week, chicks were reared under four different levels of light intensity (5, 20, 35, and 50 lx) and the lighting duration was maintained at 18-hours light : 6-hours dark (18L : 6D). The feed intake and body weight were measured weekly. At 35 days of age, 12 birds per treatment were randomly selected for blood sampling, eye measurement, and carcass analysis. There were no significant differences in body weight gain, feed intake, and feed conversion ratio among treatments. Triglyceride levels in the serum were significantly higher in the 5 lx treatment, and creatinine was significantly lower in the 5 lx treatment ($p < 0.05$). The heterophil : lymphocyte ratios decreased significantly as light intensity increased ($p < 0.05$); however, other blood cell compositions were not affected by light intensity. Interleukin-6 content was significantly higher in the 5 lx treatment than in other treatments ($p < 0.05$), but the content of tumor necrosis factor-α was not significantly different among treatments. Serum corticosterone concentration was significantly higher at 5 lx than at 20, 35, and 50 lx ($p < 0.05$). The corneal diameter was the highest in 5 lx treatment ($p < 0.05$), and tended to increase as the light intensity decreased. Other eye parameters were not significantly different among treatments, but displayed a tendency to increase as the light intensity decreased. Carcass yield and part yields were not affected by light intensity. Meat quality parameters (pH, color, cooking loss, and water-holding capacity) did not show significant difference among the treatments. The results indicate that a light intensity of 5 lx may increase physiological stress or have a negative effect on broiler welfare, even if the performance and carcass characteristics are not affected. Therefore, a light intensity of 20 lx or above is recommended considering both the growth performance and welfare of broilers.

Keywords: Broiler, Light intensity, Performance, Carcass characteristics, Stress, Welfare

Competing interests
No potential conflict of interest relevant to this article was reported.

Funding sources
This work was carried out with the support by "2021 RDA Fellowship Program of National Institute of Animal Science" and "Cooperative Research Program for Agriculture Science & Technology Development (Project No. 014831)", Rural Development Administration, Korea.

Acknowledgements
Not applicable.

Availability of data and material
Upon reasonable request, the datasets of this study can be available from the corresponding author.

Authors' contributions
Conceptualization: Kim HJ, Hong EC.
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Ethics approval and consent to participate
This experiment was approved by the Institutional Animal Care and Use Committee (IACUC) of National Institute of Animal Science, RDA (approval No. 2020-424).

INTRODUCTION

Light is an important environmental factor that affects poultry physiology. Artificial lighting programs are critical for poultry management in environmentally controlled poultry houses [1]. Artificial control of light is called lighting management, and comprises light intensity, photoperiod, and light source management. It has an important effect on the growth of broilers [2]. In particular, light intensity management can have substantial consequences on the performance and welfare of broiler [3,4].

However, most commercial broiler farms where animal welfare certification standards are not applied often lower their light intensity to reduce broiler activity and save energy [2].

Low light intensity (< 10 lx) negatively affects poultry welfare, resulting in skeletal disorders, foot pad dermatitis, and eye defect [1,5]. Furthermore, when low light intensity is maintained in poultry houses, the anatomical structure of the eyes may change, resulting in dry eye, choroiditis, glaucoma, and lens distortion [1]. These symptoms are more severe at a light intensity of 1 lx than at 5 lx [5]. In addition, the expression of exploratory activities and comfortable behavior was reported to be reduced at a low light intensity of 5 lx [6]. Therefore, the Royal Society for the Prevention of Cruelty to Animals (RSPCA) [7] and Animal Welfare Certification Standards of Korea [8] recommend a light intensity of at least 20 lx to allow broilers to easily consume feed and water, in addition to improving their welfare.

Although many studies have been conducted to investigate the effects of light intensity on the performance (body weight, feed intake, and feed conversion ratio [FCR]) and health of broilers [1, 9–11], relatively few studies have comprehensive investigated physiological responses or aspects associated with animal welfare. Therefore, this study was conducted to investigate the effects of light intensity, ranging from 5 to 50 lx, on the growth performance, blood biochemical profile, carcass characteristics, and welfare parameters of broiler chickens.

MATERIALS AND METHODS

The experimental procedure for this study was reviewed and approved by the Institutional Animal Care and Use Committee (IACUC) of the National Institute of Animal Science, Rural Development Administration (Approval No.: 2020-424).

Experimental design, birds, and housing

A total of 352 1-day-old male broiler chicks (Ross 308) were used in a 5-week experiment. During the first 7 days, the chicks were reared under the same lighting condition (30 lx) with a 22-hours light : 2-hours dark (22L:2D) photoperiod. From the second week, chicks (average body weight, 164.8±1.06 g) were assigned to four treatments consisting of four levels (5, 20, 35, and 50 lx) of light intensity. Each treatment room contained four replicate pens (2 × 2 m floor pen with rice hull bedding). At the end of the experiment, the photoperiod was maintained at 18L:6D in accordance with the Animal Welfare Certification Standard of Korea [8]. LED bulbs were used as the light source, and the light intensity was measured regularly using a lux meter placed near the floor level. Other management practices (temperature, humidity, litter, etc.) were consistent with established management guidelines [12].

Feeding management

Birds were provided with a corn-soybean meal-based commercial broiler starter (crude protein [CP] 22.5%, metabolizable energy [ME] 3,020 kcal/kg) for week 1, grower (CP 18.5%, ME

 https://doi.org/10.5187/jast.2022.e47

3,050 kcal/kg) for week 2–3, and finisher (CP 18.0%, ME 3,100 kcal/kg) for week 4–5. Birds were provided the diets on an *ad libitum* basis and had free access to water via a bell-type water dispenser throughout the experiment.

Growth performance evaluation

Body weight and feed intake were measured weekly per replication at 7, 14, 21 and 35 days of age. The FCR was calculated by dividing the body weight gain with feed intake.

Blood sampling and measurements

At 35 days of age, 12 birds per treatment were randomly selected, and blood samples were collected from their wing veins for determining blood biochemical profiles. Blood cells were analyzed for leukocytes, erythrocytes, and platelets using a hemocytometer (HematVet 950, Drew Scientific, Miami Lakes, FL, USA).

Serum biochemical composition was analyzed using a blood analyzer (AU 480 Chemistry Analyzer, Beckman Coulter, Brea, CA, USA) to determine triglyceride (TG), glucose (GLU), aspartate aminotransferase (AST), alanine aminotransferase (ALT), and creatinine (CREAT) levels.

Serum cytokines

Tumor necrosis factor-α (TNF-α) and Interleukin-6 (IL-6) were analyzed to compare the immune response in broilers according to light intensity. Cytokine analysis was performed using a commercial Chicken TNF-α ELISA Kit (MyBioSource, San Diego, CA, USA) and a Chicken IL-6 ELISA Kit (MyBioSource). In this analysis, 100 μL of the sample was placed in a 96-well plate and incubated at 37℃ for 90 min, after which an antibody was added and allowed to bind for 1 h. The wells were then washed three times with a washing solution, and 100 μL of horseradish peroxidase (HRP) conjugate working solution was added and incubated again at 37℃ for 30 min.

Absorbance was measured at 450 nm using a spectrophotometer (Epoch 2, BioTek Instruments, Winooski, VT, USA) after the addition of stop solution.

Serum corticosterone

The serum corticosterone concentration was analyzed using a commercial Corticosterone ELISA Kit (ADI-900-097, Enzo Life Science, Farmingdale, NY, USA). The serum sample (100 μL) was mixed with 50 μL of conjugate and 50 μL of antibody and then incubated at room temperature for 2 h. The mixture was washed three times, 200 μL of substrate was added, and the mixture was incubated at room temperature for 1 h. After adding the stop solution, absorbance was measured at 450 nm using a spectrophotometer (Epoch 2, BioTek Instruments).

Eye dimensions

At 35 days of age, 12 broilers with similar body weight (1.8 ± 0.07 kg) per treatment were selected and extraocular tissues were removed from the eyeball. The weight, corneal diameter, dorsoventral diameter, mediolateral diameter, and anteroposterior size were measured using a digital scale and digital calipers.

Carcass yield and part yields

At 35 days of age, 12 birds with similar body weight (1.8 ± 0.07 kg) per treatment were selected to analyze the carcass yield and meat quality characteristics. Carcass yield was calculated by dividing carcass weight with the live weight after removing the feathers, head, giblets, and feet. Subsequently, the carcass was divided into five parts (breast, legs, wings, neck, and back including bones) and weighed individually, and the cut yield of each part was calculated as a percentage of live weight.

Physicochemical characteristics of breast meat

Breast meat samples collected from 12 birds per treatment were used to analyze physicochemical parameters. The chemical composition (moisture, CP, crude fat, and crude ash) of the breast meat was determined using the AOAC method [13]. The pH was measured using a pH meter (pH-K21, NWK-Binar GmbH, Celiusstr, Germany) and color intensity (CIE L*, a*, b*) was measured using a colorimeter (CR301 Chromameter, Minolta, Osaka, Japan) calibrated with a white standard plate (Y = 92.40, x = 0.3136, and y = 0.3196).

Shear force (SF), cooking loss and water holding capacity (WHC) of the breast meat were analyzed using the method of Chae et al. [14]. For the determination of SF, each sample (average weight, 61 g) was heated individually in a polyethylene bag immersed in a 70℃ water bath for 10 min. After heating, the samples were cooled, and the cores (diameter, 1.27 cm) were taken in the longitudinal direction of the muscle fibers. SF values were detected using a Warner-Bratzler shear blade attached to a texture analyzer (Model TA-XT2, Stable Micro Systems, Surrey, UK). To measure the cooking loss, each sample within a polyethylene bag was heated in an 85℃ water bath for 45 min. After cooling for 20 min, cooking loss was calculated as the percentage of weight loss after heating. The WHC was calculated as a percentage (%) by subtracting the free water generated by centrifugation from the total water of the meat. For free water, 0.5 g of a sample from which fat and fascia (tendon) were removed, was placed in a tube, heated in a water bath at 80℃ for 20 min, and centrifuged at 448×g for 10 min. The value obtained by dividing the fat coefficient (the value obtained after subtracting the fat content from the sample, %) with the weight before and after centrifugation was calculated as a percentage.

Statistical analysis

The data obtained in the experiment was analyzed using the General Linear Model (GLM) procedure of SAS software (version 9.4, SAS Institute, Cary, NC, USA) [15]. Duncan's multiple range test was used to determine significant differences among treatments, and differences were considered statistically significant at $p < 0.05$.

RESULTS AND DISCUSSION

Growth performance

The effects of light intensity on broiler growth performance are shown in Table 1. The final body weight at 35 days of age did not show a significant difference among the treatments. Body weight gain and feeding from 7 to 35 days of age were unaffected by light intensity. Scheideler [16] reported that light intensity (ranging from 4 to 20 lx) did not affect the feed intake of broilers, and numerous studies have shown that light intensity has little effect on the feed intake [10,17,18] or body weight [5,10,18] of broilers. The results of the present study are thus consistent with those of previous studies. However, Charles et al. [17] reported that broilers raised at high light intensity (150 lx) had lower body weights at 6 and 8 weeks of age than those raised at low light intensity (5 lx). Downs et al. [19] found that low light intensity stimulated early feed intake and growth, although it had a transitory effect. Lien et al. [20] also reported that feed intake increased proportionally with 1.76 lx vs. 161.4 lx of light intensity. Blatchford et al. [1] suggested that lower body weight in a bright environment was due to the high activity of broilers under high light intensity. Deep et al. [5] stated that very bright light (100 or 150 lx) might have stimulated

 https://doi.org/10.5187/jast.2022.e47

Table 1. Effect of light intensity on growth performance of broilers from 7 d to 35 d of age

Parameters	Light intensity (lx)				SEM	p-value
	5	20	35	50		
Initial body weight on d 7 (g/bird)	166.48	164.20	163.64	164.77	1.063	0.310
Final body weight on d 35 (g/bird)	1,853.7	1,946.3	1,873.5	1,842.6	48.66	0.969
Weight gain (g/bird)	1,687.2	1,682.1	1,709.9	1,677.8	48.49	0.966
Feed intake (g/bird)	3,535.4	3,572.0	3,571.6	3,509.3	58.77	0.848
FCR (feed/gain)	2.10	2.12	2.09	2.09	0.031	0.872

FCR, feed conversion ratio.

the activity to an extent resulting in increased energy utilization for maintenance rather than for growth.

Feed conversion ratio (FCR) was not significantly different among treatments in the present experiment, which is in agreement with the findings of Buyse et al. [21], who reported that light intensity ranging from 5 to 51 lx did not affect broiler FCR. Similarly, Downs et al. [19] reported that the FCR was not noticeably affected by light intensity, and Lien et al. [11] found no significant effects of light treatment on FCR, although body weight and feed consumption were affected by light intensity and photoperiod. However, Olanrewaju et al. [22] found a difference in FCR at 28 days of age under 25 lx and 5 lx light intensity. Newberry et al. [9] suggested that a lower light intensity may improve FCR due to a reduction in activity and stimulation of muscular growth.

Blood profiles

Table 2 shows the blood cell composition of broilers according to light intensity. The heterophil :

Table 2. Effect of light intensity on blood cell composition of broilers at 35 d of age

Parameters	Light intensity (lx)				SEM	p-value
	5	20	35	50		
Leukocyte						
WBC (K/μL)	16.18	15.67	14.49	12.77	1.032	0.111
HE (K/μL)	3.97	3.81	3.30	3.53	0.325	0.483
Ly (K/μL)	9.88	9.79	9.28	9.74	0.562	0.878
HE/LY	0.40^{a}	0.38^{ab}	0.36^{ab}	0.34^{b}	0.046	0.044
MO (K/μL)	1.79	1.61	1.51	2.43	0.529	0.612
EO (K/μL)	0.43	0.41	0.35	0.30	0.046	0.203
BA (K/μL)	0.10	0.09	0.06	0.06	0.015	0.176
Erythrocyte						
RBC (K/μL)	2.13	2.12	2.14	2.09	0.047	0.905
Hb (g/dL)	8.13	8.10	8.11	7.81	0.156	0.424
HCT (%)	21.95	21.77	21.40	20.91	0.452	0.389
MCV (fL)	102.93	102.54	100.29	100.16	1.137	0.196
MCH (g/dL)	38.20	38.19	38.02	37.41	0.518	0.673
MCHC (g/dL)	37.12	37.24	37.91	37.38	0.544	0.747
Platelets	16.40	16.50	15.80	16.60	1.699	0.987

[a,b]Means in same rows with different superscripts are significantly different ($p < 0.05$).

WBC, white blood cell; HE, heterophil; Ly, lymphocyte; HE/LY, heterophil/lymphocyte; MO, monocytes; EO, eosinophils; BA, basophils; RBC, red blood cell; Hb, hemoglobin; HCT, hematocrit; MCV, mean corpuscular volume; MCH, mean corpuscular hemoglobin; MCHC, mean corpuscular hemoglobin concentration.

lymphocyte (HE/LY) ratio significantly decreased as light intensity increased ($p < 0.05$). However, other blood cell components did not show a significant difference among treatments according to light intensity. The HE/LY ratio and serum corticosterone level were used as indicators to evaluate stress in broilers [23,24]. Some studies have shown that the HE/LY ratio increases in stressful environments [25–27]. As the corticosterone level increases, the HE/LY ratio also increases in broiler chickens [28,29]. It is also known that the corticosterone level indicates the acute stress response, whereas the HE/LY ratio is related to the chronic stress response of the immune system [30]. Weimer et al. [31] reported that the HE/LY ratio was positively correlated with corticosterone levels in broilers reared under different light intensities and flooring types.

In the present study, the HE/LY ratio was the lowest in the 50 lx light group and the highest in the 5 lx group. This implies that 5 lx of light intensity induced more stress in the birds compared with those in brighter environments. However, Dereli Fidan et al. [32] reported a higher HE/LY ratio in broilers in the brighter light (20 lx) group than in those in the dim and reducing light group (5 to 1.25 lx). Weimer et al. [31] also reported that the HE/LY ratio was higher for birds in the brighter light treatment (10 lx) than in those in dim light treatments (2 and 5 lx). In contrast, Lien et al. [11] reported that the HE/LY ratio at 40 days of age was unaffected by light intensity (10. 76 lx vs 1.76 lx). The variation in these results is presumed to result from the different range of light intensity, experimental period, and environmental conditions in each experiment.

The effects of light intensity on serum biochemical profiles are presented in Table 3. Blood parameters such as cholesterol, TG, GLU, and total protein levels can be used as indicators of stress [33,34]. Serum TG levels were significantly higher in the 5 lx treatment than in other treatments ($p < 0.05$). This result is in agreement with that of Dereli Fidan et al. [32], who reported that TG levels were significantly higher in the dim light (5 to 1.5 lx) group compared with those in the bright light (20 lx) group. However, blood GLU levels were not affected by light intensity in the present study. AST and ALT concentrations indicate the health of the liver, and the lower the concentration, the better the liver status [35–37]. Light intensity in the present experiment did not influence AST and ALT levels. The CREAT level was the lowest in the 5 lx treatment and gradually increased as the light intensity increased ($p < 0.05$). CREAT is an index used to assess renal function, with a high CREAT content indicating better renal function [38].

Cytokine and corticosterone concentrations

IL-6 levels in serum were significantly higher in the 5 lx treatment than in other treatments ($p < 0.05$; Table 4). However, TNF-α content was not significantly affected by light intensity. Serum corticosterone levels were significantly higher in the 5 lx treatment than in the 20 lx, 35 lx, and 50 lx treatments ($p < 0.05$).

IL-6 is secreted by immune cells in the body and strongly stimulates the secretion of the

Table 3. Effect of light intensity on serum biochemical parameters of broilers at 35 d of age

Parameters	Light intensity (lx)				SEM	*p*-value
	5	20	35	50		
TG (mg/dL)	43.82[a]	36.65[ab]	35.15[ab]	30.36[b]	3.091	< 0.05
GLU (mg/dL)	242.05	244.11	244.66	246.60	6.734	0.972
AST (U/L)	306.88	300.13	291.33	301.51	17.550	0.938
ALT (U/L)	2.67	2.73	2.57	2.59	0.140	0.847
CREAT (mg/dL)	0.230[b]	0.234[ab]	0.244[a]	0.246[a]	0.004	< 0.05

[a,b]Means in same rows with different superscripts are significantly different ($p < 0.05$).

TG, triglyceride; GLU, glucose; AST, aspartate aminotransferase; ALT, alanine aminotransferase; CREAT, creatinine.

https://doi.org/10.5187/jast.2022.e47

Table 4. Effect of light intensity on serum cytokines and corticosterone concentration of broilers at 35 d of age

Parameters	Light intensity (lx)				SEM	*p*-value
	5	20	35	50		
Cytokine (pg/mL)						
IL-6	46.87[a]	29.99[b]	30.31[b]	29.15[b]	2.540	< 0.05
TNF-α	76.63	74.66	74.73	72.48	2.743	0.766
Cortisol (ng/mL)						
Corticosterone	13.70[a]	10.90[b]	9.96[b]	9.93[b]	0.014	< 0.05

[a,b]Means in same rows with different superscripts are significantly different ($p < 0.05$).

IL-6, interleukin-6; TNF-α, tumor necrosis factor-α.

hormone cortisol [39]; it may, therefore, be regarded as an indicator of stress. In the present study, IL-6 levels showed a trend similar to that of corticosterone levels. TNF-α, which is mainly secreted during inflammation [40], showed a tendency to decrease as light intensity increased, although no significant difference was observed.

The release of corticosterone is activated by environmental stressors in the adrenal cortex [41], and serum corticosterone levels are widely used in animal stress and welfare studies [42]. The highest corticosterone concentration was detected in the 5 lx treatment. In a report by Weimer et al. [31], the corticosterone level in birds at 2 lx was 20% higher than that at 5 lx, and tended to increase as light intensity decreased from 10 lx to 5 and 2 lx.

Very high or low light intensity may cause stress and thus negatively affect chicken welfare [21,31,43]. Although the mechanism by which light intensity causes stress in broilers has not yet been clearly identified, it is known that low light intensity limits broiler behavior [20]. The flicker effect (ripples of light) of LED bulb may also cause stress in birds [44]. The flicker effect of the light source is a very important factor in the current poultry industry, and although it is known that chickens do not recognize the flicker effect of 100 Hz [45], few studies have investigated this.

Eye dimensions

There was no significant effect of light intensity on broiler eye weight, dorsoventral diameter (height), anteroposterior size (length), or mediolateral diameter (horizontal), although these parameters tended to increase as light intensity decreased (Table 5). However, the corneal diameter was significantly larger in the 5 lx treatment than in other treatments ($p < 0.05$), displaying a tendency to increase as light intensity decreased.

The light intensity influences the dimensions of the chicken eye [1,5]. Deep et al. [5] reported significant differences in eye weight, corneal diameter, dorsoventral diameter, mediolateral diameter, and anteroposterior size at a low light intensity (1 lx). Blatchford et al. [1] also reported that broilers

Table 5. Effect of light intensity on eye dimensions of broilers at 35 d of age

Parameters	Light intensity (lx)				SEM	*p*-value
	5	20	35	50		
Eye weight (g)	1.96	1.96	1.89	1.88	0.025	0.057
Corneal diameter (mm)	7.83[a]	7.40[b]	7.22[b]	7.08[b]	0.090	< 0.05
Dorsoventral diameter (mm)	17.11	17.00	17.09	16.82	0.161	0.575
Mediolateral diameter (mm)	17.81	17.59	17.58	17.17	0.597	0.131
Anteroposterior size (mm)	11.73	12.36	12.15	12.37	0.221	0.162

[a,b]Means in same rows with different superscripts are significantly different ($p < 0.05$).

raised at 5 lx light intensity tended to have heavier eyes than those raised at 50 lx.

In the present study, no significant difference was detected among treatments, except for corneal diameter, although most eye dimensions tended to decrease as light intensity decreased from 50 lx to 5 lx. Some differences between this result and those of previous studies are presumed to be based on the range of illumination and the light source, and further research is necessary to determine the exact cause.

Carcass yield and physicochemical characteristics of meat

Light intensity did not significantly affect carcass or part yields of broilers at 35 days of age (Table 6). The results of this study are consistent with those reported by Olanrewaju et al. [18,22]. Generally, carcass yield and part yields are closely related to the performance of broilers [46,47]. It is presumed that the similar growth performance among treatments resulted in no difference in carcass yield in this study. However, Downs et al. [18] showed that the breast meat ratio decreased and the wing ratio increased when the light intensity was lowered form 20 lx to 2.5 lx . Dereli Fidan et al. [48] reported that carcass yield and breast meat ratio were higher in bright light (20 lx) treatments, although leg yield was increased under dim light conditions. This discrepancy is thought to be due to the different age at slaughtering. In the present study, carcass yield was measured at the age of 35 days (conventional marketing age in Korea), but in other studies, the birds were slaughtered at 42 days of age.

Moisture, CP, crude fat, and crude ash content of breast meat did not differ significantly among treatments. Meat quality parameters, including pH, color, cooking loss, water holding capacity, and shear force of breast meat were not affected by light intensity (Table 7). However, Dereli Fidan et al. [48] reported a higher pH in broilers grown under bright light. This was attributed to the higher glycogen content in the muscle due to less stress in birds in bright environments. The same authors also found that the L* value was lower in the dim light group than in the bright light group, and concluded that dim light led to rapid postmortem glycolysis, with decreased pH and increased L* values. Other meat quality parameters, including a*, b*, cooking loss, and water holding capacity were found to be unaffected by light intensity by Dereli Fidan et al. [48], which is consistent with the finding of the present study.

CONCLUSION

As mentioned previously, the Animal Welfare Certification Standards of Korea [8] recommend a light intensity of ≥20 lx. The results of this study showed that a light intensity of 5 lx had a negative influence on the welfare parameters of broilers, whereas there was little difference between the 20 lx and higher light intensity treatments. Dim light may increase the physiological stress in broiler,

Table 6. Effect of light intensity on carcass yield and part yield of broilers at 35 d of age (% of live weight)

Parameters	Light intensity (lx)				SEM	*p*-value
	5	20	35	50		
Carcass yield	73.39	74.27	77.73	73.84	2.049	0.434
Breast	16.44	17.59	17.79	17.28	0.641	0.471
Legs	22.15	22.05	23.10	21.93	0.629	0.546
Wings	7.58	7.14	7.15	7.15	0.308	0.685
Neck	3.97	3.83	3.73	3.43	0.188	0.231
Back	16.44	17.59	17.79	17.28	0.640	0.471

 https://doi.org/10.5187/jast.2022.e47

Table 7. Effect of light intensity on breast meat quality characteristics of broilers at 35 d of age

Parameters	Light intensity (lx)				SEM	*p*-value
	5	20	35	50		
Chemical composition						
Moisture (%)	75.75	76.43	76.19	75.75	0.203	0.078
Crude protein (%)	22.26	21.53	21.83	22.45	0.290	0.149
Crude fat (%)	1.17	1.06	1.17	1.06	0.152	0.909
Crude ash (%)	1.19	1.21	1.17	1.23	0.036	0.675
pH	5.64	5.73	5.77	5.67	0.046	0.203
Color						
L*	56.25	58.12	57.07	59.41	1.177	0.294
a*	1.64	1.57	1.46	1.46	0.259	0.953
b*	9.57	9.42	8.27	10.19	0.736	0.348
Physical characteristics						
Cooking loss (%)	19.64	18.22	20.42	21.20	0.903	0.156
Water holding capacity (%)	56.38	57.71	58.20	58.36	0.629	0.128
Shear force (N)	21.72	18.82	19.17	21.93	1.526	0.355

even if performance and carcass characteristics are not significantly influenced. Therefore, a light intensity of 20 lx or above is recommended for both productivity and welfare of broilers.

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