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Review

Influence of Artificial Lighting on the Performance and Egg Quality of Commercial Layers: a Review

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ABSTRACT

In Brazil, the egg production chain produces fresh eggs for the consumer market and for processing. Layers are housed in battery cage systems. Rearing and development farms are separate from egg-production farms. Considering the recent advance of Brazilian chicken egg production, scientific knowledge on management practices are required to disseminate and to consistently apply this knowledge to improve such practices. Artificial lighting is widely used in poultry reproduction, both in the production of hatchable eggs and of commercial eggs. Light is required for the release of hormones responsible for reproduction; however, the best lighting practices to stimulate laying poultry during the reproductive period still need to be determined, with the aim of saving electric energy, and therefore, to dilute production costs and comply with environmental sustainability requirements. This review showed that layers are indeed photostimulated with more than 12 hours of light, independently of the artificial lighting program applied. Results demonstrate that artificial lighting programs influence egg production, but not egg quality parameters. Intermittent lighting programs are good alternatives when layers are housed in open-sided houses, which are typically used in Brazil. Transcranial light reception is the most important route for the stimulation of reproduction in poultry.

INTRODUCTION

Chicken egg production has experienced remarkable development in the last few years compared with previous decades and with the other sectors of the Brazilian poultry industry. According to the Brazilian Institute of Geography and Statistics (IBGE, 2012), 2.563 billion egg dozens were produced in 2011, representing a 4.3% increase relative to 2010. In addition, the total number of hens housed in 2011 was 118.915 million, which corresponded to a 3.2% increase compared with 2010. Egg production and the number of hens housed are expected to increase in 2012 due to the recent opening of new markets for the exports of poultry products.

In commercial egg production systems in Brazil, birds are reared in open-sided houses, benefitting from the existing natural environmental resources, as the country is located in a tropical region, with long photoperiods. Most commercial layer houses are equipped with ventilation/exhaustion fans, side curtains, foggers, etc., to provide adequate environmental control with aim of achieving efficient bird performance. However, the technological development of the houses of the last decades did not take into account the possible limitations of the use of electric energy, considering the global trend of saving natural and non-renewable resources.

Layers have been submitted to genetic improvement to produce more eggs at a lighter body weight and with lower feed intake. As a result, egg operations need to face the challenges of supplying the high nutritional requirements of layers and of designing management practices adapted to the increasingly automated and environmentally controlled facilities and to high stocking densities. According to Pavan (2005), both in Brazil and in the USA, there is a trend of housing more hens per cage in order to reduce production costs.

An interesting aspect of the physiology of egg-laying poultry is that they do not require long and continuous periods of light. This phenomenon is called "subjective day", which indicates that adult hens in lay ignore periods of dark between the 14-16 hours of light stimulation. Subjective day is the period during which the bird is awake and physiologically active, even if it is in the dark. This allows the use of intermittent lighting programs for laying hens, which are programs that include more than one period of light (photophase) and one period of dark (scotophase) within a 24-h cycle (Gewehr & Freitas, 2007; Freitas *et al.*, 2010).

In Europe and in the USA, such programs have been tested and are widely applied for layers maintained in closed sheds. The aim is to reduce the use of artificial lighting while maintaining bird performance and concentrating egg-laying time (Ernst *et al.*, 1987; Boshouwers & Nicaise, 1993; Sauveur, 1996). Artificial lighting is a tool commonly applied to delay or to stimulate egg synthesis, as the circulating levels of the luteinizing hormone (LH) and of the follicle-stimulating hormone (FSH) increase within a single day of exposure to long photoperiods.

In Brazil, this issue is not frequently discussed because daily artificial lighting is applied for shorter periods in the open-sided houses compared with countries that rear layers in closed sheds. Therefore, research on this matter, using multidisciplinary analyses involving animal performance, environment, and electric energy consumption, and considering genetics, nutrition, and management practices, should be developed in Brazil.

Because electric energy derives from natural and non-renewable resources, its consumption should be carefully considered in animal production systems. In this context, all studies on the rational use of energy in such systems are significant, as the preservation of natural resources is essential for the sustainable development of the production chain.

This literature review aimed at analyzing the utilization of artificial lighting in commercial egg production. The effects of the different artificial lighting programs on layer performance and egg quality reported in Brazilian and foreign research studies are discussed, as well as studies on light perception by poultry and the physiological basis of the stimulation of the poultry reproductive system by light.

DESCRIPTION OF THE IMPACT OF LIGHT ON POULTRY

Light perception

Poultry perceive light through photoreceptors that transform the energy contained in photons in biological signals. In the eye, the energy of the photons is transformed by photosensitive pigments in the cones and rods of the retina, and transmitted through neurons to the brain, where the signal is integrated in an image.

However, light perception for reproductive processes does not depend on eye photoreceptors. It was demonstrated that photoreceptors in the hypothalamus are biological transformers that convert photon energy into neural impulses. These impulses affect the endocrine system that controls ovarian activity in females, and therefore, their reproductive and behavioral functions and secondary sexual characteristics (Morris, 1973; Etches, 1994).

According to Sauveur (1996), as opposed to mammals, the transcranial route is more important than the ocular route for perception of light information in birds. That author showed that darkening the head of sparrows with black paint blocked their sexual response, while depriving the eye of access to light did not have any effect.

However, considering that there are physiological differences among bird species, specific studies on this subject with egg-laying chickens are required, as they may reveal sexual characteristics that may pass unnoticed by the farmers.

Circadian rhythm

Ovulation depends on an endogenous mechanism that is closely related to external factors. The synchronization of these factors is called circadian rhythm and allows ovulation to occur regularly during lay. Layers use circadian rhythms to perceive the duration of the day and they are most sensitive to light between 11 and 15 hours after the light is turned on. During this photosensitive phase, a neural-hormonal mechanism controls the reproductive functions (Boni & Paes, 1999).

The circadian rhythm, also called biorhythm, is the physiological control of the metabolic activities of an individual by the light. Under natural lighting conditions, physiology changes during the 24 hours of the day (Freitas *et al.*, 2003). According to Sesti & Ito (2000), chickens are not constantly stimulated during the entire photoperiod, but only on two important times of this period. They are initially sensitized when the lights are turned on and then 11-15 later. This is called the photosensitive phase and will determine if the bird will perceive the day as long or short. It must be noted that birds are not stimulated when days are short, whereas long days will trigger and maintain the hormonal flow that controls ovulation.

Considering that the stimulation of reproduction requires a light period, studies on artificial lighting management to delay or to stimulate gonad activity are becoming increasingly important. Different lighting management practices have been applied to delay oviposition in broiler breeders maintained in dark house systems, and to stimulate egg laying in commercial layers submitted to continuous light. According to Boni & Paes (1999), the main objective of housing broiler breeders during the development phase in dark houses is to prevent the release of sexual hormones (around 16 and 22 weeks of age) at the same time as growth hormone release, that is, before body development is completed.

Lighting programs for layers

Lighting programs used in layer production are classified according to photoperiod into hemeral and ahemeral. *Hemera* means day in Greek. Hemeral lighting programs consist of 24-h periods divided in light phases (photoperiod or photophase) and dark phases (scotoperiod or scotophase). Hemeral programs are used in open-sided houses, which take advantage of natural light (Campos, 2000).

Hemeral programs are classified as continuous or intermittent. In continuous programs, artificial lighting complements natural lighting to stablish a long and continuous photoperiod, while intermittent programs alternate light (photophases) with dark periods (scotophases). When the number of hours of photophases and scotophases is similar, intermittent programs are called symmetrical, and asymmetrical when different photophases and scotophases are applied. Asymmetrical hemeral programs have been used in egg production for energy-saving purposes (Rowland, 1985). Such programs allow workers to perform their activities inside the house during working hours (during the day).

Ahemeral lighting programs are used to improve eggshell quality and egg size, without affecting egg production. They are applied in environmentally-controlled facilities mainly in Europe and in the United States (Ernst *et al.*, 1987). Such programs may increase labor costs because daily tasks need to be performed outside regulated working hours, which, however, could be compensated by the production of larger eggs. Ahemeral programs apply photophases and scotophases that are shorter or longer, but not equal to 24h, and may continuous or intermittent (Etches, 1996).

Some intermittent programs have specific designations: the Cornell program and the biomittent program. In the Cornell program, 2 hours of light (2L), 4 hours of dark (4D), 8 hours of light (8L), and 10 hours of dark (10D) are supplied (2L:4D:8L:10D). It was developed by Tienhoven and Ostrander (1976) at Cornell University. The bird interprets this program as 14L:10D, ignoring the period of four hours of dark and considering a night period of 10 hours. The program was created to allow farmers to perform their eight hours of activities during the natural photoperiod.

The biomittent lighting program consists of fractioning the time of alternate light and dark cycles (25%L:75%D). According to Morris & Butler (1995), the objectives of the programs are to increase egg size and to improve eggshell quality. In the biomittent program, only 15 min of light are supplied per hour during the stimulation period, which may be interesting as it reduces lighting in 75% and improves feed efficiency in 5-7%. However, studies have shown that egg size is reduced in 0.5-1% when this program is applied (Rowland, 1985).

Morris *et al.* (1988) demonstrated that the Cornell program reduces electric energy consumption and feed intake and promotes higher egg production. On the other hand, despite reducing feed intake, egg size and weight are also reduced when the biomittent program is applied before hens are 22 weeks old (Morris *et al.*, 1990).

Light intensity

Egg production is reduced if light intensity is insufficient (Ostrander & Turner, 1962). Therefore, a luxmeter should be used to precisely determine light intensity in layer houses. The minimum light intensity required for maximum egg production is 5.38 lux in dark houses for layers (Skouglund *et al.*, 1975). According to Cotta (2002), in open-sided houses, 10 lux are needed at cage or bird's head height. This recommendation is accepted by the Illuminating Engineering Society of North America (IESNA, 2001), which performed a study that determined that a daily period of 14 hours of light for optimal egg production and that more than 17 hours of light negatively affect egg production. Because the visual system of chickens respond to light radiation within the visible spectrum range of 664-740 nm, the lamps used in layer houses should emit light within this range. The IESNA (2001) also recommends 10 lux as minimum light intensity for egg production. Light intensities higher than 10 lux do not bring any additional benefits and in fact may have negative effects on egg production as they may favor aggressive behaviors, hyperactivity, and cannibalism among hens.

Application of lighting programs

Both photoperiod and light intensity affect egg production. Lighting programs are fully integrated in modern layer management, with clear effects on performance. However, the light spectrum of each type of lamp needs to be considered, independently of lamp type (incandescent, fluorescent, sodium vapor, etc.), as mentioned by Etches (1996). Birds perceive not only the colors visible to humans, but also those in the shorter and longer ends of the spectrum. Birds are particularly sensitive to ultraviolet light, producing more reproductive hormones (Boni & Paes, 1999); however, not all lamps used for the artificial lighting in poultry production supply this wavelength.

Artificially changing the photoperiod is one of the most powerful management tools available for breeding poultry. It may delay or advance the onset of lay, synchronize egg-laying time, and influence egg production rate, eggshell quality, feed efficiency, and egg size (Etches, 1994). The reproductive system is not stimulated when days are short. On the other hand, long photoperiods stimulate the sexual function of layers and increase egg production. Long days are those which photoperiod is longer than 12 hours (Etches, 1996).

Several hypotheses were proposed in the past to try to explain the relationship between the reproduction cycle of poultry and photoperiod, but according to Sauveur (1996), none was proven. Rowland (1985) highlights two theories proposed for commercial poultry. The photoinductive theory assumes the presence of an endogenous rhythm (biological clock) with a cycle of around one day that is called circadian rhythm. The natural variation of the daily photoperiod acts as a conditioning factor of this clock, having a synchronizing role. The second theory is called photosensitive theory and assumes the presence of a model of external coincidence. Cycles of light and dark "train" the body to produce hormones during a specific period. The theory tries to demonstrate that birds are not equally sensitive to light during the day, and present maximum sensitivity 10-15 hours before dawn. Therefore, only long days are photostimulating (Sauveur, 1996). The second hypothesis, according to Malpaux *et al.* (1996), allows including periods of dark during the light phase, as these periods of dark are ignored by the birds. These hypotheses are not mutually exclusive. The model of external coincidence offers a better explanation because it was demonstrated in several experiments (Rowland, 1985), but neither theory make any restrictions as to the use of intermittent lighting for the stimulation of reproduction.

One of the most interesting physiological phenomena of breeding poultry is that they do not require long and continuous periods of light. Egg production can be stimulated by intermittent lighting programs (cycles of light and of dark). This lighting management is based on the concept of subjective day, which is the period during which the bird is awake and physiologically active, despite being in the dark. This concept allows including periods of dark during artificial lighting periods to stimulate egg production, shortening the artificial lighting period, but has no negative effects on performance.

Intermittent programs are based on the concept of subjective day. This theory assumes that mature laying hens in lay that were previously trained to a continuous and long photoperiod require only the information that their biological day is starting or ending, and ignore periods of dark within the time required to stimulate lay. This information can be given by a mere flash of light, and the bird thereafter ignores intermediate periods of dark. Understanding this phenomenon allows the application of intermittent lighting programs for layers. The concept of subjective day is illustrated in studies carried out with chickens and later with quails by Bacon & Nestor (1975). This theory was globally accepted after the 1980s, and was imprecisely called lighting program applied at the end of the laying cycle to improve eggshell quality (Sauveur, 1996). An intermittent lighting program may be defined as a program that includes more than one period of light (photophase) and one period of dark (scotophase) ina 24-h cycle. Evaluating the effect of intermittent lighting programs on layer performance, Morris (1973) concluded that they can be applied in commercial egg production, and should be further explored.

Freitas *et al.* (2005) compared the effects of an intermittent lighting program, natural lighting on days of increasing lighting, and a continuous lighting program on the performance of layers at the end of the laying cycle. The authors concluded that the intermittent lighting program or only natural lighting on days of increasing lighting can be applied in open-sided houses to maintain performance.

Gewehr & Freitas (2007) published a literature review on the utilization of intermittent lighting programs for layers maintained in open-sided houses, discussing different lighting programs, the physiological basis of light stimulation of reproduction, and research results. They concluded that the results obtained until then indicated that intermittent lighting does not negatively affect the performance of commercial layers.

Further research is needed to elucidate some aspects of the physiological processes involved in egg synthesis; however, studies have shown that intermittent lighting programs do not interfere with the physiology of egg synthesis.

Lighting of layer houses using light-emitting diode (LED) technology

Rozenboim *et al.* (1998) evaluated a new lighting system using monochromatic light for layers. In total, 45 layers were distributed in 15 cages per room (3 per cage) and submitted to three treatments: 0.1 and 0.01 $W.m^{-2}$ light intensity using LED lamps or 0.1 $W.m^{-2}$ using compact fluorescent lamps (PL or control treatment). In each LED room, three wavelengths were tested: 560 nm (n=9), 660 nm (n=9), 880 nm (n=6), as well as 660 using intermittent lighting (15 min light and 45 min dark) (n=9). In the room with PL lamps, birds were exposed to 12 h of light and 12 h of dark. At 21 weeks of age, the light period was increased to 12.75 h using 5.5 h with LED lamps and 7.25 h with LP for groups 1 and 2, and group 3 received 12.75 h of PL lighting. Up to 28 weeks of age, lightning was increased by 0.5 hour per week of light for all three groups until 16 h of light in week 28. Egg production and feed intake data were collected daily, and eggs for egg component analysis were collected weekly for 10 weeks. The authors concluded that, when optimal light spectrum is used, light intensity can be dramatically reduced, causing significant reduction in feed intake. A significant reduction in egg production, however, was observed in all groups exposed to 880 nm. This lighting method may benefit farmers as it allows reducing production costs. The obtained feed intake and electric energy cost reductions may increase net income in 20-30%, depending on feed costs. It was also observed that 0.01 $W.m^{-2}$ light intensity significantly reduced feed intake, independently of light spectrum. In this experiment, egg weight was not affected by light color or intensity.

Er *et al.* (2007) evaluated the effect of LED lighting on the egg quality of commercial layers. Hy-line layers were exposed between 19 and 52 weeks to 15-lux light intensity for 16 hours daily, using blue, red, green LED or incandescent lamps placed on top of each cage. The results showed that layers exposed to incandescent light laid heavier eggs than those exposed to red LED lamps, which produced the lightest eggs. Blue LED light reduced egg length and width, and changed egg shape, which became progressively round as hens aged. Red LED light reduced egg width, and egg shape became longer as hens aged. Egg weight tended to decrease with age when hens were exposed to blue and red light compared with green and incandescent lights. The quality of the eggs laid by layers exposed to green light were the most affected and was better compared with the other treatments.

Xie *et al.* (2008) evaluated the effect of monochromatic LED lighting (red, green, white, or blue) on the immunity of broilers reared up to seven weeks and did not find any differences in antibody titers among birds exposed to blue, green, and white light. The authors concluded that blue and green LED light had a stronger effect in terms of enhancing the immune response compared with red LED light, and that blue LED light may alleviate the response to stress of broilers.

Borille *et al.* (2008) compared the performance of commercial layers submitted to artificial lighting by LED lamps with different colors and conventional incandescent lamps. In total, 360 ISA Brown layers, 56-week-old at the start of the experiment, were exposed to six light sources: blue, yellow, green, red, and white LED lamps and incandescent 40-W lamps. A 17-h of continuous lighting program was adopted, and birds were fed a diet based on corn and soybean meal. Egg production was significantly different among the treatments, and the best results were obtained under red and white LED and incandescent lamps. The authors also observed that egg weight, feed intake, and internal egg quality (albumen height, specific gravity, and Haugh units) were not influenced by light source, and concluded that the replacement of incandescent lamps by red or white LED lamps does not have any negative effect on the egg production of commercial layers.

Chen *et al.* (2008), studying the effect of artificial lighting on broiler performance and myofiber growth, reared 276 broilers under artificial lighting using red, green, blue, or white LED lamps. In the starter phase (0-26 days), broilers maintained under green monochromatic light had the best performance, whereas in the next phase (27-49 days), those reared under blue light presented better performance. The authors demonstrated that blue and green light promoted myofiber growth due to more effective stimulation of testosterone secretion.

FINAL CONSIDERATIONS

This review showed that layers are indeed photostimulated with more than 12 hours of light, independently of the artificial lighting program (continuous or intermittent) applied.

Results demonstrate that artificial lighting programs influence egg production, but not egg quality parameters. Literature suggests that egg-laying species show the same behavior relative to the physiology of egg synthesis, ovulation, oviposition, and ovulation cycle.

Intermittent programs are good alternative for lighting of layers maintained in open-sided houses, which are typically used in Brazil for commercial egg production, because such programs provide better cost-benefit ratio.

It is well established in literature (Mobarkey *et al.*, 2010) that birds perceive light through both the transcranial and ocular routes. However, the transcranial route is more important for the stimulation of reproduction in commercial layers (Foss *et al.*, 1972; Rocha, 2008; Oishi & Lauber, 1973). On the other hand, endogenous hormonal rhythms may be synchronized by ocular route, indicating to the birds the times to sleep, to awake, and to feed (Jácome, 2009; Rocha, 2008). Considering the need of a light period and the perception of light through the cranial route to stimulate reproduction, studies on the regulation of artificial lighting to delay or to activate egg laying are increasingly important. Their results can make significant contributions to improve the management of commercial layers and broiler breeders during the rearing and development phases.

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