Impact of Light Intensity on Broiler Live Production, Processing Characteristics, Behaviour and Welfare

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ABSTRACT

Two trials were conducted with the objective of investigating the effect of light intensity, approximately within the practical levels at confinement barns (1, 10, 20 and 40 lx), on production, processing characteristics and welfare of broilers raised to 35 d of age. In each trial, 950 Ross x Ross 308 chicks were placed randomly in each room with replication of individual light intensity treatment in two environmentally controlled experimental rooms. Within each large room, a small pen with 25 male and 25 female chicks was used for recording behaviour. Data were analyzed as a randomized complete block design, considering trial as a block. All chicks were exposed to 40 lx light intensity and 23 h light for the first 7 d, followed by treatment light intensity and 17 h day length thereafter. Body weight and feed consumption were determined at 7, 14, and 35 d of age. At the conclusion of each trial, 60 birds per treatment were processed to determine the detailed meat yield. For each replicate, behaviour was recorded for the 24 h period, starting at 16 or 17 d of age. At 23 d of age, serum samples were collected from three birds per room at the start, middle and end of light and dark periods, respectively, for melatonin estimation. Skeletal and foot pad, and ocular health were monitored at 31 and 32 d of age, respectively. Broiler live production (BW, FC, FCR and mortality) was unaffected by light intensity. Carcass, thigh and drum yield as a percentage of live weight decreased linearly with increasing light intensity. The 1 lx treatment resulted in heavier wings as a percentage of live weight. Birds exposed to 1 lx rested more and had reduced expression of foraging, preening, dust-bathing, stretching and wing-flapping behaviours in comparison to other light intensities, over the 24 h period and 17 h light phase. Light intensity did not affect circadian behavioural rhythms (24 h period) and behavioural patterns over the 17 h light phase. Diurnal rhythms of serum melatonin were also unaffected by light intensity with all treatments demonstrating a pronounced rhythm. Skeletal health was unaffected by light intensity but ulcerative foot pad lesions decreased linearly with increasing light intensity. Birds exposed to the 1 lx intensity had heavier and larger eyes. In conclusion, light intensity did not affect broiler production, behavioural and physiological rhythms and mortality but did affect carcass characteristics. Increased ulcerative foot pad lesions, ocular dimensions and altered behavioural expression at 1 lx light intensity are indicators of reduced broiler welfare.

Key words: broiler, light intensity, health, productivity, well being, rhythms

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DEDICATION

"This thesis is dedicated to my parents, who have always encouraged me to follow my dream

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LIST OF ABBREVIATIONS

AP	Anterio-posterior
BW	Body Weight
cd	Candela
clux	Illuminance for poultry
d	Day
D	Diopter
DV	Dorso-ventral
ep	Encephalic photoreceptor
fc	Foot candle
FI	Feed Intake
FCR	Feed Conversion Ratio (Feed to Gain; F:G)
GnRH	Gonadotropin Releasing Hormone
GH	Growth Hormone
h	Hour
IGF-1	Insulin like Growth Factor 1
lx	SI unit for light intensity
ML	Medio-lateral
NS	Non-significant
PTFE	Polytetrafluroethylene
RHT	Retinohypothalamic tract
SDS	Sudden Death Syndrome
Sr	Steradian
UV-A	Ultraviolet A

1. Introduction

Chickens are visually well equipped, and therefore light plays an important role in their well being and productivity. In addition to physiological evidence (ocular structure), visual capacity of chickens is also reflected by their preference for bright light as compared to dim light. Commercially, broilers are reared under artificial light consisting of three components – photoperiod, wavelength, and intensity. All of these components play an important role in broiler management by affecting production and welfare. The present study was focussed on the effects of light intensity on broiler chickens.

Light intensity manipulation is a widely adopted management tool affecting broiler production, behaviour and welfare. Most management guides recommend a reduction in intensity after the early brooding period but there is some debate as to the appropriate level that should be used. A usual recommendation is for light intensity to be 5 to 10 lx during the grow-out period but many producers use levels as low as 1 to 2 lx. Comments from industry indicate that the rationale for using very low light intensity is improved feed efficiency, reduced mortality due to sudden death syndrome and reduced carcass damage (scratches, bruises) because of decreased activity. However, these advantages are not confirmed by scientific investigation. Examination of the literature reveals that broiler production (BW, FI, FCR, mortality) was unaffected by light intensity within the range of 1 to 150 lx but the use of low to very low light intensity has negative effects on broiler processing characteristics and welfare. These have included reports of reduced carcass and tender yield, decreased early uniformity, increased carcass bruising, leg disorders and ocular defects and birds being more fearful. Some of these are contrary to industrial perception as mentioned earlier.

Although there is considerable research on light intensity, a critical evaluation of the work suggests that there continues to be a need for research in this area because of the use of inadequate experimental design and the use of inappropriate light intensity levels after the initial brooding phase. Problems with the research include lack of replication, small numbers of birds per replication, and complications due to confounding effects of other experimental factors (photoperiod, wavelength). Also, research has often only compared two intensities (very dim and very bright), which is not helpful in assessing the response of birds to intensities at practical levels in confinement barns (1 to 40 lx).

Based on this assessment, the present research (two experiments) was designed with the following objectives:

- To define the impact of light intensity on the live production, processing characteristics behaviour and welfare of broiler chickens raised to 35 days of age and
- To provide data that can be used to model lighting programs.

In order to achieve these objectives, four different levels of light intensity (1, 10, 20, 40 lx), approximately within the practical levels used in commercial barns, were used to determine the impact of light intensity on broiler live production, processing characteristics and welfare, using a large number of birds and completing the experiments under near commercial conditions.

2. LITERATURE REVIEW

2.1. The Avian Eye

Birds are well recognized for their vision and this has been expounded upon on numerous occasions. For example, Rochon-Duvigneaud (1943) stated that the "*pigeon is nothing else but two eyes and two wings*". Although this statement is directed to the pigeon, it holds for other avian species as well, including the chicken (Gunturkun et al., 2000). Similarly, ornithologists such as Sinclair (1985) describe birds as "*Flying Eyes*".

Birds are classified as one of the most visually pendent species among the vertebrates having a dominant sense of vision and tremendous ability to recognise colour. Sensitivity of avian eyes is reflected by the fact that the human eye, which is visibly well equipped, has only 40 % of the optic nerve axons in comparison to chicken or pigeon eyes (Binggeli and Paule, 1969; Gunturkun et al., 2000). The relative size of avian eyes is largest among all animal species and the weight of both eyes of the domestic fowl is similar to that of their brain, thus further reflecting the importance of vision (Appleby et al., 2004). The lateral location of chicken eyes extends the visual area to 300^0, but limits the binocular vision in contrast to mammals such as humans possessing frontally located eyes (Appleby et al., 2004). The avian retina is completely devoid of vascularisation, so in order to supply nutrients to the retina, birds have a unique structure protruding from the optic nerve towards the vitreous called the pecten (Figure 2.1). The pecten is comprised of blood vessels and extra vascular stromal cells, provide nutrition to the eye and alleviate glare at high light intensity (Gunturkun et al., 2000). The nutrient furnishing function of the pecten has been revealed by various gradient studies including oxygen and nutrient flow from the pecten to the retina and vitreous, respectively (Bellhorn and Bellhorn, 1975.)

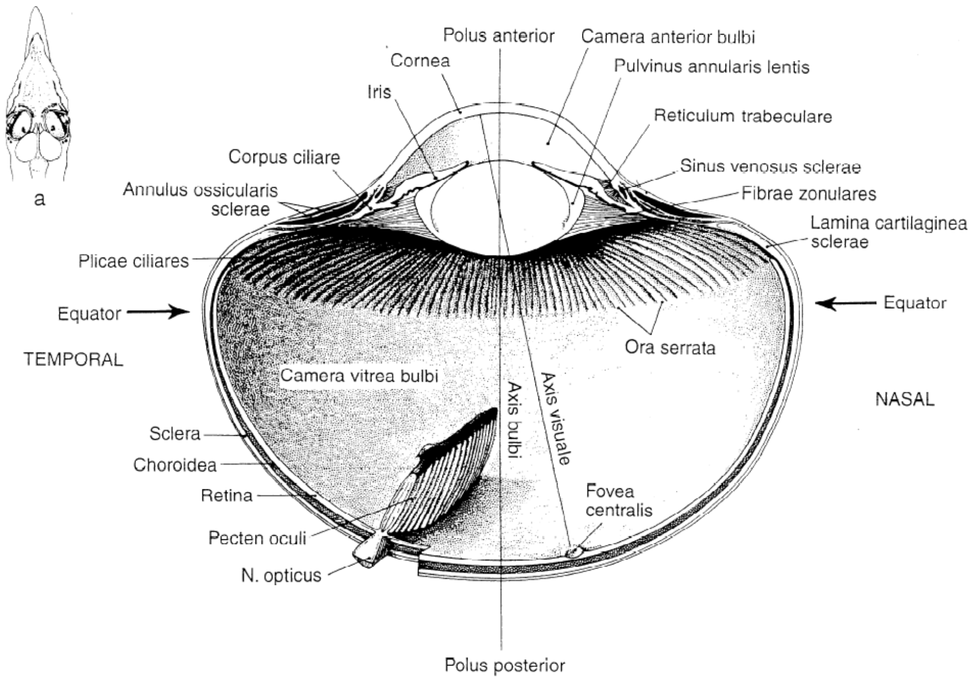

Figure 2.1. Horizontal section of the chicken eye. (Taken from Gunturkun et al., 2000).

2.1.1. Avian Eye Shape

Birds have four different types of eye shape that vary among species. Shapes are classified as spherical, oval, bell and tubular. Songbird eyes are characterised by spherical cornea while the domestic fowl possesses oval shaped eyes, flattened from front to back. Bell shaped eyes with protruding cornea characterize prey birds such as the hawk. Nocturnal birds (owl) possess tubular eyes characterised by a broad, smaller, and semi-spherical protruding retina (Smythe, 1975). The shape of avian eyes varies with biological needs, for example, bell or tubular shaped eyes, commonly possessed by prey birds, result in increased visual acuity by creating a large image on the retina (Gunturkun et al., 2000).

2.1.2. Avian Visual Acuity

Visual acuity refers to the sharpness of vision and is determined by the ability of the eye to precisely perceive and differentiate fine details. Acuity has a direct relationship with anterior focal length (i.e. increasing anterior focal length directly increases visual acuity) based on the principle that increased focal length results in spreading of the image over the large retinal surface and subsequently to more photoreceptors (Martin, 1993). Visual acuity is determined by both photoreceptors and ganglion cells present in the eye, as information gathered by photoreceptors has to be sent to the brain for processing via ganglion and bipolar cells. Birds possess a high ratio of these cells to photoreceptors (Sinclair, 1985).Visual acuity is affected by light wavelength and intensity. For example, studies with pigeons demonstrated improved visual acuity under yellow light and with increasing illuminance (Emmerton, 1983). Some prey birds such as *Aquila audax* possess visual acuity that is almost double as compared to humans under similar conditions (Reymond, 1985).

2.1.3. Avian Accommodation

Accommodation refers to the ability of eyes to focus on objects at different distances by altering corneal and lens structure, thus changing the refractive power of the eye, measured as dioptres **(D)** (Gunturkun, 2000). Chickens have the ability to see objects lying at different distances by changing the optical or refractive power of the lens from 8 to 17 D (Walls, 1942; Schaeffel et al., 1986; Martin, 1993). For avian eyes, accommodation can be achieved by dynamic or static processes, based on the specific mechanisms involved.

Dynamic accommodation is achieved by altering the refractive power of the lens as well as the cornea. In pigeons and chickens, both the cornea and lens are responsible for accommodation in contrast to owls and ducks that use lenticular (lens) mechanisms (Martin, 1993). Alteration in the refractive power of the lens and cornea is accomplished by ciliary muscles utilising mechanisms including but not limited to squeezing and forward movement of the lens (Slonkar, 1918; Meyer, 1977). Birds, such as hawks, also possess a specialised muscle known as Crompton's muscle (a type of ciliary muscle), that aids in altering the shape of the cornea (Sinclair, 1985).

Some birds, such as pigeons, quail, chickens, and sand hill cranes, also possess a unique feature of focusing on objects on the ground without using the above mentioned dynamic method (Gunturkun, 2000). It is accomplished by asymmetries in the optical system i.e. emmetropic (eye with no optical defect) in some parts (upper lateral) and myopic (blurring of far away objects) in other (lower lateral) parts of the eye, but the extent of lower field myopia varies with the height of bird's eye from the ground (Hodos and Erichsen, 1990). Lower field myopia increases with decreasing elevation and thus helps in focussing objects at various distances on the ground simultaneously with the objects in upper visual fields (Fitzke et al., 1985; Gunturkun, 2000). In conclusion, possession of both dynamic and static accommodation mechanisms by chickens further reflects their dominant sense of vision.

2.1.4. Avian Spectral Sensitivity

The avian retina consists of rods and cones, acting as photoreceptors. Chickens possess two types of cones, single and double. Cones, irrespective of type, help in vision during the bright light, but double cones are suggested to be specifically involved in the perception of magnetic field or polarised light (Delilus et al., 1976; Beason and Swali, 2001). In contrast, rods help in vision during dark or dim light, thus comprising the major photoreceptor in nocturnal birds (Blough, 1956; Bowmaker, 1980).

Oil droplets are the unique structure of chicken eyes, located distally at the inner segment of cones (Emmerton, 1983). The colour of these oil droplets varies from transparent to pale yellow, orange, green or red, depending on the amount of carotenoid pigment present (Goldsmith et al., 1984). These oil droplets allow only light of specific wavelength to pass and thereby act as a filter that helps to prevent blurring and also protects birds from detrimental effects of ultraviolet rays (Lythgoe, 1979; Kirschfeld, 1982; Goldsmith, 1990). Oil droplets also amplify the incidence of light on photoreceptors and thus serve as a function of lens (Young and Martin, 1984).

The spectral sensitivity of birds depends on the interaction of specific oil droplets and corresponding visual pigments. Transmittance through oil droplets, in combination with the absorptance of visual cone pigments, determines the spectral sensitivity of birds (Gunturkun, 2000). The human eye possesses three types of cone pigments (violet, green and red), having a peak sensitivity of 450, 550 and 700 nm, respectively. The chicken eye also has an extra cone pigment with a peak sensitivity of 415 nm (ultraviolet-A; **UV-A**). The presence of coloured oil droplets and four different types of cone pigments, in contrast to three in humans, results in a different spectral sensitivity for birds (chickens and pigeons), including the ultraviolet-A **(UV-A;** 370-580nm**)** area of the spectrum (Chen and Goldsmith, 1986). UV-A radiation is responsible for synthesis of vitamin D, and it was suggested that the amount of UV-A radiation produced by fluorescent lamps is sufficient to achieve this benefit in broilers. Vision in the UV-A spectral region is found to support foraging as grain seeds and straw can reflect UV-A rays and act as cues for chickens. In addition to supporting foraging , vision in the UV-A region also helps in orientation while flying and sexual signalling as feathers are suggested to reflect UV-A light (Maddocks et al., 2002; Lewis and Gous, 2009).

2.1.5. Avian Light Perception

Light signals are perceived by the avian brain either through eyes (retina) or direct penetration of skull tissue. Retinal perception of light by birds is similar to other species. The light signal forms the physical image on the retina after traversing through the cornea, anterior chamber, lens and the vitreous body. In the retina, light signals are transduced to electric impulses, directed towards the brain through various neural channels (Gunturkun, 2000). In contrast, light signals directly reaching the brain are perceived by encephalic or pineal photoreceptors. Through these photoreceptors (retinal or extra retinal), external information is made accessible to circadian pacemakers, governing the behaviour and physiology of the birds (Figure 2.2).

Perception of light depends on its intensity and wavelength. Light with higher intensities (> 4 lx) and longer wavelength are suggested to be more capable of penetrating the skull tissue and having a direct effect on the pineal gland and hypothalamus, in contrast to dim light (< 4 lx) perceived through the eyes (Benoit, 1964; Lewis and Morris, 2006). Furthermore, the peak sensitivity of avian retinal photoreceptors is in the range of 545-575 nm (Lewis and Morris, 2000).

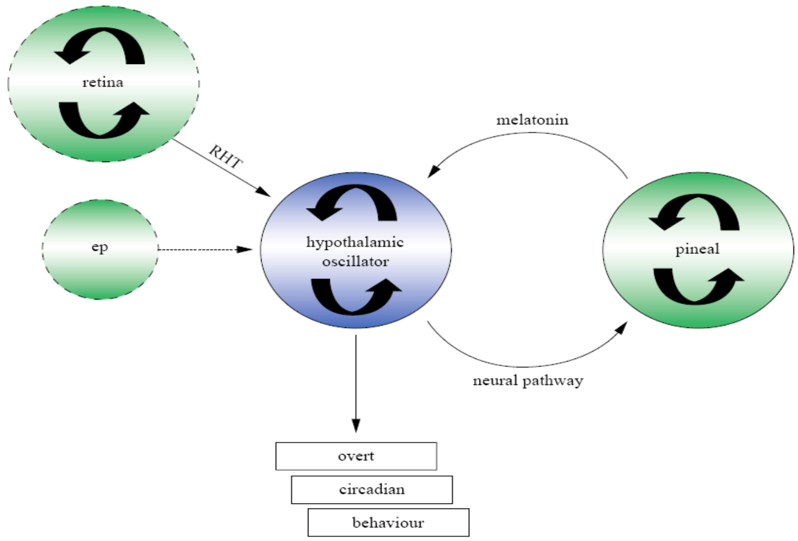

Figure 2.2. Pathways showing avian circadian pacemakers and photoreceptor sites (green background) influencing the pacemaking system. ep = encephalic photoreceptors; RHT = Retinohypothalamic tract (Taken from Gwinner and Brandstatter, 2001).

2.2. Light

Light is a form of energy that is transmitted as electromagnetic radiation. Light has also been defined as an alliance of electromagnetic radiation and our response to it (Pritchard, 1985a). Animal eyes are able to see only a specific part of this electromagnetic radiation spectrum, referred to as visible radiation, but birds have a more extended spectrum due to the uniqueness of their eyes. For the reader's understanding, important terms related to light are described in table 2.1.

Table 2.1. Description of some key terms related to light (Pritchard, 1985b).

Item	Description
Radiant flux	It is defined as total power of electromagnetic radiation emitted or received and is measured in Watts. It includes both visible and invisible radiations.
Irradiance	It refers to the amount of radiant flux or power emitted per unit of surface area and is measured in watts per square meter (W/m^2).
Luminous flux	It is the radiant flux of the electromagnetic radiation which is visible to the eye and is measured in lumens (lm). It is calculated as the product of radiant flux and photopic luminous efficiency of human eyes at a given wavelength.
Luminous efficacy	It is defined as the maximum attainable luminous output for a unit power output and is measured in lumens/watt
Luminance intensity	It is defined as the measure of luminous flux per steradian (sr) emitted in a specific direction and is measured in the candela (cd).
Lux (lx)	It is the measure of illuminance or light intensity and is equal to 1 lumen per square meter ($1lm/m^2$). Some light meters still uses foot candle (fc) as a unit of light intensity, and a foot candle is equal to 9.6 lx.

2.2.1. Components of Light in Poultry Management

Artificial light for commercially housed broilers can be characterized by photoperiod (distribution of light), wavelength (colour) and intensity (degree of brightness).

2.2.1.1. Photoperiod

Photoperiod refers to the distribution of light and consists of a scotophase (the duration of darkness) and a photophase (duration of light) over a 24 h period. Typically, broilers are reared under 23L: 1D during their first week of life followed by variable daylengths for the rest of the grow-out period. Research at the University of Saskatchewan has studied the impact of graded levels of daylength on production and welfare indices (K. Schwean-Lardner, University of Saskatchewan, Saskatoon, Saskatchewan, personal communication). The results demonstrate that long daylengths (23 h) have a negative impact on broiler growth rate, feed efficiency, comfort behaviours and welfare. This, plus other research will be used to determine or evaluate codes of practice and/or legislation on acceptable broiler lighting programs.

2.2.1.2. Wavelength

Wavelength affects the colour of light and is often referred to as the quality of light. Knowledge of the impact of wavelength on poultry productivity is not extensive but there are indications that it can impact bird performance. Broilers exposed to blue or green lights were heavier at 35 d of age as compared to red or white light (Rozenboim et al., 1999). The effect of light wavelength on broiler growth is age dependent with green light stimulating early weight gain (3 d) in contrast to blue light having late growth enhancement (Rozenboim et al., 1999). Furthermore, research results suggest that this age-dependent effect of coloured light is attributed to satellite cell proliferation (Halvey et al., 1998) and increased testosterone concentration due to green and blue light, respectively. Meat quality of broilers reared under green and blue light is better than those reared under incandescent lamps (Karakayaa et al., 2009). In terms of behaviour, broilers exposed to bright red light were found to be more active as compared to dim green light (Prayitno et al., 1997), but it is hard to differentiate the effect of colour and intensity of light based on this experiment. A variety of light sources is used in the broiler industry to emit light of different wavelength and thus affect their growth, production and behaviour.

2.2.1.3. Light Intensity (Illuminance)

The brightness of light is referred to as light intensity. Brightness is defined as the quantity of luminance flux falling on a unit area of a surface and is measured in units of lx, equivalent to lumens per meter square. Currently, a uniform recommendation for the optimum level of light intensity to be used after the initial brooding phase is lacking.

2.2.1.3.1. Measurement of Illuminance

Light intensity is typically measured with the aid of a light meter, converting physical radiation from a source to a photometric measurement of the human perception of illuminance (Lewis and Morris, 2006). Illuminance is calculated as:

$I = W \times V_{\lambda} \times 683 \times (1/4\pi) \times (1/d^2)$

Where:

I = Illuminance (lx)

W = radiant flux in watts (W)

V_{λ} = the spectral luminous efficiency (lm/W)

d = distance from the light source (m)

2.2.1.3.2. Illuminance for Poultry

A typical light meter measures the human perception of illuminance which is quite different from that of birds, so measurements with units of lx are not considered suitable for measurement of a bird's illuminance perception (Prescott and Wathes, 1999). Birds are able to perceive electromagnetic radiation in the UV-A portion of the spectrum but modern light meters implement filtering techniques, making the devices insensitive to radiation at wavelengths less than 400 nm and therefore, underestimate the impact of illuminance on poultry vision. Illuminance for birds can be estimated using the following equation:

$I = (w \times s \times 683)/(12.556 \times d^2)$,

Where:

I = Illuminance (clux),

w = power output in 5-10 nm segments (W),

s = relative sensitivity of domestic fowl,

d = distance from light source (m) and

683 = maximum luminous efficacy for humans (lm/W) (data unavailable for birds)

Illuminance obtained by this equation is measured as gallilux or clux (Lewis and Morris, 2006).

2.2.1.3.3. Light Intensity and Broiler Production and Processing Characteristics

Body weight (BW), feed intake (FI), feed conversion ratio (FCR) and mortality are commonly measured indicators of broiler live production. The majority of previous research demonstrated that broiler live production was unaffected by light intensity (Table 2.2). Cherry and Barwick (1962) argued that difficult management of broilers in dim light (0.2 lx) might be responsible for decreased body weight. Newberry et al. (1986) completed two experiments using 0.5, 10, 20, 30 lx and 0.1,1, 10, 100 lx. Body weight was unaffected by light intensity but feed intake and FCR (F:G) increased with increased intensity in experiment 2 at 6 and 9 wks of age. Total mortality and mortality due to sudden death syndrome (SDS) were unaffected by light intensity treatments.

A majority of previous research studies included only two levels of light intensity (high or low) and found that broiler productivity was unaffected by light intensity. Newberry et al. (1988) compared two levels (6 and 180 lx) of light intensity and found that BW, FI and FCR were the same for both levels. Kristensen et al. (2006) compared two levels (5 and 100 lx) of light intensity and two light sources, and revealed that light intensity had no effect on broiler live production (BW, FI, FCR and mortality). Lien et al. (2008) compared 5 and 150 lx and found that BW and FI of broilers exposed to 5 lx were higher than those given 150 lx. In conclusion, research consistently shows that light intensity from 1 to 150 lx does not affect broiler live production as demonstrated by BW, FI, FCR and mortality.

Table 2.2. Effect of light intensity on broiler performance

Study	Light intensity (lx)				
Cherry and Barwick, 1962	0.2	5	-	-	P value
BW (g; 68 d)	1557	1594	-	-	< 0.05
FI (g/bird)	4746	4822	-	-	NS
FCR	2.68	2.68	-	-	NS
Mortality (%)	2.9	2.9	-	-	NS
Skogland and Palmer, 1962	20	50	100	-	
BW (lbs; 70 d)	3.82	3.79	3.76	-	NS
FI (g/bird)	NR	NR	NR	-	-
FCR	NR	NR	NR	-	-
Mortality (%)	NR	NR	NR	-	-
Newberry et al., 1986	0.1	1	10	100	
BW (g; 63)	3438	3432	3421	3401	NS
FI (g/bird)	Increased with increasing intensity at 6 wks				< 0.05
FCR (F:G)	2.04	2.05	2.06	2.07	< 0.05
Mortality (%)	7.9	10.2	9.9	8.8	NS
Newberry et al., 1986	0.5	10	20	30	
BW (g; 63)	3367	3348	3330	3364	NS
FI (g/bird)	Not affected				NS
FCR (F:G)	2.11	2.11	2.15	2.11	NS
Mortality (%)	9.5	8.1	9.0	9.4	NS
Deaton et al., 1988	2	52	-	-	
BW (g; 63)	3302	3305	-	-	NS
FI (g/bird)	NR	NR	-	-	
FCR (F:G)	2.13	2.14	-	-	NS
Mortality (%)	4.63	5.25	-	-	NS
Blatchford et al., 2009	5	50	200	-	
BW (g; 42)	Not affected (2.30±0.02)				NS
FI (g/bird)	NR	NR	NR	-	
FCR (F:G)	NR	NR	NR	-	
Mortality (%)	Not affected				NS

NR = Not reported; BW = Body weight; FI = Feed intake; FCR = Feed conversion ratio; F:G = Feed to gain; NS = Non significant.

Light intensity was also studied in relation to the broiler carcass characteristics and a majority of the studies failed to find any major effect. Deaton et al. (1988) studied two levels of light intensity (2 or 52 lx) and found that the proportion of abdominal fat pad was unaffected by light intensity. In contrast, Charles et al. (1992) reported that carcasses of broilers exposed to 150 lx had a lower percentage of fat and higher percentage of protein as compared to those exposed to 5 lx. Furthermore, the abdominal fat pad size also decreased with exposure to 150 lx. They suggested that increased activity of broilers with bright light might be responsible for decreased carcass fat content and abdominal fat at the high light intensity.

The dim light intensity was also related to increased wing and leg yield. Down et al. (2006) reported that decreasing light intensity (10 lx from d 0-7; 5 lx from d 7-14 followed by 2.5 lx until d 56) resulted in larger legs and wings and suggested that it might be at the expense of breast meat. Similarly, Lien et al. (2008) found that wing yield increased with broiler exposure to dim light intensity (1 lx) as compared to 150 lx. In contrast, breast meat yield was unaffected by light intensity (Lien et al., 2007 and 2008)

In conclusion, light intensity has minor effects on broiler processing characteristics as demonstrated by increased wing and leg yield with dim light. The increase in these portions has been hypothesized due to increased carcass fat content, but more research is warranted to accurately determine this effect.

2.3. Animal Welfare

Animal welfare is a broad term that embraces biological functioning and subjective feelings. It is defined as the state of an individual in relation to its attempt to cope with the external environment. Failure to cope or difficulty in coping with the external environment is speculated to be poor welfare (Broom, 1991). The Farm Animal Welfare Council (DEFRA, 2002) has defined animal welfare by five freedoms: freedom from discomfort, freedom from hunger and thirst, freedom from pain, injury and disease, freedom to express normal behaviour and freedom from fear and stress. Duncan (2005) described good animal welfare as the presence of positive feelings (pleasure) and absence of negative feelings (suffering).

Duncan (2005) suggested that animal welfare is a broad term including feelings, mental and physical health, harmony with the environment, ability to adapt without suffering. Considering its broad nature, it is very difficult to assess animal welfare using a single indicator, but is only adequately assessed using wide range of indicators, including production, mortality and health, physiological, ethological and immunological measures (Broom, 1991).

2.3.1. Light Intensity and Broiler Welfare

Light intensity is an important management tool that can be used to improve broiler welfare without affecting broiler production. Light intensity effects on broiler welfare are noted for physical health and behaviour. In terms of physical health, light intensity has been suggested to affect ocular, foot pad and skeletal health. In regard to behaviour, expression of comfort behaviours and alteration of circadian behavioural rhythms are noted to be affected by light intensity and are considered indicators of reduced welfare.

2.3.1.1. Light Intensity and Ocular Morphology

Research on the impact of light intensity on eye morphology has included studies involving turkeys, hens and broilers. In all cases, rearing chicken under dim light resulted in ocular enlargement characterised by heavier and bigger eyes. Similarly, turkeys exposed to 1.1 lx had bigger and heavier eyes as compared to those given 11, 110 or 220 lx (Siopes et al., 1983, 1984). Recently, Blatchford et al. (2009) reported heavier eyes with dim light (5 lx) in contrast to bright light (50 and 200 lx), but the researchers were unable to find any difference in eye size. Furthermore, they found evidence of choroiditis in 20% of the broilers exposed to 5 lx. It was suggested that increased eye size (medio-lateral diameter and anterio-posterior size) may lead to myopia and reduced refractive power, thus affecting visual acuity (Harrison et al., 1968; Siopes et al., 1984).

In addition to eye enlargement, dim light also resulted in choroiditis, lens damage and pigmented peripheral areas and non-pigmented white bands in the retina (Harrison et al., 1968; Jenkins et al., 1979; Siopes et al., 1984; Thompson and Forbes, 1999). Overall, rearing chickens under dim light (≤ 5 lx) result in altered ocular morphology characterised by inflammation and increased eye weight and size, thus having potential to affect the behaviour and welfare of broilers.

2.3.1.2. Light Intensity and Skeletal and Foot Pad Health

Reports of the impact of light intensity on broiler skeletal health have not been consistent. Researchers have hypothesized that increasing light intensity would increase activity and thereby exercise, and that the increased exercise would improve skeletal health. Light intensity can affect skeletal health of broilers by affecting their activity level. Rearing broilers at 180 lx as compared to 6 lx resulted in decreased incidence of skeletal problems (Newberry et al., 1988) but the results were not reproducible. Furthermore, most of the previous research demonstrated that skeletal health was unaffected by light intensity ranges from 1 to 200 lx. Newberry et al. (1986) reported that light intensity ranges from 0.5 to 100 lx had no effect on skeletal disorders of broilers. Similarly, Kristensen et al. (2006) studied two levels of light intensity (5 and 100 lx) and found that leg health was unaffected. In a similar fashion, Olanrewaju et al. (2007) found that broilers exposed to light levels of 0.2 to 20 lx have similar skeletal health as demonstrated by gait-score. The incidence of tibial dyschondroplasia was also unaffected by light ranges from

2.2 to 20 lx (Hester et al., 1987). Recently, Blatchford et al. (2009) researched three levels of light intensity (5, 50 and 200 lx) and found that gait score was unaffected by light intensity.

Foot pad dermatitis is a multi-factorial problem associated with various factors including diet and litter quality. Diets deficient in biotin and riboflavin were found to induce foot pad dermatitis in broilers because of changes to skin structure and thereby increased foot susceptibility to irritation. Litter quality is the most important factor affecting the incidence of foot pad dermatitis because of its direct contact with the foot. Stocking density, temperature, humidity, ventilation, litter material and dietary components are factors affecting litter quality and subsequently foot pad health (Berg, 1998). Light intensity has also been shown to affect the incidence of foot pad disorders. It has been suggested that decreased activity and increased resting associated with dim light resulted in an increased incidence of foot pad erosions (Blatchford et al., 2009). They suggested that decreased activity with dim light results in increased contact time between the foot and litter, leading to greater foot pad erosions. Alternatively, light intensity might have affected litter quality, thereby resulting in differences in foot pad health.

In conclusion, the impact of light intensity on broiler skeletal health is inconsistent, but it is clear that dim light (less than 5 lx) is related to increased incidence of foot pad lesions. Recent studies have shown that light intensity in the range of 1 to 200 lx has no effect on broiler skeletal health and mobility. The diminished effect of light intensity on skeletal health as time progresses may be due to intensive selection of modern broilers for leg health, thus reducing the overall incidence of skeletal problems.

2.3.1.3. Light Intensity and Broiler Behaviour

Light intensity has pronounced effects on broiler behaviour by affecting their visible acuity (Kristensen et al., 2002). Bright light was found to increase the activity levels of birds. Newberry et al. (1988) studied two levels of light intensity (6 and 180 lx) and reported that broilers exposed to 180 lx stood, walked and had more total activity (feeding, drinking, walking and standing). Similarly, walking and feeding increased with exposure to light intensities of 200 lx as compared to 6 lx (Davis et al., 1999). Kristensen et al. (2006) reported that use of light intensities of 100 lx resulted in increased standing as compared to 5 lx. In addition to broilers, light intensity studies with laying hens and turkeys also revealed similar results with increased activity at brighter light levels (Hughes and Black, 1974; Siopes et al., 1984; Hester et al., 1987; Kjaer and Vestergaard, 1999). Recently, Alvino et al. (2009) studied the impact of three levels of light intensity (5, 50 and 200 lx) on broiler activity and found that broilers exposed to 5 lx rested more in contrast to other intensities but walking and standing remained unaffected. Overall, bright light results in increased activity but it is unclear whether this effect is linear or there exists a threshold beyond which the activity levels remain the same as most of the previous studies, demonstrating an activity effect, used only two levels of light intensity (very high or low).

Comfort behaviours are categorised as behaviours performed after fulfillment of basic needs and when birds are free from suffering (Duncan and Mench, 1993). Therefore, the decreased expression of comfort behaviours may indicate reduced welfare associated with a particular environment. Comfort behaviours include preening, dust-bathing, foraging, wing-flapping, stretching and feather-ruffling (Wood-Gush, 1971). Few studies have been conducted to determine the effects of light intensity on detailed behavioural expression and in particular comfort behaviours. Davis et al. (1999) found that broilers exposed to light intensities of 200 lx resulted in increased litter-directed behaviour as compared to 6 lx. Recently, Alvino et al. (2009) showed that broilers exposed to 5 lx demonstrated reduced expression of preening and foraging behaviour as compared to those birds exposed to 50 and 200 lx.

2.3.1.4. Light Intensity and Broiler Behavioural Rhythms

Day-night contrast acts as a strong signal governing the circadian behavioural rhythms of broilers. Recently, Alvino et al. (2009) revealed that diurnal behavioural rhythms of broilers were diminished at light intensity of 5 and 1 lx during the day and night, respectively, with a more even distribution of behaviours over the 24-h photoperiod. Furthermore, they suggested that uniform distribution of behaviours might disrupt the normal rhythms of birds, thus resulting in an arrhythmic flock. Commercially, broiler producers use varying levels of light intensity during the day and night, further reflecting the importance of day-night contrast. In addition to circadian rhythms, day-night contrast also affects melatonin rhythms. Previous research demonstrated the diminished circadian melatonin rhythms with use of dim light during the day in comparison to bright light (Brainard et al., 1982; Griffith and Minton, 1992; Vera et al., 2005). Melatonin is a central hormone governing behavioural rhythms. Thus, diminished behavioural rhythms at 5 lx may suggest the alteration of melatonin rhythms as well. In conclusion, dim light may be detrimental to broiler welfare as demonstrated by diminished behavioural and physiological rhythms.

2.4. General Comments

It can be concluded that chickens have a highly developed sense of vision that reflects the diurnal nature of their activity. This is indicated by their large eye size, the ability to differentiate colour and their extended spectral sensitivity and visible acuity. However, adequate illuminance or intensity is necessary for the chicken's sense of vision to work to its full capabilities (Prescott et al., 2003). Furthermore, preference testing with avian species also demonstrated inclination for bright light in comparison to dim light (Shervin, 1997; Prescott and Wathes, 2002). The presence of unique ocular structure and bird's preference reflects the importance of bright light for chickens.

Research over a wide range in light intensity (1-150 lx) leads to the conclusion that broiler live production is unaffected but dim light can have some effect on carcass characteristics. Light intensity can also affect broiler welfare with evidence that dim light results in reduced welfare by increasing eye weight and size, increasing incidence of foot pad lesions and negatively affecting the expression of comfort behaviours and the nature of circadian behavioural rhythms.

Effect of Light Intensity on Broiler Production, Processing Characteristics, and Welfare

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3. IMPACT OF LIGHT INTENSITY ON BROILER PRODUCTION, PROCESSING CHARACTERISTICS AND WELFARE

3.1. Abstract

Manipulation of light intensity is an important management tool affecting broiler production and well being. Despite considerable research on light intensity, there is still a debate on the optimum level to be used for intensively housed broilers. Two trials were conducted with the objective of investigating the effect of light intensity, within the practical levels at confinement barns (1, 10, 20 and 40 lx), on production, processing characteristics and welfare of broilers raised to 35 d of age. Each light intensity treatment was replicated in two environmentally controlled rooms in each trial with 950 Ross x Ross 308 chicks per room. Data were analyzed as a randomized complete block design with trial serving as a block. All chicks were exposed to 40 lx light intensity and 23 h light for the first 7 d followed by treatment light intensity and 17 h day length thereafter. Body weight and feed consumption were determined at 7, 14, and 35 d of age. At the end of each trial 60 birds per treatment were processed to determine the detailed meat yield. Skeletal and foot pad, and ocular health were monitored at 31 and 32 d of age, respectively. Body weight, feed consumption, feed-to-gain ratio and mortality were unaffected by light intensity. Carcass, thigh and drum yield as a percentage of live weight decreased linearly with increasing light intensity. The 1 lx treatment resulted in heavier wings as a percentage of live weight. Light intensity had no effect on skeletal health but ulcerative foot pad lesions decreased linearly with increasing light intensity. Birds exposed to the 1 lx treatment had heavier and larger eyes. In conclusion, light intensity did not affect broiler production and mortality but did affect carcass characteristics. The 1 lx light intensity treatment had a negative impact on broiler welfare as demonstrated by increased deep ulcerative foot pad lesions and eye size.

Key words: broiler, health, light intensity, meat yield, performance.

3.2. Introduction

Light is as an important management tool to regulate broiler production and welfare by modulating various behavioural and physiological pathways. Artificial lighting for broilers consists of three aspects: photoperiod, wavelength and light intensity. All of these aspects have significant effects on broiler production and welfare. The effects of photoperiod on broiler production and welfare were intensively studied in the past (Classen and Riddell, 1989, 1991; Sørenson et al., 1999; Classen et al., 2004). Similarly, a number of studies have investigated the effects of wavelength (Rozenboim et al., 1999; Lewis and Morris, 2000; Rozenboim et al., 2004).

Light intensity has also been studied in the past but relatively few studies have shown significant effects on broiler production. In general, light intensity ranging from 1 to 150 lx has been found to not affect body weight, feed consumption and feed-to-gain ratio (Skogland and Palmer, 1962; Newberry et al., 1988; Kristensen et al., 2006; Lien et al., 2007; Blatchford et al., 2009). If significant effects have been found, they have generally been deleterious effects of low light intensity on poultry production and welfare. Negative effects have included reduced carcass and tender yield, decreased early uniformity, increased incidence of leg disorders and ocular defects, altered behavioural expression and birds being more fearful (Hughes and Black, 1974; Newberry et al., 1988; Lien et al., 2007; Blatchford et al., 2009; Alvino et al., 2009). Dim light was found to induce buphthalmia, altered retina (peripheral darkened areas and non pigmented white bands), choroiditis, lens damage, inflammation and increased eye size and weight (Harrison et al., 1968; Jenkins et al., 1979; Siopes et al., 1984; Thompson and Forbes, 1999; Blatchford et al., 2009). Skeletal health was improved by stimulating activity at higher light intensity but the effects were not consistent (Newberry et al., 1986, 1988; Blatchford et al., 2009). Dim light has increased leg and wing yield as a percentage of live weight (Downs et al., 2006; Lien et al., 2008). Charles et al. (1992) has shown that dim light resulted in increased fat and decreased protein concentration in the carcass. Bright light was suggested to improve welfare, with broilers having more pronounced behavioural rhythms and comfort behaviours (Alvino et al., 2009).

Jurisdictions have established regulations in relationship to light intensity. An example is the European Union (EU), which has legislated the use of at least 20 lx light intensity for broiler production after the initial brooding phase (Council of the European Communities, 2007). Despite published negative effects on broiler production and welfare, the broiler industry still uses and recommends dim lighting (less than 5 lx). Most management guides recommend a reduction in intensity after the early brooding period, but there is a debate as to the appropriate level that should be used. Our interaction with industry revealed that these recommendations are based on the perception that very low light intensities improve feed efficiency, reduce mortality due to sudden death syndrome (**SDS**) and reduce carcass damage (scratches, bruises) because of reduced activity. However, these advantages have not been confirmed by scientific investigation, and in some cases are contrary to published data. Higher light intensity has been shown to increase bird activity and aggressive behaviour (Hester et al., 1987; Newberry et al., 1988; Kjaer and Vestergaard, 1999), but a specific negative effect of higher light intensity within the range of 1 to 100 lx has not been scientifically demonstrated in broiler chickens.

Based on this assessment, the present study was designed with the aim of examining the effect of four levels of light intensity (1, 10, 20, 40 lx) within the practical levels in confinement barns on broiler production, welfare and processing characteristics.

3.3. Material and Methods

Experiments were approved by the Animal Care Committee of the University of Saskatchewan and were performed in accordance with recommendations of the Canadian Council on Animal Care (1993) as specified in the Guide to the Care and Use of Experimental Animals.

3.3.1. Birds and Housing

More than 14,000 Ross × Ross 308 male and female day-old broiler chicks were obtained from a commercial hatchery for two successive trials and reared under four different levels of light intensity (1, 10, 20, 40 lx). Equal numbers of male (475) and female (475) chicks were randomly placed in eight different environmentally controlled rooms with a trial end density of 32 kg/m^2 based on chick placement numbers. An equal amount of straw (7.5 to 10 cm thick) was placed in each room. The room temperature was 34º C at chick placement and gradually decreased until it was 22º C by d 28. In each room, 12 tube feeders (79 birds per feeder) having a pan circumference of 113 cm were placed to provide *ad-libitum* feed to the broilers. At 28 d of age small feeders were replaced by larger ones with a pan circumference of 135 cm. Each room was provided with 11 drinkers each having 6 nipples, thus resulting in approximately 14 birds per nipple. Feed was obtained from a commercial feed company (Federated Co-operatives Ltd, Saskatoon, SK, Canada). The major feed ingredients were based on corn and soybean meal with specific energy and amino acid levels in starter, grower and finisher diets.

3.3.2. Lighting Treatments

All birds were kept under an intensity of 40 lx and 23 h day length from 0 to 7 d of age. At 7 d of age, experimental treatments consisting of four levels (1, 10, 20, 40 lx) of light intensity were randomly assigned to eight rooms with 17 h of constant day length. Light was provided by incandescent bulbs and intensity during dark periods was 0 lx. Light intensity was recorded near the floor, approximately at the bird's height, three times each week at 6 positions in each room using a light meter (Acklands-Grainger, Inc., Ontario, Canada) with peak sensitivity at 550-570 nm. Average values for each light intensity treatment are depicted by Table 1. A spectroradiometer (ASD FR Pro, Analytical Spectral Devices, Inc., USA) was used to record the illumination quality. Using a fibre-optic probe, intensities of light reflected from a horizontal Polytetrafluorethylene (**PTFE**) surface approximately 15 cm from the floor were recorded for each of the 4 treatment levels. Light quality measures were recorded at 4 different locations within 2 different rooms at the conclusion of the second trial. For each location and light intensity (1, 10, 20, 40 lx), the spectral radiance of reflected light was recorded three times at wavelengths ranging from 350 nm to 1750 nm, and the spectral resolution was 3 nm between 350 and 700 nm and 10 nm at wavelengths longer than 700 nm. Figure 1 shows the mean spectral radiance, combining data from all locations (n = 8) and replicate measures (n = 3); each data point on each curve represents an average reading of 24 measures. Dimming incandescent bulbs, using a common rheostat, results in shifting of dominant electromagnetic energy toward the red and infrared regions of the spectrum. In contrast, dimming other light sources (compact fluorescent lamps, cold cathode fluorescent lamps, and light-emitting diodes) causes a downward scaling of energy at all wavelengths. Thus, the spectra of illumination, at a given intensity indicated by a light meter, will be different, depending on the illumination source.

Table 3.1. Average light intensity (lx) reflecting each treatment for two trials (n = 180)

Item	Treatment (lx)			
	1	2	3	4
Trial 1	1.1±0.02	10.3±0.10	19.3±0.16	40.5±0.32
Trial 2	1.2±0.16	9.6±0.09	19.5±0.09	39.5±0.21

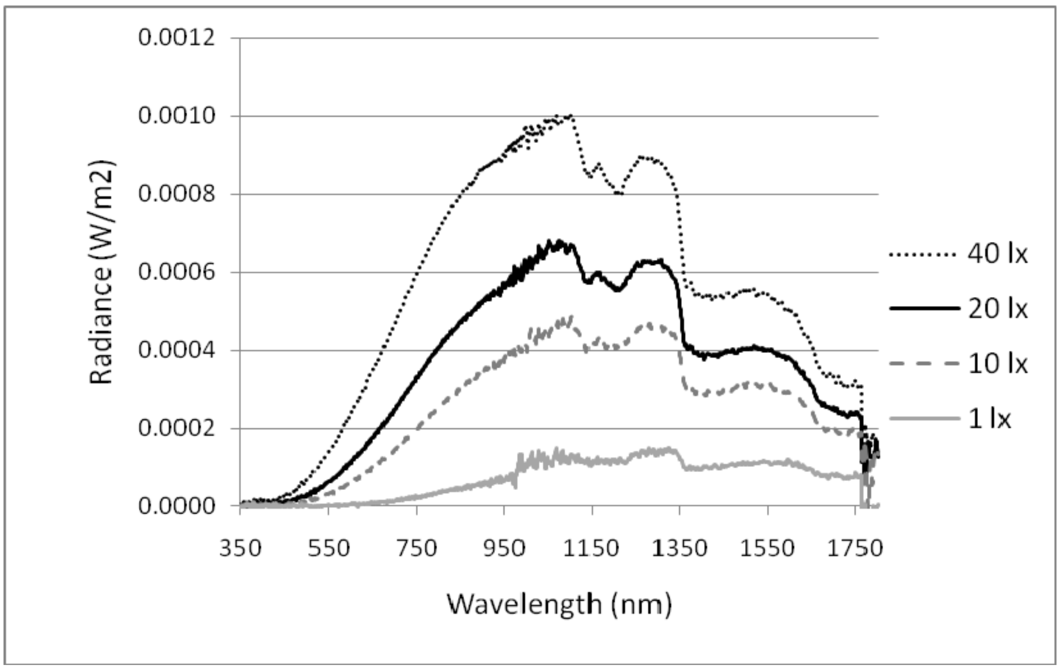

Figure 3.1. Quality of light (spectral radiance) as affected by light intensity.

3.4. Data Collection

Body weight (**BW**) and feed intake (**FI**) were measured on a room basis at 0, 7, 14 and 35 d of age and feed efficiency (feed-to-gain ratio; **F:G**) was determined for relevant time periods. Rooms were checked for dead birds twice daily and total mortality was calculated as a percentage of live birds at the start of each trial. Detailed causes of mortality were determined by the Prairie Diagnostic Services at the University of Saskatchewan. At 31 d of age, 15 males and 15 females were randomly selected from each room and assessed using subjective scoring techniques for skeletal health (0 to 5; Garner et al., 2002) and foot pad health (0 to 2; Ekstrand et al., 1998). In the present study, mild superficial lesions (category 1) were judged to not be a welfare problem, so were combined with category 0 (no visible lesions). In contrast, ulcerative lesions (category 2) were not as severe as described by Ekstrand et al. (1998) but were interpreted as a painful condition, thus compromising broiler welfare. The right eye was collected from 5 males and 5 females per room at 32 d of age and dimensions (weight, corneal diameter, medio-lateral (**ML**) diameter, dorso-ventral (**DV**) diameter and anterio-posterior (**AP**) size) were noted immediately after extirpation, using a digital caliper. At 35 d of age, feed and water were withdrawn 4 and 2 h, respectively, prior to loading birds for transport to slaughter. Broilers (15 males and 15 females per room) were randomly selected for meat yield determination, double wing banded and weighed individually after 2 h of feed withdrawal. Birds were processed at a commercial processing plant and then wing banded birds were returned to the University of Saskatchewan for detailed meat yield assessment: breast (skin, *Pectoralis major* and *Pectoralis minor)*, left drum (skin, meat, bone), left thigh (skin, meat, bone), intact right drum, intact right thigh, wings, abdominal fat and back and rack (remaining carcass) as a percentage of live weight.

3.5. Statistical Analysis

A completely randomized block design with trial serving as block was used in order to account for the variation among two successive trials. Data were checked for normality using the Shapiro-Wilk test prior to analysis. Data were analyzed using Proc GLM and Proc REG of SAS (SAS Institute, 2002). Percentage data were first log transformed then analyzed. Means were separated using the Duncan's multiple range test and the level of significance was fixed at $P \leq 0.05$ unless otherwise stated.

3.6. Results

3.6.1. Production Characteristics and Mortality

Body weight gain and FI from 7 to 14 d of age (Table 3.2) were unaffected by light intensity but birds exposed to 1 lx had lower F:G than other treatments. BW gain, FI and F:G from 0 to 35 d of age (Table 3.2) were not affected by light intensity level. Total and individual causes of mortality were not affected by light intensity level. The incidences of SDS for the 1, 10, 20 and 40 lx treatments were 1.4, 1.3, 1.4 and 1.7 %, respectively.

3.6.2. Carcass Characteristics

Carcass, thighs and drums yield, as a percentage of live weight, decreased linearly with increasing light intensity. Broilers reared under 1lx had heavier wings as a percentage of live weight in contrast to other treatments. Light intensity affected the percentage of remaining carcass (back and rack), but a specific trend was not apparent. All other processing characteristics were not affected by light intensity (Table 3.3).

3.6.3. Foot Pad and Skeletal Health and Eye Size

Light intensity levels affected foot pad health. The incidence of no visible and mild superficial lesions (category 0+1) increased linearly with increasing light intensity. In contrast, incidence of ulcerative painful lesions (category 2) decreased linearly with increasing light intensity from 1- 40 lx (Table 3.4).

Skeletal health and bird mobility as assessed by gait scoring were not affected by light intensity (Table 3.4).

Broilers reared under 1 lx had heavier eyes as compared to rearing under other light regimes. Similarly these birds also had larger eyes, as indicated by a greater corneal diameter, medio-lateral (**ML**) diameter, dorso-ventral (**DV**) diameter and anterio-posterior (**AP**) size (Table 3.5).

Table 3.2. Effect of light intensity on broiler production parameters

	Light intensity (lx)				
Item	1	10	20	40	SEM
BWG[1] (7-14 d)	0.250	0.244	0.245	0.246	0.003
BWG (0-35 d)	2.188	2.091	2.109	2.114	0.027
FI[1] (7-14 d)	0.345	0.347	0.345	0.346	0.003
FI (0-35 d)	3.791	3.785	3.758	3.749	0.011
F:G[1] (7-14 d)	1.379[b]	1.422[a]	1.405[ab]	1.410[a]	0.007
F:G (0-35 d)	1.702	1.772	1.737	1.733	0.007
% Mortality (0-35 d)	6.02	6.63	6.18	5.85	0.421

[1] BWG = body weight gain (kg), FI = feed intake (kg), F:G = feed-to-gain ratio (kg:kg).
[a,b] Means within a row with different superscripts differ significantly ($P \leq 0.05$).

Table 3.3. Effect of light intensity on broiler carcass characteristics (% of live weight)

	Light intensity (lx)				
Item	1	10	20	40	SEM
Live weight (kg)	2.32	2.34	2.29	2.28	12.26
Carcass*	68.94^{a}	69.28^{a}	68.38^{b}	68.32^{b}	0.104
Pectoralis major	15.81	15.62	15.82	15.53	0.052
Pectoralis minor	3.59	3.58	3.63	3.63	0.020
Total breast	19.40	19.20	19.44	19.15	0.057
Breast skin	2.13	2.18	2.15	2.05	0.022
Right thigh (whole)*	6.06	5.99	6.00	5.93	0.018
Left thigh meat	4.33	4.38	4.35	4.29	0.018
Left thigh skin	0.86	0.84	0.86	0.87	0.010
Left thigh bone	0.87	0.87	0.90	0.86	0.007
Right drum (whole)*	4.82	4.80	4.80	4.73	0.014
Left drum meat	3.09	3.05	3.06	3.02	0.011
Left drum skin	0.53	0.51	0.52	0.51	0.006
Left drum bone	1.27	1.30	1.28	1.26	0.007
Wings**	7.72^{A}	7.56^{B}	7.51^{B}	7.51^{B}	0.018
Abdominal fat	0.75	0.83	0.78	0.87	0.018
Remaining carcass	17.1^{ba}	17.3^{a}	17.0^{b}	17.4^{a}	0.048

^{a,b} Means within a row with different superscripts differ significantly ($P \leq 0.05$).
^{A,B} Means within a row with different superscripts differ significantly ($P \leq 0.01$).
* = Linear regression with $P \leq 0.05$.
** = Quadratic regression with $P \leq 0.05$.

Table 3.4. Effect of light intensity on broiler foot pad and gait score (31 d)

Item	Light intensity (lx)				SEM
	1	10	20	40	
Foot pad score[1]					
0+1*	60.83	70.59	71.67	74.17	2.110
2*	39.17	29.41	28.33	25.83	2.105
Gait score[2]					
0	16.7	18.3	20.0	20.0	1.783
1	36.7	39.2	36.7	34.2	2.202
2	41.7	40.0	40.8	41.7	2.248
3	4.2	2.5	2.5	4.2	0.820
4	0.8	0.0	0.0	0.0	0.208
5	0.0	0.0	0.0	0.0	0.000
3+4+5	5.0	2.5	2.5	4.2	0.844

[1] Ekstrand et al. (1998); % of birds observed; 0 = no lesion, 1 = mild superficial lesion, 2 = ulcerative lesion.
[2] Garner et al. (2002); % of birds observed; 0 = perfect gait, 5 = immobile.
*= Linear regression with $P \leq 0.05$.

Table 3.5. Effect of light intensity on broiler right eye dimensions (32 d)

Item	Light intensity (lx)				SEM
	1	10	20	40	
Eye weight (g)*	1.70[a]	1.61[b]	1.61[b]	1.60[b]	0.014
Corneal diameter (mm)*	7.19[a]	7.04[b]	7.03[b]	6.97[b]	0.024
Dorso-ventral diameter (mm)*	15.92[a]	15.70[b]	15.60[b]	15.61[b]	0.050
Medio-lateral diameter (mm)*	16.62[a]	16.46[ab]	16.31[b]	16.31[b]	0.051
Anterio-posterior size (mm)*	12.21[A]	11.72[b]	11.45[b]	11.68[b]	0.086

[a,b] Means within a row with different superscripts differ significantly ($P \leq 0.05$).

* = Linear regression with $P \leq 0.05$.

3.7. Discussion

The present study was designed to examine the effects of light intensity on broiler production and processing characteristics. The 7-14 d performance (BW and FI) of broilers was unaffected by light intensity, thus reflecting that there is no immediate negative impact of reducing light intensity from 40 to 1, 10, 20 lx, respectively, with all broilers adapting equally. In contrast, improved 7-14 d F:G of the broilers exposed to 1 lx was the result of a numerical increase in the BW (P = 0.16) and decrease in the FI (P = 0.61), but this effect is transient and overall 0-35 d F:G was unaffected.

Light intensity had no effect on overall (0-35 d) broiler live performance, indicated by insignificant differences in BW, FI and F:G. These effects are similar and in agreement with most previous research (Skogland and Palmer, 1962; Newberry et al., 1986, 1988; Kristensen et al., 2006). In contrast, Cherry and Barwick (1962) and Charles et al. (1992) found improved BW and F:G with low light intensities (1 and 5 lx) in contrast to birds given much brighter light (100 and 150 lx) as compared to the present study (40 lx). Very bright light (100 and 150 lx) might have stimulated the activity of broilers to the extent that they utilized more energy for maintenance instead of growth. Recently, Lien et al. (2008) have shown increased BW and FI with dim light (1 lx) in comparison to 150 lx. The observed difference was due to the increased FI with low light intensity, contrary to the present study where intensity did not affected FI. In the present study, with small differences in treatment levels and using a growth-oriented broiler strain, no impact of light intensity on overall live broiler performance was found.

Broiler mortality was not affected by light intensity. Total mortality was further subdivided into causes of death but there, again, was no effect of light intensity on these individual mortality categories, including SDS. The present study is in agreement with most previous research

(Newberry et al., 1986; Deaton et al., 1988; Kristensen et al., 2006; Downs et al., 2006; Lien et al., 2007). It was argued in the past (Ononiwu et al., 1979) that bright light results in stress attributed to cannibalism and aggression, and this might contribute to the higher incidence of SDS mortality. However, cannibalism and aggression are not common in broiler systems and therefore this is not a likely mechanism. Because the majority of research shows no effect of light intensity on mortality, and selection has occurred against metabolic and skeletal diseases (McKay et al., 2002), it can be concluded that an impact of light intensity on mortality is unlikely.

Most carcass characteristics were not affected by light intensity but exceptions were carcass, thighs, drums and wings yield as a percentage of live weight. Carcass yield decreased linearly with increasing light intensity from 1 to 40 lx. Charles et al. (1992) found that dim light (5 lx) resulted in increased fat and decreased protein levels of the carcass and suggested that this might be due to decreased activity of birds kept in dim light. This is supported by other research where increased activity of broilers with environmental enrichment devices (perches) resulted in less thigh fat (Simsek et al., 2009). Our research (Chapter 4) has also demonstrated that birds exposed to dim light (1 lx) rested more and thus supports this hypothesis. Thighs and drums, as a percentage of live weight, decreased linearly with increasing light intensity in the present study. Similar results were obtained by Downs et al. (2006). Birds in this study exposed to the 1 lx treatment produced heavier wings, similar to findings by Downs et al. (2006) and Lien et al. (2008). Furthermore, the fat content of these parts (thighs, drums and wings) is higher as compared to breast meat (Probst, 2009). Breast skin, indicative of carcass fat content, tended to be higher ($P = 0.11$) in birds exposed to 1 or 10 lx, providing some support for an increase in carcass fat deposition. Abdominal fat pad was also recorded to ensure that the total of all parts equaled to 100 %, but these values have been previously found to be an inaccurate indicator of carcass fat content because of variable removal during mechanical evisceration at the slaughtering plant. Further research is required to determine if the increased carcass fraction represented by thighs, drums and wings from birds reared under the dim light may be explained by the increased fat proportion of the carcass.

In addition to an activity effect on carcass composition in birds given low light intensity, it can be speculated that a physiological response may also be involved. Adequate light intensity is required to stimulate the receptors responsible for gonadotropin releasing hormone (**GnRH**) release in the hypothalamus as these receptors are suggested to be sensitive to light directly passing through the skull instead of perception of light by eyes (Robinson et al., 2003). Dim light (less than 5 lx) may not be able to penetrate the skull (Morgan et al., 1995), thus light at this intensity may be unable or less likely to excite the receptors to release GnRH. Decreased testicular size in turkeys (Siopes et al., 1983) and FSH concentration (Lewis et al., 2005) in pullets under dim light (1 and 3 lx, respectively) also support this hypothesis. GnRH is responsible for secretion of sex steroids and gonadal development in both males and females. Sex steroids (androgens and estrogens) play an important role as anti-lipogenic agents in the animal and human body (Mayes and Watson, 2004; Chen et al., 2005). They are also involved in expression of genes responsible for growth hormone (**GH**) and insulin-like growth factor-1 (**IGF-1**) release (Danielle et al., 1996; Mateescu and Thonney, 2005). Both GH and sex steroids act simultaneously as anti-lipogenic agents and cause less fat to be deposited in the carcass. Overall, lower light levels can affect GnRH secretion, resulting in lower concentrations of sex steroids and GH and may ultimately cause greater amounts of fat deposition in the carcass as demonstrated by heavier thighs, drums and wings.

Foot pad dermatitis is a multi factorial problem including various endogenous and exogenous factors (Berg, 1998). Previous research has shown that increasing broiler activity by reducing stocking density and providing a natural photoperiod resulted in decreased incidence of foot pad lesions (Ferrante et al., 2006). Recently, Blatchford et al. (2009) also found an increased incidence of hock and foot pad erosions with dim light. The increased incidence of ulcerative foot pad lesions with decreasing light intensity is likely due to more time spent resting, thus resulting in increased contact time between the foot and litter as suggested by Blatchford et al. (2009). Our research has also found increased resting at low light intensity and therefore supports their suggestion (Chapter 4). The incidence of ulcerative lesions is of greater significance in the modern broiler industry as these wounds are undoubtedly painful and result in reduced welfare of broilers.

The use of dim light (1 lx) in this study caused a change in the anatomical structure of the chicken's eyes. This is similar to previous studies where eye changes were characterized by the incidence of buphthalmia, choroiditis, glaucoma, and lens distortion (Harrison et al., 1968; Jenkins et al., 1979; Siopes et al., 1984; Thompson and Forbes, 1999; Blatchford et al., 2009). All or some of these changes might impair the bird's vision and therefore compromise its welfare. Blatchford et al. (2009) found that birds reared under light levels of 5 lx had heavier eyes, but did not find the differences in eye size as noted in the present study. The minimum light intensity in the current research was 1 lx, compared to the 5 lx by Blatchford et al. (2009). This suggests that decreasing light intensity from 5 to 1 lx causes further changes in the ocular structure of broilers. A larger eye may produce pressure on the optic nerve which lies at the caudal aspect of the eye ball, and this pressure could induce nerve damage (Morrison et al., 2005). Pressure-induced damage of the optic nerve can result in a painful condition as it would also be accompanied by the release of inflammatory mediators (ecosanoids) responsible for hyperalgesia (Tracey and Walker, 1995). Increased eye size and dimensions along with inflammatory changes as evidenced in the past may result in a painful condition for broilers reared under dim light, thereby resulting in poor welfare.

Eyes grow in a rhythmic fashion with higher growth during periods of light and reduced growth during darkness. The lack of this rhythm results in increased eye growth (Jody et al., 2006). Lauber and McGinnis (1966) have shown that birds kept under long continuous photoperiod (24 L: 0 D) had larger eyes. Similar results were found by Jensen and Matson (1957). Disrupted rhythmic secretion of melatonin might be responsible for increased growth of eyes under a long continuous photoperiod in contrast to short photoperiods with a normal melatonin rhythm (Schwean-Lardner et al., 2010). If low light intensity affects secretion of melatonin and other physiological functions because of the absence or a reduced amount of trans skull light penetration, a disrupted eye growth could be a consequence. However, our work has shown that melatonin circadian rhythms are unaffected by light intensity ranging from 1 to 40 lx (Chapter 4). This suggests that abnormal eye growth with dim light is caused by a mechanism other than rhythm disruption. Alternately, the rhythm disruption is independent of melatonin.

Overall, the increased weight and size of the eye with dim light, as discovered in this study, may be due to adaptation or patho-physiological mechanisms, but more research is warranted to accurately define the effect.

3.8. Conclusions

Light intensity has no effect on broiler production parameters (BW, FI, F:G and mortality) within the range tested herein. Carcass, thigh and drum yield, as a percentage of live weight, decreased linearly with increasing light intensity. Treatment using the 1 lx light intensity resulted in increased wing yield in contrast to other intensities. Increased eye weight and size and increased incidence of deep ulcerative foot pad lesions with the 1 lx intensity, indicates reduction in broiler welfare.

4. EFFECT OF LIGHT INTENSITY ON BROILER BEHAVIOUR AND CIRCADIAN RHYTHMS

4.1. Abstract

Light intensity manipulation is an important management tool affecting broiler behaviour and physiology but still there is a debate regarding the optimum level to be used in confinement barns. Two trials were completed to study the impact of light intensity (1, 10, 20 and 40 lx) on behaviour and circadian rhythms of broilers raised to 35 d of age. In each trial, 950 Ross x Ross 308 chicks were housed per room with replication of individual light intensity treatment in two environmentally controlled rooms. Within each large room, a small pen with 25 male and 25 female chicks was used for recording behaviour. Data were analyzed as a randomized complete block design with trial acting as a block and level of significance was fixed at $P \leq 0.05$. All chicks were provided with 40 lx intensity and 23 h light until shifting to treatment light intensity and 17 h daylength at 7 d of age. For each replicate, behaviour was recorded for a 24 h period, starting at 16 or 17 d of age. At 23 d of age, three birds per room were bled at the start, middle and end of light and dark periods for melatonin estimation using RIA. When summarized over the 24 and 17 h observation period, birds exposed to a light intensity of 1 lx rested more and expressed fewer comfort behaviours in comparison to other light intensities. Behavioural patterns over the 17-h light period were unaffected by light intensity. Similarly, all birds exhibited diurnal rhythms for feeding, resting, walking, standing, dust-bathing and preening behaviours with little or no activity during the 7 h of darkness. Diurnal rhythms of serum melatonin were unaffected by light intensity with all treatments producing a pronounced rhythm. In conclusion, despite having prominent circadian physiological and behavioural rhythms, birds exposed to light intensities of 1 lx rested more and had reduced comfort behavioural expression, potentially indicating a reduced welfare state.

Key words: broiler, light intensity, behaviour, rhythm, melatonin and welfare

4.2. Introduction

Light intensity manipulation is a commonly used management tool in the poultry industry, applied during both growing and reproduction phases. It is relatively well researched in topic with regards to broiler chickens (Skogland and Palmer, 1962; Newberry et al., 1986; Kristensen et al., 2006; Lien et al., 2007; Blatchford et al., 2009) with a primary emphasis on production (body weight, feed intake and feed conversion ratio) and health. In general, research has shown that the impact on production traits has been small or lacking (Chapter 3). In addition to understanding the impact of broiler management techniques such as light intensity on production characteristics, these must also be acceptable from a welfare standpoint.

Less emphasis in research has been placed on the welfare implications of light intensity. Welfare-related research has included assessment of bird health with an impact noted for the incidence of skeletal disorders, foot pad health, and ocular defects (Newberry et al., 1988; Blatchford et al., 2009). For all of these parameters, dim (< 10 lx) light has been found to increase the frequency of their incidence and therefore is suggested to be detrimental to the welfare of broilers.

Welfare is best assessed using a multi dimensional approach, consisting of production, health and feelings. Duncan (1993) suggests that welfare is not necessarily represented by good health or productivity but it depends upon *"What the animal feels"*. Behaviour is a non invasive and non intrusive technique (Dawkins, 2004) to measure an animal's feelings; thus behaviour acts as a vital indicator of animal welfare (Gonyou, 1994).

Relatively few studies have been conducted to examine the effect of light intensity on broiler behaviour, a key indicator of bird welfare. Reduced activity of broilers with dim light (6 lx) compared to bright light (180 lx) was observed by Newberry et al. (1988). The expression of exploratory and comfort behaviours has been found to decrease with exposure to dim light (Alvino et al., 2009). Furthermore, they noted an even distribution of behaviours over a 24-h photoperiod in broilers exposed to a light intensity of 5 lx in contrast to birds exposed to 50 or 200 lx, which demonstrated distinct behavioural day-night rhythms. The lack of rhythms when light intensity was 5 lx during the day was suggested by the authors to be a welfare consideration as it result in interruption of normal circadian rhythms of a flock. Possibly contributing to the lack of rhythm was the use of 1 lux during the scotoperiod, which may not have been sufficient contrast to 5 lx during the daytime period to induce a day-night behavioural cycle.

In addition to day-night contrast, melatonin is also responsible for governing the circadian rhythms of animals (Reiter, 1993). The main source of plasma/serum melatonin in chickens, house sparrows and starlings is the pineal gland in contrast to quail and pigeons where the retina is a source in addition to the pineal gland (Pelham, 1975; Janik et al., 1992). Arylalkylamine-N-acetyltransferase (AA-NAT) is an enzyme involved in the rate limiting step of the melatonin biosynthesis pathway, thus modulating the secretion of melatonin. Rhythmic expression of AA-NAT in the pineal gland with a peak during the night and a decreased concentration at the onset of day is responsible for diurnal rhythms in blood melatonin (Herichova et al., 2001). Light can control the pineal AA-NAT activity through the eyes or by direct penetration of the skull, thereby modulating the diurnal rhythms of melatonin (Morgan et al., 1995). The perception of light through the eyes or skull depends on the quality of light. Longer wavelengths and bright light are better able to penetrate the skull (Benoit, 1964). On the other hand, the sensitivity of retinal photoreceptors also varies with the wavelength of light, with a peak at 545-575 nm (Lewis and Morris, 2000). The effect of photoperiod on melatonin rhythms has been demonstrated in turkeys (Zawilska et al., 2007) and laying hens (Lewis et al., 1989), but the impact of day light intensity in broilers is lacking. Commercially, broilers are reared under dim light (< 1 to 5 lx), thus making it of interest to look at the effect of light intensity during the photoperiod on broiler melatonin rhythms.

Given a choice, birds may also indicate a preference for greater light intensity. Preference testing with hens and turkeys revealed the preference for brighter light (5, 10, 25 lx) as compared to the dim light (< 1 lx) (Shervin, 1997; Prescott and Wathes, 2002). Similarly, Berk (1997) demonstrated that broilers were more inclined towards bright light (20 lx) in contrast to dim light (0.05 lx). Overall, precocial poultry species prefer to live in a bright environment as compared to the dark. Preference for bright light by poultry species is compatible with the bird's eye structure. The retina of the avian eye contains extensive single and double cones, responsible for vision during the lighted conditions (Meyer and May, 1973). The presence of four different types of retinal cones covered with specific oil droplets is responsible for extending the spectral sensitivity to the ultra violet-A **(UV-A)** portion of the spectrum (Govardovskii and Zueva, 1977; Hart et al., 1999). These also explain their ability to perceive objects in natural day light. Despite the fact that biological evidence points to an animal evolved for activity during lighted periods, the use of dim light for commercially housed broilers is common.

The present research used four photophasic light intensities (1, 10, 20, or 40 lx) and 0 lx intensity during the dark period to study the effects of light intensity on behaviour and circadian melatonin and behavioural rhythms of broilers reared to 35 d of age.

4.3. Material and Methods

The research was conducted in accordance with recommendations of the Canadian Council on Animal Care (1993) as specified in the Guide to the Care and Use of Experimental Animals after approval of the experimental protocol by the Animal Care Committee of the University of Saskatchewan

4.3.1. Birds and Housing

Ross × Ross 308 chicks (> 14,000) were used for the present study. All the chicks were obtained from a commercial hatchery (Lilydale Inc., Wynyard, Saskatchewan, Canada) and 425 males and 425 females were randomly placed in each room for two consecutive trials with a trial end density of 32 kg/m^2. An adequate number of feeders and drinkers were placed in each room, providing ad-libitum feed and water throughout the study (Chapter 3). In each room, a small pen with 25 male and 25 female chicks was used for behaviour recording, using infrared cameras. An equal amount of straw (7.5 to 10 cm thick) was placed in each room including the small pen. The temperature was 34ºC on d 0 and gradually reduced, until it was 22 º C by d 28. The major feed ingredients were corn and soybean meal with specific energy and amino acid levels in starter, grower and finisher diets (Chapter 3).

4.3.2. Lighting Treatments

All birds were kept under an intensity of 40 lx and 23 h daylength from 0 to 7 d of age. At 7 d, experimental treatments consisting of four levels (1, 10, 20, 40 lx) of light intensity were randomly assigned to eight rooms with 17 h of constant daylength. Light was provided by incandescent bulbs (100 W) without using dawn and dusk, and light intensity during dark periods was maintained at 0 lx. Light intensity was recorded, three times each week at six positions in each room using a light meter (Acklands-Grainger, Inc., Ontario, Canada), approximately at the level of bird's height (Chapter 3). A spectroradiometer (ASD FR Pro, Analytical Spectral Devices, Inc., USA) was used to record the illumination quality. It confirmed previous findings that, reducing light intensity using incandescent light sources, resulted in shifting of dominant spectral radiance towards the red end of the visible spectrum (Chapter 3).

4.4. Data Collection

Broiler activity was recorded by placing an infrared camera over each small pen in the experimental rooms. For each replicate, behaviour was recorded at 16 or 17 d of age for a 24 h period. Instantaneous scan sampling was used to decode the behavioural expression from the electronic media (compact disc). Individual birds (small pen) involved in feeding (at feeder), drinking (under the drinker), resting, standing, walking, running, foraging, dust-bathing, preening, stretching, wing- flapping and feather- ruffling) were counted at every 10 min interval for the 24 h observation period . A well defined broiler ethogram was developed to minimize the chances of error in diagnosing a particular behavior (Wood-Gush, 1971). Resting and standing behaviours were categorized as inactive; walking and running as locomotory; feeding and drinking behaviours as consummatory; foraging as exploratory; dust-bathing, preening, stretching, feather-ruffling and wing-flapping as comfort. It is very difficult to differentiate between resting and sleeping, thus they were jointly categorized as resting. Comfort behaviours were defined as *"behaviours performed for care and grooming of body, thus providing them physical comfort"* (Wood-Gush, 1971).

Three birds were randomly selected from each room at the start, middle and end of light and dark periods, respectively at 23 d of age for blood collection using decapitation technique and resulted serum samples were analysed for melatonin estimation using a radioimmunoassay **(RIA)** kit (Labor Diagnostika Nord GmbH & Co. KG).

4.5. Statistical Analysis

Data were analyzed as a completely randomized block design with trial as a block, using Proc GLM, Proc Reg and RS Reg of SAS (SAS Institute, 2002). The Shapiro-Wilk test was used to check the normality of data, prior to analysis. Melatonin data were analyzed by comparing concentrations at the start, middle and end of light and dark periods, respectively. Behaviour data were analyzed independently for the 24 h period, 17 h light and 7 h dark phase. Over the 17 h of light period, Proc Reg and RS Reg were also used to determine the behavioural patterns. Percentage data were log transformed before analysis. Duncan's multiple range test was used for mean separation, wherever needed and the level of significance was fixed at $P \leq 0.05$ unless otherwise stated.

4.6. Results

4.6.1. Inactive Behaviours

Birds exposed to light intensities of 1 lx rested more as compared to other treatments over the 24 h period (Table 4.1) and 17 h light phase (Table 4.2), but light intensity had no effect on the portion of birds resting over the 7 h dark phase (Table 4.3) when almost 97 % of the birds were resting. Light intensity had no effect on standing behaviour over the 24 h period (Table 4.1), 17 h of light (Table 4.2) and 7 h of dark phases (Table 4.3).

4.6.2. Locomotory Behaviours

The percentage of birds involved in walking over the 24 h period (Table 4.1) and 17 h light phase (Table 4.2) tended to increase linearly ($P = 0.1$) with increasing light intensity but the effect is minor. Expression of walking behaviour over the dark period was affected by light intensity but a specific trend was lacking and the percentage of birds involved was low (less than 0.3 %; Table 4.3). The percentage of birds involved in running was low (less than 0.5 %) irrespective of light intensity treatments over the 24 h period (Table 4.1), 17 h light (Table 4.2) and 7 h dark phases (Table 4.3).

4.6.3. Consummatory Behaviours

The percentage of birds involved in feeding and drinking over the 24 h period (Table 4.1), 17 h light (Table 4.2) and 7 h dark phases (Table 4.3) was unaffected by light intensity.

4.6.4. Exploratory and Comfort Behaviours

Light intensity affected foraging behaviour with birds exposed to 1 lx foraging less over the 24 h period (Table 4.1) and 17 h light phase (Table 4.2) in contrast to other intensities. Foraging behaviour over a 7 h dark phase was unaffected by light intensity (Table 4.3) and only noted to a limited extent.

Birds exposed to 1 lx preened less as compared to other light intensity treatments over the 24 h period (Table 4.1) and 17 h light phase (Table 4.2). Dust-bathing behaviour over the 24 h (Table 4.1) and 17 h light phase (Table 4.2) tended to be lower with 1 lx ($P = 0.09$ and 0.06, respectively) in contrast to other intensities. Both preening and dust-bathing were almost absent during a 7 h of dark phase (Table 4.3). Expression of stretching behaviour over the 24 h period

(Table 4.1) and 17 h light phase (Table 4.2) was affected by light intensity with birds exposed to 1 lx stretching less in contrast to other treatments. The percentage of birds performing feather-ruffling and wing-flapping tended to be lower with exposure to 1 lx over the 24 period ($P = 0.1$ and 0.07; Table 4.1) and 17 h of light phase ($P = 0.1$ and 0.09; Table 4.2).

Table 4.1. Effect of light intensity on broiler behaviour over a 24 h period

Category	Item[1]	Light intensity (lx) 1	10	20	40	SEM
Inactive	% Resting*	75.37^{a}	68.92^{b}	70.59^{b}	67.28^{b}	0.775
	% Standing	4.00	4.01	4.27	4.68	0.345
Locomotory	% Walking	1.66	2.00	2.20	2.22	0.111
	% Running	0.21	0.21	0.15	0.16	0.035
Consummatory	% Feeding	9.35	11.03	10.02	10.70	0.304
	% Drinking	6.91	6.09	7.14	7.23	0.303
Exploratory	% Foraging	0.79^{b}	3.22^{a}	2.13^{ba}	3.39^{a}	0.394
Comfort	% Preening*	1.43^{b}	3.42^{a}	2.84^{a}	3.52^{a}	0.285
	% Dust-bathing	0.02	0.19	0.10	0.14	0.029
	% Stretching	0.14^{b}	0.51^{a}	0.34^{ba}	0.47^{a}	0.049
	% Feather-ruffling	0.01	0.08	0.04	0.04	0.010
	% Wing-flapping	0.09	0.23	0.15	0.14	0.021

[a-b] Means within a row with different superscripts differ significantly ($P \leq 0.05$).
[1] % of birds performing a particular behaviour.
* = Linear regression with $P \leq 0.05$.

Table 4.2. Effect of light intensity on broiler behaviour over the 17 h light phase

		Light intensity (lx)				
Category	Item[1]	1	10	20	40	SEM
Inactive	% Resting*	66.05[a]	61.13[b]	59.38[b]	58.87[b]	1.152
	% Standing	4.89	4.34	5.20	5.55	0.428
Locomotory	% Walking	2.33	2.54	3.09	2.77	0.124
	% Running	0.31	0.24	0.21	0.20	0.039
Consummatory	% Feeding	13.18	14.11	14.14	13.83	0.161
	% Drinking	9.74	7.93	10.07	9.23	0.411
Exploratory	% Foraging*	1.12[b]	4.03[a]	3.01[a]	4.16[a]	0.421
Comfort	% Preening**	2.04[b]	4.41[a]	4.01[a]	4.40[a]	0.302
	% Dust-bathing	0.02	0.24	0.14	0.16	0.034
	% Stretching**	0.19[b]	0.63[a]	0.48[a]	0.60[a]	0.049
	% Feather-ruffling	0.01	0.1	0.05	0.05	0.012
	% Wing-flapping	0.12	0.29	0.22	0.19	0.024

[a-b] Means within a row with different superscripts differ significantly ($P \leq 0.05$).
[1] % of birds performing a particular behaviour.
* = Linear regression; ** = Quadratic regression.

Table 4.3. Effect of light intensity on broiler behaviour over the 7 h dark phase

		Light intensity (lx)				
Category	Item[1]	1	10	20	40	SEM
Inactive	% Resting	98.01	96.84	97.81	98.61	0.286
	% Standing	1.83	2.61	2.03	0.98	0.272
Locomotory	% Walking	0.02[b]	0.26[a]	0.08[b]	0.29[a]	0.038
	% Running	0.00	0.00	0.00	0.00	0.000
Consummatory	% Feeding	0.07	0.13	0.04	0.01	0.019
	% Drinking	0.05	0.06	0.03	0.08	0.013
Exploratory	% Foraging	0.00	0.05	0.00	0.00	0.011
Comfort	% Preening	0.00	0.00	0.00	0.02	0.003
	% Dust-bathing	0.00	0.02	0.00	0.00	0.004
	% Stretching	0.01	0.00	0.012	0.00	0.005
	% Feather-ruffling	0.00	0.00	0.00	0.00	0.000
	% Wing-flapping	0.00	0.02	0.00	0.00	0.003

[a-b] Means within a row with different superscripts differ significantly ($P \leq 0.05$).
[1] % of birds performing a particular behaviour.

4.6.5. Behavioural Pattern over the 17 h Light Phase

When summarized over the light period, light intensity had no effect on the patterns of feeding, walking, resting, standing, running, dust-bathing, and preening behaviours (data not shown). Furthermore, feeding, walking, resting, standing and dust-bathing behaviours showed well defined patterns over the light period as reflected by statistical interpretation over the 17 h light phase (Table 4.4). Peaks for feeding, walking and standing occurred at the start and end of the light period. On the other hand, the percentage of birds resting was lower at the start and end of the light period. Dust-bathing behaviour has a unique pattern with a peak occurring at 8 to 12 h after the start of the light period. Preening behaviour decreased linearly during the light period, with peak frequency occurring at the onset of the day.

4.6.6. Diurnal Behavioural and Melatonin Rhythms

Light intensity didn't affect diurnal behavioural rhythms with all treatments showing distinctive differences between day and night activities. As an example, feeding behavioural rhythms over the 24 h period are depicted by Figure 4.1. All other behaviours displayed comparable rhythms with no or very little activity during the dark period.

Melatonin concentration was lower during the light as compared to the dark period. Diurnal melatonin rhythms over the 24 h period were unaffected by light intensity. All treatments showed pronounced rhythms with peak levels occurring during the dark and lowest levels during the day (Figure 4.2).

Table 4.4 Statistical interpretation of behavioural patterns over the 17 h of light phase

Item	Light intensity (lx)			
	1	10	20	40
	$P^{(r)}$	$P^{(r)}$	$P^{(r)}$	$P^{(r)}$
% Resting**	< 0.0001	< 0.0001	<0.0001	<0.0001
% Feeding**	< 0.0001	< 0.0001	<0.0001	<0.0001
% Preening *	< 0.0001	< 0.0001	< 0.0001	0.001
% Standing**	< 0.0001	< 0.0001	0.0002	<0.0001
% Walking**	< 0.0001	< 0.0001	<0.0001	<0.0001
% Dust-bathing**	0.04	0.0008	<0.0001	0.0003

$^{(r)}$ = Regression analysis; * = Linear regression; ** = Quadratic regression.

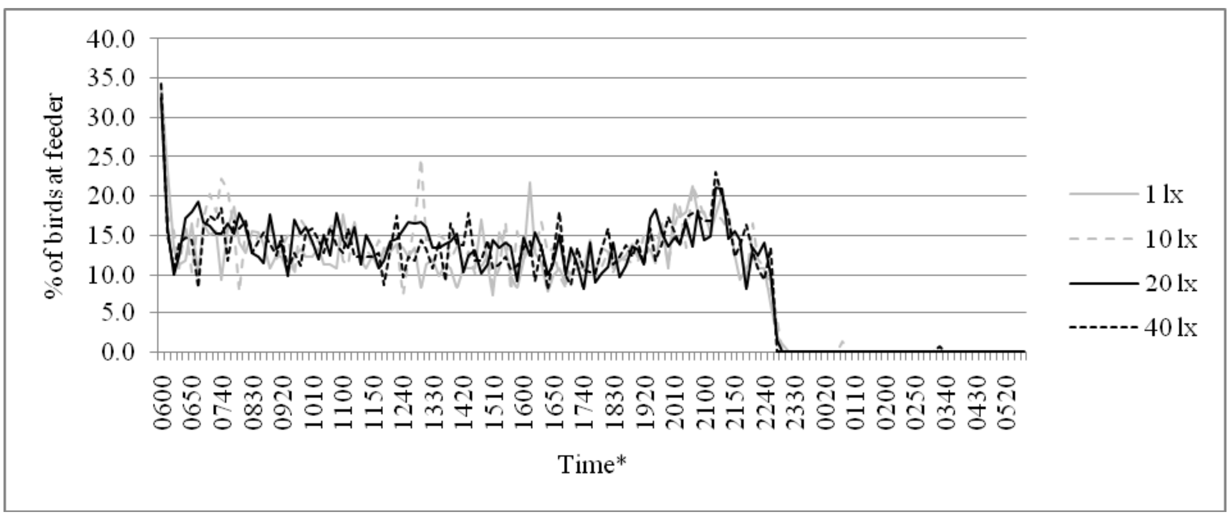

Figure 4.1. Effect of light intensity on feeding behavioural rhythm over the 24 h period. *Lights on at 0600 and off at 2300.

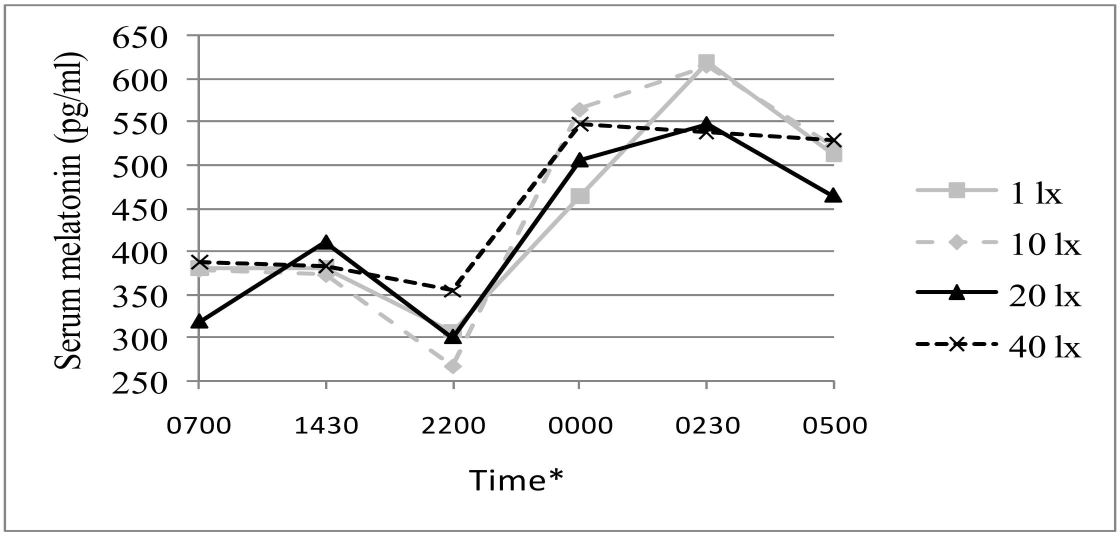

Figure 4.2. Effect of light intensity on serum melatonin levels (pg/ml) over the 24 h photoperiod. ***Lights on at 0600 and off at 2300.

4.7. Discussion

A key objective of the present research was to examine the effect of light intensity on broiler behaviour. Light intensity had no effect on consummatory behaviours (feeding and drinking) which is in agreement with a previous study (Newberry et al., 1988). Similarly, Alvino et al. (2009) did not find a difference in feeding behaviour due to light intensity but found that birds exposed to light intensity of 5 lx spent more time drinking in contrast with those exposed to 200 lx over the 24 h period. Lack of difference in feeding behaviour may not be surprising based on the lack of light intensity effects on productivity (Chapter 3) and the high motivation for feeding in broilers. The effect of light intensity on drinking behaviour in the study of Alvino et al. (2009) contrasts this logic but it is noteworthy that no difference was seen during the 16 h light phase. This presence of drinking during the dark period may relate to the intensity of light during that period and will be discussed later.

Birds exposed to a light intensity of 1 lx rested more in contrast to other intensities and these results are in agreement with previous research (Newberry et al., 1988; Alvino et al., 2009). Increased resting with dim light may have welfare and economic significance by increasing the incidence of breast blisters and foot pad lesions (Cherry and Barwick, 1962; Blatchford et al., 2009; Deep et al., 2010). Even though dim light affects resting, it did not affect standing, walking or running behaviour in a meaningful way. Others have also shown that standing is unaffected by light intensity (Alvino et al., 2009), but Newberry et al. (1988) found that birds exposed to bright light (180 lx) stood and walked more as compared to the dim light (6 lx). This discrepancy may be explained by the use of very bright light in the study of Newberry et al. (1988) in contrast to 40 lx used in the present study. The percentage of birds involved in walking tended to increase with increasing light intensity over the 24 h period but the impact is very small, which is in agreement with Alvino et al., 2009 who demonstrated that walking was unaffected by light intensity. The difference in results between these studies might also be related to the genetic changes in growth potential and consequent mobility over the years.

Birds exposed to a light intensity of 1 lx foraged less in contrast to birds exposed to other (higher) intensities. Similar results were found by Alvino et al. (2009), where birds exposed to a light intensity of 5 lx spent less time foraging as compared to birds exposed to brighter light (50 and 200 lx). An increased frequency of litter-directed behaviours (scratching and pecking) was also observed in birds exposed to increasing light intensity (6, 20, 60 and 200 lx; Davis et al., 1999). Increased expression of foraging behaviour under bright light may be explained in terms of increased visual acuity of birds at brighter light (Kristensen et al., 2002). There may also be an effect of light wavelength on foraging. Domestic chickens are sensitive to ultraviolet light due to the presence of a specific cone pigment sensitive to the light in the ultraviolet region of the spectrum (Govardovskii and Zueva, 1977). Ultraviolet light has been found to be responsible for increased foraging by providing appropriate cues (Maddocks et al., 2002). Furthermore, Lewis et al. (2000) suggested that straw (litter material) and cereal seeds may reflect ultraviolet light and thus be responsible for effective cues for foraging. Although the incandescent light provided little energy in the ultraviolet region of the spectrum, the spectral radiance of light emitted by incandescent lamps at 1 lx ranged from approximately 650 to 1750 nm in contrast to 400 to 1750 nm for the light at higher intensities (10, 20 and 40 lx). One can speculate that light at shorter wavelengths in close proximity to the ultraviolet region of spectrum might also affect foraging.

Light intensity had a significant effect on individual behaviours including preening and stretching, and a similar non-significant trend was noted for other comfort behaviours (dust-bathing, feather-ruffling and wing-flapping). Preening is an important behaviour that improves plumage condition by distributing oil from the uropygial gland and consuming parasites residing on the skin (Appleby et al., 2004). Birds exposed to dim conditions (1 lx) preened less as compared to other light intensity treatments. Similarly, Vandenberg and Widowski (2000) reported an increased expression of preening behaviour in hens exposed to bright high-pressure sodium lamps. Increased time spent preening by birds reared under bright light (50, 200 lx) as compared to the dim light (5 lx) was also observed by Alvino et al. (2009). Expression of dust-bathing behaviour tended to decrease with the exposure dim light (1 lx). Dust-bathing behaviour is controlled by various internal and external stimuli (Appleby et al., 2004). Light and the presence of fellow birds performing dust-bathing are the important external stimuli modulating the dust-bathing behaviour. Increased frequency of dust-bathing due to the presence of fellow hens performing dust-bathing and by light stimuli (photoflood light) was reported by Duncan et al. (1998). Taking into account these factors, it can be speculated that the inferior vision of broilers at dim light (1 lx) might be responsible for the decreased expression of dust-bathing by affecting social facilitation.

Broilers exposed to dim light (1 lx) stretched less in contrast to other light intensity treatments. Previously, broilers exposed to bright red light tended to stretch more often as compared to the dim blue light (Prayitno et al., 1997). Expression of wing-flapping and feather-ruffling tended to decrease with exposure to dim light (1 lx). To our knowledge, no study has monitored the impact of light intensity on these two comfort behaviours of broilers. Appleby et al. (2004) and Wood-Gush (1971) documented that preening, dust-bathing, stretching, feather-ruffling and wing flapping are important comfort behaviours of domestic fowl. Furthermore, Duncan and Mench (1993) suggested that these luxury behaviours can only be expressed after the fulfillment of basic needs and the absence of negative affective states (pain and suffering).

Overall, the decreased expression of comfort behaviours with exposure to dim light might reflect the negative affective states of broilers reared under these conditions, thus compromising their welfare. The increase in resting seen for broilers in the 1 lx treatment is counter balanced by a decrease in comfort behaviours.

Over the light phase, feeding, walking, resting, standing, dust-bathing and preening behavioural patterns were unaffected by light intensity. Feeding behaviour has a pronounced pattern with a peak occurring at the start and end of the light period. The peak at the start of the day reflects bird hunger after the dark phase and the peak at the end of light phase demonstrates the ability of broilers to anticipate approaching darkness (Appleby et al., 2004). Patterns of walking and standing coincide with that of feeding behaviour with peaks occurring at the start and end of the light phase. The pattern of preening during the day showed a linear decrease with peak activity occurring at the start of the day. Lubor et al. (1992) observed increased preening behaviour in broiler breeders at the onset of the light phase. Preening behaviour helps in oiling the feather with lipids or wax from the uropygial gland (Appleby et al., 2004). Disorganization of feathers and oil depletion due to lack of preening over the dark phase, might result in the increased expression of preening at the onset of the day, but more research is warranted to accurately understand this effect. Dust-bathing behaviour has a pronounced pattern with peak activity occurring after 8 to 12 h from the beginning of the light phase. Similar rhythms have been observed in White Leghorns, Japanese quail and broilers (Statkiewicz and Schein, 1980; Vestergaard, 1982; Raginski et al., 2010; Schwean-Lardner et al., 2010). The presence of a unique dust-bathing pattern over the series of broiler behaviour studies conducted in our lab might reflect that the onset of the day may acts as a signal for dust-bathing.

Recently, Alvino et al. (2009) demonstrated diminished circadian behavioural rhythms in broilers exposed to light intensities of 5 and 1 lx during the light and dark periods, respectively. They suggested that the difference in day and night intensity failed to provide a strong signal for synchronization of these circadian rhythms. In the present study, pronounced behavioural and melatonin rhythms were noted for all light intensity treatments including 1lx. The difference in this work is that the light intensity was 0 lx during the dark period and potentially this contrast was a sufficient zeitgeber. Based on these findings, it can be concluded that day-night contrast acts as an important factor governing the behavioural rhythms but more research using different combinations of day-night intensities is required to accurately define the contrast needed to develop behavioural and physiological circadian rhythms. Further, emphasizing the importance of understanding rhythm synchronization is the suggestion that a lack of circadian rhythms is a welfare concern (Alvino et al., 2009).

As noted above, light intensity had no effect on diurnal melatonin rhythms with all birds having distinct rhythms. The level of serum melatonin peaked during the dark period followed by a decrease at the onset of the light period in a fashion previously observed in other avian species (Binkley et al., 1973; Kumar and Follett, 1993; Gwinner et al., 1997). The presence of diurnal melatonin rhythm in different avian species is attributed to the similar rhythmic expression of a key enzyme (AA-NAT) responsible for melatonin synthesis (Binkley et al., 1973; Herichova et al., 2001). Melatonin inhibition in the pineal gland is triggered by a light signal either through the eyes or direct penetration through the skull tissue (Morgan et al., 1995). The presence of identical melatonin rhythms irrespective of light intensity, indicates that the pineal gland of modern broiler chickens has the ability to perceive the light ranges from 1 to 40 lx either through their eyes or direct penetration of the skull and it is able to distinguish between day and night; the consequence is a circadian melatonin and behavioural rhythms.

4.8. Conclusions

Broiler behaviour was affected by light intensity with birds reared under dim light resting more and expressing a lower level of comfort behaviours. Broilers demonstrated distinct behavioural and physiological rhythms, unaffected by light intensity ranges from 1 to 40 lx. A reduced welfare state for broilers exposed to dim light was demonstrated by the reduced expression of comfort behaviours.

5. OVERALL DISCUSSION

Light intensity was studied in the past in relation to broiler production and health but still there is a lack of an appropriate light intensity protocol essential for improving broiler production without compromising bird welfare. Broiler production and welfare are two important aspects, which need to be studied before making a recommendation to the broiler industry. Use of inadequate experimental design (replication, low bird numbers), confounding treatments, and the use of only two levels of light intensity (either too low or high) are some of the issues that reduce the value of some previous light intensity studies. The present research was designed to examine the impact of light intensity within the range of intensities found in confinement facilities using a large number of birds per replication and adequate replication (four). Also the scientific approach of using graded levels of light intensity permits a more powerful experimental approach to understand the impact of this aspect of light management. Two experiments were completed to extensively study the effects of light intensity on broiler live production, processing characteristics and welfare.

The present research found no effect of light intensity from 1 to 40 lx on broiler live production (BW, FI, F:G) from 0 to 35 d of age. Most of the previous studies reached the same conclusion (Skogland and Palmer, 1962; Newberry et al., 1986, 1988; Kristensen et al., 2006) so this research adds to an already strong conclusion that light intensity, within the limits of these tests, does not affect broiler productivity. Mortality was also unaffected by light intensity and this also is true for specific causes of death. In particular, SDS, which was the major cause of metabolic mortality, did not even show a trend within the light intensity range examined. Based on the present study and previous findings, it can be concluded light intensity, ranging from, 1 to 40 lx does not affect broiler live production or death loss.

In addition to live production, processing characteristics are economically important indicators in the broiler industry. Importantly, the most valuable portion of the carcass in North America, breast meat, was unaffected by light intensity, similar to the findings of Lien et al., (2007 and 2008). In contrast, carcass, thigh and drum yield as a percentage of live weight decreased linearly with increasing light intensity within the intensity range of 1 to 40 lx. Similarly, broilers exposed to dim light (1 lx) had greater wing yield in contrast to other intensities. The effect of lower light intensity on leg and wing yield has been found previously (Down et al., 2006; Lien et al., 2008) and suggests a true biological effect. Charles et al. (1992) demonstrated an increased carcass fat content of broilers exposed to dim light, and it is possible that increased fat deposition might be responsible for the meat yield changes seen in this research. It is noteworthy that all affected portions have an increased tendency for fat deposition in comparison to breast meat. Furthermore, breast skin, an indicator of carcass fat deposition, tends to increase with exposure to light intensities of 1 and 10 lx. Increased fat in the carcass, thighs, drums and wings with dim light might be explained, either on the basis of decreased activity under dim light conditions or a physiological mechanism involving GnRH secretion, but more research is required to accurately determine this effect. Determining the effect of light intensity on total body composition would be a useful scientific approach to understand this finding.

Based on these findings, it can be concluded that broiler live production was unaffected by light intensity ranging from 1 to 40 lx, and there was no evidence to support the claim that dim light (less than 5 lx) results in improved feed efficiency and lower mortality due to SDS. Light intensity had minor effects on broiler processing characteristics without affecting breast meat, and it is hard to say if these effects are beneficial to the processing industry, without determining the accurate cause of increased carcass yield, on the proportion of thighs, wings and drums.

For a sustainable broiler industry, it is important that a management technique be acceptable from both production and welfare standpoints. Animal welfare is a widely discussed topic these days among producers, animal care groups, non-government organisations and consumers, due to a rising awareness of providing a high quality life to domesticated animals.

Assessing animal welfare is very difficult, but using a multi-dimensional approach is widely considered the most appropriate. Therefore, it was chosen for the present research and included investigating the effects of light intensity on production, physical health (skeletal, foot pad and ocular), behaviour (maintenance and comfort behaviours), and the presence of behavioural rhythm indicators. Broiler productivity didn't reflect any negative or positive effects of light intensity on broiler welfare. Skeletal health or mobility, as demonstrated by levels of mortality and culling due to leg weakness and gait score, was unaffected by light intensity. This is in agreement with some (Newberry et al., 1986; Blatchford et al., 2009) but not all studies (Newberry et al., 1988). In the latter study, better skeletal health was found for exposure to brighter light and was suggested to be due to beneficial effects of increased exercise. Previously, an activity effect of light intensity was observed only with the use of very low or very bright light (Newberry et al., 1988). Recently, Alvino et al.,(year) showed that there was a shift from comfort behaviours to resting with exposure to light levels of 5 lx as compared to 50 lx and 200 lx, without affecting expression of walking and standing. The present study also reached the same conclusion with a minor effect on the percentage of birds walking. In conclusion, light intensity above a threshold (> 5 lx), didn't have a major effect on broilers' walking ability which was perceived previously as a beneficial effect of bright light.

Foot pad lesions are recognized as a significant welfare issue in the broiler industry due to the pain associated with these lesions. The increase in incidence of ulcerative foot pad lesions seen in this research and also the research of Blatchford et al. (2009) suggest that this is an important welfare concern. It is suggested that the increased incidence is due to more or more continuous contact of the foot pad with irritants in the litter and this is supported by increased resting of birds given dim light shown in this thesis and also by other work (Blatchford et al., 2009). It has been known for some time that birds exposed to dim light have increased eye weight and size (Harrison et al., 1968; Thompson and Forbes, 1999; Blatchford et al., 2009) and our research confirmed this finding. The impact of an increase in eye size on welfare can be debated, particularly in birds marketed at a young age but larger eyes were suggested to have potential to press the optic nerve, resulting in a painful condition. Overall, light intensity of 1 lx was found to be detrimental to broiler health as indicated by increased incidence of foot pad lesions and greater eye weight and size. The present study observed the negative effects of dim light, and Blatchford et al., (2009) documented detrimental effects of light intensities near 5 lx, suggesting that light intensities less than 5 lx resulted in reduced broiler welfare, but more research is warranted to define the precise level (between 5 and 10 lx) necessary to prevent these unacceptable effects.

The impact of light intensity on broiler behaviour has not been extensively studied in the past, but in the few studies completed, dim light has been shown to result in decreased activity and reduced expression of comfort behaviours (Newberry et al., 1988; Blatchford et al., 2009). Our results agreed with these findings except the effect of light intensity on broiler activity was not observed. Increased resting can be considered a welfare consideration because of its association with an increased incidence of foot pad lesions and breast blisters (Cherry and

Barwick, 1962; Blatchford et al., 2009; Deep et al., 2010). Comfort behaviours are suggested to be expressed in the absence of any affective states, thus decreased expression at the 1 lx intensity also suggests reduced broiler welfare. Overall, reduced expression of comfort behaviours and increased resting with the exposure to light at levels of 1 and 5 lx reflects potential welfare considerations.

Circadian rhythms are important biological characteristics of birds and other animals and are synchronized by external factors such as daylight. Melatonin and behavioural activities are examples of circadian rhythms. Expression of behaviours without diurnal synchronisation was suggested to be a welfare consideration (Blatchford et al., 2009) as broilers lacking synchrony might result in interruption of the normal rhythms of flock-mates. Studies on the impact of daylength on broiler welfare support this concept (Schwean-Lardner et al., 2010). A melatonin rhythm was not found for broilers given 23 h of light per day suggesting asynchrony of the flock. These birds also demonstrated signs of sleep deprivation that the authors suggested could be due to disruption of flock-mates because patterns of feed and water intake, and other activity are not synchronized. Light intensity may have an impact on circadian rhythms because at low light intensity birds may not be able to differentiate between night and day, thereby losing the major zeitgeber responsible for rhythm synchrony. Recent evidence of diminished behavioural rhythms in broilers exposed to dim light (Blatchford et al., 2009) support that concept, but strong rhythms irrespective of light intensity in the present study appear to be in contrast. A factor that may explain the difference between studies is the use of different light intensity (1or 0 lx) during the dark period. It is probable that an adequate day-night contrast is essential in developing diurnal behavioural rhythms and this has been shown indirectly in other species. Day-night contrast was found to affect circadian melatonin rhythms in tench (a fish), hamsters and pigs, where research showed more distinct rhythms under bright photophasic light as compared to dim light (Brainard et al., 1982; Griffith and Minton, 1992; Vera et al., 2005). Because melatonin is a hormone responsible for governing behavioural rhythms in animals (Reiter et al., 1993), it is logical that day-night contrast would also affect behavioural rhythms. In the present research, light intensity had no effect on circadian melatonin rhythms with all birds having pronounced rhythms and consequently these birds also demonstrated distinct behavioural rhythms. Understanding the nature of differences in day-night intensity levels that set circadian rhythms is an area that requires further research. Based on the importance of these differences, the night light intensity in broiler barns may be required prior to setting the correct day intensity level.

In conclusion, considering the impact of light intensity on broiler production and welfare, there is no justification for using dim light (less than 5 lx) for commercial broiler production as there are signs of compromised welfare without any production benefit; an exception may be minor effects on processing characteristics. Reduced welfare at low light levels (1 lx) is reflected by an increased incidence of foot pad lesions and larger ocular dimensions, and the reduced expression of comfort behaviours and increased resting. This research provides data that permits modelling of lighting program and consequently sustainable broiler production.

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Appendix 1

IPSF 2010 Abstract

International Poultry Scientific Forum, January 25-26, 2010, Atlanta, GA, USA

Impact of light intensity on commercial broiler production, mortality and processing characteristics

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Manipulation of light intensity is an important management tool affecting broiler production and well being. Despite considerable research on light intensity, there is still debate on the optimum level to be used for intensively housed broilers. Two trials were conducted with the objective of investigating the effect of light intensity within the practical levels at confinement barns (1, 10, 20 and 40 lux) on production and processing characteristics of broilers raised to 35 d of age. Each light intensity treatment was replicated in two environmentally controlled rooms in each trial with approximately 950 Ross x Ross 308 chicks (equal number of males and females) per room. Data were analyzed as a randomized complete block design with trial serving as a block. All chicks were exposed to 40 lux light intensity and 23 h light for first seven days followed by treatment light intensity and 17 h daylength thereafter. Body weight and feed consumption were determined at 7, 14, and 35 d of age. At the end of each trial 60 birds (30 males and 30 females) per treatment were processed to determine the detailed meat yield. Body weight, feed consumption, feed conversion ratio and mortality were unaffected by light intensity ($P > 0.05$). Broilers exposed to dim light (1, 10 lux) had heavier carcass weight ($P = 0.001$) as a percentage of live weight in contrast to bright light (20, 40 lux). Thighs ($P = 0.02$) and drums ($P = 0.02$) decreased linearly with increasing light intensity from 1 to 40 lux. The 1 lux treatment resulted in heavier wings as compared to other treatments ($P = 0.0001$). All other processing characteristics were not affected by light intensity ($P > 0.05$). Overall, broiler production and mortality were not significantly affected by light intensity levels, but differences were noted in some processing characteristics (carcass weight, thighs, drums, and wings).

Appendix 2

JAM 2010 Abstract

ADSA-PSA-AMPA-CSAS-ASAS JAM, July 11-15, 2010, Denver, CO, USA

Impact of light intensity on broiler biological rhythms and welfare

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Light intensity (LI) manipulation is an important management tool affecting broiler behaviour and physiology but still there is debate for optimum level to be used. Two trials were completed to study the impact of light intensity within the practical levels in confinement barns (1, 10, 20 and 40 lux) on biological rhythms and welfare of broilers raised to 35d of age. In each trial, approximately 950 Ross x Ross 308 chicks were housed per room with replication of individual LI treatment in two environmentally controlled rooms. Within each large room, a small pen with 25 male and 25 female chicks was used for recording behaviour. Data were analyzed as a randomized complete block design with trial serving as a block. All chicks were provided with 40 lux intensity and 23 h light until shifting to treatment LI and 17 h daylength at 7d of age. For each replicate, behaviour was recorded for a 24 h period, starting at 16 and 17d of age. At 23d of age, three birds per room were bled at the start, middle and end of light and dark periods for melatonin estimation using RIA. Skeletal and foot pad, and ocular health were monitored at 31 and 32d of age, respectively. When summarized over 24h observation period, birds exposed to 1 lux rested more and had reduced expression of foraging, preening, dust-bathing (P=0.09), stretching and wing-flapping (P=0.07) behaviours in comparison to other light intensities. Diurnal rhythms of serum melatonin were unaffected by LI with all birds having a pronounced rhythm. Broilers exposed to 1 lux had heavier and bigger eyes as compared to other treatments. LI had no effect on skeletal health but deep ulcerative foot pad lesions decreased linearly with increasing LI. In conclusion, despite having prominent biological rhythms, birds exposed to 1 lux demonstrated reduced welfare as indicated by altered behavioural expression, increased foot pad lesions and eye size.

Appendix 3

List of Conferences Attended, Presentations, Manuscripts and Awards

1. **Deep, A.,** K. Schwean-Lardner, T.G. Crowe, B.I Fancher and H.L. Classen. 2010. Effect of light intensity on broiler production, processing characteristics and welfare. Poult. Sci. 89:2326-2333.
2. **Deep, A.,** K. Schwean-Lardner, B.I. Fancher, H.L. Classen. Impact of light intensity on commercial broiler production, mortality and processing characteristics. **International Poultry Scientific forum, 2010: 13.**
3. **Deep, A.,** Schwean-Lardner, K., Classen, H.L., Fancher, B.I. 2010. Impact of light intensity on commercial broiler production, mortality and processing characteristics. February 2010. **Available from URL: http://www.feedinfo.com.**
4. **Deep, A.,** K. Schwean-Lardner, T, G. Crowe, B.I. Fancher, H.L. Classen. Impact of light intensity on broiler biological rhythm and welfare. **Poultry Science Association, Annual meeting. Denver, 11-15 July, 2010.**
5. K. Schwean-Lardner, B.I. Fancher, H.L. Classen, **A. Deep** and C. Raginski. Let there be light AND DARK! The use of darkness in broiler photoperiod. **Poultry Service Industry Workshop, Oct 5-7, 2010, Banff, AB, Canada.**
6. **Deep, A.,** K. Schwean-Lardner, T, G. Crowe, B.I. Fancher, H.L. Classen. Impact of light intensity on broiler production and welfare. **CPEPC Technical Symposium, June 4, 2010, Saskatoon, SK, Canada**
7. **Deep, A.,** K. Schwean-Lardner, T, G. Crowe, B.I. Fancher, H.L. Classen. Impact of light intensity on broiler behaviour and rhythms. **Prairie Poultry Meeting, 2010, Edmonton, AB, Canada.**
8. Certificate of Achievement for best Graduate student presentation at International Poultry Scientific Forum- 2010, Atlanta, GA, USA.
9. Poultry Service Industry Workshop (PSIW-2010) scholarship to attend **PSIW, Banff, Oct 5-7, 2010.**
10. Harris and Lauretta and Raymond Earl Parr Postgraduate Scholarship, 2010.
11. University of Saskatchewan Student Travel Award for presenting a scientific abstract at **International Poultry Scientific Forum, Atlanta, Georgia, January, 2010**
12. College of Agriculture and Bioresources Education Enhancement Grant for presenting a scientific abstract at **International Poultry Scientific Forum, Atlanta, Georgia, January, 2010**
13. Herb R. and Marian H. Clark Scholarship, **2008-09.**
14. Dollie Hantelman Postgraduate Scholarship, **2009.**