https://doi.org/10.46344/JBINO.2024.v13i04.05

‘

NON-IMPACT OF VARIOUS LIGHT SPECTRUM COLORS OVER 12 HOURS DAILY ON HATCHING PARAMETERS OF JAPANESE QUAIL.

Zelal Alsaftli[1], Batoul Almer Suliman[2]

[1]*Animal Production Department, agriculture college, Hama University, Hama, Syria.*

[2]*Animal Production Department, agriculture college, Hama University, Hama, Syria.*

Email: zelalsaftli@gmail.com

ABSTRACT

Study was carried to estimate the effects of different wavelengths of light on hatching potential traits, including egg weight loss, hatch of fertile percentages, embryonic mortality, hatching weight, and chick quality as well as hatch window and hatching time of Japanese quail eggs.A total of 800 hatching Japanese quail eggs were equally divided into four incubation treatment groups:a dark control group, and three treated groups with blue, red, and green LED light, for a 14- day incubation period. The light sourced from LED lamps with the intensity of 200 lux at eggshell level for 12 h d^{-1} throughout incubation.Results indicated that exposing eggs to different light wavelengths during incubation does not influencethe hatchability of fertile eggs, quality, weight and length of chick. In addition,no differences were observed among the treatments in terms of eggs weight loss, hatch window, and hatching time ($p>0.05$).In conclusion, these results indicateno significant effects on hatchability of fertile eggs, embryo mortality, eggs weight loss, hatch window, and hatching time or day-old chick quality when eggs are exposed to red, green, and blue light.

KeyWords: Hatchability, light LED, incubation, quality, Japanese quail.

INTRODUCTION

It is known that good productivity rates in a hatchery are directly related to the factors that make up the incubation environment, such as temperature, humidity, egg turning, carbon dioxide concentrations and light (Archer, 2017; Drozdova et al., 2019). Despite literatures highlighting the importance of light during incubation, most commercial hatcheries are still incubating eggs in complete darkness. Light is likely not used in commercial hatcheries because early lighting sources, like incandescent and fluorescent lamps, can harm embryos by generating heat that accelerates development and may lower hatchability(Archer and Mench, 2014b; Archer et al., 2017). The emergence of LED lamp technology has the potential to eliminate this issue, as these energy - efficient lamps are increasingly replacingtraditional lighting sources without generating ambient heat (Zhang etal., 2016; Archer et al., 2017).

Data from the literature indicate that bird embryos can respond to light stimuli due totheir sensory system,primarilyinvolving the retina and pineal gland, developing early in embryonic growth(Zeman et al., 1992; Reed and Clark, 2011). Erwin et al. (1971)confirmed that respond to light begins on the third day of development in bird embryos. Similarly, other studies have demonstrated that both retinal cells(PIERCE, 1999) and pineal cells(Haldar et al., 2003) are already present in quail embryos from the beginning of embryogenesis. However, the mechanisms through which physiological responses occur are not clearly elucidated.

Exposure to white and red LED lights during eggs incubation enhanceschickquality by improving navel maturation (Archer, 2017; Archer et al., 2017), reducing early embryonic mortality, and increasing the number of non-defect chicks compared to dark conditions(Archer et al., 2017; Huth and Archer, 2015). In Japanese quails, Farghly and Mahrose (2012)showed greater hatching weight and lower embryonic mortality of chicks exposed to continuous incandescent light compared to darkness, and observed no difference in activity, appearance, leg conformation and appearance of the birds' navel. These results are related to physiological and metabolic responses to light during embryogenesis, due to the higher rate of embryonic development caused by exposure to light (Farghly and Mahrose, 2012; Archer, 2017).

The photoperiod and the timing of light exposure during incubation are crucial for post-hatch effects (Archer et al., 2009; Özkan et al., 2012; Archer and Mench, 2013; Archer and Mench, 2014a). However, not only the photoperiod, light intensity and wavelength are involved in the perception of light by the embryo, but also characteristics such as the thickness and color of the eggshell (Maurer et al., 2011; 2015).

The exact mechanisms through which light during incubation affects embryonic development and hatchability are unknown, but melatonin may play a role(Drozdova et al., 2019).

Short wavelengths, like monochromatic green light, are linked to the establishment of the circadian rhythm in embryos. Compared to dark conditions, green light can shorten incubation time,increase hatch weight, and enhance hatchability in broiler chickens(Shafey and Al-Mohsen, 2002).

Studies show improvements in hatchability with the use of monochromatic white, red lights or a combination of both(Archer, 2016; 2017; Archer et al., 2017). Furthermore, these lights also improved chick quality by enhancing navel maturation (Huth and Archer, 2015; Archer, 2016; 2017; Archer et al., 2017), and promoting better post-hatch welfare, leading to reduced fear responses and lower stress susceptibility compared to green light and dark incubation (Archer, 2017).

These findings indicate thatusing light during egg incubation can yield positive effects. This study aimed to assessthe impact of different light spectrum colors for 12 hours per day in artificial incubators on Hatching Parameters of Japanese Quail.

MATERIALS AND METHODS

Birds and samples

All experimental procedures adhered to the guidelines of the Local Experimental Animal Care Committee and received approved from the ethics committee of the Department of Animal Production, Faculty of Agriculture, Hama University, Syria.The study involved 800 Japanese quail eggs,which were randomly divided into four experimental groups usingfour replicate incubators. Eight calibrated single-stage incubators (Victoria Inc., Quaglie I-36 and H-24; Italy) were utilized.Two incubators served as the control group,operating without light (0L:24D, Dark), while the other six were illuminated with green(560 nm), red (650 nm) or blue (480 nm)LED lights for 12 h d at 200 lux throughout the incubation period. Four LED strips were mounted on metal frames on the left side of each incubator.

Incubation protocol

The eggs were incubated atstandard temperature 37.8°C and 55%RH,with automatic turning at a 45° angleevery two hours from day 2 to day 14. On day 15, viable eggs were set at 37.5 °C and 75% RH, with no turning during the final 3 days.

Hatching Traits

This study measured egg weight loss, embryonic mortality, hatch percentages, and hatch window:

Egg Weight Loss: Before incubation, 50 eggs per replicate were weighedto establish initial weight and re-weighed at 14 days to calculate weight loss (%)

Egg weight loss % = (initial egg weight – weight at 14 days)/initial egg weight × 100

Hatchability Percentage:

Hatchability of all eggs % = {(Number of hatched chicks/ Number of eggs placed in the setter) × 100}.

Hatchability of fertile % = {(Number of hatched chicks/Number of fertilized eggs) × 100}.

Embryonic Mortality: At 18 d of incubation, all hatched chicks were removed from the hatch basket,and unhatched eggs were examined to diagnoseembryo mortality, excludinginfertile eggs. Only the number of fertile unhatched eggs was used to calculate the percentages of early mortality (0-7 days), middle mortality (8-14 days), and late mortality (15-18 days).

Hatch Window, Time of Hatching: From 365 and 416 hours of incubation, transferred eggs were individually checked every 3 hours, and hatched chicks were recorded to determine the exact hatch window and hatch time in hours.

Weight and LengthChicks: A sample of 80 hatched chicks was weighed at hatch, each chick was weighed on a digital scale with a capacity of 0.5 kg and precision 0.01g. The length of chicks was measured by using caliper vernier (0.01 mm).

Chick Quality: It was assessedusingthe Pasgar© Score system, which evaluates reflex, navel, legs, beak, and yolk, deducting one point for each negative criterionfrom a total of 10 points(Tona et al., 2003; Kolańczyk, 2020).

Statistical Analysis

Data on hatching traits and chickquality were analyzed using a one-way ANOVA withSAS 9.4 for Windows (SAS Institute Inc.), withsignificanceset at P ≤ 0.05. Means were comparedusing Fisher's LSD test based on the model:

$$Y_{ij} = \mu + T_i + e_{ij}$$

(where;Yij is the observation, μ isthe overall mean,$T_i$isthe treatment effect, and e_{ij} is random error).

RESULTS

All treatments showed no significant differences in eggs weight loss, hatchability of fertile eggs, hatch window, or hatching time (Table 1). The embryonic mortality rate was also similar among treatments (p> 0.05) (Table 2). Additionally, body weight, length, and quality of quail at hatch did not differ in among treatments (p> 0.05) (Table 3).

DISCUSSION

The current study's findings were consistent with those ofRozenboim et al. (2003) in turkeys, Shafey (2004)in layers, and Sabuncuoğlu et al. (2018) in Japanese quail. No differences in hatch rates of fertile eggs were observed among various photoperiods when Cobb broiler hatching eggs were exposed to full-spectrum fluorescent light (Archer et al., 2009; Archer and Mench, 2014a). Recent studies indicated that exposure to green, white, blue, or red light LEDs for 12 hours did not affect the hatching of fertile eggs in layers(Hannah et al., 2020; Wang et al., 2020; Geng et al., 2021; Özkan et al., 2022; Tang et al., 2023). Similarly, studies on broilers(Tong et al., 2018; Li et al., 2021; Riaz et al., 2024)found no significant differences. Additionally, earlierresearch confirmed that continuous lighting during incubation, including green(Zhang et al., 2012; 2014; 2016), white (Yameen et al., 2020), or blue light (Zhang et al., 2012), did not have a significantlyimpact hatch rates of fertile eggs.

As shown in Table 2, exposure of Japanese quail eggs to different spectrums of light did not have any impact on embryos mortality during periods of incubation. This is consistent with previous researchin both embryo mortality and hatchability(Archer et al., 2009; Archer and Mench, 2014a; Archer, 2017; Tong et al., 2018; Li et al., 2021; Tang et al., 2023). Riaz et al. (2024)found that exposing eggs to white fluorescent light or a combination of green and red light for 12 hours daily during incubation didn't affect hatchability, embryo weights, embryonic index, or embryonic death.Archer (2018)suggested that lighted incubation may have a cumulative effect rather than merely improving embryo viability at specific times.Previous literatures indicatethat exposure to light during incubation significantly enhances hatchability(Archer et al., 2017; Abd El Naby et al., 2021; Abdulateef et al., 2021; Riaz et al., 2021).However, illuminatinglighter brown color broiler hatching eggs with high light intensity (1430–2080 lux) negatively affects hatchability andincreases embryo mortality, likely due to excessive light penetrationthrough the eggshell (Shafey et al., 2005).

Light spectrum and strain have a significant impact on the hatching performance. According to Archer (2015b), Cobb 500 broiler eggs had a 3% higher hatchability under white light than red light. While White Leghorn eggs showed a 7% increase in hatchability under red light compared to white light.This variationmayresult from the different ways broiler and layer eggs filter light, influenced by their shell pigments (Huth and Archer, 2015).

Hluchý et al. (2012)found that white light resulted in higher hatchability for Ross broiler eggs compared to red and blue light. Similarly, Şeremet-Tuğalay and Bayraktar (2021)confirmed that continuous green light was more effective than red light in terms of hatch of fertile eggs in broilers, which may return to higher death in shell (%) and pipping embryo death (%). Recent study was conducted by Safwan et al. (2023) found that there were no differences on hatch of fertile eggs in Japanese quail when exposed to different dichroic lights (Green plus Red, Green plus Blue; and Blue plus Red) for 12 hours of light with 250 lux. However, it was observed that embryonic mortality rates were higher in comparison to dark incubation conditions. It is unclear what the mechanism is behind the improvement in hatchability and embryo mortality.

The differences in hatchability and embryo mortality between previous studies and our current researchmay resultfromseveral factors, including the type of light source, light spectrum composition, bird strain, breeder age, and eggshell characteristics such as thickness and pigment deposition.

The current study found no differences in chicks' weight, length, or quality amonggroups (Table 3).This agrees with previous research, which indicatingthat light does not affectchicks'quality or hatchingweight (Zhang et al., 2012; Archer, 2015a; Tong et al., 2018; Wang et al., 2020; Li et al., 2021), and does not influence length in broilers (Archer, 2015b; Li et al., 2021; 2023), or layers (Özkan et al., 2022).conversely, some studies suggest that a specific lighting regimeduring incubation can improve the condition of the navel at hatch. A 12L:12D photoperiod reduced the incidence of unhealed navels and defects in newly hatched chicks compared to those incubated in darkness (Archer, 2017; 2018; Archer et al., 2017; Li et al., 2023). Their findings indicated that photostimulation during incubation may enhance navel maturation and increase the number of non-defective chicks compared to those incubated in darkness (Archer, 2015a; 2015b; 2017; 2018). However, there was non-significant difference in the quality of newly hatched chick among experimental groups.

Table 1- Impact of colored photoperiodic light during incubation on hatching traits.

Wavelength	Egg weight	Egg weight loss %	Hatchability of all eggs (%)	Hatchability of fertile eggs (%)	Hatch window (h)	Hatching Time (h)
Dark	11.74 NS	11.81 NS	77.5 NS	86.15 NS	32.25 NS	403.75 NS
Blue	11.62	11.50	80	86.97	30	403
Red	11.55	11.42	78	87.69	29.25	400.75
green	11.52	11.61	81	87.58	28.5	400
SEM	0.11	0.08	5.25	3.31	4.88	7.13
P-value	0.792	0.30	0.156	0.625	0.147	0.203

NS: non-significant differences ($p>0.05$)

Table 2-Impact of colored photoperiodic light during incubation on embryonic mortality.

Wavelength	Early dead	Middle Dead	Late dead	Total
Dark	4.43 NS	3.46 NS	6.62 NS	12.5 NS
Blue	5.44	3.46	4.72	12
Red	4.49	4.09	4.28	11
green	5.38	3.41	4.15	11.5
SEM	2.32	2.44	1.83	3.5
P-value	0.671	0.916	0.081	0.705

NS Non-significant differences ($p>0.05$)

Table 3 -Impact of colored photoperiodic light during incubation on body weight, length and quality of quail at hatch.

Wavelength	Weight (g)	length (mm)	Quality (points)
Dark	7.68 NS	103.13 NS	8.65 NS
Blue	7.55	102.51	8.68
Red	7.77	103.30	8.85
green	7.59	102.57	8.95
SEM	0.02	0.80	0.09
P-value	0.09	0.53	0.47

NS Non-significant differences ($p>0.05$)

While no significant differences in chick weight or defects were observed in layers, broilers experienced a decrease in both under lighted incubation (Huth and Archer, 2015).Archer (2015b)found that White Leghorn chicks gained significantly more weight under white light than red light, while broilers were unaffected. Hluchý et al. (2012)reportedthat Ross 308 broiler chicks hatchedunder white light weighed more (47.17±3.08 g) than those under blue light (42.13±2.07 g).

This confirms that different strains response uniquely to light, highlighting the need for studies on how bird's embryos react to various light patterns during incubation.

Light exposure during incubation did not impacthatching time orhatch window in this study,consistent with findingsin Japanese quail (Sabuncuoğlu et al., 2018), broilers (Rozenboim et al., 2004; Özkan et al., 2012; Zhang et al., 2016; Tong et al., 2018), and layers (Wang et al., 2020).In contrast,earlier studies reporteda reduction in hatch time due to light exposure (Walter and Voitle, 1972; Fairchild and Christensen, 2000; Shafey and Al-Mohsen, 2002).According to the findings of(Hannah et al., 2020), the hatch window may be influenced by the strain, with each strain responding differently to a 12L: 12D photoperiod during incubation underblue LED.

Chen et al. (2022)showed that incubating Yangzhou goose eggs under monochromatic green light for 12 hours reduced hatching time compared to darkness (710.3 vs. 719.5 h, $p < 0.01$) with no effect on hatching window. Moreover, the result of the present study further suggest that the hatching window of Japanese quail eggs is not synchronized with Intermittent light exposure, regardless of the color of the light used.

The current study founded no differences in moisture loss percentages of eggs among the treatments, which is consistent with (Zhang et al., 2016). However, Safwan et al. (2023)demonstrated that combining red with blue or greenlight increased egg loss compared to combination of green and blue light or darkness in Japanese quail.This suggested that light heating is not a contributing factor to the results.

The duration of light could potentially serve as a crucial factor influencing moisture loss.

A study by Yameen et al. (2020)found that broilers eggs incubatedunder continuous white light exhibited greater moisture loss than those under intermittent light for 12hours daily, likely due to higher eggshell temperatures. On the other hand, Abd El Naby et al. (2021)confirmed that Black Bronze turkey eggs incubated in darkness experiencedthe greatest total weight loss compared to those incubated under red and blue light. Additionally, light intensity may alsoimpact moisture loss, where dichromatic light (green + red) at150 and 250lux was found to increase total weight loss in comparison to 350 lux or dark in Japanese quail (Ali et al., 2023).

The literature on color lighting programs during poultry incubation reveals significant contradictions. Inconsistent findings likely stem from variations in species, genetic strains, environmental conditions, and research methods. These discrepancies underscore the need for careful interpretation and additional research.

CONCLUSIONS

This study found that exposing Japanese quail eggs to different LED lightcolors at 20 lux for 12 hoursdaily during did not significantlyaffect egg weight loss, hatchability, embryo mortality, hatch window, hatching time or day-old chickquality.

DECLARATIONS

Corresponding author

Correspondence and requests for materials should be addressed to ZelalAlsaftli; E-mail: zelalsaftli@gmail.com; ORCID: https://orcid.org/0000-0001-7091-5204

ACKNOWLEDGMENTS

The authors express their gratitude to Hama University for their support of this study. Additionally, our appreciation goes out to the dedicated staff at Animal Production Department in Agriculture faculty for their care and effort toward this research.

Authors' contribution

Both authors contributed equally to research work execution, analysing, interpreting the data and manuscript preparation.

Data availability

The datasets used and/or analysed during the current study available from the corresponding author on reasonable request.

Ethical considerations

The incubation trials conducted as part of this research were carried out in strict accordance with the ethical guidelines and protocols established by the Research Ethics Committee of the funding agency. The welfare and humane treatment of all animals involved in the trials were of paramount concern, and every effort was made to ensure their well-being throughout the experimental process. Additionally, the collection and handling of data from participating farmers adhered rigorously to the principles outlined in the Data Privacy Act of the Syria. The confidentiality and privacy of farmer related information were strictly maintained, and all data were handled with the utmost sensitivity and in compliance with relevant legal and ethical standards. All methods were performed in accordance with the relevant guidelines and regulations.

Conflict of interests

The authors declare no competing interests.

REFERENCES

Abd El Naby W, Basha H, Ibrahim S and Abo-Samaha M (2021). Effects of red and blue light during the incubation of Turkey eggs on hatchability performance and expression pattern of some myogenic regulatory genes. Journal of World's Poultry Research 11(1): 129-135 https://doi.org/10.36380/jwpr.2021.17

Abdulateef S, Al-Bayar M, Majid A, Shawkat S, Tatar A and Al-Ani M (2021). Effect of exposure to different light colors on embryonic development and neurophysiological traits in the chick embryo. Veterinary World 14(5):

1284.https://doi.org/10.14202/vetworld.2021.1284-1289

Ali S, Sherzada S, Usman M, Khan E, Rehman A, Riaz M, Elahi U, Hussain M, Latif H and Saleem K (2023). Impact of different light intensities to Japanese quail eggs on hatching results and post-hatch performance. Tropical Animal Health and Production 55(6): 387 https://doi.org/10.1007/s11250-023-03780-4

Archer G (2015a). Effect of exposing layer and broiler eggs to red or white light during incubation. International Journal of Poultry Science 10.3923/ijps.2015.491.496.https://doi.org/10.3923/ijps.2015.491.496

Archer G (2015b). Timing of light exposure during incubation to improve hatchability, chick quality and post-hatch well-being in broiler chickens: 21 or 18 days. International Journal of Poultry Science 14(5): 293-299 https://doi.org/10.3923/ijps.2015.293.299

Archer G (2016). Spectrum of white light during incubation: warm vs cool white LED lighting. Int. J. Poult. Sci 15(9): 343-348 https://doi.org/10.3923/ijps.2016.343.348

Archer G (2017). Exposing broiler eggs to green, red and white light during incubation. Animal, 11: 1203-1209. Animal 11(7): 1203-1209.https://doi.org/10.1017/s1751731117000143

Archer G (2018). Effect of two different commercially available white light LED fixtures on broiler hatchability and chick quality. British poultry science 59(3): 251-256 https://doi.org/10.1080/00071668.2018.1436160

Archer G, Jeffrey D and Tucker Z (2017). Effect of the combination of white and red LED lighting during incubation on layer, broiler, and Pekin duck hatchability. Poultry science 96(8): 2670-2675.https://doi.org/10.3382/ps/pex040

Archer G and Mench J (2013). The effects of light stimulation during incubation on indicators of stress susceptibility in broilers. Poultry Science 92(12): 3103-3108.https://doi.org/10.3382/ps.2013-03434

Archer G and Mench J (2014a). Natural incubation patterns and the effects of exposing eggs to light at various times during incubation on post-hatch fear and stress responses in broiler (meat) chickens. Applied Animal Behaviour Science 152: 44-51 https://doi.org/10.1016/j.applanim.2013.12.010

Archer G and Mench J (2014b). The effects of the duration and onset of light stimulation during incubation on the behavior, plasma melatonin levels, and productivity of broiler chickens. Journal of animal science 92(4): 1753-1758.https://doi.org/10.2527/jas.2013-7129

Archer G, Shivaprasad H and Mench J (2009). Effect of providing light during incubation on the health, productivity, and behavior of broiler chickens. Poultry science 88(1): 29-37 https://doi.org/10.3382/ps.2008-00221

Chen Z, Qu X, Feng C, Guo B, Zhu H and Yang L (2022). Monochromatic green light stimulation during incubation alters hepatic glucose metabolism that improves embryonic development in Yangzhou goose eggs. International Journal of Molecular Sciences 24(1): 405.https://doi.org/10.3390/ijms24010405

Drozdova A, Okuliarova M and Zeman M (2019). The effect of different wavelengths of light during incubation on the development of rhythmic pineal melatonin biosynthesis in chick embryos. Animal 13(8): 1635-1640.https://doi.org/10.1017/s1751731118003695

Erwin W, Boone M and Barnett B (1971). Response of the developing embryo to light. Poultry science 50(6): 1883-1884.https://doi.org/10.3382/ps.0501883

Fairchild B and Christensen V (2000). Photostimulation of turkey eggs accelerates hatching times without affecting hatchability, liver or heart growth, or glycogen content. Poultry science 79(11): 1627-1631.https://doi.org/10.1093/ps/79.11.1627

Farghly M and Mahrose KM (2012). Effects of light during storage and incubation periods on pre and post hatch performance of Japanese quail. Egypt. J. Poult. Sci 32: 947-958

Geng A, Zhang Y, Zhang J, Zeng L, Chang C, Wang H, Yan Z, Chu Q and Liu H (2021). Effects of light regime on the hatching performance, body development and serum biochemical indexes in Beijing You Chicken. Poultry Science 100(8): 101270.https://doi.org/10.1016/j.psj.2021.101270

Haldar C, Fukada Y and Araki M (2003). Effects of gonadal steroids on pineal morphogenesis and cell differentiation of the embryonic quail studied under cell culture conditions. Developmental brain research 145(1): 71-79.https://doi.org/10.1016/S0165-3806(03)00215-3

Hannah W, Astatkie T and Rathgeber B (2020). Hatch rate of laying hen strains provided a photoperiod during incubation. Animal 14(2): 353-359.https://doi.org/10.1017/s1751731119002039

Hluchý S, Toman R, Cabaj M and Adamkovičová M (2012). The Effect of White and Monochromatic Lights on Chicken Hatching. Animal Science and Biotechnologies 45(2): 408-410

Huth J and Archer G (2015). Effects of LED lighting during incubation on layer and broiler hatchability, chick quality, stress susceptibility and post-hatch growth. Poultry science 94(12): 3052-3058.https://doi.org/10.3382/ps/pev298

Kołańczyk M (2020). Evaluating chick quality. *The Poultry Site [cited 2022 Jul 03]*, from https://www.thepoultrysite.com/articles/evaluating-chick-quality

Li X, McLean N, MacIsaac J, Martynenko A and Rathgeber B (2023). Effect of photoperiod during incubation on embryonic temperature, hatch traits, and performance of 2 commercial broiler strains. Poultry Science 102(6): 102632.https://doi.org/10.1016/j.psj.2023.102632

Li X, Rathgeber B, McLean N and MacIsaac J (2021). Providing colored photoperiodic light stimulation during incubation: 1. Effects on embryo development and hatching performance in broiler hatching eggs. Poultry Science 100(9): 101336.https://doi.org/10.1016/j.psj.2021.101336

Maurer G, Portugal S and Cassey P (2011). An embryo's eye view of avian eggshell pigmentation. Journal of Avian Biology 42(6): 494-504.https://doi.org/10.1111/J.1600-048X.2011.05368.X

Maurer G, Portugal S, Hauber M, Mikšík I, Russell D and Cassey P (2015). First light for avian embryos: eggshell thickness and pigmentation mediate variation in development and UV exposure in wild bird eggs. Functional Ecology 29(2): 209-218.https://doi.org/10.1111/1365-2435.12314

Özkan S, Yalçın S, Babacanoğlu E, Kozanoğlu H, Karadaş F and Uysal S (2012). Photoperiodic lighting (16 hours of light: 8 hours of dark) programs during incubation: 1. Effects on growth and circadian physiological traits of embryos and early stress response of broiler chickens. Poultry science 91(11): 2912-2921.https://doi.org/10.3382/ps.2012-02426

Özkan S, Yalçın S, Bayraktar Ö, Bilgen G, Dayıoğlu M, Bolhuis J and Rodenburg T (2022). Effects of incubation lighting with green or white light on brown layers: hatching performance, feather pecking and hypothalamic expressions of genes related with photoreception, serotonin, and stress systems. Poultry Science 101(11): 102114.https://doi.org/10.1016/j.psj.2022.102114

PIERCE M (1999). Circadian organization in quail retina: Differential regulation of melatonin synthesis and iodopsin gene expression in vitro. Visual neuroscience 16(5): 843-848.https://doi.org/10.1017/s0952523899165040

Reed W and Clark M (2011). Beyond maternal effects in birds: responses of the embryo to the environment. Integrative and Comparative Biology 51(1): 73-80.https://doi.org/10.1093/icb/icr032

Riaz M, Bergman M, Schober J, Olawagbenga E, Christensen K and Fraley G (2024). Red-green or full-spectrum white LEDs have no effects on incubation or post-hatch production variables in broilers. Journal of Applied Poultry Research 33(1): 100384.https://doi.org/10.1016/j.japr.2023.100384

Riaz M, Mahmud A, Hussain J, Rehman A, Usman M, Mehmood S and Ahmad S (2021). Impact of light stimulation during incubation on hatching traits and post-hatch performance of commercial broilers. Tropical animal health and production 53: 1-8.https://doi.org/10.1007/s11250-020-02492-3

Rozenboim I, Huisinga R, Halevy O and El Halawani M (2003). Effect of embryonic photostimulation on the posthatch growth of turkey poults. Poultry science 82(7): 1181-1187.https://doi.org/10.1093/ps/82.7.1181

Rozenboim I, Piestun Y, Mobarkey N, Barak M, Hoyzman A and Halevy O (2004). Monochromatic light stimuli during embryogenesis enhance embryo development and posthatch growth. Poultry science 83(8): 1413-1419.https://doi.org/10.1093/ps/83.8.1413

Sabuncuoğlu K, Korkmaz F, Gürcan E, Narinç D and Şamlı H (2018). Effects of monochromatic light stimuli during embryogenesis on some performance traits, behavior, and fear responses in Japanese quails. Poultry Science 97(7): 2385-2390.https://doi.org/10.3382/ps/pey105

Safwan M, Mehmood S, Sherzada S, Usman M, Hashmi S, Ali S, Rehman A, Riaz M, Elahi U and Hussain M (2023). Effects of prenatal dichromatic light exposure on hatching results and post-hatch performance of Japanese quail. Tropical Animal Health and Production 55(6): 379.https://doi.org/10.1007/s11250-023-03801-2

Şenmet-Tuğalay Ç and Bayraktar Ö (2021). The Effects of Monochromatic Lighting on Hatch Window and Hatching Performance in Broiler Breeder Eggs. International Journal of Innovative Approaches in Agricultural Research 5(3): 303-310.https://doi.org/10.29329/ijiaar.2021.378.5

Shafey T (2004). Effect of lighted incubation on embryonic growth and hatchability performance of two strains of layer breeder eggs. British poultry science 45(2): 223-229.https://doi.org/10.1080/00071660410001715821

Shafey T, Al-Batshan H, Ghannam M and Al-Ayed M (2005). Effect of intensity of eggshell pigment and illuminated incubation on hatchability of brown eggs. British poultry science 46(2): 190-198.https://doi.org/10.1080/00071660500065789

Shafey T and Al-Mohsen T (2002). Embryonic growth, hatching time and hatchability performance of meat breeder eggs incubated under continuous green light. Asian-Australasian Journal of Animal Sciences 15(12): 1702-1707.https://doi.org/10.5713/ajas.2002.1702

Tong W, Tong Q, Li B, Zheng W, Pan J, Wang X, Liu X and Jin K (2023). Effects of different light-emitting diode light on hatch performance, embryo development, eye structure, and plasma melatonin in layer incubation. Poultry Science 102(10): 102977.https://doi.org/10.1016/j.psj.2023.102977

Tona K, Bamelis F, De Ketelaere B, Bruggeman V, Moraes VM, Buyse J, Onagbesan O and Decuypere E (2003). Effects of egg storage time on spread of hatch, chick quality, and chick juvenile growth. Poult Sci 82(5): 736-741.https://doi.org/10.1093/ps/82.5.736

Tong Q, McGonnell I, Demmers T, Roulston N, Bergoug H, Romanini C, Verhelst R, Guinebretière M, Eterradossi N and Berckmans D (2018). Effect of a photoperiodic green light programme during incubation on embryo development and hatch process. Animal 12(4): 765-773.https://doi.org/10.1017/S1751731117002117

Walter J and Voitle R (1972). Effects of photoperiod during incubation on embryonic and post-embryonic development of broilers. Poultry Science 51(4): 1122-1126.https://doi.org/10.3382/ps.0511122

Wang P, Sun Y, Fan J, Zong Y, Li Y, Shi L, Isa A, Wang Y, Ni A and Ge P (2020). Effects of monochromatic green light stimulation during embryogenesis on hatching and posthatch performance of four strains of layer breeder. Poultry science 99(11): 5501-5508.https://doi.org/10.1016/j.psj.2020.06.074

Yameen R, Hussain J, Mahmud A and Saima (2020). Effects of different light durations during incubation on hatching, subsequent growth, welfare, and meat quality traits among three broiler strains. Tropical Animal Health and Production 52(6): 3639-3653.https://doi.org/10.1007/s11250-020-02401-8

Zeman M, Gwinner E and Somogyiova E (1992). Development of melatonin rhythm in the pineal gland and eyes of chick embryo. Experientia 48: 765-768.https://doi.org/10.1007/BF02124299

Zhang L, Zhang H, Qiao X, Yue H, Wu S, Yao J and Qi G (2012). Effect of monochromatic light stimuli during embryogenesis on muscular growth, chemical composition, and meat quality of breast muscle in male broilers. Poultry science 91(4): 1026-1031.https://doi.org/10.3382/ps.2011-01899

Zhang L, Zhang H, Wang J, Wu S, Qiao X, Yue H, Yao J and Qi G (2014). Stimulation with monochromatic green light during incubation alters satellite cell mitotic activity and gene expression in relation to embryonic and posthatch muscle growth of broiler chickens. Animal 8(1): 86-93.https://doi.org/10.1017/s1751731113001882

Zhang L, Zhu XD, Wang XF, Li JL, Gao F and Zhou GH (2016). Green Light-emitting Diodes Light Stimuli during Incubation Enhances Posthatch Growth without Disrupting Normal Eye Development of Broiler Embryos and Hatchings. Asian-Australas J Anim Sci 29(11): 1562-1568.https://doi.org/10.5713/ajas.15.0976