The effect of monochromatic, combined, and mixed light-emitting diode light regimes on growth traits, fear responses, and slaughter-carcass characteristics in broiler chickens

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Received: 14 March 2022 / Accepted: 31 August 2022 © The Author(s), under exclusive licence to Springer Nature B.V. 2022

Abstract
This study aims to determine the effects of blue and green monochromatic, blue-green combination, and blue-green mixed led lighting systems on growth, fear, and carcass characteristics of broilers reared in an extensive indoor system. Experimental groups were formed as follows; 1-conventional (incandescent), 2-blue, 3-green, 4-blue-green combined (blue for the first 10 days, then green), 5-green–blue combined (green for the first 10 days, then blue), and 6-blue-green intermittent (alternating every 5 min) monochromatic lightings. It was detected that the average values of the body weight of chickens at 42 and 56 days of age in the green–blue group were higher than those of the other treatment groups (both \( P < 0.05 \)). It was determined that the broilers in the green and green–blue groups had higher means of the \( \beta_0 \) parameter of Gompertz model. The tonic immobility, emergence test, home cage avoidance test, a looming human test, and box plus experimenter test were applied to determine the fear responses. It was determined that the worst results for fear responses of broilers were in the intermittent lighting group and green–blue combined group. As a result, it was determined that the application of green monochromatic lighting in the first 10 days of the fattening period and blue monochromatic lighting in the following period positively affected growth and slaughter-carcass characteristics. However, it was found that broilers reared under green–blue combined lighting had high fear levels.

Keywords Lighting · Monochromatic · Tonic immobility · Fear · Poultry behavior

Introduction
To achieve maximum efficiency in commercial poultry production, the birds must be subjected to optimal environmental conditions. Lighting is one of the most critical environmental factors in intensive indoor production (Pal et al., 2019; El-Sabrout et al., 2022). Birds have highly specialized visual systems and more types of cones than mammals. The light is received by receptors and transmitted to the hypothalamus in chickens. The stimulation of the hypothalamus varies depending on the wavelength of light. Thus, the physiological events caused by different wavelengths also differ (Prescott et al., 2003; Kram et al., 2010; Yang et al., 2018). In recent years, different artificial lighting programs have been widely used to increase the productive performance of broilers. The light supplement’s source, type, spectrum, and intensity are important environmental factors in modern broiler management (Zhang et al., 2012; Olanrewaju et al., 2018). In recent years, the energy-efficient, narrowband emission of light-emitting diode (led) sources makes lighting technology valuable in poultry (Soliman and El-Sabrout, 2020).

Halevy et al. (1998) reported that blue and green light accelerated the development of chicks. Researchers stated that because of the decrease in the wavelength of light, muscle satellite cells (new cells) multiply faster. Fernandes et al. (2018) reported that the muscle fiber diameters of broilers treated with blue monochromatic illumination were higher than those illuminated with green and red. Many previous studies have focused on the effect of light spectrum on the growth performance in broilers. Broilers reared under green or blue light showed significantly more body weight gain and greater muscle growth than birds reared under other light spectra (Rozenboim et al.,...
It is known that the number of opsin cells in the eye that detects green light is higher after hatching and that the number of opsin cells that detect blue light is higher after the first 7–10 days of age (Rozenboim et al., 2003). Green light accelerates broiler muscle growth during the early stage, whereas blue light stimulates growth in the later stage (Rozenboim et al., 1999, 2004a; Cao et al., 2008). Some researchers have also focused on the combination or mixed-use of light wavelengths based on the differences in the development of opsin cells in the retina (Rozenboim et al., 2003; Olanrewaju et al., 2006; Guevera et al., 2015; Soliman and El-Sabrout, 2020). Further research revealed that the body weight and meat quality of broilers reared under green and blue monochromatic light combinations or green and blue mixed lighting systems were superior to those raised in white (Rozenboim et al., 2004b; Karakaya et al., 2009).

Cao et al. (2008, 2012) reported that green monochromatic lighting promotes the growth and development of broilers during the early stage (up to 26 days old), while blue promotes growth during the later stage (between the ages of 27 and 49 days). Blue-green and green–blue combinations also had positive effects. This study aims to examine the effects of blue and green monochromatic, blue-green combination, and blue-green mixed led lighting systems on the growth characteristics, fear responses, and slaughter-carcass traits of broilers reared in an extensive indoor system.

### Materials and methods

The study was carried out at Akdeniz University (Antalya-Turkey) and with the decision of the Animal Experiments Local Ethics Committee of Akdeniz University, dated 18.10.2019 and numbered 128. The animal material of the study consisted of 300 1-day-old Ross 308 broiler chickens purchased from a commercial company. In the experiment, the principles of SCAHAW (Scientific Committee on Animal Health and Animal Welfare) for the extensive indoor broiler production system were applied. Six experimental groups (each with 2 replications) were formed with 50 chickens in each group at a stock density of 8.33 chickens/m². Wing numbers were assigned to all chicks at the beginning of the experiment, and body weights were weighed individually every week with a digital scale with a precision of 0.01. Thanks to the wing numbers, all measurements taken throughout the experiment were recorded individually. The experimental groups consisted of 1-traditional lighting (incandescent white bulb: C), 2-blue monochromatic lighting (480 nm: B), 3-green monochromatic lighting (560 nm: G), 4-blue-green combined monochromatic lighting (blue for the first 10 days, then green: BG), 5-green–blue combined monochromatic lighting (green for the first 10 days, then blue: GB), and 6-blue-green mixed lighting (alternating every 5 min: MBG). Chicks were randomly housed in 6 light-controlled floor pens (each has two compartments), and LED bulbs were mounted at a suitable height to provide homogeneous lighting inside the pens, and it is ensured that there is no different light or reflection for all pens. The room temperature was maintained at 32 °C for the first week and then reduced by 1 °C every 2 days until it reached 24 °C on day 23, which was maintained until the end of the experiment. The relative humidity was maintained between 60 and 65 percent on average throughout the experiment. Chicks were fed ad libitum a starter feed containing 21.5% CP and 11.93 MJ/kg of ME (1–21 days), while a grower feed containing 19.0% CP and 11.93 MJ/kg of ME was used between the 21st and slaughter days (Narınıç et al., 2015).

To obtain the estimates of individual growth curve parameters, all birds were weighed weekly from hatching to 8 weeks of age. The Gompertz nonlinear regression model (1) was used to estimate the growth curve of each chick.

\[
y_i = \beta_0 e^{(-\beta_1 e^{-\beta_2 t})}
\]

where \( y_i \) is the weight at age \( t \), \( \beta_0 \) is the asymptotic (mature) weight parameter, \( \beta_1 \) is the scaling parameter (constant of integration), and \( \beta_2 \) is the instantaneous growth rate (per day) parameter (Narınıç and Genç, 2021). Parameter estimations were performed by the NLIN procedure of SAS 9.3 software (SAS Institute Inc., Cary, NC). The Gompertz growth model has an inflection point, which is found by dividing the adult weight parameter by the number \( e \). (Alkan et al., 2012). The coordinates of the point of inflection, weight (2), and time (3) at the inflection point (IPW) were obtained as follows (Narınıç et al., 2017).

\[
IPW = \beta_0/e
\]
The tonic immobility durations were measured to determine the fear responses of 10 chickens randomly selected from the experimental groups every week. For the application of the tonic immobility test, the expert operator laid the bird on its back on a special device with its head hanging down. The operator placed one hand on the chicken’s chest gently and without pressure, and waited for 10 s for the animal to immobilize. At the end of 10 s, the operator took his hand slowly and measured the immobility time of the bird with a stopwatch. In the measurement of the inactivity time, the maximum value was determined as 300 s (Campo and Davila, 2002). The emergence test was applied to determine the fear status of 10 chickens randomly selected from the experimental groups every week. During the implementation of this test, a box with three closed sides and one open side was used. The broiler to be tested was placed in this box, and the movements of the animal in the box were observed inconspicuously, and the evaluation was made according to the time the broiler left the box. If the bird recessed to go out, it was considered passive, and if it came out in a short time, it was considered active (Jones, 1987). When the broilers were 42 and 56 days old, home cage avoidance tests were applied twice a day using 10 randomly selected birds from each group. During the test, the reactions of the broiler to people and objects were measured. The operator doing the test approached the application cage and brought an object (colored stick) towards the animal; the evaluation was based on the bird’s response. The assessment was based on the bird’s reactions: if it stands calmly without reacting, it is unresponsive (code: 0), if it runs to the opposite end of the cage, it is recessive or cowardly (code: 1), and if it approaches the human and tries to examine the object it has extended, it is evaluated as curious and active (code: 2) (Jones, 1995). Another test applied to determine the fear status of birds is the box plus experimenter test. This test was carried out by using 10 chickens randomly selected from the experimental groups each week. In the box plus experimenter test, the reaction of broilers to a human standing behind a net was measured. In the test, avoidance (code: 1), examination (code: 2), and fear (code: 3) situations were evaluated according to the approach or distance of broiler chickens (Jones, 1993). Similarly, the looming human test was applied to measure fear behaviors for 10 randomly selected broiler chickens from each group on a weekly basis (Jones et al., 1981). To measure the reactions of broilers, an observer entered the cage with a camera and recorded a video by walking slowly from one end of the chamber to the other between the broilers on the ground. Evaluation is also made according to the number of animals remaining close to the observer (Jones et al., 1981).

At 8 weeks of age, the body weights of all broiler chicks were determined 8 h after feed withdrawal and slaughtered in an experimental processing plant. The birds were manually cut, bled out, scalded (55 °C, 2 min), defeathered with equipment, manually eviscerated, and the abdominal fat pad (from the proventriculus surrounding the gizzard down to the cloaca) was taken, chilled in an ice-water tank, and drained. The next day, after carcass dissection, the breast with bone and the remaining abdominal fat on cold carcasses were weighed using an electronic digital balance with a sensitivity of 0.01 g. Slaughter and dissection were performed by the same experienced operators. Cold carcass, breast, leg, wing, and total fat pad yields were calculated in relation to body weight at 8 weeks of age (Narinc et al., 2014).

To test the difference between experimental groups in terms of performance traits in chickens, the analyses of variance were applied using the SAS 9.3 GLM procedure (SAS, 2009). Treatment means were separated using Duncan’s multiple range test. The significance level was P < 0.05 for comparing the means. The Rank transformation was used for the nonnormally distributed data. A generalized linear mixed-effects model with the logit function was used in the statistical analysis of the binomial or ordinal data of mortality and behavior traits in the experimental groups, and the differences between the groups were analyzed by the Tukey-Kramer method using the SAS 9.3 GLIMMIX procedure (SAS, 2009; Sabuncuoğlu et al., 2018).

Results

The general mean of mortality was found to be 4.33% for all experimental groups. The mean values of mortality in C, B, G, BG, GB, and MBG groups were 2%, 6%, 8%, 0%, 8%, and 2%, respectively (not presented in a table). There was no statistically significant difference in mortality between the experimental groups (P > 0.05).

The mean values of weekly body weights and Gompertz growth model parameters of broilers in experimental groups and statistical analysis results are presented in Table 1. In terms of the body weights of the broilers at 42 and 56 days of age in the experimental groups, it was determined that the average body weight of the chickens in group GB, where green monochromatic lighting was used for the first ten days and then blue, was greater than the average body weight of the chickens in the other experimental groups (both P < 0.05). The highest mean values for the mature weight parameter and inflection point weight of the Gompertz growth model were found in the G and GB experimental groups (P < 0.05). There were no statistical differences between the groups in terms of other parameters of the growth model. The growth curves of broiler chickens in the experimental groups obtained by the Gompertz model are presented in Fig. 1.
The average durations of tonic immobility in the experimental groups of broiler chickens are shown in Table 2 together with the results of the statistical analysis. While the highest mean value of tonic immobility duration was found in the MBG group, the mean values of the chickens in the B, G, and BG experimental groups were the lowest. The mean values of the percentage of animals moving away in a looming human test performed in the study and statistical analysis results are presented in Table 3. Among the experimental groups, the highest mean value (45.31%) was measured in the group with mixed monochromatic lighting, while the lowest average value (25.69%) was found in the blue monochromatic lighting group ($P < 0.05$). The average values of the inactive duration of birds and the percentages of active birds in the emergence test and statistical analysis results are

Table 1 The mean values of weekly body weights and Gompertz model parameters of broilers in experimental groups, and statistical analysis results

| Group | BW 42 | BW 56 | $\beta_0$ | $\beta_1$ | $\beta_2$ | IPW | IPT |
|-------|-------|-------|----------|----------|----------|-----|-----|
| C     | 2126.39<sup>a</sup> | 3320.47<sup>c</sup> | 6737.79<sup>c</sup> | 5.24 | 0.036 | 2479.63<sup>c</sup> | 45.60 |
| B     | 2206.25<sup>c</sup> | 3347.93<sup>c</sup> | 6973.45<sup>b</sup> | 5.85 | 0.039 | 2568.46<sup>b</sup> | 45.57 |
| G     | 2234.84<sup>b</sup> | 3446.70<sup>b</sup> | 7174.42<sup>a</sup> | 5.09 | 0.038 | 2644.21<sup>a</sup> | 43.02 |
| BG    | 2232.07<sup>b</sup> | 3354.87<sup>c</sup> | 6797.61<sup>c</sup> | 5.26 | 0.033 | 2492.73<sup>c</sup> | 50.23 |
| GB    | 2282.86<sup>a</sup> | 3522.19<sup>a</sup> | 7149.82<sup>a</sup> | 5.11 | 0.035 | 2634.22<sup>a</sup> | 46.81 |
| MBG   | 2237.77<sup>b</sup> | 3427.62<sup>c</sup> | 6809.26<sup>c</sup> | 5.30 | 0.036 | 2511.45<sup>c</sup> | 46.35 |
| SE    | 16.55 | 27.49 | 31.24 | 0.46 | 0.001 | 12.12 | 1.74 |

$P$ value 0.023 0.000 0.000 0.128 0.554 0.000 0.224

The statistical significance level was $P = 0.05$ and Duncan was used as a multiple comparison test. There is a statistically significant difference between the means with different letters in the same column ($P < 0.05$). The parameter $\beta_0$ represents the asymptotic weight, $\beta_1$ represents the integration coefficient, and $\beta_2$ represents the instantaneous growth rate; IPW, inflection point weight; IPT, inflection point age

Table 2 The average values of the tonic immobility durations of the broiler chickens in the experimental groups in the study, and statistical analysis results

| Group | Tonic immobility duration (s) |
|-------|-----------------------------|
| C     | 159.08<sup>b</sup> |
| B     | 105.39<sup>c</sup> |
| G     | 132.13<sup>c</sup> |
| BG    | 129.08<sup>c</sup> |
| GB    | 151.57<sup>b</sup> |
| MBG   | 182.22<sup>a</sup> |
| SE    | 6.414 |

$P$ value 0.020

The statistical significance level was $P = 0.05$ and Duncan was used as a multiple comparison test. There is a statistically significant difference between the means with different letters in the same column ($P < 0.05$)

Table 3 The average values of a looming human test results of the broiler chickens in the experimental groups in the study, and statistical analysis results

| Group | Percentage of animals moving away (%) |
|-------|--------------------------------------|
| C     | 36.61<sup>c</sup> |
| B     | 25.69<sup>d</sup> |
| G     | 34.04<sup>c</sup> |
| BG    | 34.47<sup>c</sup> |
| GB    | 41.51<sup>b</sup> |
| MBG   | 45.31<sup>a</sup> |
| SE    | 1.09 |

$P$ value 0.000

The statistical significance level was $P = 0.05$ and Tukey–Kramer was used as a multiple comparison test. There is a statistically significant difference between the means with different letters in the same column ($P < 0.05$)
presented in Table 4. Table 5 displays the average values of the percentages obtained by classifying animals as passive, active, or cowardly in the home cage avoidance test, as well as the statistical analysis results. The mean values of the percentages of the box plus the experimenter test and the statistical analysis results are presented in Table 6.

The mean values of cold carcass weight, cold carcass yield, and weights of carcass parts of broiler chickens in the experimental groups and statistical analysis results are presented in Table 7. While the differences between the experimental groups in terms of cold carcass yields were not statistically significant, the average value of slaughter weight of chickens in the BG experimental group was found to be higher than those of the other groups ($P<0.05$). Similar to the cold carcass weight characteristic, the GB experimental group had the greatest mean values for breast and back-neck weights ($P<0.05$).

### Discussion

Similar to this study’s findings, Rozenboim et al. (2004a) reported that the experimental group whose illumination was switched from green to blue on the tenth day of the experiment had the chickens with the greatest average body weight at the end of the experiment. The GB group in the current study had a greater mean body weight than the single, combined, and mixed groups (Table 1). Rozenboim et al. (2004a), Guevera et al. (2015), and Olanrewaju et al. (2016) also found similar results. Oke et al. (2021), who found similar results, determined that green-to-blue monochromatic illuminations at 14 and 28 days of age led to the greatest body weight at the end of the experiment.

In a study carried out by Karadavut et al. (2017), growth samples of Japanese quails treated with white, red, green, and yellow monochromatic lighting were analyzed with Gompertz, Broody, and Von Bertalanffy nonlinear regression models. According to the goodness-of-fit criteria, the Gompertz growth model was found to be the best-fitted model, but estimation values of model parameters were not presented in their study (Karadavut et al. 2017). Moreover, to our knowledge, there is no study in the literature on the effects of monochromatic lighting applications on the growth curve parameters of broiler chickens. While the average values ($6797.61–7174.42$ g) of estimations of $\beta_0$ parameters for treatment groups in this study were higher.

### Table 4

| Group | Passive time (s) | Percentage of active birds (%) |
|-------|-----------------|--------------------------------|
| C     | 85.70           | 46.25                          |
| B     | 94.08           | 40.00                          |
| G     | 86.41           | 52.50                          |
| BG    | 74.42           | 40.00                          |
| GB    | 75.92           | 40.00                          |
| MBG   | 79.54           | 43.75                          |
| SE    | 4.38            | 2.35                           |
| $P$ value | 0.790         | 0.543                          |

The statistical significance level was $P=0.05$ and Tukey–Kramer was used as a multiple comparison test. There is a statistically significant difference between the means with different letters in the same column ($P<0.05$).

### Table 5

| Group | Percentage of passive birds (%) | Percentage of cowardly birds (%) | Percentage of active birds (%) |
|-------|---------------------------------|---------------------------------|-------------------------------|
| C     | 22.50$^a$                      | 37.50$^a$                      | 37.50$^a$                    |
| B     | 70.00$^a$                      | 20.00$^b$                      | 10.00$^c$                    |
| G     | 33.75$^d$                      | 41.25$^e$                      | 25.00$^f$                    |
| BG    | 50.00$^b$                      | 45.00$^e$                      | 6.25$^g$                     |
| GB    | 38.75$^c$                      | 36.25$^a$                      | 25.00$^b$                    |
| MBG   | 23.75$^c$                      | 43.75$^c$                      | 32.50$^a$                    |
| SE    | 2.12                           | 2.20                           | 2.00                         |
| $P$ value | 0.000                      | 0.014                          | 0.000                        |

The statistical significance level was $P=0.05$ and Tukey–Kramer was used as a multiple comparison test. There is a statistically significant difference between the means with different letters in the same column ($P<0.05$).

### Table 6

| Group | Avoiding (%) | Exploring (%) | Fear (%) |
|-------|--------------|---------------|----------|
| C     | 10.00        | 0.00          | 0.00     |
| B     | 0.00         | 0.00          | 0.00     |
| G     | 10.00        | 10.00         | 0.00     |
| BG    | 0.00         | 0.00          | 0.00     |
| GB    | 0.00         | 10.00         | 0.00     |
| MBG   | 0.00         | 10.00         | 0.00     |
| SE    | 0.02         | 0.03          | -        |
| $P$ value | 0.555         | 0.700         | -        |

The statistical significance level was $P=0.05$ and Tukey–Kramer was used as a multiple comparison test. There is a statistically significant difference between the means with different letters in the same column ($P<0.05$).
than the mean values of $\beta_0$ parameters (5453.80–6282.35 g) reported by Topal and Bölükbaşı (2008), who analyzed the growth samples of female and male broiler chickens using the Gompertz growth model. In addition, the mean values of $\beta_1$ parameters (5.09–5.85) were found to be similar to the $\beta_1$ averages (4.91–5.31) reported by Topal and Bölükbaşı (2008). Demuner et al. (2017), who modeled the growth samples of Ross, Cobb, and Hubbard broiler genotypes up to 56 days of age with the Gompertz function, reported that the mean values of the $\beta_0$ parameter were between 6401 and 7009 g, similar to the results of this study. Analyzing the growth data of commercial chickens raised in an alternative system up to 56 days of age with the Gompertz model, Marcato et al. (2008) reported that the mean values of the $\beta_0$ parameter for Ross and Cobb genotypes were 6627.84 g and 6812.30 g, respectively. According to the results of this study, it was determined that the broiler chickens in the G and GB groups had higher mean values of mature weight parameter, and similarly mean values of the weight of inflection point in the G and GB groups were higher. The mean values of body weights of the broilers at 42 and 56 days of age treated with continuous green monochromatic lighting were lower than those of the GB group ($P < 0.05$). However, there is no difference between the averages of the G and GB groups in terms of the mature weight parameter of the Gompertz growth curve. It is thought that this surprising situation arises because the green light applied in the G group after the inflection point suppresses the growth.

Sultana et al. (2013a) conducted a study investigating the effects of blue, green, yellow, and white monochromatic lighting on behavior traits and fear responses in ducks. They reported that ducks treated with yellow and white lighting had higher tonic immobility durations than those in blue and green monochromatic lighting groups. In a study conducted by Sultana et al. (2013b), it was found that chickens grown under red LED light exhibited longer durations of tonic immobility. Within that study, there was no difference between the duration of tonic immobility of chickens in the green LED group and the control groups with incandescent bulbs. Additionally, it has been shown that blue monochromatic lighting shortens the duration of tonic immobility. Researchers hypothesized that a light wavelength between 440 and 570 nm can reduce chickens’ fear responses (Sultana et al., 2013b). Mohamed et al. (2016) also reported that mulard ducks reared with white and red lighting had longer tonic immobility durations than those reared with green and blue lighting. Researchers stated that ducks illuminated with green and blue monochromatic lights had lower fear levels. Mohamed et al. (2017) investigated the effect of monochromatic lighting on the fear level of broiler chickens, and reported that the fear level of chickens with green and blue monochromatic lighting was lower.

In this study, when the effects of different monochromatic lighting applications on the fear level of broilers were examined (Table 2), it was determined that the highest average of tonic immobility time (182.22 s) was in the BG group ($P < 0.05$). The mean values of duration of tonic immobility in broilers treated with continuous blue, continuous green, and blue-green alternating monochromatic lighting were found to be lower than those of the other groups ($P < 0.05$). These results were consistent findings with the for ducks and broilers by Sultana et al. (2013a, b) and Mohamed et al. (2016, 2017). The shorter tonic immobility period of broilers reared under blue and green light may be due to the calming effect of these light colors (Prayitno et al. 1997), and birds become less active and less aggressive under these conditions (Mohamed et al. 2016; Pal et al., 2019; El-Sabrout et al., 2022). In the study, the highest mean value of tonic immobility duration was measured in broilers that were exposed to intermittent blue-green light every 5 min. It is thought that the application of intermittent lighting causes fear and anxiety in birds.

In birds, high levels of fear of humans cause a decrease in egg production, worsening in growth and feed efficiency, adversely affecting product quality and decreasing

| Group | Cold carcass (g) | Cold carcass (%) | Breast (g) | Leg (g) | Wing (g) | Back-neck (g) |
|-------|-----------------|-----------------|------------|---------|----------|---------------|
| C     | 2762b           | 79.64           | 1011bc     | 793     | 248      | 715b          |
| B     | 2597c           | 77.88           | 965c       | 758     | 266      | 618d          |
| G     | 2751b           | 79.18           | 1086b      | 809     | 251      | 625d          |
| BG    | 2788b           | 80.95           | 1072b      | 822     | 262      | 688c          |
| GB    | 3053a           | 78.52           | 1175a      | 853     | 286      | 776e          |
| MBG   | 2820b           | 79.16           | 1061b      | 804     | 269      | 678c          |
| SE    | 53.82           | 1.27            | 24.46      | 16.9    | 5.99     | 13.91         |
| $P$ value | 0.021       | 0.344           | 0.016      | 0.089   | 0.158    | 0.012         |

The statistical significance level was $P = 0.05$ and Duncan was used as a multiple comparison test. There is a statistically significant difference between the means with different letters in the same column ($P < 0.05$).
reproductive activities as well as increasing aggression, coping difficulties, and suppression of the immune system (Barnett et al., 1993; Gross and Siegel 1982; Jones 1996). Visual or physical contact with humans may cause behavioral inhibition, withdrawal, panic, and violent escape reactions in chickens as a result of adrenal responses, and in some cases, injury and deformation may occur (Jones 1996). Fear reactions, such as panic or violent escape attempts, not only waste energy and therefore incur a metabolic cost but can also cause death in birds due to squatting and entrapment (Waiblinger et al., 2006). In the emergence test, the mean values of passive duration of broiler chickens in different experimental groups varied between 74.42 and 94.08 s, and there was no statistical difference between the groups ($P > 0.05$). Similarly, the application of different monochromatic lighting did not affect the percentage of active birds, and the ratios of active animals varied between 40.00 and 52.50% ($P > 0.05$). As can be seen from Table 5, in terms of the ratio of passive birds, the chickens with conventional lighting in the control group and the chickens with intermittent lighting in the MBG group had the lowest mean values (22.50% and 23.75%, respectively, $P < 0.05$). In terms of the ratio of active animals, the mean values of the chickens in the control group and the intermittent lighting group were found to be higher than those of the other groups (37.50% and 32.50%, respectively, $P < 0.05$). This supports the view reported by Khaliq et al. (2018) and Hesham et al. (2018) that broilers reared under blue and green light are calmer. In addition, similar to the results of the tonic immobility test, it is considered that intermittent lighting creates fear and anxiety in birds, as the number of passive chickens in this experimental group is low and the number of active chickens is high. As shown in Table 6, there was no statistical difference between the groups regarding the percentage of birds demonstrating avoidance and exploration behaviors (both $P > 0.05$). In addition, no fearful behavior was found in the experimental groups of animals during the box plus experimenter test. These results indicate that this test is not sensitive enough to detect fear responses.

It is already known that green monochromatic lighting accelerates muscle growth and stimulates early growth (Halevy et al., 1998; Soliman and El-Sabrout, 2020; El-Sabrout et al., 2022). In a study conducted by Soliman and Hassan (2019), it was found that blue monochromatic lighting boosted the secretion of metabolic hormones and dramatically improved carcass weight and some performance traits in comparison to red monochromatic and traditional white lighting. Bayraktar and Altan (2005), who compared different light sources and blue and green LED lighting in broilers, reported that the carcass yield of chickens with blue and green LED lighting was higher than those of other groups. In a study conducted by Mohamed et al. (2017), broiler chicks were exposed to monochromatic white, green, and blue lights. In terms of carcass weight and yield, researchers claimed that birds treated with white monochromatic lighting had higher average values (1400 g and 71.30%, respectively). The results of Mohamed et al.’s (2017) study, which are inconsistent with our study results and many other studies, are thought to be due to the animal material used. As shown in Table 7, the mean values of breast weight and back-neck weight of broilers treated with green monochromatic lighting for the first 10 days of the fattening phase, followed by blue monochromatic lighting, were greater than those of the other lighting groups ($P < 0.05$). Cao et al. (2008) who applied different monochromatic lighting programs in broilers reported that the weights of carcass, breast, and thigh of broilers exposed to blue monochromatic lighting were higher than those of other groups. In addition, Ke et al. (2011) claimed that the carcass yield of broilers treated with blue monochromatic lighting was higher than those using green, white, and red monochromatic lighting. However, Liu et al. (2010) observed that birds reared under green monochromatic light had higher breast muscle weights than those of birds with blue, red, and white lighting.

Rozenboim et al. (2004a) and Classen et al. (2004) determined that green monochromatic lighting can increase the growth of young broilers more, while blue monochromatic lighting is more effective after the first period and warns the birds about growth. In this study, it was determined that broiler chickens treated with green monochromatic lighting for the first 10 days and then blue monochromatic lighting had higher averages in terms of both growth performance and slaughter-carcass characteristics. When the findings of the tests performed to determine the fear state of the chickens were examined, it was determined that the worst results were in the intermittent lighting group (MBG), in which a blue and green light conversion was applied every 5 min. The second worst results were also found for broilers treated with green–blue combined monochromatic lighting (GB). As a result, it was determined that the application of green monochromatic lighting in the first 10 days of the fattening period and blue monochromatic lighting in the following period positively affected growth and slaughter-carcass characteristics in line with the findings reported by Rozenboim et al. (2004a) and Classen et al. (2004). In addition, it has been demonstrated that broilers reared under green–blue monochromatic lighting exhibit significantly less aggressive behavior and keep calm even when fear levels are high.

**Author contribution** All listed authors have made substantial contributions to the research design, or the acquisition, analysis, or interpretation of data, and drafting of the manuscript or revising it critically. All authors have approved the submitted version.
Funding This work was supported by The Scientific and Technological Research Council of Turkey (TÜBİTAK). Project Number: 2209-A.

Data availability Not applicable.

Code availability Not applicable.

Declarations

Ethical statement There is the decision of the Animal Experiments Local Ethics Committee of Akdeniz University, dated 18.10.2019 and numbered 128.

Conflict of interest The authors declare no competing interests.

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