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LED in production systems of laying hens: An alternative to increase sustainability

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The Brazilian poultry production currently has a substantial impact on the national and international economy. Brazil ranks sixth in the world rankings of the largest egg producers. However, the activity still has barriers related to management and facilities, such as high waste of electrical energy due to the low energy efficiency of the lighting systems. The artificial lighting programs represent an important management tool to accelerate or delay sexual maturity of laying, stimulate the release of reproductive hormones, increase the egg production, besides promoting improvements in the shell quality and the size of the eggs. There is a large number of lamps that are available for use in artificial lighting systems, however, each light source has different characteristics (light intensity, wavelength, color, temperature and fluctuations) which may cause positive or negative effect on hens performance, egg quality and production costs. The LED technology is an innovative alternative that can improve the sustainability of the activity, since it has better energy efficiency, longer lifetime and emits light of different colors. This literature review aims to discuss the beneficial characteristics of the LED and its effects on the production of commercial layers.

Key words: Eggs, electric energy, layer production, layers, lighting program.

INTRODUCTION

The poultry production affects substantially the international economy. In 2015, the egg production in Brazil reached 39.5 billion units. This historical record surpassed 6.1 billion units as compared to the previous

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Table 1. Correlation between the wavelength (nm) of the light and the perceptions of the different colors.

| Color sensation | Wavelength (nm) |
|------------------|-----------------|
| violet           | 380 – 435       |
| blue             | 435 – 500       |
| green            | 500 – 565       |
| yellow           | 565 – 600       |
| orange           | 600 – 630       |
| red              | 630 – 780       |

Lewis and Morris, 1998.

year (ABPA, 2016). Brazil is the sixth largest egg producer, after China, United States, India, Japan and Mexico. Brazil represents 3.34% of the world’s total egg production (SEAB, 2012/2013). Hens are photo responsive animals and the light stimulus acts positively on the physiology of the reproductive system triggering the release of hormones that are essential to maintain the egg production (Etches, 1994). The use of artificial lighting, for breeder hens and commercial layers, represents a low cost useful strategy (Mendes et al., 2010). The lighting programs encourage the growth and stimulate the reproductive system, resulting in an increased egg production (Freitas et al., 2010). The photoperiod manipulation can anticipate or delay the start of the eggs production, improve the quality of the shell and the size of the eggs, because of the feeding efficiency maximization by the light regime (Etches, 1994). Although, it seems to be a prominent picture, the poultry farming still has some barriers in terms of management and installations. One of them is the high electricity waste in its various stages of production. Therefore, the management of the electrical energy is important to reduce the final costs of the production (Jordan and Tavares, 2005; Jacomé, 2010).

Various light sources have already been tested in egg production sheds, however, studies are still performed to reach greater durability and lower cost (Nunes et al., 2013). Alternatively, to minimize energy costs, the LED has been used in aviculture due to its better energy efficiency and useful life. In addition, it is available in several colors (Molina et al., 2015).

Whereas, the LED technology is an innovative alternative and it can improve the sustainability of the activity, this literature review aims to present the beneficial characteristics of the LED and its effects on the production of commercial layers.

FEATURES OF THE VISUAL SYSTEM OF HENS

Light originates from a broad spectrum of electromagnetic waves, and the visible portion is relatively small and composed of wavelengths sized 350 to 800 nm (Nunes et al., 2013). The hens have two types of photoreceptor cells in the retina of the eyes, which are the rods and cones. The rods are numerous, with maximum sensitivity of 507 nm (blue light) and they allow the eyesight in low-light environments (<0.4 lux), but they are unable to distinguish colors. In contrast, the cones are sensitive to brighter levels of illuminance (from 0.4 to 44 lux) and they allow the color perception (Lighting, 1988; Lewis and Morris, 1998; Mendes et al., 2010).

There are three types of cones with sensitivity peaks that are responsible for the primary colors perception, which are: 450 (blue), 550 (green) and 700 nm (red), which when stimulated together produce the white color sensation (Pritchard, 1995; Lewis and Morris, 1998). In humans, the cones are responsive to electromagnetic radiation between 400 and 730 nm, with a maximum response of 555 nm. However, the hens’ eyes have an additional type of cone in the retina, and sensitivity peak is close to 415 nm, but may transmit wavelengths shorter than 400 nm. It means that the hen can see a part of the ultraviolet range and see colors differently as compared to humans.

The maximum sensitivity of hens occurs in the green-yellow band (545-575 nm) of the spectrum (Mobarkey et al., 2010), which is similar to the human beings. However, the spectral sensitivity of the hens between 400 and 480 nm and between 580 and 700 nm is higher than the human’s one. Due to this fact, birds can notice some brighter light sources as compared to the human perception, but the additional degree of brightness will vary with the source (Lewis and Morris, 1999). Table 1 presents the correlation between the wavelengths and the perceptions of the different colors.

Light is perceived by photoreceptors that transform the energy stored in the photons into biological signal. In the eye, the energy of the photons is transformed by the photosensitive pigments contained in the rods and cones, and transmitted by the neurons to the brain where the signal is integrated to an image (Etches, 1994). The perception of light through the eyes is strongly related to the behavior and the well-being of the hens. Prescott and Watches (1999) state that broiler may show behavior deviations when there is an excess or shortage of light, damaging their well-being and productivity.

Reproductive physiology and involved hormones

There are three theories to explain the effect of light on the reproductive activity of hens. One of them is through the eye, another is by the pineal gland and the third is the most accepted and is directly related to the hypothalamus (Etches, 1994). A study showed that...
dimming the head of sparrows with black paint makes its sexual response to be blocked; however, there was no effect in blocking the light access to the eye (Sauveur, 1996).

Besides the retina, the hens can notice the light through the pineal gland located in the dorsal surface of the brain. The avian pineal gland is particularly involved in the control of circadian rhythms and sexual activity (Caneppele et al., 2013). The circadian rhythm coordinates a time schedule of biochemical, physiological, immunological and behavioral events, that will determine the productive performance (feed intake, motor activity, body temperature, among others) of health of lot (Abreu and Abreu, 2011).

In the dark period, there is melatonin release, produced by the pineal gland (Huang et al., 2013). Melatonin reduces the levels of LH and FSH, both bind to their receptors in theca and granular cells of the ovarian follicle, inhibiting the production of androgens and estrogens by small follicles and the production of progesterone by prevulatory larger follicles (Rocha, 2008).

The perception of light depends mainly on hypothalamic photoreceptors that are biological transformers that convert the energy of the photon into neural impulses. These neural impulses are then amplified by the endocrine system to control the ovarian and testicular function and consequently, the multiple reproductive functions, behavior and secondary sexual characteristics (Etches, 1994).

The hypothalamus is the main hormone control center, and it is located in the basis of the brain near the pituitary. Hypothalamus receives neural, environmental and hormonal signals, inside and outside the animal, and it uses this information to control the pituitary, gonads and other organs. The neurosecretory cells of the hypothalamus communicate directly with the pituitary through the bloodstream. The gonadotropin releaser hormone or GnRH is the primary hypothalamic hormone responsible for stimulating the anterior pituitary to release luteinizing hormone (LH), follicle stimulating hormone (FSH) and prolactin (Proudman, 1994).

Young birds have high levels of LH in the early development of the ovary. The small follicles produce androgens and estrogens that result in growth and pigmentation of the comb and the wattles and growth of the oviduct. As the puberty begins, the LH performs a negative feedback on the pituitary, which lowers its secretion. The estrogen levels declines while progesterone increases, as the follicles go through maturation until they reach the necessary size for ovulation. When the follicle is mature, the high secretion of progesterone culminates in releasing of LH and ovulation (Proudman, 1994).

One of the main functions of the ovaries is the production of steroid hormones which are essential for the growth and function of the reproductive system. Progesterone acts on the secretion of albumen (follicle maturation) and peak induction of LH (ovulation). The androgens act on secondary sexual characteristics (comb and wattle). The estrogens act on the egg yolk synthesis by the liver, the calcium transport from spinal bones from the bark to the gland (Bahr and Johnson, 1991; Rutz et al., 2007).

Following this concept, the short days are not able to stimulate the secretion of gonadotropins because the photosensitive phase is not entirely illuminated. In this situation, the production and release of LH are harmed and may interfere with reproductive functions, behavior and secondary sex characteristics of birds (Etches, 1994; Rocha, 2008).

Some works have been conducted in order to evaluate the effect of different light sources on the concentration of the reproductive hormones like estradiol in the bloodstream (Gonguttananun and Gunata, 2012) and concluded that different types and colors of lamps can increase blood estradiol concentration.

**Artificial lighting system for laying poultry**

The lighting program that is used in laying poultry (laying hens and quail) aims to stimulate the reproductive tract of birds and increase the production of eggs (Etches, 1994). The artificial light is routinely used in lighting systems for commercial laying hens which may delay or accelerate sexual maturity, stimulate egg laying and improve weight gain in laying poultry and arrays (Freitas et al., 2005; Araujo et al., 2011). The delay in the beginning of the egg production through light control determines a better quality of shell, less eggs with two yolks or deformed eggs, and lower mortality due to prolapse (Araujo et al., 2011).

The light presence during the night improves the growth and adaptation to the environment in the first days of life and throughout the growing period (Nunes et al., 2014). Several light programs can be used in aviculture, but the ideal lighting program to be provided to laying poultry should be the one that provides the highest egg production with minimum feed intake and electric energy usage (Freitas et al., 2010). However, in order to achieve the required illuminance, the producers normally install artificial lighting systems composed of a large number of high-powered lamps, and low efficiency, which cause a substantial raise in the final costs (Nunes et al., 2013).

A new technology has been widespread in the poultry market as an alternative to increase the sustainability of the production system. They are the LEDs or LED. Some studies were developed in order to test LEDs use in poultry systems to replace traditional light sources (fluorescent and incandescent lights), and they have shown that the LED does not cause changes in the performance and egg quality of commercial laying hens.
as compared to other light sources, therefore, it can be used to replace the traditional lighting systems (Borrile et al., 2013; Jacomé et al., 2012).

In Brazil, the use of open poultry houses allows the use of artificial light only to complement the natural daylight period, however it does not exclude the use of strategies to minimize wastes on electric energy, considering that recently the successive increases in the electricity cost have been a barrier to the sector. According to Gongruttanun and Guntapa (2012) and Santana et al. (2014), LED is an effective technological alternative to maximize the production and reduce expenses with electric energy.

CHARACTERISTICS OF LIGHT SOURCES

There are several types of available lamps, and each one offers a different light spectrum, which influences the production and quality of the eggs (Etches, 1994). Knowing the characteristics of different sources of light and the effects of these on the physiology and welfare of birds is essential for the implementation of an efficient light program.

The visual environment has some properties, such as: illuminance (luminous flux), spatial variation of lamps, color temperature (Kelvin) and the oscillations of the lamps. The perception of these properties depends on the spectral sensibility of birds which is different from humans (Prescott and Watches, 2000; Mendes et al., 2010). Thus, the hens and humans can perceive colors differently. For example, hens can perceive ultraviolet and infrared radiation (Menes et al., 2013). Several works have been conducted (Gougruttanun and Guntapa, 2012; Silva et al., 2012; Jacomé et al., 2012; Hassan et al., 2013; Borrile et al., 2013; Mendes et al., 2013) in order to analyze the effects of different light sources on the egg quality and the performance of commercial laying hens.

The luminous intensity provided to the birds can affect the productive performance, so it is necessary to adapt the type of the lamp, taking into account the chromatic intensity oscillation, the temperature, the illuminance distribution and the quantity of lux (lumen perpendicar incidence on a surface of 1 square meter) (Mendes et al., 2010). The luximeter should be used to determine precisely the luminous intensity in lighting systems (Borrile et al., 2014).

In addition to the wavelength and the light intensity that can vary according to each production phase as well as the type of production, other important principles involved in lighting are: light incidence duration and distribution of light sources (Mendes et al., 2013). These principles can influence positively the performance of the hens (Mendes et al., 2010; Gougruttanun and Guntapa, 2012).

In order to improve efficiency and minimize production costs, different light sources have been used. Compact fluorescent lamps and sodium vapor have been used in place of incandescent bulbs, however LEDs has been used in poultry houses demonstrating positive results superior to fluorescent. LEDs provide superior illuminance and life as compared to traditional light sources used in layer hen's production.

Types of lamps

Choosing the type of lamp for a lighting program depends on a few factors such as: cost, durability, maintenance and efficiency. Using a proper light program and a correct number of lamps according to the environment, there will be no differences in the performance. However, the energy consumption can be a limiting factor to the use of certain light sources (Araújo et al., 2011).

Incandescent bulbs are commonly used to provide uniform illumination, however its conversion rate from electrical energy to luminous energy is low, which generates a large amount of heat (Jordan and Tavares, 2005; Borrile et al., 2013; Mendes et al., 2013) and provides a low durability, increasing the production costs (Jordan and Tavares, 2005).

Fluorescent lamps may be an alternative to incandescent lamps, considering that they produce greater brightness per Watt. However, its luminous intensity decreases with time, which means that luminous flux depreciation occurs. Besides, they have a higher initial cost (Mendes et al., 2013), and they are susceptible to power fluctuations. These problems make it difficult to maintain uniform light intensity in the whole livestock production cycle (Long et al., 2015). Another drawback is that the fluorescent lamp maximum efficiency occurs when the air temperature is between 21 and 27°C. If the temperature is out of these limits, the efficiency is reduced (Araújo et al., 2011). The sodium vapor lamp has also been used as a useful and saving light source (Mendes et al., 2010).

According to Etches (1994), the type of lamp that is used (incandescent, fluorescent, sodium vapor) does not matter, however it is known that each lamp offers a different light spectrum and this factor can influence the production and quality of the eggs.

Environmental lighting technology has greatly advanced in the recent years, and traditional light bulbs are being gradually replaced by light emitting diode (LEDs) lamps (Gongruttanun and Guntapa, 2012; Santana et al., 2014). The main advantage of the LED is the energy saving (80% less energy waste as compared to incandescent bulbs and 50% compared to fluorescent lamps), longer shelf life and color diversity (Molino et al., 2015).

Light emitting diode (LED)

The LED emerged in the 60s and nowadays it is
known worldwide due to its high luminous efficiency and long life (Liu et al., 2010). In addition, the cost of the technology has decreased significantly since its first development and it has become more accessible to the poultry industry (Long et al., 2015).

The light emitted by the LEDs is monochrome and the color depends on the crystal and impurity of the material that is used in the production. The light frequency emitted by the electron also determines its color (Moreira, 2009; Valentine et al., 2010). Its colors include red, orange, yellow, green, blue, violet, purple, and also ultraviolet and infrared, and it can provide a more natural environment for the hens, ensuring better expression of their behavior (Araújo et al., 2013).

Studies have been conducted in order to test different LED colors on performance and egg quality of commercial laying hens. Borriile et al. (2015) worked with laying poultry in the second production cycle, in which the effect of different LED colors was not noticed in the performance characteristics and quality of eggs. In contrast, Borriile et al. (2013) observed a better performance in laying hens exposed to red, white LED and incandescent bulbs as compared to the blue, green and yellow LED.

Evaluating three light sources, Valentine et al. (2010) observed that the LED bulbs required 12 times lower electric consumption as compared to 60 W incandescent light bulbs that have the same luminosity. Besides, the LED bulbs are 5 times smaller than a 15 W fluorescent lamp. The lifetime of a LED bulb is approximately 50,000 h while the compact fluorescent and incandescent last for 8000 and 1000 h, respectively. Therefore, the LED bulb has an 8 times longer lifespan than a fluorescent lamp and 50 times longer than the incandescent (Liu et al., 2010).

Using LEDs lamps, Gongruttanananun and Guntapa (2012) showed savings of 84.6% in the electric energy waste, as compared to red and white fluorescent lamps. Additionally, the birds exposed to the red LED have produced more eggs during the first week. Testing the same sources of light, Rozenboim et al. (1998) observed a 17% reduction in electricity using the LED.

Despite the considerable savings of the energy cost, there are still some limitations before introducing the use of LEDs. During an experiment with Dekalb white lineage, it was shown that hens exposed to the fluorescent lamps presented better feed conversion, greater egg size per housed bird and better uniformity. LED lamps caused less uniformity and its intensity decreases by 27% after 3360 h of use. Facing these results, it is necessary to deal with parameters like humidity and light spectrum. The sensibility of hens is different from humans, so it is necessary to evaluate the levels of light intensity in the different stages of production, and also the phases of the day (Long et al., 2015).

Molino et al. (2015) evaluated the effect of different sources and intensities of light in the production and the egg quality. These researchers observed a higher production, and better quality of eggs by the effect of LED and compact fluorescent lamps as compared to incandescents lamps. The best light intensity was 5 lux as compared to 10, 15 and 22 lux per m².

Nunes et al. (2014) evaluated performance, characteristics, reproductive system morphology (ovary and oviduct) and egg quality of Japanese quail exposed to green, blue, red LED and fluorescent lamps. The results showed that there was no significant difference between the treatments for performance and morphology. However, greater egg weights from the hens exposed to fluorescent lamp was observed as compared to green and blue LED. On the other hand, Jacome et al. (2012) evaluated the effect of orange, blue and white LED lamps in the production and quality of quail eggs and did not find any difference between the treatments.

Hassan et al. (2013) also evaluated the effect of LED on performance characteristics, ovarian morphology and reproductive hormones of laying hens exposed to red, green, blue LED and combinations: red x green, red x green x blue and fluorescent lamp. The results showed a greater egg production in treatments with red LED and combination of red x green, and heavier eggs were observed in treatments with blue and green LED. Estradiol and FSH levels, in the blood, were higher for LED red treatments and combination red x green. Hens treated with blue LED delayed the production with 15 days as compared to those treated with red LED. Ovarian weight and number of follicles were higher for the treatment with red LED.

CONCLUSION

According to the results presented in this analysis, it can be concluded that the LED lamps represent an efficient technology to reduce the energy costs without damaging the performance and egg quality of the commercial layers.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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