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Light wavelength on different poultry species

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Factors involved in light management of poultry include source, intensity, duration, uniformity and wavelength (light colour) of light. Research trials have examined the effects of short (blue and green) and long wavelengths (orange and red) on animal welfare, body weight gain, and egg productions in chickens, quail, turkeys, geese and ducks. Blue or green illuminations have a positive effect on body weight and red or white are beneficial to the production of eggs in chickens and quail. During the pre- and post-maturity periods of turkeys, blue light was preferred in the pre-maturity period, whereas the red or white light was better for the post-maturity period. Any noticeable change has not been observed within the body weight gain among the geese under different coloured light; whereas white-coloured light has played an important role in their egg production and semen quality. Positive results have been seen for body weight gain by exposure to red and white light in ducks. The available literature shows that different wavelengths can have positive or negative effects on welfare, body weight gain and egg production of the poultry.

Keywords: performance; poultry; wavelength of light; welfare

Introduction

Light has five basic characteristics: source, intensity, duration, uniformity and wavelength (light colour) (Manser, 1996). With the increasing importance of production and welfare, there are several studies that have investigated the effect of illumination on poultry. Smith and Phillips (1959) conducted studies related to the effects of light on turkey poults concerning feed intake which ultimately led to the production of further research and improvement in this field (Egbuniwe and Ayo, 2016). According to these studies, light wavelength (colour) affects the behaviour, welfare, growth and performance of the poultry (Manser, 1996; Prayitno *et al.*, 1997; Rozenboim *et al.*, 1999a; 1999b; Classen, 2003; Riber, 2015). The following review focuses on the effect of light wavelengths on poultry.

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Physiology of poultry's eye

The vision system of poultry is entirely different from that of humans (Barber *et al.*, 2006). Eyes are the most developed sensory organs of poultry. In comparison with humans, poultry have better visual skills including a large colour spectrum, vibration-free vision sensitivity, vision harmony and vision acuity (Prescott *et al.*, 2003). Vision constitutes 70% of their perception and the weights of their eyes are proportionally heavier than their brain. Birds have eyes positioned on the two sides of their heads with a small central binocular angle and a wide monocular angle that provides for a wide field of view (Lewis and Morris, 2006).

Visible light has a wavelength ranging from 380 nm to 740 nm, lying between invisible infrared light rays (longer wavelengths) and invisible UV rays (shorter wavelengths) (Parvin *et al.*, 2014). The human eye is most sensitive at a wavelength of 555 nm, while a bird's eye is most sensitive at a wavelength of 562 nm (Lewis and Morris, 2006). The human eye is able to perceive a very narrow area, which is between 400-700 nm wavelengths (North and Bell, 1990; Prescott and Wathes, 1999a). However, poultry are able to perceive wavelengths up to 320 nm (Prescott and Wathes, 1999b).

There are three basic factors that affect vision in poultry. These factors are retinal detection, pineal gland detection and hypothalamus detection (Lewis and Morris, 2006). The retina ensures that birds see their environment clearly and are able to react accordingly, and ensures that the effect of light is directed towards growth and behaviour (Wilson and Lindstrom, 2011). There are two types of photoreceptors in the retina: cones and rods. Unlike human beings, poultry have a pair of cone detectors (King-Smith, 1971; Kram *et al.*, 2010). Rod cells cannot perceive the colours, it can only perceive white through its rhodopsin photopigments and thus, ensures that objects be better distinguished in the dark. The cone cells contain iodopsin photopigments and possess five different subtypes of cone photoreceptors which include four single cones and one pair cone cell (Kram *et al.*, 2010; Egbuniwe and Ayo, 2016). These photoreceptors are blue (450 nm), green (550 nm), red (700 nm) and violet (415 nm), the last being different from that of humans. By means of violet photoreceptors, poultry can see UV-A rays that are below the human visual spectrum (Wortel *et al.*, 1987; Lewis *et al.*, 2007). The function of the other pair cone cell is not exactly known, but it is thought that it mediates the perception of colourless movement (Kram *et al.*, 2010). In this way, unlike humans, poultry can perceive light rays in a different form and see some light sources in a brighter form (Pyrzak *et al.*, 1987; Thrush, 1999).

The pineal gland is located in a triangular area behind the brain, between the cerebral hemisphere and cerebellum, and involves functional photoreceptors. The pineal gland has an effective role in the secretion of serotonin and melatonin hormones. These hormones play a detrimental role in the functions of circadian rhythm, various endocrine functions, mobility, body temperature and mating season of poultry (Pelham *et al.*, 1972; Prayitno *et al.*, 1997; Baxter *et al.*, 2014). If the light intensity is over 4 L (bright), it penetrates into the skull and reaches the pineal gland, repressing the secretion of serotonin and melatonin hormones (Lewis and Morris, 2006).

The hypothalamus is located in the deep brain tissue in the preoptic section of the forebrain. Depending on light intensity, the hypothalamus directly controls the gonadotropin releasing hormone (GnRH), homeostasis and physiological structure (Lewis and Morris, 2006; Baxter *et al.*, 2014). Another significant difference between birds and humans is the fact that birds are able to perceive light through extra-retinal photoreceptors in the hypothalamus and in the pineal gland (Siopes and Wilson, 1980; Foster and Follett, 1985; Lewis and Morris, 2006). Most especially, the long wavelength

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light directly penetrates into the skull and brain, then reaches the hypothalamus since it possesses a high amount of energy (Baxter *et al.*, 2014). Furthermore, lights having a short wavelength need to be implemented on high density in order to affect the hypothalamus (Benoit, 1964; Hartwig and Van Veen, 1979; Baxter *et al.*, 2014).

Different wavelengths of light directly penetrate the hypothalamus, which cause different effects (Lewis and Morris, 2006). Extra-retinal photoreceptors are considered to react to the red zone of the electromagnetic spectrum (Cedden and Göğer, 1999). It was reported that red-light having a long wavelength (>650 nm), which is penetrated to the hypothalamus, caused a total of 36 changes on ducks, 40 changes on quail and 100-1000 changes on doves.

The effects of light wavelength on different poultry species

According to previous studies, the light wavelength or light colour affects the behaviour, welfare and performance of the poultry (Manser, 1996; Prayitno *et al.*, 1997; Rozenboim *et al.*, 1999a; 1999b; Classen, 2003). Therefore, since light management affects growth, productivity, and behaviours, it is an important factor in poultry production.

THE EFFECTS OF LIGHT WAVELENGTH ON BROILERS

According to recent studies (Prayitno *et al.*, 1997; Classen, 2003) relating to the effects of light wavelength, the spectral distribution of light and susceptibility to the colour of light may vary with broiler age. In the earlier stages of development, short wavelengths (blue, green) have a stimulating effect on rapid development. When approaching maturity, long wavelengths (orange, red) have an accelerating effect on development and sexual maturity (Prayitno *et al.*, 1997; Classen, 2003).

Smith and Phillips (1959) determined that feed efficiency of broilers raised under green light was better than those raised under blue, red or orange lights. In a similar way, Rozenboim *et al.* (1999a) reported that the feed efficiency of broilers raised under green light was better than those raised under white, blue or red lights. However, Cherry and Barwick (1962) could not find any significant difference in body weight between the broilers raised under either red or white fluorescent lights.

Foss *et al.* (1972) reported that body weight in male broilers raised under green light was significantly higher than those under blue, red or white lights. The broilers raised under purple or green light grew faster than those raised under red or white lights (Foss *et al.*, 1972; Wabeck and Skoglund, 1974; Rozenboim *et al.*, 1999b). Wabeck and Skoglund (1974) found that the best feed utilisation took place in broilers raised under blue and green light. Furthermore, broilers raised under blue and green lights gave the highest body weight, whereas red light caused a lower body weight at the slaughtering age.

Prayitno *et al.* (1997) conducted two different trials in order to examine the effects of light wavelength and intensity on behaviour and leg disorders in broilers. Bright red light illumination increased the mobility and thus reduced mobility disorders. Moreover, it was suggested that illumination with stimulant light is preferable in the early rearing periods.

Lewis and Morris (2000) reported a negative interaction between body weight and light wavelength in broiler chickens raised in the light wavelength between 530-750 nm and a decrease of about 50 g in body weight for every 100 nm increase in wavelength.

Bayraktar and Altan (2005) found that the determinant factor in the performance of broiler chickens was related to spectral distribution rather than the perceived light colour. Although giving the same colour, blue or green LEDs were better than blue or green fluorescent tube lights in terms of broiler performance.

For breeding, narrow band blue (470 nm) light is more effective than the wide band

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blue light, and narrow band green (570 nm) light is more effective than the wide band green light in poultry. Green wavelength (570 nm) improved both development and feed efficiency, with increased body weight by more than 250 g (approximately 15%) and at least 0.11% improvement in the efficiency of feed utilisation at 42 days of age in comparison to other tested light colours (Bayraktar and Altan, 2005).

Khosravinia (2007) investigated colour preferences of the broiler chickens with coloured feed and light illumination in his study. The study was conducted over a course of 42 days with 2000 broiler chicks, and showed that the birds preferred green light and green coloured feeds.

Sultana *et al.* (2013) focused on the effects of single-light and mixed-light LED illumination on behaviour and fear-response on broiler chickens. Findings indicated that the red and red-yellow illuminations increased mobility of chickens and fear-responses, while the blue and green-blue illuminations reduced activity, and led the broilers to spend the majority of their time sitting.

Hogshead (2015) used 120 broilers in a study to examine the effects of light colour on performance and the immune system. Total immunoglobulin Y (IgY) levels in the serum increased at the 35th and 42nd day of age in broilers raised under red light. Maximum body weights were observed in broilers raised under blue light (3150 g), whereas the lowest body weights were in those raised under green light (2745 g).

Rozenboim *et al.* (1999a) found no significant difference in the mortality rate among the broilers raised under white, green, blue or red lights. However, Bayraktar and Altan (2005) reported that the mortality in birds under green fluorescent light reached 8.87% at week six of age which was significantly higher than other light groups (white-heat lamp, cold white fluorescent, daylight fluorescent, blue fluorescent, blue LED, low white fluorescent, green LED). The researchers attributed this high death rate to the negative effect caused by a high body weight gain which took place within the first two weeks for broilers raised under the green fluorescent lighting.

THE EFFECTS OF LIGHT WAVELENGTH ON LAYING HENS

D'Eath and Stone (1999) investigated the effects of colourful light illumination on behaviours of layer hens. Brown Lohman laying hens (84 weeks-old) were raised under white, red and blue light. Hen flocks raised under a red light affected the hierarchical order compared to the those raised under a blue light. Furthermore, individual behaviour increased under a red light when compared to a blue light.

Lewis *et al.* (2007) used 448 White Lohman laying hens in order to evaluate the effect of green light illumination, and concluded that the usage of green light in poultry houses does not have a positive effect on the growth and productivity period of laying hens. Reddy *et al.* (2012) conducted a study which raised 24 White Leghorn laying hens under an incandescent lamp providing white light for 72 weeks. Afterwards, the chickens were separated into two groups for the purpose of raising one group under a 450 nm wavelength light and the other group under a 650 nm wavelength light. Egg production from birds kept under the 650 nm light was 49.9% in the beginning of the trial and then increased to 83.3% when the chickens reached the 82nd week. For those raised under a 450 nm light production was 51.1% in the beginning of the trial and decreased to 46.4% on the 82nd week. They concluded that the extra-retinal photoreceptors located in the hypothalamus play an important role in egg production. The long wavelength can easily penetrate into deep tissues in comparison to the short wavelengths, increasing secretion of GnRH I mRNA from the hypothalamus. Under tropical conditions, red illumination used for more than four hours and less than 12 hours will affect positively egg production. The use of a long wavelength under a red light reverses the reduction of egg production.

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Hassan *et al.* (2013) conducted a study in order to find out the effects of coloured light illumination on laying hens. A total of 600 Brown Hy-Line laying hens at their 12th week of age were used in the experiment. Egg production increased for hens raised under red light in comparison to those raised under white, green or blue lights. The colour of the eggshell became darker under red light. In addition, it was observed that FSH concentration significantly increased in hens raised under the red and red-green mixed illuminations.

Borille *et al.* (2013) compared the performance of laying hens raised under different wavelength LEDs and incandescent lamps. They reared 360 Brown Lohmann laying hens under blue, yellow, green, red or white LEDs and incandescent lamps. The use of white and red LEDs did not have a negative effect on egg production, weight nor the internal egg quality parameters in the commercial laying hens. Pyrzak *et al.* (1987) reported that the highest egg production was found under red light. However, Borille *et al.* (2013) observed that the highest egg production was found under white light.

Baxter *et al.* (2014) studies the effect of light wavelength being redirected by retinal or extra retinal photo-receptors, or both. They examined the sighted or blind male and female chickens over a course of 15 weeks. The study revealed no significant difference between sighted and blind chickens in terms of egg production. Egg production was not affected by exposure to retinal stimulus. This demonstrated that red-light illumination is necessary and adequate in order to increase the number of eggs.

Svobodova *et al.* (2015) carried out a study to evaluate the effects of light wavelength on the air quality of poultry houses, performance of laying hens and the microbiological structure in egg shells. In the trial, brown ISA layer hens aged from 22 to 75 weeks old kept in four poultry houses with a total of 14,000 hens in each poultry house. Light sources included blue, green, red and yellow coloured LED lamps. It was reported that daily egg production was 83.90% under the green light, 84.77% under the blue light, 86.75% under the yellow light, and 87.01% under the red light. Svobodova *et al.* (2015) observed that the lowest mortality rate was 12.65% for the hens raised under the red light, whereas the highest mortality was 14.30% for the hens raised under the blue light.

THE EFFECTS OF LIGHT WAVELENGHT ON ROOSTERS

Lewis and Morris (2006) reported that the biggest stimulation on roosters appears when they are exposed to white or red light, regardless of any criteria taken into consideration for sexual maturity. A study with 32 days old broiler roosters showed no change in testicular weight in roosters kept under red, green, blue or white light. It should be noted that a higher level of plasma testosterone concentration was found under the blue light in comparison to the green light. Testosterone concentration at an average level was seen under the white and red light. Lewis and Morris (2006) pointed out the possibility that the 32 days-old broiler roosters might have been too young to react in a photosexual manner.

The effects of light wavelength on quail

Woodard *et al.* (1969) researched the effects of different wavelengths on egg production and egg shell strength in laying Japanese quail. Results indicated that, regardless of the weight of the egg, long wavelength (red) affects egg production and egg shell strength. These parameters were higher in birds kept under green light in comparison with blue and white lights.

Sarıca (1998) studied the effects of light colours (white fluorescent, red and green) on growth, liveability, feed consumption, feed conversion ratio, slaughter and carcass characteristics of quail during the growth period, and found that light colour applied

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to quail caused differences in body weight, liveability, feed conversion ratio and some slaughter and carcass characteristics. Observations revealed that the quail had more positive results, in terms of these properties, under green light, although this colour had a delaying effect on the development of testicles and ovaries. All of the characteristics (except liveability) showed that green light can be used during quail fattening and to delay the age of sexual maturity.

Bobadilla-Mendez *et al.* (2016) carried out research on the reproduction of quail. The aim of the research was to study the effects of different light sources on the anatomical and physiological characteristics of female quail reproduction. Light sources included an incandescent lamp, compact fluorescent and LED. White, red and green colours were used in the LED lamps within each of the three groups. LED white light illumination was the most effective in activating reproduction, accelerating the initiation of sexual maturity and increasing the development of reproductive organs.

The effects of light wavelength on turkeys

Lewis and Morris (2006) reported the effects of light wavelength on the body weight gains of 16 weeks-old males and 18 weeks-old female turkeys. They recorded the usage of red (650 nm) or white light as more effective than blue light (450 nm). Since turkeys perceive the red or white light brighter than the blue light, they had faster growth in the environment with the brightest illumination. With sexual maturity starting in female turkeys at the 18th week and male turkeys at the 16th week, it was observed that the concentration of sex hormones increased in turkeys raised under a red light, which induced the turkeys' growth. However, in the period before sexual maturity, growth was suppressed in turkeys raised under the light range starting from where the green light turns into yellow (565 nm) and then red. Therefore, commercial red and green lamps have not been suggested for use in the period before sexual maturity. The commercial green lamps correspond for 50% of green colour, as well as 25% of yellow, orange and red light and these ultimately negatively affected their growth rate. In commercial blue lamps, any problems were not found in their usage because the lamps only involve 3% of yellow, orange and red light. These findings support the use of the blue light for turkeys during the early period, while the red light was used post-maturity.

In laying turkeys, Lewis and Morris (2006) reported that red and white light illumination induced early ovarian development, and short wavelengths have a low effect on the egg production of turkey breeders. In comparison to male turkeys raised under red or white light, those raised under a blue light with a 5 L intensity resulted in less settled behaviour and lower sexual and social activities (Lewis and Morris, 2006). The researchers stated that turkeys generally prefer environments where short wavelengths are used and have a tendency to prefer blue colour. In adult turkeys, no behavioural stress indicators have been found under blue, green, red or white lighting (Lewis and Morris, 2006).

The effects of light wavelength on geese

Zeman *et al.* (1990) found that geese exhibit seasonal reproduction activity under natural light conditions. Daily lighting schedules play an important role in the initiation of egg production and is needed for sustained egg production (Gongruttananun and Guntapa, 2012).

Chang *et al.* (2016a) studied the effects of blue, red and white lights on 10-month-old

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White Roman geese. Geese raised under these coloured lights did not cause any change in weight gain. Those raised under red and white light demonstrated a significantly longer laying period, produced more eggs and liveability in comparison to those raised under blue light.

Chang *et al.* (2016b) evaluated the effects of white, red and blue light on sex hormones and the semen quality of male geese. The study used thirty, three-year-old male Roman geese, which were separated into three groups and used to observe the effects of white, red and blue illuminations. The results revealed that the different light colours did not change the levels of testosterone and oestradiol. White light ensured better quality of semen in Roman male geese (sperm mobility, sperm liveability and sperm rate) in comparison to the blue and red illuminations.

The effects of light wavelength on ducks

The preference for blue wavelengths reflects the colour type that is preferred by Pekin ducks based on their retina physiology and anatomy. (Campbell *et al.*, 2015). Short wavelength (blue-sensitive) cones of many water fowl, including ducks, have proved to be more numerous than long wavelength cones (red-sensitive). In other poultry species, the long wavelength cones are more numerous (Hart *et al.*, 1999).

Kim *et al.* (2014) examined the effects of different wavelengths produced from LED lamps on the growth and meat quality of Peking ducks. The highest body weight was found in ducks raised under the red light, suggesting that long wavelengths are needed for maximum growth. It has been determined that LED red and blue colours are useful for growth and green for increasing meat quality (Kim *et al.*, 2014). For feed conversion ratio, the best result was obtained under the green light during the early growth period and blue light in later phases (Cao *et al.*, 2008).

Campbell *et al.* (2015) examined whether previous findings claiming that blue light increased body weight and reduced stress in broilers held true for ducks. The researchers monitored 225 newly-hatched ducks under white, red and blue lights for 35 days. Performance of ducks under red light demonstrated small differences in comparison to those kept under white light. Levels of corticosterone in blood increased for the ducks raised under blue light. However, body weight, carcass quality and growth hormone (GH) levels in blood for those raised under blue light was lower than the ones raised under red or white light. Campbell *et al.* (2015) demonstrated that blue wavelengths have negative effects on growth, performance and the welfare of Peking ducks as opposed to the previous findings of broiler chickens (Rozenboim *et al.*, 2004; Zhang *et al.*, 2014). The conclusions of this study reports that the white light ensures the best possible environmental conditions for Peking duck breeding.

Lewis and Morris (2006) conducted a study on male mallard ducks (green-headed) reared under wavelengths ranging from 436 nm to 836 nm. Testicular growth was found to be high at 617 nm (orange), 664 nm (dark orange), 708 nm (light red) or 740 nm (red) wavelengths. These results indicated that the wavelength reaching the hypothalamus that affects photosexual response is between 617 nm and 740 nm. On the other hand, some studies showed that light still reached the hypothalamus at a wavelength of 400 nm, although light intake increased when the wavelength shortened.

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Conclusions

In studies on broiler chickens, green and blue light gave positive results on body weight while red light negatively affected weight gain. In laying hens, red and white light triggers the early development of ovaries and an increase in egg production. Furthermore, the highest mortality rate in laying hens occurred under blue light, whereas the lowest rate occurred under red light. In studies on roosters, the highest stimulation of sexual maturity was recorded under red and white lights. However, based on the rate of testosterone in blood, an increase was found in the use of blue light. Similar to broiler chicken responses, green light plays a major role in the overall body weight gain of quail. Turkeys kept under red light were found to have a significant increase in body weight gain after these weeks. In geese, light colours did not cause any noticeable change on body weight gain, in comparison to other poultry. Observations led to the conclusion that the most suitable coloured lights for breeding geese is white. Similarly, turkeys and chickens' most preferred light colour is red, while geese prefer white. However, ducks showed negative results in terms of circulating hormone levels in blood, performance and carcass quality when reared under blue light. The most suitable light colour for duck breeding is white. In order to optimise profit, production and animal welfare, light wavelength must be considered together with the light source when rearing poultry for growth or breeding.

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