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Research Article

# Effect of LED Light Color and Stocking Density on Growth Performance, Carcass, and Meat Quality Characteristics of Japanese Quails

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## ABSTRACT

This study was conducted to evaluate the effect of LED light color and stocking density on the growth performance, carcass, and breast meat quality characteristics of quails. The experiment comprised 720 1-day-old mixed-sex Japanese quails (*Coturnix coturnix japonica*) randomly divided into 6 experimental groups with 4 replicates in each group. Experimental treatments included three different LED light colors (white, monochromatic blue, and monochromatic green) and two different stocking densities (100 and 200 $cm^2$/bird) in a 3x2 factorial design. The feed intake and body weight of quails were measured weekly. At 42 days of age, 20 quails per treatment group were randomly selected for carcass and breast meat quality characteristics analysis. Body weight gain was significantly higher in the blue and green LED light treatments (P<0.05). Quails reared at 200 $cm^2$/bird significantly determined the highest body weight gain (P<0.001). Quails reared at 200 $cm^2$/bird had the best ratio of feed conversion ratio (P<0.01). Breast meat yield and weight were higher in quails reared at blue LED light. Blue LED light tended to increase the water-holding capacity of breast meat (P<0.01). The breast meat L* value decreased significantly as stocking density (200 $cm^2$/bird) increased (P<0.05). However, despite the difference in $pH_{15}$, $pH_u$, and L* value of breast meat, other meat quality characteristics were not different among the stocking density groups. In conclusion, it is shown that mono-crop monochromatic blue or green LED light and 200 $cm^2$/bird floor space have a utilization effect on quail performance traits.

**Keywords:** LED light color, Meat quality, Performance, Quail, Stocking density

## Introduction

The feed conversion ratio, growth rate, and food security of poultry species have continually developed with the advancement of intensive genetic selection, management, and nutrition [1]. Birds have highly improved vision and are sensitive to light as management practices. The primary biological rhythms in poultry, as in other animals, are seasonal and diurnal, both mediated by light. The circadian rhythms in quails are essential for their survival and reproduction. These rhythms are influenced by the detection of light through photoreceptors in their eyes, which signal the suprachiasmatic nucleus in the brain to coordinate various physiological and behavioral processes with the daily and seasonal changes in light. This synchronization helps quails adapt to their environment and optimize their chances of reproductive success [2].

The suitable light environment (light duration, source, wavelength, and intensity) has indirect or direct effects on the economically significant growth performance traits, physiology, metabolism, and welfare of birds [3-5]. The stimulation of the hypothalamus by different wavelengths of light can affect various physiological events in poultry, such as their circadian rhythm and growth. For example, exposure to short wavelengths of light (blue and green light) can suppress melatonin production and stimulate activity, while exposure to long wavelengths of light (red and orange light) can promote melatonin production and induce sleepiness [6-8].

Having used monochromatic lighting on broilers and turkeys in the breeding process using LED light, Mohamed et al.[3] and Oke et al.[9] indicated that blue and green LED light had positive effects on growth performance. Halevy et al.[10] reported that green and blue light accelerated the growth development of chicks. It has been reported that green light accelerates broiler muscle growth during the early period of development, while blue light stimulates growth in the later period [11,12]. It was found that the usage of white or red color light as more body weight gains (BWGs) than blue light in turkey [13]. Yang et al.[14] found significant differences in broiler body weight, and some meat quality among the quails raised under blue, green, yellow, or red LED lights. Environmental, physiological, and biological factors during the growth period can influence the susceptibility of birds to PSE (pale, soft, and exudative) meat, ultimately impacting meat quality characteristics. Additionally, light, as a significant environmental factor, may influence the quality of breast meat [15]. Ke et al.[16] determined that green-blue light improves carcass weight and quality by increasing pH value and water holding capacity (WHC) in broilers. Also, blue and green (short wavelength light) LED lighting has been shown to reduce measures of fear in broilers [3] and ducks [17].

Stocking density is essential factor for the birds among all the management practices. The quails are typically provided with a certain amount of floor area per bird to ensure they have enough space for movement and to reduce stress. The guideline you mentioned recommends a floor area of 130-150 cm² per quail during this period. This allows for a suitable environment for quails to lay eggs and move around without overcrowding. The high stocking density can reduce the growth performance of the bird [18,19]. In addition, a high stocking density can be stressful and can negatively affect quail's immunological and physiological performance [20]. Önel and Aksu [21] found no significant difference in the meat color variables (L*, a*, and b*) among the quails raised stocking density.

Yet, further investigations are needed to understand how light color in combination with different stocking density affects quail production, carcass, and meat quality. Therefore, the present study was designed to investigate the effect of different LED light colors (white, blue, and green) and stocking density (100 and 200 cm²/bird) on growth performance, carcass, and meat quality characteristics of Japanese quails during their growth period extending from day 1 to day 42.

# Material and Methods

## Ethical Statement

All the experimental procedures involved in this study were performed after ethical approval was taken from the Animal Care and Use Committee of Aydin Adnan Menderes University (64583101/2022/96).

## Experimental Design and Treatments

This study was conducted at the Poultry Research Unit of Aydin Adnan Menderes University, Aydın, Türkiye for six weeks.

In this way, LED light bulbs were arranged inside the cages, and bulbs were installed with LED (CATA CT-4277, Türkiye) of 9W power in each cage. The LED light color treatments were assessed by light wavelength. LED light groups were white (400-770 nm), blue (480 nm), and green (560 nm) in which LED light was applied continuously (24 h light a day). Each one of the LED light color groups is managed under one of two different stocking density (100 and 200 cm²/bird) groups.

A total of 720 1-day-old mixed-sex Japanese quails *(Coturnix coturnix japonica)* chicks were initially weighted individually so that the cages had similar initial weight distribution and were randomly assigned to six groups in a 3x2 factorial design, involving three LED light color (white, blue, and green) and two stocking density (100 and 200 cm²/bird). Each group consisted of 4 replicates with 20 quails in each; hence, a total of 80 quails were subjected to the treatment. The quail chicks were kept in chick-rearing cages with a size of 25x44x30 cm and in the same position and number of heaters, feeders, and drinkers throughout the experiment. The quail chicks were subjected to a temperature of 33°C during the first three days of age followed by a gradual reduction of 3°C every week until 23°C was attained. The relative humidity was 50-60% constant throughout the experiment.

## General Management

All quails were fed with balanced diets (0-14 d; 2910 kcal ME/kg, 24% crude protein, and 15-42 d; 2900 kcal ME/kg, 22% crude protein). Feed and water were ensured *ad libitum* throughout the study [22].

## Performance Parameters

Weekly weights of quails were evaluated as individuals. Quails were weighed at the start of the experiment and at the end of each week to ascertain the body weight and cumulative BWG of the overall experimental duration. The feed intake was also weekly recorded on a per-replicate basis. The feed conversion ratio (FCR) was calculated by dividing the feed intake with BWG. Experimental quails were observed and recorded for mortality rate in each cage daily, and survival analysis was conducted.

## Carcass and Meat Quality Measurements

At the end of the experiment, five quails from each replicate cage (20 quails/group; 120 quails in total) were randomly selected, weighed, and slaughtered by decapitation followed by soft scalding, evisceration, exposition of the carcass, cutting and weighting the boneless breast meats, and finally storage at 4°C for 24 h. The dressing percentage was determined by dividing the hot carcass weight by the preslaughter weight and multiplying the result by 100. Additionally, the breast meats were separated, weighed, and expressed as percentages of the slaughter weights.

In the present study, breast meats were used to evaluate meat quality characteristics. The pH of breast meat was measured at 15 min ($pH_{15}$) and 24 h ($pH_u$) after slaughter using a digital pH meter (Testo 205, Lenzkirch, Germany). A pH meter was used to measure the breast pH by inserting the probe 2-2.5 cm into the breast meat. Breast meat color was measured by using the digital color meter (Konica Minolta Sensing, Inc., Osaka, Japan) by the principles of the International Commission on Illumination (CIE). Color values of L*, b*, and a* indicate lightness, yellowness, and redness, respectively. Breast meat pH and color were measured followed by the measurement of cooking loss (CL) and WHC. In the CL method described, meat samples were placed in polyethylene bags and cooked in a water bath until they reached an internal temperature of 75°C. After cooking, the samples were cooled for 15 min under running tap water, removed from the bags, dried with filter paper, and weighed [23]. To measure WHC, the meat samples were first placed between two filter papers to remove excess surface moisture. Then, a 2250 g weight was applied on top of the filter papers for 5 minutes, to extract the water from the meat sample. After removing the weight, the samples were weighed again to determine the final weight. The WHC was calculated by subtracting the final weight from the initial weight of the sample and dividing this by the initial weight. The result was then multiplied by 100 to express the value as a percentage [24]. Three different measurements were taken for breast meat color and pH, and then the average of these values was used to minimize the variations.

## Statistical Analysis

The data were analyzed using the SPSS 22.0 (Statistical Package for the Social Sciences for Windows, IBM Corp., Armonk, NY, US). Data were tested for normality using Shapiro-Wilk's test. Using Levene's test, the assumption of homogeneity of variances was verified. Analysis of variance was performed with the GLM (Univariate General Linear Model) procedure to reveal the effects of performance, carcass, and meat quality characteristics. Significant differences among group means were determined by Duncan's multiple range tests as post-hoc tests. The chi-square test was used for the mortality rate. Survival curves were plotted using the Kaplan–Meier method, and data were analyzed by the log-rank test, with P<0.05 indicating statistical significance.

***Table 1.*** *Influences of LED light color and stocking density on body weight gain of quails[1]*

| Treatment Main Effects | Body Weight Gain (g) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | n | d 0-7 | n | d 0-14 | n | d 0-21 | n | d 0-28 | n | d 0-35 | n | d 0-42 |
| Expected mean (μ) | 720 | 22.63 | | 59.77 | | 106.03 | | 153.05 | | 193.02 | | 209.42 |
| **LED light treatment** | | | | | | | | | | | | |
| White | 240 | 21.78$^{b}$ | 240 | 58.65 | 240 | 106.45 | 236 | 150.77$^{b}$ | 236 | 189.57$^{b}$ | 235 | 205.63$^{b}$ |
| Blue | 240 | 23.22$^{a}$ | 240 | 60.46 | 240 | 105.97 | 239 | 153.21$^{ab}$ | 238 | 195.34$^{a}$ | 239 | 212.24$^{a}$ |
| Green | 240 | 22.88$^{a}$ | 239 | 60.21 | 238 | 105.67 | 234 | 155.17$^{a}$ | 233 | 194.16$^{a}$ | 231 | 210.39$^{ab}$ |
| **Stocking density** | | | | | | | | | | | | |
| 200 $cm^2$/bird | 240 | 24.07 | 240 | 61.34 | 240 | 109.22 | 240 | 157.14 | 236 | 195.41 | 235 | 214.83 |
| 100 $cm^2$/bird | 480 | 21.18 | 479 | 58.20 | 476 | 102.84 | 476 | 148.97 | 471 | 190.64 | 470 | 204.01 |
| Pooled SEM[2] | | 0.18 | | 0.36 | | 0.57 | | 0.67 | | 0.92 | | 1.12 |
| **LED color x stocking density** | | | | | | | | | | | | |
| White - 200 $cm^2$/bird | 80 | 23.09 | | 60.20 | | 107.89$^{abc}$ | | 153.65 | | 192.18 | | 210.36 |
| White - 100 $cm^2$/bird | 160 | 20.47 | | 57.09 | | 105.00$^{bcd}$ | | 147.89 | | 186.97 | | 200.90 |
| Blue - 200 $cm^2$/bird | 80 | 24.93 | | 62.08 | | 110.90$^{a}$ | | 157.20 | | 196.90 | | 217.76 |
| Blue - 100 $cm^2$/bird | 160 | 21.52 | | 58.86 | | 101.03$^{d}$ | | 149.22 | | 193.78 | | 206.71 |
| Green - 200 $cm^2$/bird | 80 | 24.20 | | 61.78 | | 108.86$^{ab}$ | | 160.56 | | 197.16 | | 216.36 |
| Green - 100 $cm^2$/bird | 160 | 21.56 | | 58.64 | | 102.47$^{cd}$ | | 149.79 | | 191.16 | | 204.43 |
| Pooled SEM[3] | | 0.44 | | 0.88 | | 1.38 | | 1.61 | | 2.21 | | 2.70 |
| **Treatment interaction effects** | P Value | | | | | | | | | | | |
| LED light color | | 0.003 | | 0.090 | | 0.853 | | 0.026 | | 0.025 | | 0.044 |
| Stocking density (SD) | | <0.001 | | <0.001 | | <0.001 | | <0.001 | | 0.009 | | <0.001 |
| LED light color x SD | | 0.589 | | 0.999 | | 0.044 | | 0.309 | | 0.802 | | 0.901 |

***n:*** *The total number of quails in the group,* $^{a, b, c, d}$ *Means with different superscript letters in the same column differ (P<0.05)*
[1] *Data presented as the least square means,* [2] *Pooled SEM for main effects,* [3] *Pooled SEM for interaction effect*

***Table 2.** Effect of LED light color and stocking density on cumulative feed intake consumption, feed conversion ratio, and mortality of quails*

| Treatment Main Effects | Cumulative Feed Intake (g/bird) | | | | | | | Cumulative Feed Conversion Ratio (g of feed/g of gain) | | | | | | Total Mortality, % |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | n | d 0-7 | d 0-14 | d 0-21 | d 0-28 | d 0-35 | d 0-42 | d 0-7 | d 0-14 | d 0-21 | d 0-28 | d 0-35 | d 0-42 | |
| Expected mean (μ) | 24 | 35.42 | 119.19 | 204.04 | 273.85 | 332.59 | 325.04 | 1.56 | 1.99 | 1.93 | 1.79 | 1.72 | 1.56 | |
| **LED light treatment** | | | | | | | | | | | | | | |
| White | 8 | 33.88 | 114.69 | 201.23 | 278.57 | $330.29^{b}$ | $332.48^{a}$ | 1.55 | 1.96 | 1.93 | $1.85^{a}$ | $1.74^{a}$ | $1.62^{a}$ | $2.5^{ab}$ |
| Blue | 8 | 36.08 | 121.41 | 205.70 | 173.53 | $341.26^{a}$ | $331.45^{a}$ | 1.58 | 2.02 | 1.95 | $1.76^{b}$ | 1.76a | $1.58^{a}$ | $0.4^{b}$ |
| Green | 8 | 36.31 | 121.46 | 201.23 | 269.46 | $326.22^{b}$ | $311.21^{b}$ | 1.56 | 2.01 | 1.90 | $1.76^{b}$ | $1.67^{b}$ | $1.47^{b}$ | $3.8^{a}$ |
| **Stocking density** | | | | | | | | | | | | | | |
| 200 $cm^2$/bird | 12 | 39.66 | 126.48 | 212.27 | 285.82 | 344.71 | 322.85 | 1.65 | 2.06 | 1.95 | 1.82 | 1.77 | 1.51 | 2.5 |
| 100 $cm^2$/bird | 12 | 31.18 | 111.89 | 195.81 | 261.88 | 320.47 | 327.24 | 1.47 | 1.92 | 1.91 | 1.76 | 1.68 | 1.61 | 2.1 |
| Pooled SEM[1] | | 0.41 | 1.22 | 1.30 | 1.57 | 1.98 | 3.23 | 0.02 | 0.01 | 0.01 | 0.01 | 0.01 | 0.02 | |
| **Significance of main effects** | | | | | **P value** | | | | | | **P value** | | | **P value** |
| LED light color | | 0.051 | 0.055 | 0.330 | 0.087 | 0.017 | 0.024 | 0.790 | 0.172 | 0.347 | 0.005 | 0.031 | 0.003 | 0.044 |
| Stocking density (SD) | | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | 0.505 | <0.001 | <0.001 | 0.116 | 0.008 | 0.006 | 0.006 | 0.721 |
| LED light color x SD | | 0.892 | 0.601 | 0.323 | 0.634 | 0.662 | 0.088 | 0.808 | 0.455 | 0.802 | 0.773 | 0.621 | 0.067 | |

***n:** The number of pens, [a, b] Means with different superscript letters in the same column differ (P<0.05), [1] Pooled SEM for main effects*

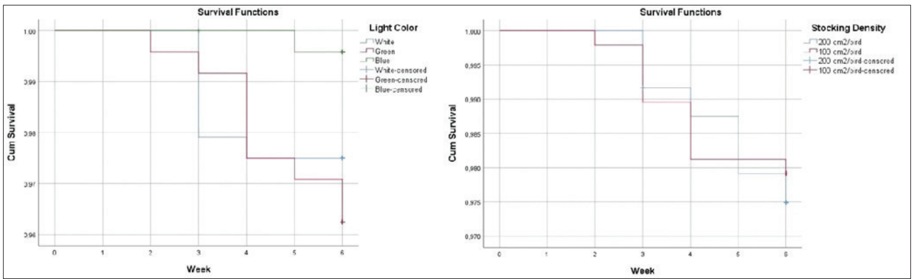


**Fig 1.** Effect of LED light color and stocking density on survival rates of quails

# Results

The BWG was found the highest in the blue LED light (212.24 g) group (P<0.05), and 200 $cm^2$/bird (214.83 g) group (P<0.001). Blue light-200 $cm^2$/bird combined was found highest (217.76 g), but no significant between interactions at 0-42 d *(Table 1)*. Cumulative feed intake (CFI) was suppressed green LED light group compared to white and blue LED light (P<0.05) at 0-42 d. There was no significant between stocking density groups for FCR. LED light color affected CFI (P<0.01) of quails from 0 to 42 days of age. Quails reared under 200 $cm^2$/bird density groups had better FCR than those 200 $cm^2$/bird groups (P<0.01). It's apparent from the obtained results mortality rate was significantly (P<0.05) reduced with blue LED light. However, stocking density has no significant effect on the mortality ratio *(Table 2)*. A survival curve showing the survival probability of quails over time across farms is shown in *Fig. 1*. At the beginning of the study, the white, blue, and green color groups had 240 chicks, per group. In the $6^{th}$ week, the survival rate in the white, blue, and green groups was 97.5%, 96.3%, and 99.6% respectively (P<0.05). The 200 $cm^2$/bird, and 100 $cm^2$/bird groups had 240 and 480 chicks at the beginning of the study. In the $6^{th}$ week, the survival rate was 97.5%, and 97.9% in the corresponding treatments (P<0.05). LED light color significantly affected the yield and weight of the breast (P<0.01). The stocking density has a statistically not significant effect on live weight, carcass yield, breast yield, and weight *(Table 3)*. Compared with the white LED group, blue and green LED light increases in $pH_{15}$ $pH_u$ value of breast meat. The differences between 100 and 200 $cm^2$/bird stocking density groups for $pH_{15}$, $pH_u$, and L* values were significant *(Table 4)*.

*Table 3. The least-square means for live weight, carcass, and breast meat yield in LED light color and stocking density groups[1]*

| Treatment Main Effects | Live Weight (g) | Carcass Yield (%) | Breast Meat Yield (%) | Breast Meat Weight (g) |
|---|---|---|---|---|
| Expected mean (μ) | 214.21 | 75.75 | 19.70 | 31.86 |
| **LED light treatment** | | | | |
| White | 214.73 | 75.75 | 19.78[a] | 32.00[a,b] |
| Blue | 215.88 | 75.86 | 20.61[a] | 33.65[a] |
| Green | 212.03 | 75.65 | 18.72[b] | 29.93[b] |
| **Stocking density** | | | | |
| 200 cm²/bird | 219.12 | 75.72 | 19.62 | 32.48 |
| 100 cm²/bird | 209.30 | 75.79 | 19.79 | 31.23 |
| Pooled SEM[2] | 2.51 | 0.17 | 0.21 | 0.43 |
| **Treatment effects** | | | | |
| LED light color | 0.814 | 0.872 | 0.002 | 0.003 |
| Stocking density (SD) | 0.053 | 0.822 | 0.697 | 0.150 |
| LED light color x SD | 0.436 | 0.271 | 0.834 | 0.251 |

[a, b] *Means with different superscript letters in the same column differ (P<0.05),* [1] *Data presented as the least square means*
[2] *Pooled SEM for main effects*

*Table 4. Effects of LED light color and stocking density groups on breast meat quality characteristics of quails[1]*

| Treatment Main Effects | Breast Meat | | | | | | |
|---|---|---|---|---|---|---|---|
| | $pH_{15}$ | $pH_u$ | L* | a* | b* | CL (%) | WHC (%) |
| Expected mean (μ) | 6.43 | 5.57 | 43.42 | 16.18 | 12.29 | 20.88 | 5.05 |
| **LED light treatment** | | | | | | | |
| White | 6.52[a] | 5.63[a] | 44.22 | 16.69 | 12.48 | 21.85 | 4.76[b] |
| Blue | 6.36[b] | 5.46[c] | 42.62 | 15.48 | 12.50 | 21.03 | 5.64[a] |
| Green | 6.39[b] | 5.55[b] | 43.43 | 16.38 | 11.87 | 19.78 | 4.76[b] |
| **Stocking density** | | | | | | | |
| 200 cm²/bird | 6.38 | 5.59 | 42.74 | 16.36 | 12.03 | 20.77 | 4.94 |
| 100 cm²/bird | 6.47 | 5.51 | 44.11 | 16.01 | 12.54 | 20.99 | 5.16 |
| Pooled SEM[2] | 0.02 | 0.01 | 0.29 | 0.21 | 0.23 | 0.43 | 0.13 |
| **Treatment effects** | | | | | | | |
| LED light color | 0.002 | <0.001 | 0.080 | 0.056 | 0.459 | 0.145 | 0.009 |
| Stocking density (SD) | 0.019 | 0.004 | 0.019 | 0.407 | 0.276 | 0.798 | 0.402 |
| LED light color x SD | 0.142 | 0.744 | 0.341 | 0.268 | 0.887 | 0.149 | 0.614 |

[a, b] *Means with different superscript letters in the same column differ (P<0.05),* [1] *Data presented as the least square means,* [2] *Pooled SEM for main effects*

## Discussion

BWG, which is the production parameter, was significantly increased in poultry reared under blue and green LED light compared to those reared under white LED light with the best performance achieved. In the study, the green LED light resulted in better FCR of quails at 0-35 d and at 0-42 d. In line with previous a study [4], the broilers reared under white LED added with blue-green LED light had higher BW than broilers reared under white LED light. Mohamed et al.[3] determined higher BWG and better FCR in blue and green LED light groups compared to those in the white LED group. The findings suggest that the color or wavelength of light used in quail housing can impact their growth and feed efficiency. This observation could have practical implications for quail farming, as optimizing lighting conditions may improve production outcomes. However, some studies have reported no effect of light color (light wavelength) on FCR and BW [25,26]. In the study, the highest FI was determined in the group with white LED lighting (P<0.05). Some studies indicate that when exposed to short wavelength light quails [27], ducks, and turkeys [13] broiler chickens [12] tend to have faster growth rates compared to when they are exposed to long wavelengths. Mohamed et al.[28], reported that due to the calming effect of blue and green LED light makes birds less active and fearful. This could explain the better growth performance of the quails in blue and green LED light groups, as their visible spectrum included blue and green due to a light short wavelength.

The present study showed that high stocking density (HSD) decreased the BWG and FCR but had no significant effect on feed intake. Cicek et al.[29], Aro et al.[30], and Abdel-Azeem [31], Mahrose et al.[32] also reported HSD in quail farming can have various effects on bird performance, including BWG, FCR, and FI. The specific effects of stocking density can vary depending on various factors, including quail genetics, management practices, and environmental conditions. Scientific researchers often conduct studies to determine the optimal stocking density for quail production to balance growth performance, feed efficiency, and animal welfare. The performance parameters including BWG and FCR were not affected by stocking density in Japanese quails [33]. The non-significant alterations in feed intake in the study disagree with decreased feed intake as the field per quail decreases as stated by other researchers [34,35]. Decreasing floor allowance in quail was associated with a marked significant decrease in BW. The BWG for quails reared at the low SD was high due to more availability of fields for drinking and feeding. This statement suggests that the amount of space quails have in their environment can have a significant impact on their body weight and growth. Providing quails with more space for movement and access to food and water seems to result in better body weight gain.

There was no significant effect of LED light color on carcass yield in the study. The LED light color was the variable of interest, and the carcass yield of quails was the outcome measure [25,26,36,37]. The blue LED light group found the highest breast meat yield and weight (P<0.01). Consistent with those results, Cao et al.[12] reported that the breast weights of broilers exposed to blue LED lighting were higher than those of other light groups. The blue or green LED lighting may promote post-hatch muscle growth because of increased satellite cell density in the breast muscle as well as a 1.6-fold increase in expression of the growth hormone receptor during early post-hatch stages [10]. According to these results, it can be said that the blue LED lighting improved breast yield and weight.

Low stocking density has led to an increase in live weight, but this has not reached statistical significance. Carcass yield, breast meat yield, and weight were not significantly influenced by the stocking density. The effect of stocking density on carcass yield and breast meat weight was found to be statistically non-significant in quails [18,32]. On the other hand, Abdel-Azeem [31] and Hassanein [38] observed that increasing stocking density negatively affects carcass weight. According to these results, it can be said that the effects of the stocking density on performance parameters and carcass yield of quail are contentious due to different density rates. The effects of light color and stocking density on quail performance parameters and carcass yield can vary depending on multiple factors, including the specific conditions of the quail operation. Research in this area is ongoing to find optimal combinations of lighting and stocking practices that balance production efficiency with the welfare and well-being of the birds. Quail producers need to consider these factors carefully and potentially conduct their trials to determine the best practices for their circumstances.

In this study, white lighting increased breast meat $pH_u$ indicating better breast meat quality that was characterized by increased meat color (a*) and lower protein damage which confirms previous results [39,40]. It was shown that breast meat WHC was significantly decreased by the white and green LED light group. In the study, no effects of LED light color were found on L*, a*, b* values, and CL of quail breast meat. Zhang et al.[41] showed that the green light may slightly decrease the WHC of breast meat, and this effect was not significant. Overall, white, and green LED lights only affect a few of the general meat quality characteristics, and this effect was significant enough to be beneficial to meat quality.

El-Moniary et al.[42] reported that the pH value is a direct response to muscle acid content, which affects the color and WHC of breast meat. Our results suggest breast meats of quails in 200 $cm^2$/bird had significantly higher lightness, compared with those in the 200 $cm^2$/bird no perch group (P<0.05). It can be said that the increased $pH_u$ and decreased L* value found here with 200 $cm^2$/bird indicates their utility effect on meat quality and results in improved welfare due to the low stocking density.

In overall conclusion, despite that white and blue LED light was effective in reducing mortality, the monochromatic blue and green light was beneficial to the growth performance of quails. This study showed that a lower stocking density provided more action space for quails. The low stocking density suppresses the growth performance traits of quails. The blue LED light resulted in heavier breast meat compared to those of the green LED light group. In contrast, stocking densities did not significantly influence the carcass parameters of quails. During the rearing period, the white and green LED lights resulted in higher $pH_u$ and lower WHC. Therefore, a blue or green LED light is recommended for the growth performance of quails reared at low stocking density. The suitability of the blue-colored, 200 $cm^2$ per bird combination treatment for quails will depend on scientific evidence and the well-being of your quail flock. Be sure to conduct thorough research and consider all relevant factors before implementing any changes in scientific studies. It is essential to have scientific data or research that supports the use of this combination treatment. If this treatment has been tested and proven to be effective in improving quail health, well-being, or productivity, it can be a suitable choice.

### Availability of Data and Materials

The datasets used and/or analyzed during the current study are available from the corresponding author (E. Dereli Fidan) upon reasonable request.

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### Author Contributions

EDF contributed to literature searches and study design. EDF and MK conceived and supervised the study. EDF and MK collected and analyzed data. All authors contributed to the critical revision of the manuscript and have read and approved the final version.

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