Best practice lighting management for Australian layers

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by L. Hewitt

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Foreword

In a recent consultation exercise (conducted by Australian Eggs) with industry leaders, lighting was identified as an area where concentrated development and extension projects would be of great benefit.

This is a critical review of science-based evidence and best management practices relating to lighting for laying hens, and recommendations for further research and extension (with associated materials in the form of factsheets) to encourage continuous improvement within the industry.

This project was funded from industry revenue which is matched by funds provided by the Australian Government.

This report is an addition to Australian Eggs Limited's range of peer reviewed research publications and an output of our R&D program, which aims to support improved efficiency, sustainability, product quality, education and technology transfer in the Australian egg industry.

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About the Author

Leisha is a consultant on animal welfare practice, industry standards and quality assurance frameworks, with a particular emphasis on animal welfare at slaughter. She has held research and lecturer positions at Murdoch University (WA) and Bristol University Vet School, where she managed the Veterinary Continuing Education Unit and contributed to the Animal Welfare Training programme. As part of the Animal Welfare Training Group at Bristol she was responsible for the implementation of training programmes and consultancy activities, particularly in the area of livestock production, transportation, stunning and slaughter. She is a member of the OIE technical committee on the killing of farmed reptiles and has been called upon in a technical expert capacity by OIE, Government and Meat Industry bodies, RSPCA and EFSA panel.

She holds a PhD in Clinical Veterinary Science, an MSc Meat Science, BSc Agriculture and Environmental Science (Honours in Animal Science), Cert IV in Training and Assessment, Post Graduate Certificate of Education, and Diploma in Quality Management. Leisha is a qualified Lead Auditor and Animal Welfare Assessor.

Other current research topics include:

- development of animal welfare standards and practical assessment protocols across a broad range of livestock species and systems
- risk analysis of pig production and processing
- development of outcome-based measures and practical tools to assess animal welfare
- welfare assessment of new technologies in livestock production and processing
- review of commercial stunning methods in poultry.

Leisha is a specialist in the development and implementation of animal welfare standards. She has been involved in the development, implementation, verification and review of numerous livestock conformity assessment schemes; relating to farms, abattoirs, hatcheries and packing stations.

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Abbreviations

CFF	Critical Fusion Frequency
EFSA	European Food Safety Authority
FCR	Feed conversion ratio
h	Hour
H:L	Heterophil:Lymphocyte ratio
min	Minute
nm	Nanometre
OIE	World Organisation for Animal Health (formerly ‘Office International des Epizooties’)
RSPCA	Royal Society for the Prevention of Cruelty to Animals
TI	Tonic Immobility

Executive Summary

The project is a critical review of science-based evidence and best management practices relating to lighting for laying hens, and recommendations for further research and extension (with associated materials in the form of factsheets) to encourage continuous improvement within the industry.

In a recent consultation exercise (conducted by Australian Eggs) with industry leaders, lighting was identified as an area where concentrated development and extension projects would be of great benefit.

Globally, layer chickens are housed in a variety of different systems - including outdoor enclosures, which utilise natural daylight; and large caged units, which incorporate predominantly artificial lighting programmes. The increasing environmental complexity seen in laying hen systems is an effort to drive productivity and address welfare concerns. Lighting is a complex topic because it includes several characteristics (photoperiod, intensity, and spectral composition), which have many interactive effects.

This review considers lighting conditions during the pullet rearing and laying periods. It considers the effect of lighting on bird welfare (health and behaviour) and production (laying performance, onset of lay, egg weight, growth, and timing of sexual maturity).

In addition to the review of scientific literature, a series of interviews with industry leaders (producers and technical experts) were conducted. The aim of this exercise was to provide context to the scientific research and provide a practical insight into optimum lighting conditions.

The review also presents a number of recommendations for further research and industry extension, in the context of the current understanding of production requirements, animal welfare concerns and advancement in lighting technology.

1 Introduction

Lighting is a critical factor in the management of livestock, which can influence health, productivity and welfare. It is a complex topic because it includes several characteristics (photoperiod, intensity, and spectral composition), which can have many interactive effects. Modern poultry systems (both egg and meat production) use the manipulation of light in an attempt to control behaviour and improve production.

Light can influence many biological responses in birds – for example, growth, hormone levels and immune status. Poultry also have extra-retinal photoreceptors in several parts of their brain that are directly sensitive to light (Lewis & Gous, 2009; Pan et al., 2014; Karakaya et al., 2009). These photoreceptors are involved in the regulation of sexual maturation and behaviour (Lewis & Gous, 2009), diurnal patterns and activity levels (Karakaya et al., 2009). Hence, lighting programmes directly (through the eye) and indirectly influence many physiological processes, including laying, growth rate, skeletal development, and behavioural issues. With laying hens, light influences the development and function of the bird's reproductive system, influencing the age at which a hen starts laying and the number of eggs produced. In pullets, light manipulation influences the rate sexual maturity is reached and the corresponding start of egg production (Bolla, 2007).

The effects of photoperiod, wavelength and light intensity on meat chicken health and production (stimulation and control of feed intake and growth) has been studied extensively in the past, but there have been fewer comparative studies in laying hens. In laying hens, the effects of photoperiod have been studied, however, the impact of light intensity and spectral composition is not as well understood, and the scientific results show some inconsistency. The main effects that have been found are generally deleterious effects of long photoperiods, continuous illumination, continuous darkness, low illuminance and coloured light on the integrity of the eye and on bird behaviour (for example, feather pecking and cannibalism). The positive production benefits of lighting, namely hen day egg production (rate of lay), feed conversion, weight gain, sexual maturity and egg weight have not been studied scientifically to the same extent, however, there is an increasing amount of industry information and opinion (based on experience) available. Relevant definitions relating to poultry lighting and the terms used in this review are included in Section 2.1. Terms included in Section 2.1 appear in **bold** in the document to aid cross-referencing.

Jurisdictions have established legislation in lighting conditions for poultry, with standards and guidelines for poultry production imposed or recommended by organisations such as the Royal Society for the Prevention of Cruelty to Animals (RSPCA), major supermarket retailers, and the Australian Government. Legislation and standards focus on the provision of appropriate lighting to allow for the following:

- adequate flock inspection
- access to feed and water
- minimising abnormal or injurious behaviour
- supporting optimal production
- providing rest periods for birds and allow for appropriate behaviours
- supporting normal eye development and bird health.

Most commercial poultry are produced in indoor housing, with the majority of birds being exposed to artificial lighting rather than natural daylight. Factors such as photoperiod (light-dark cycles), light intensity, wavelength (and therefore type of light source) will all exert separate and combined effects.

During pullet rearing, lighting programmes are primarily used to control the rate and age at which pullets reach sexual maturity. The overall aims of a lighting regimen during pullet rearing are to:

- stimulate feed intake;
- influence sexual maturity; and
- control undesirable behaviour.

Once laying hens are moved into a production environment, the aim of a lighting programme is to:

- maximise egg numbers;
- control egg weight;
- influence time and location of egg-laying; and
- control undesirable behaviour.

Photoperiod, light intensity and wavelength all have implications for laying hen welfare and production, and are manipulated by producers to varying degrees to achieve the desired outcomes.

2 Methodology

A search of scientific and technical literature published in the period 2000 to 2018 was carried out using Web of Science (Thomson Reuters, New York). The searches were carried out in the period February-July 2018. References were collated in an Endnote® Database (Thomson Reuters, New York). Relevant articles were those that described the influence of lighting conditions in laying hens. Articles relating to broiler chicken production, as they related to health and production parameters, were also considered where appropriate. Titles and abstracts of the retrieved documents were screened against structured inclusion/exclusion criteria, and the remaining 144 articles were read in full during preparation of the review. The scope of the review does not extend to lighting conditions for parent stock, breeding, incubation and hatching.

In addition to the literature review, nine people participated in an interview process to gather background information for this review, broaden its scope and provide a practical context to the reported science. The respondents included seven producers and two specialist poultry advisors (a veterinarian and a breeding company representative). Their overall perception was that poultry lighting was a complex area with serious repercussions for production, bird health and welfare if not effectively managed. They felt that much of the scientific information and extension material was written in a European context and did not always take into consideration the Australian environment and farming systems.

During the interviews, respondents were asked to nominate areas where future research effort would be best directed, to improve the understanding of effective lighting management. All respondents believed that additional research and development was needed, however, they also held the view that further education and extension material directed towards producers was also required.

2.1 Lighting definitions

In this review the following terms and definitions apply:

Age at first lay	The day when 50% of hens lay an egg.
Ahemeral	When the total period of light and dark does not equal 24 hours (either shorter or longer). For example, a dark period of 14h followed by a light period of 14h. Cycle lengths up to around 28 hours are used.
Critical fusion frequency (CFF)	The lowest frequency at which a flickering light source is seen as continuous.
Fluorescent	An electric light where electrical current is used to excite mercury vapour, producing short-wave ultraviolet light and causing a phosphor coating on the inside of the light to glow.
Hemeral lighting	When the total period of light and dark equals 24 hours
Hen day egg production	A percentage that reflects the number of eggs produced by a flock that day (or period of time) divided by the number of birds in the flock. Also called rate of lay.
Incandescent	An electric light with a wire filament heated to such a high temperature that it glows with visible light (incandescence).
Intensity	The quantity of light falling on the unit area of a surface.
Intermittent lighting	More than one light and dark period in 24 hours.
LED	Light-emitting diode.
Lux	A measure of light intensity, measured as lumen per m2, where lumen is a measurement of the intensity of the radiation. Standard lux meters simply measure the intensity of the radiation in the range between 300 and 800 nm (visual light).
Monochromatic	Of a single wavelength or frequency (containing only one colour).
Photoperiod	The period of light given to birds in a 24-hour period.
Scotoperiod	The period of darkness given to birds in a 24-hour period.
Sexual maturity	The time point when the birds reach 5% of their hen day egg production.
Spectral composition	The wavelengths that make up light.
Spectral sensitivity	**Colour sensitivity bright conditions.**
Step-up/step-down lighting programme	Raising or decreasing light regimens at various stages of production to give a longer/shorter light period.
Tetrachromats	Organisms possessing four types of cone cell in the eye.
Trichromatic	Colour vision that is sensitive to all three primary colours.
Wavelength	Measure of light (in nanometres). One wavelength equals the distance between two successive wave crests or troughs.

3 Avian vision

Key points

- Poultry are tetrachromats, meaning that they see colour differently and at a different intensity to humans.
- Poultry have their maximum sensitivity in the 545-575 nm part of the light spectrum.
- Poultry can see in the UVA part of the ultraviolet part of the spectrum.
- Light is perceived by retinal and extra-retinal photoreceptors, meaning that the brain is also simulated by light that passes through the skull.
- Poultry lighting programmes (and introduction of artificial light) can potentially affect the birds' ability to use their visual system to its fullest extent.

This short section describes the pathway of light transmission in poultry and the processes that take place following photoreception. The work on avian vision normally compares and contrasts the vision of birds with that of humans, highlighting anatomical differences and the consequential effect on how light is perceived.

Poultry have large eyes, relative to the size of their brain, located on the side of their head. The position of the eyes provides them with a wide-range of monocular vision and limited binocular vision. Within the eye there are two types of photoreceptor cell, termed rods and cones. Rods are associated with vision in low light conditions, whilst cones are responsible for vision under normal daylight conditions.

Poultry have four types of cone in the retina of the eye (making them **tetrachromats**), and this means that they are likely to see colour differently from **trichromatic** humans (Lewis & Morris, 2000; Lewis & Gous, 2009; Pan et al., 2014). Both humans and poultry have their maximum sensitivity in the same part of the spectrum (545-575 nm), but poultry are more sensitive to the blue and red parts of the spectrum (Lewis & Morris, 2000). The fourth retinal cone also allows them to see in the UVA part of ultraviolet radiation (wavelength range of 350-450 nm), in addition to blue, red and green. The estimation of a hen's visual range is light with a wavelength of 350 to around 780 nm (Lewis & Gous, 2009; Karakaya et al., 2009; Durmus & Kalebasi, 2009). Furthermore, the sensitivity to each colour, which depends on the density of specific photoreceptor types, is different between birds and humans (Figure 3-1). For example, chickens perceive red light 3 times brighter than humans. This superior capability to see colour (Hodos, 2012) and a wider spectrum of wavelengths suggests that birds see complex light (like white light) differently to humans.

Light is perceived by retinal and extra-retinal photoreceptors. The reproductive system of birds is not stimulated by the light that is observed by the eye, but by light that stimulates the pituitary glands, after passing through the skull. The longer wavelengths (red) of visible light are more capable of reaching the brain than shorter wavelengths.

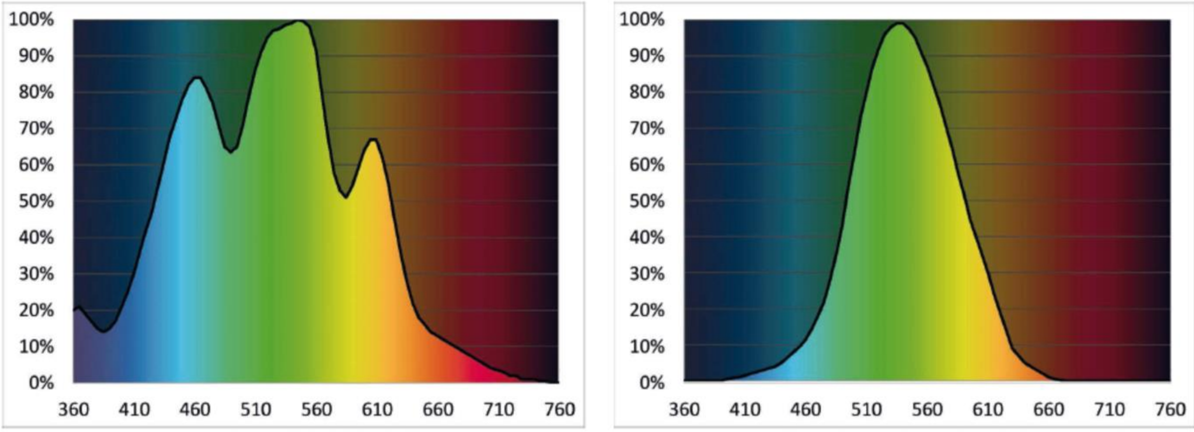

Figure 3-1 Chicken (left) and human (right) phototopic spectral response

Adapted from Hy-Line International Technical Services Team factsheet – Prescott and Wathes, 1999; Schubert, 2006.

Poultry lighting programmes (and introduction of artificial light) can potentially affect the birds' ability to use their visual system to its fullest extent. For example, the use of an inappropriate spectral output may have implications for the development of deleterious behaviours such as feather pecking, where a lighting environment rich in red wavelength may attract birds to a spot of blood or inflamed skin.

4 Important aspects of lighting

4.1 Photoperiod

Key points

- Conventional lighting programmes comprise of a single period of light (photoperiod) and a single period of darkness (scotoperiod) in 24 hours.
- Step-up or step-down programmes involve increasing or decreasing the length of the light period throughout production (with or without a change in intensity of light).
- Poultry are photoperiodic animals that rely on changes in photoperiod to time reproduction.
- Most of the work on photoperiod is related to broiler chicken production, though there is a body of evidence that relates to pullet rearing and egg laying.
- Intermittent lighting programmes involve using more than one photoperiod within a 24-hour period.
- Ahemeral lighting programmes are not common in Australia and are therefore not considered in detail.
- Intermittent lighting programmes are becoming more common in Australia, particularly in an effort to reduce costs associated with egg production.

A conventional lighting programme comprises of a single period of light (**photoperiod**) and a single period of darkness (**scotoperiod**) in 24 hours (**hemeral** lighting programme). Lighting programmes that do not cycle every 24 hours, but may be longer or shorter, are called **ahemeral.** Photoperiods can be described as constant or changing. Constant photoperiods involve providing poultry with the same length of light period (within each 24-hour period) throughout production. Changing photoperiods (also known as **step-up** or **step-down** programmes) involve increasing or decreasing the length of the light period throughout production.

Comparing the relative influence of photoperiod, illuminance and wavelength on poultry, the biggest response is associated with changes in photoperiod. Photoperiodic responses depend on the type and age of the bird. Studies on the impact of photoperiod on productivity, health and behaviour are primarily focused in broiler chicken production research. Commercial broiler production is not generally designed to accommodate sleep and rest, with lighting regimes manipulated to give increased feeding opportunities. Therefore, in broiler chicken production systems, the photoperiod is generally long (with a short dark period), hence most research in this area focuses on either continuous or near-continuous lighting conditions. A wider range of photoperiods are used in pullet rearing and laying hen systems, although these have not been studied to the same extent. Interpretation of the literature on the effects of photoperiod is complicated by the practice of step-down and step-up programmes (Downs et al., 2006) as many of the studies focus on the effects of a constant photoperiod.

Intermittent lighting programmes involve using more than one photoperiod within a 24-hour period. This use of this type of programme has only just started to emerge in Australia and has received relatively little scientific attention in laying hens. There are three categories of intermittent light programme for layers: asymmetrical patterns, symmetrical patterns with full light, and symmetrical patterns with restricted light (Lewis et al., 2001; Morris, 2004).

Biomittent lighting (15 min light and 45 min darkness repeated for 15 h, then 15 min light, 30 min dark and 15 min light, followed by 8 h darkness) is an example of an asymmetrical pattern. This type of pattern saves electricity and, more importantly, reduces feed consumption without any alteration in rate of lay or egg size, and can be used in imperfectly blacked out houses where light infiltration is possible (Morris, 2004).

Interview respondents

- All of the respondents felt that photoperiod is the single aspect of lighting that has the biggest impact on birds during rearing.
- The vast majority of respondents used a single photoperiod (constant or changing) during both rearing and laying.
- Some producers have introduced intermittent lighting for newly placed chicks and for programmes where midnight feeding had been introduced in an attempt to improve feed intake during the cooler part of the day.
- It was commonly agreed that lights off time should be consistent to allow birds to anticipate and prepare for the dark period.

Recommendation

Research, development and extension needs to be focused on:

- the benefits of intermittent lighting particularly for young chicks after placement
- the potential impact of intermittent lighting on production and welfare in pullets and laying hens
- the topic of midnight feeding, to ensure that it does not impact negatively on production and welfare of laying hens
- the benefits on intermittent lighting from a cost saving perspective (reduction in energy and feed costs).

4.2 Light intensity (illuminance)

Key points

- Light intensity (illuminance) is generally measured in lux.
- Lux is not an appropriate measure for illuminance as perceived by poultry.
- This has led to a degree of inconsistency between studies that report the effects of light intensity or wavelength.
- Sunlight can provide light of a high intensity, including exposure to UV radiation.
- Some poultry systems use a dawn/dusk sequence to increase and decrease intensity gradually between light and dark periods.
- Light intensity must be sufficient to allow poultry to be inspected and personnel to work safely.
- Light intensity at placement must allow chicks to find food and water.

Light **intensity** (illuminance) is the quantity of light falling on the unit area of a surface. It is generally measured in **lux**, which is a photometric unit calculated from the spectral power output of a light source and the sensitivity of the human eye. As previously discussed, despite having their maximum sensitivity in the same part of the spectrum (545-575 nm), there is a difference in sensitivity to certain wavelengths between humans and poultry. However, poultry are more sensitive to the blue and red parts of the spectrum, meaning that the 'lux' is not an appropriate measure for illuminance as perceived by poultry (Lewis & Morris, 2000; Prescott et al., 2003). This has led to a degree of inconsistency between studies that report the effects of light intensity or wavelength, and as such a degree of caution should be taken in regard to interpretation of data. An alternative measure, specific for illuminance as perceived by poultry (galliluminance), has been developed, however, this measure is rarely accounted for in studies on the effects of light colour on poultry, which usually provide the same lux for different colours. This may lead to confounding information when studying the effects of colour and intensity (Lewis & Morris, 2000).

Another source of light is natural sunlight, but its effects on chicken behaviour and welfare has not been significantly researched, even though is has relevance to free range systems. The light intensity of natural light on a sunny day may be as high as 100,000 lux (Kristensen et al., 2007), and it also provides UV radiation (Lewis & Gous., 2009), which is not always emitted by artificial light sources. The provision of natural light has been shown to influence behaviour (Lewis et al., 2000; Richards et al., 2011), and health (EFSA, 2010; Bailie et al., 2013).

It has also become more common in poultry systems to adjust intensity gradually between light and dark periods, thus providing birds with a dawn/dusk period to help them prepare for the light/dark period (Tauson, 2004). No recent studies could be found on the welfare advantages of providing progressive light programme transitions at dawn and dusk, apart from empirical observations that birds appear more distressed with abrupt light changes, especially with a large contrast between light and dark. The ability of hens to habituate to abrupt light changes has not been scientifically investigated.

Recommendations for light intensity may vary depending on the housing system (caged vs non-caged systems). In practical terms, light intensity must be of a sufficient level to allow the flock to be inspected, including the monitoring of bird health, feed and water consumption, and behaviour. It is also important that chicks at placement are provided with sufficient light to allow them to find feed and water. Recommended light intensity for the first 3-7 days (20-50 lux) is generally higher than for the rearing/growing period for commercial flocks (5-10 lux) (Aviagen, 2014; Hy-line, 2016a; Hy-line, 2016b).

Interview respondents

- The majority of interview respondents felt that dawn/dusk sequences were not important in a caged laying system.
- The majority of interview respondents regarded the use of a dawn/dusk sequence during rearing as particularly important, especially as young birds may be susceptible to fright during light and dark period transitions. One producer felt that this was particularly important in cage rearing systems.
- One producer felt that dawn/dusk sequences are a useful feature of the overall system, but was concerned that they allow birds to habituate to abrupt darkness, for example during a power failure.
- Three producers felt that extended dimming periods may increase smothering, therefore when dimming used it should be done relatively quickly (around 5 minutes, rather than 15 minutes) to get birds to settle quickly for the dark period.
- One producer specifically stated that dawn/dusk sequences were helpful in aviary systems when birds were being trained to jump. It helped to encourage birds up on to the slats, therefore reducing the likelihood of floor eggs.
- One producer routinely used a sequence of turning lights off (as an alternative to dimming intensity) as means of providing a dawn/dusk period. They felt that this had a positive effect on encouraging birds to move into roost areas.

Recommendation

Research, development and extension needs to be focused on:

- determination of the aspects of natural light that are crucial for behaviour and welfare of the adult hen; including any perceived aversion or preferences for natural light
- the effects of the intensity of natural daylight, including impact of UVA
- the impact of dawn/dusk dimming, particularly in relation to length of dawn/dusk period and the possible relationship with reported smothering incidents in pullets
- the use of sequential lights off (as an alternative dimming light intensity) to provide a dawn/dusk period.

4.3 Light source

Key points

- Different light sources are used to illuminate hen facilities, determining the wavelength that birds are exposed to.
- There has been a general move towards lighting systems with a greater longevity and energy efficiency.
- LEDs are being increasingly selected as the lighting system of choice by producers.
- Some types of artificial light may be perceived by hens to flicker, which may or may not be detrimental to their welfare.

A variety of light sources is used to illuminate laying hen facilities, including **incandescent**, **fluorescent** and more recently, **LED** light sources. Incandescent light bulbs have been gradually replaced by fluorescent or high-pressure sodium vapour lamps in many poultry houses because of longer bulb longevity and lower electrical usage. More recently, LEDs have been increasingly selected due to their energy efficiency and low maintenance requirements (Min et al., 2012). In some jurisdictions, it is mandatory to phase out conventional light based systems and gradually replace them with more energy efficient alternatives.

As mentioned in Section 4.4, the type of light source used will determine the wavelength that poultry are exposed to, which may or may not be have a positive impact on the hen. Light wavelength from different light sources ranges as follows:

- Fluorescent: 400-700 nm (Mohammed et al., 2010)
- Incandescent: 600-700 nm (Mohammed et al., 2010)
- High pressure sodium: 550-650 nm (Vandenberg & Widowski, 2000)
- LEDs (white light): 500-600 nm (Mohammed et al., 2010)

In the past, light sources were selected based on the human perception of light and the need for workers to perform husbandry duties in the poultry house. Little thought was given to the possibility that poultry may have a different visual perception of the lighting conditions provided.

Some types of artificial light may be perceived by hens to flicker, which could be detrimental to their welfare (Lisney et al., 2012). How this is perceived is dependent on the brightness of the light source and frequency of the current emitted by the light source (Mohammed et al., 2010). The lowest frequency at which a flickering light source is seen as continuous is known as the **critical fusion frequency** (CFF). CFF has been estimated for hens using a variety of techniques (electroretinograms, 100-118 Hz: Lisney et al., 2012; discrimination tasks, 71.5 Hz: Jarvis et al., 2002; 87-100 Hz: Lisney et al., 2011; 68.5 to 95.4 Hz: Railton et al., 2008), with behavioural methods estimating the CFF threshold as slightly lower than physiological measurements. However, under most conditions, it is thought that most chickens do not perceive flicker above 95 Hz. Mohammed et al. (2010) suggested that low 50 Hz currents emitted by some light sources may be perceived as flickering and therefore be stressful to chickens. However, the most references to this phenomenon suggest that poultry are probably not aware nor adversely affected by the flicker of artificial lighting (see review by Prescott et al., 2003). As the industry switches to more cost-effective lighting systems, research is needed to provide evidence-based information on the best alternatives to ensure optimum production without negatively impacting production and welfare.

Interview respondents

- Producers highlighted that there is a big technology gap between older farms and the modern systems that are more tailored to the needs of the chicken and energy efficiency.
- Producers stated that they were particularly interested in the use of reducing costs through the selection of energy efficient lighting systems and the refinement of lighting protocols (e.g. intermittent programmes or reduction in photoperiod).
- A large proportion of respondents felt that there was insufficient information on the different lighting technologies available and how they can be integrated into existing systems.

Recommendation

Research, development and extension needs to be focused on:

- the potential for chickens to discern flicker and the CFF associated with different light sources (for example, with AC and DC light sources)
- the use of sequential lights off to reduce intensity rather than using dimming equipment, which may have implications for flicker etc.
- the strength of hens' preference for certain light sources
- the use of novel technologies that are compatible with existing circuitry
- the production and welfare impacts of LED lighting (and other novel lighting alternatives) in poultry rearing and laying systems.

4.4 Spectral composition (wavelength)

Key points

- The optimum light spectrum for poultry is different from humans as birds can see a wider spectrum of wavelength (and hence colour).
- Spectral composition is determined by the type of light source used.
- Natural light has an even wavelength distribution between 400 and 700 nm.
- Artificial lighting is made up of long wavelength or shorter wavelength light.
- LEDs give monochromatic light.
- It is difficult to interpret the effects of spectral composition on production and welfare without the confounding effect of light intensity (as perceived by poultry).

Spectral composition (wavelength) is determined by the type of light source used (e.g. incandescent, high pressure sodium, fluorescent and LED lights), with different sources stimulating the retinal and extra-retinal photoreceptors of poultry differently. Natural light has an even wavelength distribution between 400 and 700 nm, and artificial illuminants will be made up of either mainly long wavelength light (e.g. incandescent lights) or shorter wavelength light (e.g. most LEDs).

A variety of light sources is used to illuminate laying hen facilities, including incandescent, fluorescent and, more recently, LED light sources. Fluorescent and incandescent sources that are used to produce coloured light have a varied spectral composition. LEDs have an advantage in this respect, as they give **monochromatic** light. Incandescent, fluorescent, and high pressure sodium lamps all have a defined spectrum based on their physical properties, however, LEDs can be manufactured to deliver any type of spectral output (including UV) and are thus most likely the technology of the future.

There are a number of early studies that examine the scope of behaviours and productivity of poultry under different light sources or colours, however, the intensity of the light (as perceived by poultry) for each waveform is different, meaning that it is difficult to directly compare the effects of colour in isolation. Therefore, the variation in observed responses of poultry to different wavelengths of monochromatic light may be due to the fact that the studies confound wavelength with light intensity (because treatments were wrongly equated for radiance or illuminance) (Lewis, 2010).

Interview respondents

- Producers have different preferences for light source, though do not consistently consider the impact of the waveform associated with their chosen lighting system.
- The majority of producers do not routinely use light colour, though will often use coloured lighting to manage behavioural issues.

Recommendation

Research, development and extension needs to be focused on:

- the effect of spectral composition (with appropriate adjustments for illuminance) to allow the true impact of waveform to be evaluated
- the effect of light source on wavelength needs to be provided, to enable producers to make an informed choice when purchasing new lighting equipment.

5 Effect of lighting on production

Key points

- Lighting is often manipulated in an attempt to influence production parameters in laying hens (FCR, feed intake, egg weight, number of eggs and date of first lay) and broiler chickens (growth and weight gain, feed intake, FCR, activity, carcass damage).
- This section will consider the impact of photoperiod, light intensity and wavelength on production parameters as they relate to:
  - growth and sexual maturity
  - egg production and quality.
- The majority of studies on the impact of lighting on growth and feed efficiency focus on broiler chickens.
- Laying hen studies focus primarily on timing of sexual maturation and egg production (numbers and egg weight).
- The impact of lighting on morbidity and mortality is discussed in Section 6.

5.1 Growth and sexual maturity of pullets

5.1.1 Effect of photoperiod on growth and sexual maturity of pullets

Key points

- The main effect of photoperiod during the rearing phase is the impact on the timing of sexual maturity.
- Growing pullets respond more to a change in photoperiod than to the initial or final photoperiod.
- The distribution of the light cycle (e.g. intermittent light periods of various durations) may be important but, comparatively, has received little attention in scientific studies.
- Interpretation of the literature on the effects of photoperiod is further complicated by the practice of step-down and step-up programmes, which have not been studied to the same extent as constant photoperiod.
- The majority of studies find no effect of photoperiod upon production parameters (relating to growth and feed efficiency) in broiler chickens.
- Achieving target body weight at the appropriate age is best for optimal sexual maturation following photostimulation.
- The optimum programme for pullets is considered to be an 8-10 h photoperiod followed by photostimulation with 14 h at 16-22 weeks of age.

In controlled environment housing, most pullets (layers and broilers) are placed at a day old and are provided with continuous (or near continuous) light for up to the first 72 hours. It was thought that this stimulated early feeding and subsequently reduced mortality during the critical period. However, industry is now moving towards a more intermittent programme of lighting during the first few days (Hy-line, 2016, 2016b), during which chicks are provided with shorter periods of darkness interspersed throughout a 24-hour period. Young chicks are photorefractory at this stage and need to be exposed to short days to prepare them for photostimulation prior to the laying stage (Lewis & Morris, 2006).

The main effect of photoperiod during pullet rearing is the influence on **sexual maturity** (Min et al., 2012; Liu et al., 2017). An important factor affecting the timing of sexual maturation is the age at which the changes in day length are given (Lewis et al*.,* 2002). Changes in photoperiods rather than the photoperiod itself are key to adequately stimulate the hypothalamo-pituitary-gonadal axis in pullets. Applying constant lighting during pullet rearing is equivalent to raising birds under stimulatory photoperiods and results in a lack of photosensitivity (photorefractoriness) (Lewis & Morris, 2006).

Once photosensitivity has been established, a pullet could respond to stimulation even if growth and development is not completed. Therefore, it is important to maintain short day photoperiods to allow time for sexual maturity to be controlled. Once the pullet reaches an age at which sexual maturity can be induced (related to body weight and ranging from 16 to 22 weeks of age depending on the strain), the photoperiod can be increased. Achieving target body weight at the appropriate age is best for optimal sexual maturation following photostimulation (Romero et al., 2009). Thus, producers take both age and body weight into consideration when adjusting photoperiod during rearing and stimulation of pullets.

The impact of various lighting programmes during the pullet stage and potential carry over effects into lay were studied by Lewis (2002), who examined different photostimulation protocols for pullets and concluded that the optimum programme was an 8-10 h photoperiod followed by photostimulation with 14 h at 16-22 weeks of age. Even though an abrupt photostimulation does promote earlier onset of lay (and hence the total number of eggs produced during a cycle), with advances in technology and sophistication of light controllers, producers can spread photostimulation over a longer period, with 15-30 minute increases in photoperiod per week (Bedecarrats & Hanlon, 2016). Overall, research suggests that any deviation up or down from 10 h in pullets will negatively impact the age at first egg, as a result of juvenile photorefractoriness. Modern laying strains do not appear to show the same degree of photorefractoriness as earlier strains of laying hen. Pullets of modern strains mature at about the same age whether reared on constant short (8 h) days or constant long (18 h) days (Lewis et al., 2002)

Common understanding within the industry is that growing pullets on short days reduces feed intake and suppresses growth, which may be partly responsible for the delay in sexual maturity. However, the findings of Gous and Morris (2001), in which pullets were given *ad lib* feed, showed that shorter day length did not retard sexual maturity through limitation of nutrient intake. Interestingly, Pullets on day lengths >10 h mature later despite eating more feed, though the reasons are not clear (Lewis & Morris, 2006).

Growing pullets respond more to a change in photoperiod than to the initial or final photoperiod themselves. For example, transferring pullets from long to short days tends to suppress ovarian development or activity, whereas transfers from short to long days stimulate ovarian activity. A 10 h day can act either as a long day, when it follows a period of shorter days, or as a short day when it follows a period of longer days. This makes the point that it is the contrast between the current and the preceding photoperiod that is important (Morris, 2004).

The use of intermittent programmes as an alternative to constant photoperiod has also recently received more attention as a possible tool for influencing body weight and time to sexual maturity. Das and Lacin (2014) observed higher production parameters under continuous light than constant (16L:8D) or intermittent lighting (4L:2D), while other studies found the opposite, with production parameters improved in broilers raised under intermittent light compared to continuous light (Abbas et al., 2007; Durmus & Kalebasi, 2009; Yang et al., 2015).

In broiler chickens, photoperiods of up to constant or near-constant light (e.g. 23 hours light and 1 hour dark), have been commonly assumed to improve production parameters, providing more time for feeding, leading to faster growth and higher body weight (Malleau et al., 2007). However, the majority of studies find no effect of photoperiod upon production parameters (Lien et al., 2007; Onbaşilar et al., 2008; Bayram & Özkan, 2010; Lewis et al., 2010).

Practically, the usual advice is to avoid any increase in day length for growing pullets (because it induces early sexual development), and to avoid any decrease in day length for laying birds (because it can impact on production). In lightproof houses this can be implemented quite easily, however, if pullets are likely to be exposed to natural daylight (ingress of light, for example), then supplementary light should be used to provide a constant photoperiod. It is important that day length is not reduced at point of lay, and this is a critical consideration when pullets are reared with exposure to natural daylight and then moved to a lightproof laying house.

Interview respondents

- With respect to lighting schedules for pullet rearing, producers tend to follow the recommendations from breeding companies, sometimes with minor adjustments.
- It was felt by approximately half of the respondents that chicks should be provided with a dark period during the first 24 hours.
- One interview respondent described the impact of the intensive selection of laying hens for earlier sexual maturation and the continued selection for lower adult body weights and lower feed consumption (smaller birds producing more eggs with better feed conversion) by primary breeding companies. They felt that this had resulted in some modern commercial laying birds showing signs of sexual maturation when under non-stimulatory photoperiods.
- A number of respondents stated that once the lighting pattern during pullet rearing has been selected to bring the flock into lay at the right time (and with the right egg for the market), it is relatively unimportant what pattern of lighting is used in the laying house.
- A large proportion of respondents thought that producers were generally not aware of the importance of blackout rearing to control the onset of sexual maturity. This means that it is common to see over stimulation during the rearing period.
- Most producers emphasised the importance of including the dawn/dusk sequence as part of the lighting period to avoid the early stimulation of pullets.

Recommendation

Research, development and extension need to be focused on:

- the impact of lighting during rearing to avoid problems during production
- the importance of reducing change for birds between rearing and lay, e.g. use lighting conditions in rearing that reflect those used in production. The aim of this is to influence positive behaviours before unwanted behaviours become established
- the process of bringing birds into lay (e.g. extension material on effects of lighting on bringing birds into lay, i.e. at what age and body weight should birds be stimulated)
- the importance of monitoring uniformity as birds approach lay (i.e. timing, frequency and sampling procedure).

5.1.2 Effect of light intensity on growth and sexual maturity of pullets

Key points

- Sexual maturation can be affected by very low light intensities.
- Only minimum light intensity is required to stimulate the hypothalamus and pineal gland.
- The light intensity threshold for stimulation is close to 2 lux.
- Chicks require a minimum light intensity of about 20 lux for the first three days after hatching in order to learn to find food and water.

Sexual maturation can be affected by very low light intensities (Lewis & Morris, 2006) and a minimum of 2 lux from 14 weeks of age is required for pullets to reach sexual maturity (approx. 105 days) (Morris, 2004). Although the threshold for stimulation is close to 2 lux, it is regarded as good practice to use a higher range of intensity for rearing houses, with a minimum of 10 lux to allow for personnel to work safely and to allow for some variation in intensity in different parts of the house. In some studies and industry information, there is an emphasis on the production benefits of ensuring that housing is thoroughly blacked out during rearing (Morris, 2004). Light filtering into blacked-out houses may have the effect of supplementing the intended artificial day length inside the house. If stray light is above 2 lux, birds can be stimulated into production. Morris (2004) recommends that this can be managed practically (particularly where houses are not completely lightproof) by rearing layer-strain pullets on a constant day length of 12 or 14L.

Low light intensities are often used in the broiler industry, based on the perception that they improve feed efficiency, however, there is little scientific evidence to support this advantage. In broilers, many studies have shown no effect of light intensity (at normal commercial levels) on broiler production, feed consumption or FCR (Kristensen et al., 2006; Lien et al., 2007; Blatchford et al., 2009). Though some differences are evident when very low (1-5 lux) compared to high (100-150 lux) are used (Deep et al., 2010). Greater early growth rates under long and bright photoperiods, as opposed to short and dim photoperiods, result in greater breast meat development, perhaps due to an acceleration of the progression of the growth of different carcass parts (Schwean-Lardner et al., 2006; Lien et al., 2008, 2009; Downs et al., 2006).

Interview respondents

- Respondents were very different in their approaches to light intensity during rearing.
- The general opinion amongst respondents was that young birds reared away from the hen require a minimum light intensity of about 20 lux for the first three days after hatching in order to learn to find food and water.
- The majority of respondents reduced intensity quickly after the first three days until pullets were transferred to the laying accommodation.
- A smaller number of respondents felt very strongly about using a higher light intensity during rearing to enable birds to become accustomed to the typical conditions that they would experience in the production environment.

5.1.3 Effect of wavelength on growth and sexual maturity of pullets

Key points

- Multiple photoreceptor types are present in several areas of the chicken brain.
- The role of these photoreceptors during photostimulation is unclear.
- Research on wavelength has mainly been concentrated on broilers, and positive effects of LED lighting have been found on performance.
- Sexual maturation is stimulated by red light.
- Sexual maturation is unaffected (may be inhibited) by light in the green spectrum.

Recent studies have confirmed the presence of multiple photoreceptor types in several areas of the chicken brain (Kuenzel et al., 2015), although the role of these photoreceptors during photostimulation has not been clearly established (Bedecarrats & Hanlon, 2016). Light from the red spectrum has been shown to trigger sexual maturation and stimulate egg production in hens (Mobarkey et al., 2010; Min et al., 2012; Hassan et al., 2013; Huber-Eicher et al., 2013; Baxter et al., 2014). However, whether this effect is through the stimulation of photoreceptors that are specifically sensitive to red light, or results from the higher penetration of red light remains to be determined. Light from the green spectrum was ineffective in triggering sexual maturation in chickens, and may in fact be potentially inhibitory (Mobarkey et al., 2010).

Research on the impact of wavelength has mainly been concentrated in broiler production, and positive effects of LED lighting have been found on performance (Mendes et al., 2013; Riber, 2014). One useful feature of light emitting diodes (LEDs) is that they are produced in all monochromatic colours and all possible polychromatic colour temperatures, making it possible to adjust the spectrum of the light to meet requirements. Parvin et al., 2014 studied the use of LEDs as a source of monochromatic light to determine its impact on meat quality in poultry. LEDs emitting blue, green and yellow wavelength were shown to improve meat quality parameters, resulting in softer breast and drumstick muscles, whilst white light improved lean meat and the amino acid content of meat. Cao et al. (2012) also found that combinations of monochromatic light (compared to single chromatic light), particularly green and blue, enhanced productive performance in broilers. However, a study by Jang and Velmurugu (2009) found that, with the exception of FCR, light colour had no significant effect on broiler production (growth and feed intake). Long et al. (2015) found some potentially negative production effects, associated with wavelength manipulation, such as poorer plumage quality and reduced food conversion.

5.2 Egg production and quality

5.2.1 Effect of photoperiod on egg production and quality

Key points

- An increase in photoperiod will stimulate reproduction, whereas a decrease in photoperiod will terminate lay.
- Early sexual maturity maximises egg numbers but gives smaller eggs. Late maturity maximises egg size at the expense of egg numbers.
- Intermittent lighting does not increase egg yield but offers a saving in feed consumption, related to the amount of darkness (i.e. resting time) inserted into the working day.

Laying hens rely on environmental and internal (metabolic status and body condition) cues to time reproduction (and hence egg laying). Environmental cues include photoperiod. Increasing photoperiod (photostimulation) triggers the activation of the reproductive system. Variation in photoperiod can be achieved using different lighting regimes as follows:

- continuous lighting
- photostimulatory
- ahemeral lighting programmes.

When artificial lighting systems were first introduced, initial studies evaluated continuous lighting programmes. It was believed that because seasonal breeders laid the most eggs during the longest days, exposing birds to continuous light would increase the rate of lay rapidly. However, this hypothesis was disproven with many studies showing no advancement in production with the use of continuous light. In fact, constant lighting inhibited the expression of reproductive maturity (described in Section 5.1) and resulted in a lower rate of production over the entire cycle. Continuous lighting from pullet rearing to production is not used commercially, though is regularly used at placement.

Photostimulatory programmes refer to the transfer of pullets from short (usually 10L or less) to long (12L or more) photoperiods. Multiple iterations have been developed and tested over the years (many reviewed by Lewis & Morris, 2006). This is the most common approach taken in industry for the lighting for laying birds, and was used by all the producers interviewed. As described in Section 5.1, pullet rearing can involve decreasing, constant or increasing photoperiods prior to stimulation.

Beyond sexual maturation and age at first egg, it has been proven that photostimulation is required to increase production levels during the early laying period. Sudden increases in the photoperiod lead to an earlier onset of lay, compared to slow step-up light hours, which delay sexual maturity and therefore lay (Thiele, 2009). However, with step-up lighting egg weight is improved by 1.3 g on average, but at the expense of 1.2% in total production (Lewis & Morris, 2006). As consumers generally prefer large eggs, this can be beneficial for the producer and lead to better returns. Thus, slowly stepping up light hours at weekly intervals using a time clock or computer has been adopted by some of the producers interviewed, and is recommended by primary breeders (Hy-line, 2016a, 2016b).

Ahemeral lighting programmes involve photoperiods that are not synchronised with a 24 h day. The concept of ahemeral lighting is based on the belief that if the total light and dark period matched the average time between eggs, there would be less pause days. It has been found to improve eggshell quality and egg weight, though reduces production. This lighting programme is not commonly used in industry as it is also difficult to align it with management schedules. For example, adding 2 h means an inversion of the workday schedules after 6 days. In turn, this change in work schedule will dramatically impact egg collection and routine maintenance, which could be challenging in commercial operations.

Durmus and Kalebasi (2009) found that birds exposed to an intermittent programme produced larger eggs, however, there was no difference in the age that sexual maturity was reached when either an intermittent or constant programme was used, probably because natural lighting was used for both treatment groups during the growing period. Some researchers are more skeptical of intermittent lighting programmes once lay has been established (Morris, 2004), stating that the only real benefit to production is the reduction in feed consumption, with no loss in output. This is particularly useful for producers with lightproof laying houses.

Intermittent lighting does not increase egg output (Morris, 2004; Ma et al*.,*2013) but can affect egg weight and shell thickness. This is attributed to the fact that shell formation typically occurs during the dark period under standard lighting protocols, therefore calcium availability could be increased by providing a light period in the middle of the dark period to stimulate midnight feeding (Joly, 2012). Midnight feeding is also seen as a beneficial practice, allowing birds to feed in the cooler part of the cycle (Morris, 2004).

The use of intermittent lighting programmes is often in conflict with poultry standards where, for example, they do not provide the bird with 8 hours of continuous darkness. It is felt by researchers that there is no rational basis for this limitation, as the evidence shows that mortality rates are actually lower for those intermittent lighting systems that deliver less light than the controls with which they are compared (Abreu et al., 2011; Lewis et al., 2010; Baser et al., 2010; Classen et al., 2004). A study by Geng et al. (2014) suggests that an intermittent photoperiod of 12L:2D:4L:6D is optimal for the birds' performance to give the lowest broodiness rate and the highest egg-laying rate during the whole laying period in native laying hens. Durmus and Kalebasi (2009) reported that the use of an intermittent lighting pattern (as an alternative to a step-up 16 h lighting programme) resulted in a significant increase in egg weight. However, no difference in **hen day egg** production was found.

Photorefractoriness is the inability to respond sexually to an otherwise stimulatory day length. The condition is dissipated by exposure to about 2 months of non-stimulatory photoperiods, so that sexual maturation can occur when day length increases again (for example, in spring). It can also be terminated by markedly reducing illuminance when birds are held on long days. Photorefractoriness has been almost eliminated from egg laying strains of chickens, due to the intense selection for egg numbers.

Interview respondents

- A maximum photoperiod of 16L is the basis of Australian standards. All of the producers interviewed felt that this may not be appropriate for Australian conditions. A longer day length to allow 17L for summer batches was recommended.
- A number of respondents were keen to investigate the use of intermittent lighting programmes to increase production and reduce costs, however, they were concerned about the potential conflicts with industry standards.

Recommendation

Research, development and extension need to be focused on:

- the use of intermittent programmes from rearing and through production as a means of reducing costs and correlating with worker hours, etc.

5.2.2 Effect of light intensity on egg production and quality

Key points

- An increase in light intensity is used to improve production, though high intensities may reduce production and quality.
- The recommended light intensity for laying houses is a minimum of 10 lux.
- The extent to which light intensity influences the reproductive efficiency of laying hens is not consistently reported in scientific studies.
- Variation in light intensity throughout caged systems impacts on production and quality parameters.

In laying birds, light intensity is also used as a way of improving production parameters through the manipulation of egg production (Renema et al., 2001). Egg production is associated with photoperiod and the intensity of light received by the bird. Light stimulates the anterior lobe of the pituitary gland through the optic nerve, for the release of follicle stimulating hormone (FSH) and luteinising hormone (LH). FSH increases the growth of the ovarian follicles and, upon reaching maturity, the ovum is released by the action of LH. While the eye is not essential for light stimulation of the hypothalamus in poultry, it may still be the primary site of light reception at low intensities and, as a consequence be relevant in controlled environment houses, particularly in low light intensities. The recommended light intensity for laying houses is a minimum of 10 lux, although the physiological threshold for response to changes in photoperiod is closer to 2 lux (Morris, 2004).

The extent to which light intensity influences the reproductive efficiency of laying hens is not consistently reported. Renema et al. (2001) found that the impact of light intensity on egg production is also influenced by strain, with brown egg strains appearing to be more susceptible to the negative effects of low or high light intensity, indicating the importance of matching management practices to the particular hen genotype. They found that light intensities of 1 lux and 500 lux limited the egg production efficiency of layers. The birds that received 1 lux showed a reduced rate of egg production, and those receiving 500 lux showed reduced egg and reduced shell quality.

Renema and Robinson, 2001 indicated that the effects of light intensity on egg production and quality are likely to be modulated by the impact of light intensity on feed intake. Leeson and Lewis (2004) found that mean egg weight, shell deformation, feed intake and body weight gain in lay were not significantly affected by the light intensity treatments during the rearing period. There was, however, a small but significant negative correlation of egg numbers with mean egg weight, although this only partially explained the difference in egg numbers. Variation in light intensity in multitier cage systems in semi-confined laying hen houses may also contribute to depressed laying performance and egg quality. Egg production increased, and egg weight, eggshell thickness and strength decreased as light intensity increased from the bottom to top cages (Yildiz et al., 2006).

Interview respondents

- The majority of respondents felt that the lighting intensity during the final stages of rearing should mirror that in the laying shed, particularly when birds are being moved into sheds with natural light. In these circumstances, a minimum intensity of 20-25 lux during rearing was considered to be suitable.
- Producers were cautious about reducing light intensity to manage behaviour during production, and felt that it should only used as a last resort to manage behavioural issues.
- One producer consistently used high light intensities during rearing as it was felt that birds reared in <10 lux did not perform as well as birds reared in higher light intensities.
- Some producers described the practice of switching lights off during the day to reduce power bills, however, they were aware that this was risky as it could lead to fluctuations in light intensity (which could have an affect on production even when photoperiod was effectively managed).

Recommendation

Research, development and extension need to be focused on:

- the impact of lighting conditions, particularly intensity, on production and aspects that influence production, e.g. prevalence of floor eggs
- the management of specific bird strains as related to their response to light intensity.

5.2.3 Effect of wavelength on egg production and quality

Key points

- Egg laying in poultry is under the control of deep brain photoreceptors, which require light with a high energy for penetration (i.e. red spectrum).
- Egg production and fertility is stimulated by red light.
- Egg production is inhibited by green light.
- Egg production is inhibited by blue light.
- Egg size is improved by exposure to green or blue light, compared to red light.
- Shell thickness is improved by exposure to green light, compared to red and blue light.
- Egg shell strength is improved by exposure to green light, compared to white and blue light.
- Egg length and width is reduced by exposure to blue light, compared to other wavelengths.

It has long been considered that spectral composition, particularly the amount of long wavelength red light, is important for stimulating egg laying in birds. Sexual maturity and development in pullets is known to be associated with the use of red light (Huber-Eicher et al., 2013; Baxter et al., 2014; Liu et al., 2017).

Huber-Eicher et al. (2013) studied the effects of light colour (to equal perceived intensities) on production parameters in laying birds. The results showed that light colour had effects on production parameters, with red light (640 nm) enhancing early laying performance (22 weeks), though there was no significant difference between lighting treatments on FCR and **age at first lay**. This improvement in early laying performance seen with red light supported findings by other researchers (Gongrattananun, 2011; Gustafsson & von Wachenfelt, 2009; Mobarkey et al., 2010; Borille et al., 2013; Huber- Eicher et al., 2013; Hassan et al., 2014). Svobodová et al. (2015) found that light colour did not affect hen-day egg production. Hassan et al. (2014) found that production was the lowest in blue lighting conditions.

The wavelength effect on the egg weight, egg length, egg width, eggshell index and eggshell quality has also been reported (Wang et al., 2007; Er, et al. 2007; Svobodová et al., 2015). Some authors found that light colour did not affect egg weight (Svobodová et al., 2015; Rozenboim et al., 1998 cited in Wang et al., 2007). Whereas other studies found that monochromatic lighting had an impact on egg quality characteristics (Pyrzak & Siopes, 1986 cited in Wang et al., 2007; Wang, 2007). Wang, 2007 concluded that egg weight was the lowest in red light, heaviest in white light, with the best quality shell in green light. Er, et al. (2007) and Hassan et al. (2014) also found that green light had the most profound effect on improved eggshell quality. Svobodová et al. (2015) also found that light colour only had minor effect on microbial contamination of the eggs.

Long et al. (2015) investigated the effect of LED vs. fluorescent lighting for laying hens in aviaries. They could not find any difference in egg weight, hen-day egg production, feed use or mortality rate between both lighting regimes. However, hens under fluorescent lights did have higher eggs per hen and better food conversion compared to the hens under LED during 20 to 70 week production.

Very little research studies the impact of UV radiation on egg production and quality. Lewis et al. (2010) found that UV suppressed food intake but did not influence the timing of the ovulatory cycle. It was suggested that UV (at the intensity used in this study) acts principally at the retinal level and, as a result, stimulates only behavioural responses in laying birds.

Recommendation

Research, development and extension need to be focused on:

- the impact of wavelength on production parameters (in light of the increasing popularity of monochromatic light sources).

7 Effect of lighting on bird health

Key points

- This section will consider the impact of photoperiod, light intensity and wavelength on bird health as it relates to:
  - mortality
  - pathological conditions, such as eye and skeletal health
  - physiological indicators of stress and immune function.
- The majority of studies on the impact of lighting on bird health are focused on broiler chickens.
- The impact on lighting conditions on fear and deleterious behaviours (that ultimately impact on health) are discussed in Section 8.

7.1 Mortality

Key points

- Studies on the effect of photoperiod on mortality are inconsistent.
- Mortality is unaffected by light intensity (within ranges used commercially).
- Studies on intermittent lighting programmes indicate that they may decrease mortality.

Morbidity and mortality are likely to be affected by any impact of lighting on melatonin secretion. Melatonin is a hormone controlling the circadian rhythm, with secretion peaking during darkness. It has also been shown to regulate immunity, hence possibly underlying the effects of various photoperiods on health (Kliger et al., 2000).

Studies that examine the effect of photoperiod on mortality present inconsistent results. In broiler chickens, some studies report lower mortality under shorter day-lengths (Scott, 2002; Brickett et al., 2007; Lewis et al., 2010; Schwean-Lardner et al., 2013), while others do not (Lien et al., 2007; Lien et al., 2009; Petek et al., 2010; Coban et al., 2014). Studies on the effects of intermittent lighting programmes on mortality have indicated that they increase survival rate (Abreu et al., 2011; Lewis et al., 2010; Baser et al., 2010; Classen et al., 2004).

In terms of light intensity, mortality in broiler chickens appears to be unaffected (Downs et al., 2006; Kristensen et al., 2006; Lien et al., 2007; Blatchford et al., 2009; Lien, 2009; Deep et al., 2010; Deep et al., 2013; Olanrewaju et al., 2014). Deep et al. (2013) concluded that 0.1 lux is an unacceptably low light intensity, with 3.3% mortality in the second week after the first 7 days at 40 lux, whereas keeping birds under 0.5 to 10 lux had little effect on mortality (ranging from 1 to 2% in that same week). However, in laying hen pullets, high light intensity can increase mortality, which usually associated with severe feather pecking and cannibalism (Kjaer & Vestergaard, 1999; Kjaer & Sorensen, 2002).

There are few scientific papers on the effect of spectral composition on mortality in chickens. In studies of laying hens housed under LED or fluorescent lights, there was no significant difference in overall mortality (Long et al., 2015; Liu et al., 2017). Similar results were reported by Svobodová et al. (2015) who found that although mortality appeared to be lower for hens housed in red light (12.65%) compared to blue light (14.30%), the results were not significant. Research on broiler chickens also reported no influence of spectral composition on overall mortality (Riber, 2015).

7.2 Pathological conditions

Key points

- There is general scientific agreement that continuous lighting causes changes in eye morphology and does not support normal eye development.
- Low light intensities do not support normal eye development.
- Delaying sexual maturity through the manipulation of photoperiod has little effect on bone mineralisation at the end of lay.
- Skeletal health may be improved at higher light intensities when activity is greater.
- Low light intensities make inspection of bird health more problematic.

Studies on eye morphology as affected by photoperiod indicate a U-shaped response. That being, birds subjected to a longer photoperiod (24L) were reported to have heavier and larger eyes than birds under shorter photoperiods (20L) (Schwean-Lardner et al., 2014; Lewis & Gous, 2009), but other studies found that birds kept under shorter photoperiod also have larger (Blatchford et al., 2012 for 16L) or heavier eyes (Lewis & Gous, 2009, from 18L to 2L) than birds kept under 20L. It is unclear from these studies how much these changes affect the birds' vision.

The impact of photoperiodic manipulation (and delay of sexual maturity) on skeletal integrity was studied by Hester et al. (2011). Pullets exposed to the slow lighting photoperiod had longer bones and more bone area, however, this treatment did not improve bone mineralisation or density in older adult birds at 66 weeks, and it was concluded that pullet lighting regimen had little effect on bone mineralisation at end of lay. Other studies did not detect a difference in relative asymmetry of leg bones in broilers reared under continuous light (Onbaşılar et al., 2007, 2008).

Low light intensities have been recognised as a cause of retinal degeneration, eye enlargement, myopia, glaucoma and blindness (Prescott et al., 2003; Olanrewaju et al., 2006; Lewis & Gous, 2009; Deep et al., 2010; EFSA, 2010; Blatchford et al., 2012; Deep et al., 2013; Widowski et al., 2013). Blatchford et al. (2009) noted an increase in eye weight, though found no effect of 5 lux on eye diameter or the corneal radii that have been reported under lower intensities. The welfare implications of these changes for a bird's vision are still unclear. Heavier eyes are also reported in continuously illuminated birds (Lewis & Gous, 2009; Schwean-Lardner et al., 2013). These results indicate that normal ocular development is affected by both short photoperiods and continuous illumination.

Skeletal health was reported to be improved by stimulating bird activity at higher light intensities (Blatchford et al., 2009) and the risk of fractures can be increased when light intensity is low (Widowski et al., 2013).

7.3 Stress indicators

Key points

- The scientific studies on the effect of photoperiod on heterophil:lymphocyte (H:L) ratio present inconsistent findings.
- There is no evidence to suggest that exposure to low light intensities is stressful.
- Other physiological indicators of stress appear to be unaffected by photoperiod.

The described effect of photoperiod on heterophil:lymphocyte (H:L) ratio is inconsistent between different studies. Das and Lacin (2014) observed higher H:L ratios under continuous light than intermittent light (4L:2D), whereas other studies found no difference (1L:3D: Onbaşılar et al., 2007; 2L:2D after natural daylight: Petek et al., 2010). No difference in H:L ratio was also found when comparing continuous light with an increasing light regime (14L:10D increasing to 23L:1D over the grow-out period) (Dereli Fidan et al., 2017). The H:L ratios of broilers reared under a self-photoperiod regime (i.e. provided with continuous light but with free access to a dark chamber) were lower than birds reared on continuous light (without access to a dark chamber), but higher than birds raised under a 16L:8D programme (Coban et al., 2014). Other physiological indicators of stress, such as plasma corticosterone concentration, appear to be unaffected by photoperiod (Olanrewaju et al., 2010, 2013, 2014a), as does blood glucose (Onbaşılar et al., 2007, 2008). Intermittent lighting (1L:3D), but not constant lighting (16L:8D), was seen to improve immune function compared to continuous lighting (24L:0D); spleen weight remained unaffected by lighting regime (Onbaşilar et al., 2007, 2008). Abbas et al. (2007) found that exposing broiler chickens to an intermittent lighting programme ameliorated immunosuppression associated with heat stress.

Only a few recent studies correlate physiological measures of stress with light intensity, and there is no evidence to suggest that exposure to any light intensity between 0.2 and 25 lux is stressful (plasma corticosterone concentration: Olanrewaju et al., 2008, 2010, 2013, 2014a, 2014b; O'Connor et al., 2011; H:L ratio: Lien et al., 2007). Dereli Fidan et al. (2017) observed a higher H:L ratio in birds housed in 20 lux than in birds exposed to a lighting treatment that reduced from 5 to 1.25 lux over the duration of rearing. Bayraktar et al. (2012) observed that the use of two halogen lamps to provide spot lighting (10 + 10 lux or 10 + 5 lux) in poultry houses maintained under dim lighting (filament: 10 lux) improved some welfare markers (reduced glucose concentration and increased bursa of Fabricius size) compared to a control, while tonic immobility and mortality remained unaffected. Van der Pol et al. (2015) also observed that light dimming was associated with lower bone asymmetry than abrupt light-dark transitions, which may also be indicative of lower environmental stress.

Using other measures of health, in broiler chickens, several authors have found effects of light colour on immunity. Green light is reported to promote B-lymphocyte proliferation (Li et al., 2015; Li et al., 2013). Switching between blue and green light may improve both T-cell and B-cell proliferation (Zhang et al., 2014), as well as intestinal immunity (Xie et al., 2011). Parvin et al. (2014) found that blue and green light helped to promote greater antibody production and immune function, compared to red light.

Recommendation

Research, development and extension need to be focused on:

- the welfare and production implications of behavioural changes induced by varying light programmes (and whether these changes have an affect on birds' health criteria such as mortality and feather pecking).

8 Effect of lighting on behaviour

Key points

- There is a lack of studies on the effects of flickering, different light sources, and different colour temperatures on pullet behaviour, compared to hens during production.
- This section will consider the impact of photoperiod, light intensity and wavelength on bird behaviour as it relates to:
  - behavioural repertoire – preferences, time budget, etc.
  - deleterious behaviours – feather pecking, cannibalism, smothering
  - physiological indicators of stress and immune function.
- The ability of laying hens to habituate to abrupt light changes has not been scientifically investigated.
- The early experiences of chicks and pullets not only affect the behaviour of the young bird but they can also have effects on behaviour that extend into production.

8.1 Behavioural repertoire

8.1.1 Effect of photoperiod on behavioural repertoire

Key points

- Using lighting regimes to synchronise behaviour and increase opportunities for undisturbed rest may provide welfare and production benefits in laying hens.
- Birds under near-constant light display asynchronous flock behaviour.
- Shorter photoperiods (14L-17L) increase synchronised behaviour.
- Young chicks are able to rest more when reared under a lighting pattern that simulates natural brooding.
- The early experiences of chicks and pullets not only affect the behaviour of the young bird but they can also have effects on behaviour that extend into production.

In young chicks, Malleau et al. (2007) concluded that they are able to rest more when reared under a lighting pattern that simulates natural brooding, with short (approx. 40 min) periods of dark interspersed throughout a long light period compared with an uninterrupted long light period. Chicks on the brooding cycle demonstrated high synchronised activity levels when the lights were on, and very low synchronised activity levels when the lights were off (Malleau et al., 2007). The authors hypothesised that using lighting regimes to synchronise behaviour and increase opportunities for undisturbed rest may provide more welfare benefits to young chicks than constant restricted lighting regimes.

Birds under near-constant light display asynchronous flock behaviour, which may be attributed to a lower level of melatonin (Schwean-Lardner et al., 2014). Shorter day lengths (14L-17L) increase the expression of synchronised behavioural rhythms. These results support the hypothesis that birds reared under constant, or near-constant, light are at a higher risk of suffering from sleep fragmentation, where they are disturbed by flock-mates when trying to rest (Alvino et al., 2009b).

In laying hen parent stock, during a continuous-access preference test, birds were able to select compartments illuminated with different light intensities (including a dark area). The results showed that hens selected a pattern of light exposure that involved 10 hours in the dark in intermittent bouts distributed through the 24-hour period, rather than the continuous dark period that they would experience under most commercial conditions (Ma et al., 2016).

In terms of the behavioural impact of lighting, there is a large body of work that focuses on broiler chickens. Commercial broiler production is not generally designed to accommodate sleep and rest, and lighting regimes are focused on increasing feeding opportunities. Long photoperiods (20L and 23L) have been associated with reduced walking time and comfort behaviours, such as dustbathing and preening (Schwean-Lardner et al., 2012b; Schwean-Lardner et al., 2014). When longer dark periods are introduced, birds have been observed feeding and preening at night, likely to compensate for the reduced time available during light periods (Brown, 2010; Lewis et al., 2009; Schwean-Lardner et al., 2012b). Even though more daylight hours are available with longer photoperiods, the richer behavioural repertoire was observed in birds with a longer dark period (Bassler et al*.,* 2013; Schwean-Lardner et al., 2012b), with Schwean-Lardner et al. (2012b) concluding that 16L was the optimum photoperiod for the best welfare outcomes.

8.1.2 Effect of light intensity on behavioural repertoire

Key points

- Light intensity influences the distribution of behaviours over the photoperiod. A bird's preference for a particular intensity of light changes with behavioural activity.
- The light intensity preferred by birds and the effect on activity level has been found to be different between ages and bird type, which complicates the determination of an optimal light intensity for chicken behaviour.
- It has been demonstrated that overall activity levels in birds are positively correlated with light intensity.

In general, higher light intensities have been shown to increase bird activity and behavioural rhythms (Alvino et al., 2009a; Hester et al*.,* 1987; Newberry et al., 1988; Kjaer & Vestergaard, 1999, as cited in Deep et al., 2010; Deep et al., 2012; Deep et al., 2013). However, there are few studies that scientifically demonstrate changes in activity when light intensities are in the range of 1 to 100 lux. Light intensity also influences the distribution of behaviours over the photoperiod and a bird's preference for a particular intensity of light is seen to change with behavioural activity (Alvino et al*.,* 2009b). For example, very high light intensity is preferred by hens for feeding (Prescott & Wathes, 2002). Hens also consume more feed and peck more in brighter intensities (Prescott & Wathes, 2002; Vandenberg & Widowski, 2000; O'Connor et al*.*, 2011) but prefer to rest in a darker environment (Vandenberg & Widowski, 2000). The synchronisation of behaviour is more apparent when there is a pronounced contrast in intensity between the light and dark periods. This type of synchronisation reduces sleep disturbance during the dark period (Alvino et al*.,* 2009a; Blatchford et al., 2009, 2012).

Data on chickens' light intensity preferences are limited, but studies indicate that generally chickens prefer dimly lit zones over brighter ones (broilers: Pan et al., 2014; laying hens: Ma, H. et al., 2016). However, the age of the bird influences its choice, with recent studies supporting earlier findings that young broiler pullets prefer high light intensities (200 lux) but older birds prefer lower intensities. It is likely that the difference in preference can be attributed to the lower levels of activity in older broilers where they actively seek lower intensities to rest. In laying birds, any diminishing preference of older birds for bright light may cause problems in free range laying systems. Gunnarsson et al. (2008) recommended that hens that are to be exposed to natural light as layers should experience the same lighting conditions during the rearing period. The authors found that rearing birds with natural daylight stimulates the earlier development of perching behaviour and results in a stronger diurnal rhythm with more night-time perching.

Low light intensity (<5 lux) has been associated with reduced activity compared to brighter lighting (20-320 lux) (reduced activity and increased resting: Blatchford et al., 2009; Deep et al., 2012; Senaratna et al., 2016; reduced perching: Taylor et al., 2003; Widowski et al., 2013; reduced preening and foraging: de Jong et al., 2012). However, this was not reported in other scientific studies where low intensity light (5 lux) did not influence activity levels (Kristensen et al., 2006, 2007), perching (Moinard et al., 2004; 10 lux: Chen & Bao, 2012). The accuracy of laying hens to jump between perches did not differ consistently between light intensities of 5-20 lux (Moinard et al., 2004), although lower light intensities had significant effects on the ability to jump between perches in another experiment (Taylor et al., 2003).

Light intensity may also affect nest choice, activity, environmental perception and social interaction. Kristensen et al. (2009) stated that a minimum of 5 lux is needed for hens to socially discriminate in small flocks. In addition, it might be even more important in larger flocks to detect the social signs of status or intent of the other hens.

Manipulation of light intensity is often used strategically; shading nesting areas and having brighter light in other areas can have positive effects by increasing foraging behaviours, and decreasing floor laying and cloacal cannibalism (Widowski et al., 2013). A gradual change in light intensity during change from light to dark and vice versa allows birds in non-caged systems to safely locate perches (at the onset of dark) and move in a more controlled manner to feeders (at light onset).

Interview respondents

- All of the respondents stated that even, uniform lighting in the rearing shed is very important as it impacts directly on bird behaviour.
- One respondent specifically stated that lighting intensity uniformity has a big influence on scratching behaviour and subsequent litter quality throughout the shed.

Recommendation

Research, development and extension need to be focused on:

- Light intensity, and manipulation of light intensity, as it impacts on behavioural repertoire (and implications for health and production)
- the use of a reduction in light intensity (dimming) as a tool for driving behaviour
- the effect of flicker on production and welfare outcomes.

8.1.3 Effect of wavelength on behavioural repertoire

Key points

- Hens show decreased distress calls when exposed to red light compared to white light.
- Hens show decreased feeding time when exposed to green light compared to red or white light.
- Hens show increased foraging time when exposed to green light compared to red light.
- Hens show increased pecking at objects when exposed to green light compared to red light.
- Hens are thought to be calmer in blue light, compared to other wavelengths.

Spectral composition (wavelength), as determined by light source, can influence hen behaviour with, for example, incandescent lights increasing the occurrence of nesting and active behaviours compared with fluorescent lights (Tavares et al., 2015). The light source provided to poultry may also have implications in social interactions and establishing pecking orders. As birds recognise flock mates by the colour of the parts of their body including feathers, if the light source fails to provide the appropriate wavelength for optimum avian vision or if a particular wavelength is in over abundance, social disorders may prevail. Hens are more active when exposed to fluorescent as compared to incandescent light, suggesting that hens perceive and respond differently to alternative light sources (Mohammed et al., 2010).

Although broilers were not seen to demonstrate a preference between yellow and white LED lighting (Mendes et al., 2013), a different study reported that birds demonstrated a preference for (spent more time under) a cold-white than a neutral-white LED light (Riber, 2015). Birds reared in groups under red and red-yellow LED light demonstrated more walking behaviour than birds reared under blue LED, which spent more time inactive (Sultana et al., 2013b). The results from Huber-Eicher et al. (2013) in studies on the effects of light colour (to equal perceived intensities) on bird activity were not as significant, with green light only having minor (but not significant) effects on explorative behaviour. Jang and Velmurugu (2009) found the effects of light colour on behaviour differed for age groups, with younger birds showing reduced resting behaviour in red light, whilst slightly older pullets showed increased standing and walking behaviours in birds receiving red light. Lewis et al. (2001) found that exposure to UV for the first time caused birds to react with frantic activity and vocalisation, but attributed this to an increase in the light intensity perceived by the bird rather than by UV per se.

In addition to bird activity, light wavelength has been found to affect other behaviours (nesting choice: Huber-Eicher, 2004; calming birds (blue light): Tauson, 2005; sexual signalling (UV radiation): Jones et al., 2010; egg laying (red light): Gustafsson & von Wachenfelt, 2009); defecating (white light): Gustafsson & von Wachenfelt, 2009; perching (green and blue light): Hassan et al., 2014; perching (natural light): Gunnarsson et al., 2008b).

Interview respondents

- One producer respondent believes that blue light should be avoided as it makes birds aggressive.
- One producer respondent believes that the green spectrum increases feed intake.
- Pullets reared for a production system with access to outdoor areas should be reared with access to natural light.

Recommendation

Research, development and extension need to be focused on:

- the use (and related benefits) of light colour to stimulate activity from an early age
- wavelength, and manipulation of wavelength, as it impacts on behavioural repertoire (and implications for health and production).

8.2 Deleterious behaviours

8.2.1 Feather pecking and cannibalism

Key points

- Higher light intensities have been shown to result in greater incidences and severity of feather pecking in laying hens.
- Light intensity is generally lowered to reduce activity, feather pecking and cannibalism, however, decreasing light intensity to reduce feather pecking can be counterproductive.
- Low serotonin (a consequence of light intensities <5 lux) can increase feather pecking.
- Length of photoperiod can affect the prevalence of cloacal cannibalism (vent pecking).
- Red light has no impact on feather pecking.

In laying hens, an even light distribution of a particular intensity is considered desirable to minimise problems such as floor eggs, feather pecking or smothering. Apertures that allow ingress of natural light are often shaded to avoid direct sunlight and to make sure that light is evenly distributed within the accommodation (Ferrante, 2009). In general, higher light intensities have been associated with greater incidences and severity of feather pecking in laying hens (Kjaer & Vestergaard, 1999; Kjaer & Vestergaard, 2002; Green et al., 2000; El-lethey et al., 2001; Tauson, 2005; Bestman et al., 2009; Drake et al., 2010; Mohammed et al., 2010; de Haas et al., 2014), which is a welfare concern as it can lead to cannibalism and mortality in laying flocks (Bilčík & Keeling, 2000). Another recent study compared the percentage of loose-housed flocks with or without plumage damage, according to whether they were exposed to daylight through windows or not (Yngvesson et al., 2011). Fifty percent of flocks not exposed to daylight had damaged plumage compared to 30% of flocks in houses with windows, suggesting that daylight exposure is not associated with increased risk feather pecking.

Commercial housing systems for laying hens are often kept at low light intensity as this can reduce the incidence of feather pecking (Shinmura et al., 2006) and it is said that light intensities over 10 lux are avoided to prevent feather pecking (EFSA, 2005). However, this method of control can be counterproductive as it can impair the ability of birds to identify environmental cues and cause other foraging substrates to appear less attractive than feathers (Kjaer & Vestergaard, 1999; Bright, 2007; Gilani et al., 2013; Janczak & Riber, 2015). At intensities below 5 lux, light does not pass through to the pineal gland, where it would normally suppress the production and release of serotonin and melatonin (Zawilska et al., 2004). Low serotonin levels may increase feather pecking (van Hierden et al., 2002, 2004). Gilani et al. (2013) also found that severe feather pecking during rearing, but not laying, is increased with shorter photoperiods. The length of the photoperiod may also indirectly affect the prevalence of cloacal cannibalism. An onset of lay prior to 20 weeks of age has been related to an increased risk of vent pecking (Potzsch et al., 2001).

Huber-Eicher et al. (2013) found that both red light (640 nm) and green light (though not to the same extent) reduced aggressive behaviour (as measured by the frequency of vigorous pecks and distress calls in 16-22 week old laying birds). In contrast, Sultana et al. (2013a) found that hens were more active under red LED light (compared to blue light), showing more feather pecking, ground pecking and scratching and comfort activities, and less perching. When Long et al. (2015) compared LED and fluorescent lighting (with different wavelengths) they found a slightly elevated avoidance response at 36 weeks but not at 60 weeks of age.

Interview respondents

- A large proportion of respondents stated that incorrect dimming during rearing can transfer behavioural problems into the laying period.
- All respondents felt that light intensity contributes significantly to activity, flightiness and smothering behaviour.
- All respondents stated that the lack of light uniformity is the biggest cause of behavioural issues in cages.
- One respondent described the importance of investigating and effectively managing behavioural problems in cages rather than simply reducing light intensity as a temporary solution.
- Producers using alternative systems stated that the biggest challenge in the control of behaviour is presented in free range system.

Recommendation

Research, development and extension need to be focused on:

- the optimum lighting conditions to control pecking behaviour and any associated negative impacts on production.

8.2.2 Smothering

Key points

- Smothering can account for a significant amount of mortality in non-cage and free range flocks.
- Fear levels are lower when birds are given a dark period for resting.
- Fear responses may be affected by exposure to different lighting colours and sources.
- Perception of flicker may provoke smothering.
- Uneven light intensities have been associated with smothering outbreaks.

Smothering can account for a significant amount of mortality in non-cage and free range flocks (EFSA, 2005; Bright & Johnson, 2011). Smothering may occur during panic resulting from, amongst other factors, lighting conditions.

Fear levels were found to be greater in birds housed under continuous (24L) or near-continuous (23L) light than in birds allowed longer dark periods for resting (Campo & Davila, 2002; Sanotra et al., 2002; Onbaşilar et al., 2008; Bayram & Özkan, 2010; Toplu et al., 2016).

Fear responses may also be affected by exposure to different lighting colours and sources. Sultana et al. (2013b) report that birds reared under red and red-yellow LED light were more fearful (tonic immobility) than birds reared under blue LED. Huth and Archer (2015a) found that broilers reared under light from LED bulbs were less fearful than broilers reared under compact fluorescent lighting. However, Olanrewaju et al. (2016) found no differences in tonic immobility when comparing different light treatments (compact fluorescent lighting, a neutral-LED bulb, and a cool poultry-specific filtered LED bulb).

Uneven light intensities have also been associated with smothering outbreaks. Hens are often seen aggregating in bright patches of a poultry house. This behaviour may lead to suffocation of some birds within large aggregations, and subsequently a number of historical studies cited in industry information recommend that light intensity should be fairly uniform without bright spots.

Interview respondents

- A number of interview respondents were particularly concerned about the impact of flickering light sources during dimming. They believe that some light sources cannot be effectively dimmed without causing flickering, increasing the likelihood of panic behaviour and smothering in pullets.
- Some respondents were also concerned that LED lighting may also cause unacceptable levels of flicker.
- All respondents stated that any reduction in light intensity should be carried out gradually.

Recommendation

Research, development and extension need to be focused on:

- the influence of lighting (including the impact of flicker) as a cause of smothering.

9 Assessment of lighting conditions

Light meters are used to determine lighting conditions in scientific studies and to verify compliance with requirements, though their use as a management tool is variable. Light meters measure the intensity in lux (with older meters measuring in foot candles).

The majority of meters on the market are designed based on the human retina, and do not take into consideration avian retinal sensitivity. Therefore, they do not provide an accurate measurement of how birds perceive light intensity at different wavelengths. Lewis and Morris (2006) described algorithms and equations to convert illuminance measurements into equivalent readings from a chicken's perspective, however, meters that measure light in this manner are not currently widely available.

Traditional light meters are also calibrated for white colour temperature with a spectrum between 550–560 nm. These light meters are unable to adequately measure blue or red spectrum light. It is important to be able to observe light intensity in both the visible blue and visible red spectra due to the chicken's wider visible light spectrum. A true measure of spectrum requires the use of a more complex and expensive spectrophotometer unit, which is not widely available for commercial use.

Assessing the effectiveness of light intensity and wavelength on deep-brain photoreception is even more complex, as the exact photoreceptors involved are not fully understood. Penetration of each wavelength of light depends on the energy (watts) rather than light intensity (lux).

In practice, monitoring birds' behaviour is also a very useful indicator of the impact of lighting, and should be performed routinely.

Interview respondents

- The majority of interview respondents regularly used a light meter to set up and monitor their lighting systems, however, the appropriateness of the meter (for the light source) and methodology used was variable.
- The respondents usually measured light intensity at the height of the bird, e.g. in tiered cages or at the height of the feeder.
- Respondents felt that assessors and auditors lack a fundamental understanding of lighting effects, and rely on objective measures of light rather than focusing on the outcome.

Recommendation

The industry would benefit from the development of the following extension material:

- appropriate light meters for different light sources
- methods for objectively measuring light intensity – Including work instructions for light measuring equipment and techniques
- guidance to auditors on light measurement and the interpretation of results
- guidance on the interpretation of bird behaviours and production information to evaluate the impact of the lighting programme.

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Plain English Summary

Project Title:	Best practice lighting management for Australian layers
Australian Eggs Limited Project No	1HS701US
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Objectives	The project is a critical review of science-based evidence and best management practices relating to lighting for laying hens, and recommendations for further research and extension (with associated materials in the form of factsheets) to encourage continuous improvement within the industry.
Background	In a recent consultation exercise (conducted by Australian Eggs) with industry leaders, lighting was identified as an area where concentrated development and extension projects would be of great benefit.
Research	This review considers lighting conditions during the pullet rearing and laying period. It considers the effect of lighting on bird welfare (health and behaviour) and production (laying performance, onset of lay, egg weight, growth and timing of sexual maturity). In addition to the review of scientific literature, a series of interviews with industry leaders (producers and technical experts) were conducted. The aim of this exercise was to provide context to the scientific research as well as a practical insight into optimum lighting conditions.
Outcomes	Lighting is a complex topic because it includes several characteristics (photoperiod, intensity, and spectral composition), which have many interactive effects. The review presents a number of recommendations for further research and industry extension, in the context of the current understanding of production requirements, animal welfare concerns and advancement in lighting technology.
Implications	Research and extension are required to improve the understanding of the impact of lighting on hen welfare and production.
Key Words	Lighting, laying hens, pullet rearing, photoperiod, illuminance, wavelength, welfare, production, health
Publications	N/A