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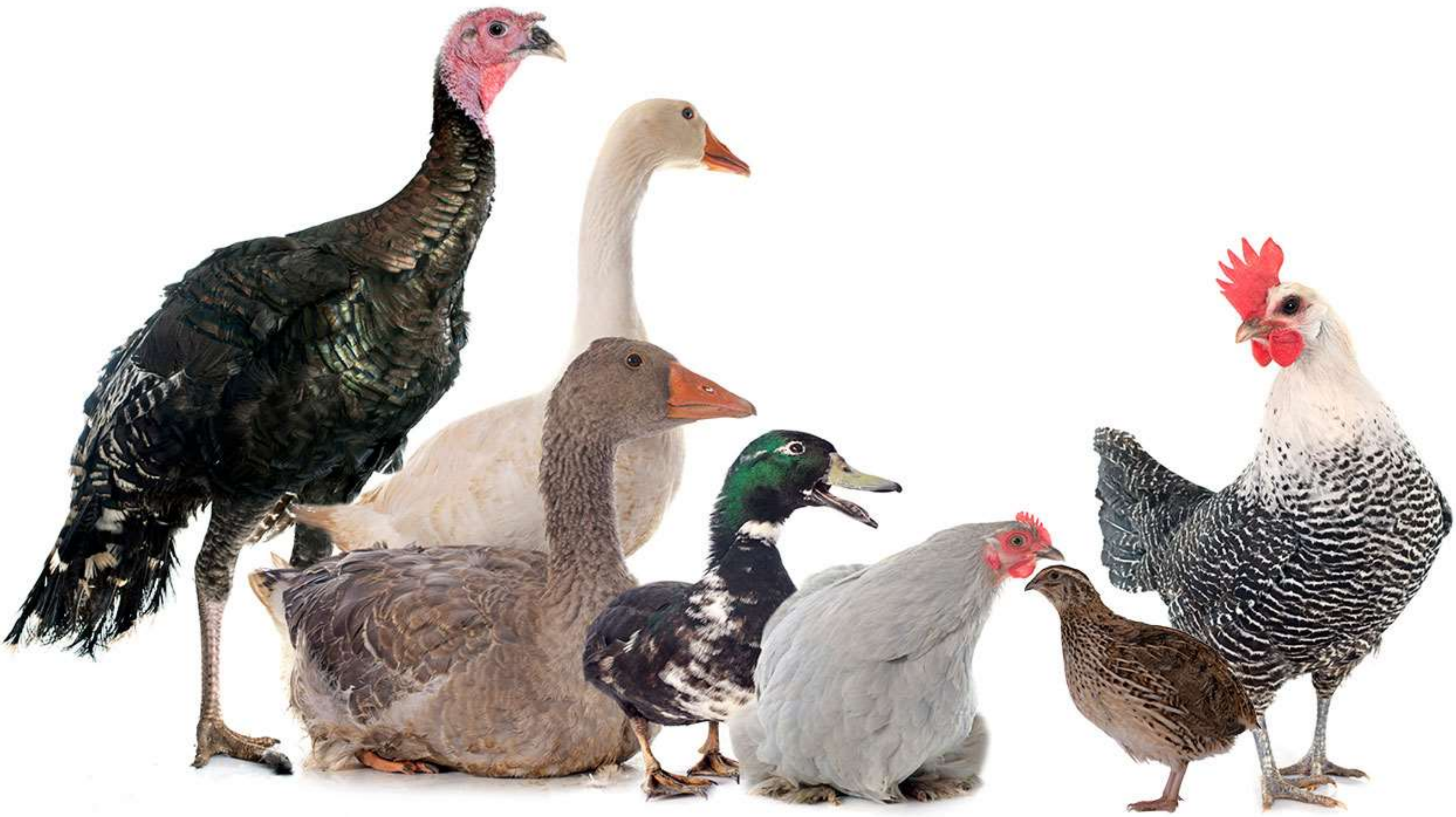
Vitenskapskomiteen for mat og miljø

Norwegian Scientific Committee for Food and Environment



VKM Report 2022:24

The use of light, restrictive feeding, fibrous feed and stocking density and the consequences for animal welfare for poultry species kept in Norway

Scientific Opinion of the Panel on Animal Health and Welfare of the Norwegian Scientific Committee for Food and Environment

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Norwegian Scientific Committee for Food and Environment (VKM)
Postboks 222 Skøyen
0213 Oslo
Norway

Phone: +47 21 62 28 00
Email: vkm@vkm.no

vkm.no

Cover photo: Tanya Samuelsen

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The use of light, restrictive feeding, fibrous feed and stocking density and the consequences for animal welfare for poultry species kept in Norway

Preparation of the opinion

The Norwegian Scientific Committee for Food and Environment (Vitenskapskomiteen for mat og miljø, VKM) appointed a project group to draft the opinion. The project group consisted of Knut Egil Bøe VKM member, Danica Grahek-Ogden VKM staff and Kristian Hoel external expert. The Committee, by the Panel on on Animal Health and Welfare, assessed and approved the final opinion[1].

Authors of the opinion

The authors have contributed to the opinion in a way that fullfils the authorship principles of VKM[2]. The principles reflect the collaborative nature of the work, and the authors have contributed as members of the project group and/or the VKM Panel on Animal Health and Welfare.

Members of the project group (in alphabetical order after chair of the project group):

Knut Egil Bøe – Chair of the project group. Member of the Panel on Animal Health and Welfare in VKM. Affiliation: 1) VKM; 2) Norwegian University of Life Sciences

Danica Grahek-Ogden – Project leader, VKM staff. Affiliation: VKM.

Kristian Hoel – External expert. Affiliation: Norwegian Veterinary Institute

Members of the Panel on Animal Health and Welfare (in alphabetical order before chair of the Panel/Scientific Steering Committee):

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[1] VKM (2018). Rutine for godkjenning av risikovurderinger.
https://vkm.no/download/18.433c8e05166edbef03bbda5f/1543579222271/Rutine%20for%20godkjenning%20av%20risikovurderinger.pdf

[2] VKM (2019). Kriterier for forfatterskap og faglig ansvar i VKMs uttalelser.
https://vkm.no/download/18.48566e5316b6a4910fc2dbd6/1561035075341/VKMs%20forfatterskapskriterier_revidert%20versjon%2020.06.2019.pdf

Knut Egil Bøe – Chair of the project group. Member of the Panel on Animal Health and Welfare in VKM. Affiliation: 1) VKM; 2) Norwegian University of Life Sciences

Tor Gjøen – Member of the Panel on Animal Health and Welfare. Affiliation: 1) VKM; 2) University of Oslo

Jacques Godfroid – Member of the Panel on Animal Health and Welfare. Affiliation: 1) VKM; 2) The Arctic University of Norway (UiT)

Andrew Janczak – Member of the Panel on Animal Health and Welfare in VKM. Affiliation: 1) VKM; 2) Norwegian University of Life Sciences

Knut Madslien – Member of the Panel on Animal Health and Welfare in VKM. Affiliation: 1) VKM; 2) Norwegian Veterinary Institute

Rolf Erik Olsen – Member of the Panel on Animal Health and Welfare in VKM. Affiliation: 1) VKM; 2) Norwegian University of Science and Technology (NTNU)

Espen Rimstad – Member of the Panel on Animal Health and Welfare in VKM. Affiliation: 1) VKM; 2) Norwegian University of Life Sciences

Øyvind Øverli – Member of the Panel on Animal Health and Welfare in VKM. Affiliation: 1) VKM; 2) Norwegian University of Life Sciences

Angelika Agdestein – Chair of the Panel on Animal Health and Welfare in VKM. Affiliation: 1) VKM; 2) Norwegian Veterinary Institute

Competence of VKM experts

Persons working for VKM, either as appointed members of the Committee or as external experts, do this by virtue of their scientific expertise, not as representatives for their employers or third-party interests. The Civil Services Act instructions on legal competence apply for all work prepared by VKM.

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Summary

Key words: VKM, (benefit and) risk assessment, Norwegian Scientific Committee for Food and Environment, Norwegian Food Safety Authority

Background

The Norwegian poultry regulation was issued 20 years ago and many of the provisions are not necessarily suited for today's farming systems. Norwegian Food Safety Authority (NFSA) has already proposed amendments to existing provisions but lacked exact knowledge on some of the animal welfare risks and did not propose amendments on those issues. NFSA also wished to introduce new legislation concerning the keeping of ducks, geese, and quail. The Norwegian Scientific Committee for Food and Environment (Vitenskapskomiteen for mat og miljø, VKM) appointed a project group to draft the opinion that was adopted by the Panel on animal health and welfare.

Method

Data and information required for this report were gathered through literature search. Searches were performed for each animal welfare factor and animal species separately and then combined. There was no restriction on language, but publication was limited to period 2001-2022. Relevance screening was performed by three evaluators jointly in the virtual meetings where articles were included or excluded based on a series of criteria. Articles were excluded if they did not relate to the terms of reference.

Uncertainties

Main source of uncertainties in evaluating the results of the literature review stems from the small number of studies, variation in study design, and the fact that the studies were not always related to either conditions or strains of poultry used in Norwegian production. There was also a great disparity in the specification of details regarding the material and methods that were used.

Conclusions

Lighting

Artificial lighting systems are used in poultry production to improve both the production and welfare of the birds. From a welfare point of view, it is important to emphasise that the lighting beneficial to production is not always beneficial for the welfare. Risk to animal welfare stems from inadequate lighting in terms of enabling normal activity of birds while preventing unwanted behaviour like aggressiveness. Variation in parameters such as the colour of the light, UV supplementation in the case of LED without UV spectrum, light

intensity and appropriateness of the photoperiod influence the welfare risks associated with these factors and vary between poultry species.

Restrictive feeding and fibrous feed

Restrictive feeding is not known to be a common practice in layer breeders of domestic fowl and turkey breeders but is a common practice for duck breeders.

Radical welfare consequences of feed and water deprivations in domestic fowl and turkeys include layers reacting with moulting and decreased egg weight and shell strength while young animals had a sleepy attitude. Kidney failure and reduced muscle mass before dying were the major pathological findings. Cannibalism as a reaction to starvation was not seen in poultry.

Fibres are not digested by fowls, but their impact on digestive physiology, nutrient metabolism and intestinal microbiome can be substantial and largely depends on the quality of fibres.

Animal density and stocking density

For chickens for meat production there is no recent data indicating that animal welfare is impaired by abiding by the Norwegian poultry regulation for animal density and stocking density. However, more recent studies point out a possible positive effect of both slow-growing breeds and environmental enrichment on animal welfare.

Both for turkeys and laying hens there seem to be no up to date/recent studies on the effect of animal density and stocking density on animal welfare that makes it possible or reasonable to suggest new and appropriate limits for animal density and stocking density.

Sammendrag på norsk

Bakgrunn

Den norske fjørfeforskriften, som regulerer velferd for fjørfe, ble utstedt for 20 år siden, og mange av bestemmelsene er ikke nødvendigvis egnet for dagens oppdrettssystemer. Mattilsynet har allerede foreslått endringer i forskriften, men på grunn av manglende presis kunnskap om noen dyrevelferdsrisikoer, har Mattilsynet foreløpig og ikke foreslått endringer på disse spørsmålene.

Mattilsynet ønsker også å innføre ny lovgivning om hold av ender, gjess og vaktel.

Vitenskapskomiteen for mat og miljø, VKM, nedsatte en prosjektgruppe for å utarbeide kunnskapsoppsummeringen. Den er godkjent av faggruppen for dyrehelse og dyrevelferd.

Metode

Data og informasjon som er brukt i denne rapporten, ble samlet inn gjennom litteratursøk. Det ble utført søk for hver dyrevelferdsfaktor og dyreart separat, og deretter ble søkene kombinert. Det var ingen språkbegrensning på litteraturen, men publisering var begrenset til perioden 2001-2022. Relevansscreening ble utført av alle tre medlemmer i prosjektgruppen i fellesskap i virtuelle møter, der artikler ble inkludert basert på en rekke kriterier. Artikler som ikke var relatert til oppdraget, ble ekskludert.

Usikkerhet

Hovedkilden til usikkerhet ved evaluering av resultatene fra litteraturgjennomgangen er det lave antallet studier, variasjon i studiedesign, og det faktum at studiene ikke alltid var relatert til verken forhold eller stammer av fjørfe som er brukt i norsk produksjon. Det var også stor forskjell i spesifikasjonen av detaljer angående materialet og metodene som ble brukt.

Konklusjoner

Belysning

Kunstige lyssystemer brukes i fjørfeproduksjon for å forbedre både produksjonen og velferden til fuglene. Fra et velferdssynspunkt er det viktig å understreke at belysning som er gunstig for produksjonen, ikke alltid er gunstig for velferden. Risiko for dyrevelferd er knyttet til at belysning som skal hindre uønsket oppførsel, som aggressivitet, kan være utilstrekkelig til at fuglene kan utøve aktivitet som er normal for fugler. Variasjon i parametere som fargen på lyset, tilskudd av UV-spekteret ved LED uten UV-spektrum, lysintensitet og hensiktsmessigheten av fotoperioden, påvirker velferdsrisikoen knyttet til disse faktorene og varierer mellom fjørfearter.

Restriktiv fôring og fiber

Restriktiv fôring (reduksjon av fôr og vann) er ikke kjent for å være vanlig praksis i oppdrett av verpehøns og kalkun, men er vanlig praksis for andeoppdrettere.

Velferdskonsekvenser av restriktiv fôring av fjørfe og kalkuner inkluderer tap av fjær og redusert eggvekt og skallstyrke, og søvnighet hos unge dyr. Nyresvikt og redusert muskelmasse før døden var de viktigste patologiske funnene. Kannibalisme som reaksjon på sult ble ikke sett hos fjørfe.

Høns fordøyer ikke fibre, men fibrene kan ha betydelig innvirkning på fordøyelsesfysiologi, næringsmetabolisme og tarmmikrobiom. Innvirkningen avhenger i stor grad av kvaliteten på fibrene.

Dyretetthet og besetningstetthet

Det ingen nyere data som indikerer at dyrevelferden til kyllinger for kjøttproduksjon er svekket ved å følge den norske fjørfeforskriften for dyretetthet og besetningstetthet. Nyere studier peker imidlertid på en mulig økt positiv effekt ved bruk av saktevoksende. Studiene viser også at miljøberikelse kan positiv effekt på dyrevelferden.

Det ser ikke ut til å være oppdaterte/nyere studier av hvilken effekt dyretetthet og besetningstetthet har på dyrevelferd for kalkuner og verpehøns, som gjør det mulig eller rimelig å foreslå nye og hensiktsmessige grenser for dyretetthet og besetningstetthet.

Abbreviations and/or glossary

Abbreviations

ADT - Avoidance distance test

BL – Blue light

CFL – Compact fluorescent light

EEG – Electro encephalogram

FPD - Footpad dermatitis

GL – Green light

IL – Incandescent light

LED – Light emitting diode

MV – Mercury vapour light

RL – Red light

SV – Sodium vapour light

UVA – Ultraviolet light, A spectrum

UVB - Ultraviolet light, B spectrum

UVC - Ultraviolet light, C spectrum

WL – White light

Glossary

Animal density: number of birds/m^2

Restrictive feeding: An actual reduction of nutrient intake below the minimum requirements of the birds.

Stocking density: kg liveweight birds/m^2

Tier cages: The poultry cages located next to each other and stacked on top of each other.

Background as provided by the Norwegian Food Safety Authority

The welfare of farmed domestic fowl and turkeys is regulated by the animal welfare law[3], regulation on the keeping of domestic fowl and turkeys[4] (hereafter poultry regulation) and the regulation on the welfare of farm animals[5]. It is more than 20 years since the poultry regulation was issued, and many of the provisions are not necessarily suited for today's farming systems. Knowledge on animal welfare topics has increased in the intervening years and the welfare of farmed poultry may not be adequately addressed by the current legislation. For this reason, the Norwegian Food Safety Authority has already proposed certain amendments to existing provisions concerning the keeping of domestic fowl and turkeys.

However, there were some provisions where we lacked exact knowledge on the animal welfare risks and did not propose amendments. Without up-to-date scientific data it is not possible to decide on the best manner to ensure the welfare of the birds.

We also wish to introduce new legislation concerning the keeping of ducks, geese, and quail. Therefore, these species have for some of the questions been included in the mandate.

Light

Light is regulated in a general manner by section 12 in the poultry regulation. For example, there shall be sufficient light for the birds to perform ordinary behaviour and it shall not have an adverse impact on their welfare. An additional requirement of minimum 20 lux applies to the keeping of broiler chickens. In 2010 EFSA in its opinion "Welfare aspects of the management and housing of grandparent stocks raised and kept for breeding purposes" identified low light intensity as one of the top five hazards for these birds. They also highlighted that very low light intensities (< 5 lux) may cause eye abnormalities as the functional development of vision may be affected, especially when these conditions occur

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[3] Lov 2009-06-19 nr. 97 om dyrevelferd https://lovdata.no/dokument/NL/lov/2009-06-19-97?q=dyrevelferd%20lov

[4] Forskrift 2001-12-12 nr. 1494 om hold av høns og kalkun https://lovdata.no/dokument/SF/forskrift/2001-12-12-1494?q=h%C3%B8ns%20og%20kalkun

[5] Forskrift 2006-07-03 nr. 885 om velferd for produksjonsdyr https://lovdata.no/dokument/SF/forskrift/2006-07-03-885?q=velferd%20produksjonsdyr

during rearing. Lower light intensities will also limit the bird's ability to perform certain behaviours such as feeding and foraging.

Since 2010 we have new knowledge concerning the importance of other light parameters such as wavelength, light spectrum, frequency, UV-light and light flicker. These parameters may be more or just as relevant as lux in securing the birds a good environment.

Restrictive feeding and fibrous feed

EFSA in their opinion of 2010 (see above) also identified restrictive feeding of breeding animals as one of the top five hazards. In recent years some research[6] on restrictive feeding has demonstrated that use of fibrous feed may have a positive impact on breeders' welfare.

Animal density and stocking density

For animal welfare reasons the poultry regulation contains provisions on density. Animal density is defined as number of birds per square meter and stocking density means live weight measured in kilograms per square meter. Since the poultry regulation entered into force in 2001, the breeds and hybrids that are kept on the farms in Norway are not necessarily the same as previously. Birds of breeds used in 2001 are probably larger or weigh more compared to twenty years ago. The legal requirements pertaining to animal density and stocking density may therefore be inappropriate and may have an impact on the birds' ability to move normally or perform comfort behaviours. Higher animal or stocking densities may also have an impact on the quality of the bedding or friable material provided or on the air quality in poultry houses.

The relevant legal requirements in the current legislation may be found in sections 25, 29, 30 – 34, 35a and 36. Please note that section 7 in the poultry regulation requires that birds are able to satisfy their physical and natural needs including performing comfort behaviours and must be able to move naturally. Natural movements include wing flapping, walking, normal posture, turning around, preening behaviour etc.

[6] F. M. Tahamtani, H. Moradi and A. B. Riber; Effect of Qualitative Feed Restriction in Broiler Breeder Pullets on Stress and Clinical Welfare Indicators; Frontiers in Veterinary Science, June 2020, Volume 7, Article 316

Terms of reference as provided by the Norwegian Food Safety Authority

The Norwegian Food Safety Authority requests the Norwegian Scientific Committee for Food and Environment to provide a scientific opinion on three topics as mentioned below.

The request includes the different phases of the production cycle of poultry species and hybrids kept and farmed in Norway. The poultry species of interest are domestic fowl (*Gallus gallus*) and turkeys, and concerning light and fibrous feed also geese, ducks, and quail unless otherwise stated. Please differentiate between breeds, hybrids, housing, and commercial production system where relevant.

Light

- Describe the welfare consequences of various artificial lighting systems used in poultry production.
- Describe the lighting parameters which are of paramount importance in avoiding risks to the bird's welfare.
- Please provide the data on the appropriate limits for the different lighting parameters.

The baseline for appropriate lighting conditions is one that stimulates birds to perform comfort behaviours such as dustbathing, investigation, play and pecking and ensures that they thrive without compromising their health.

Restrictive feeding and fibrous feed

- Describe the welfare consequences of diets and feeding systems of layer breeders of domestic fowl
- Describe the welfare consequences of restrictive feeding[7] of turkey breeders. If it is common practice to restrictively feed any of the other species' breeders, please perform the assessment also for those species.
- Describe all the welfare consequences of hunger for the poultry species concerned.
- Provide recommendations on appropriate measures to prevent, mitigate or correct the welfare consequences of hunger resulting from restrictive feeding.
- Describe the welfare consequences of use of fibrous feed and specifically its effect in mitigating hunger, reducing abnormal behaviours such as feather pecking or stimulating the birds to increased activity and in performing comfort behaviours.

[7] The amount of feed supplied to turkey breeders during rearing is restricted compared to standard turkey diet. The breeders are usually only fed once per day.

Please note that EFSA question Q-2020-00479 will investigate restrictive feeding of broiler breeders.

Animal density and stocking density

- Describe the welfare consequences for domestic fowl and turkeys of abiding by the animal and stocking density rules cf. the poultry regulation sections 25, 29, 30 – 34, 35a and 36, in general and in particular its impact both on bird behaviour and the living environment such as quality of air quality, bedding, and litter.
- Please provide data on the appropriate limits for both animal and stocking densities for both species and the different stages of the production cycle. Where relevant provide data on the appropriate limits for hybrids farmed in Norway.

Please note that that EFSA question Q-2020-00479 will assess space allowance for broiler chickens. The baseline for appropriate densities is one that stimulates birds to perform comfort behaviours such as dustbathing, investigation, play and pecking and ensures that they thrive without compromising their health, cf. the poultry regulation section 7. They must also be able to access perches, feed troughs, areas with environmental enrichments etc. without difficulty or increase in the risk of injuries.

1 Methodology and Data

1.1 Data and information gathering

Data and information required for this report were gathered through literature search.

1.2 Literature search and selection

Literature searches were undertaken using the Advanced Search Builder provided by Web of Science (WoS). Searches were performed for each animal welfare factor and animal species separately and then combined.

There was no restriction on language, but publication was limited to period 2001-2022. The search strings applied are specified in Appendix I - Literature search.

1.2.1 Relevance screening

Relevance screening was performed by three evaluators jointly in the virtual meetings. The titles and abstracts of all hits in combined searches were scanned. Articles were included or excluded based on a series of criteria, the main criteria being full manuscripts of peer-reviewed journals, evaluation of animal welfare factors in birds included in terms of reference; reported and quantified data to determine the effect of animal welfare factors on welfare indicators. Citations were excluded if they did not relate to the terms of reference.

- Literature search for light as welfare factor retrieved 211 hits of which 77 were found relevant. No hits were retrieved for turkeys and geese as well as for flicker as a welfare factor.
- Literature search for feeding related topics as welfare factor retrieved 200 hits of which 27 were found relevant.
- Literature search for animal density as welfare factor retrieved 259 hits of which 35 were found relevant.

The reference lists in selected publications were scrutinized to identify additional articles, international reviews, or reports, overlooked by the primary searches.

2 Lighting

2.1 Avian vision

Domestic poultry species have a complex visual system with 4 or 5 types of cone photoreceptors containing visual pigments that are long, medium, short or extremely short wavelength-sensitive (Hart & Hunt, 2007). This makes them capable of perceiving a much broader portion of the light spectrum, including the UV spectrum, and the combination of different wavelengths of electromagnetic radiation emitted from light sources, compared to the human eye (Archer, 2015; Md. Sohel Rana & Campbell, 2021). In addition, bird colour perception is further improved by retinal cone oil droplets, which filter light entering the cone before it reaches the visual pigments. This reduces the spectral overlap of light entering the cone photoreceptors and allows for more accurate colour discrimination within the eye (Goldsmith, 2006; Prescott & Wathes, 1999).

There are additional ways the light affects the poultry, including direct perception of light through extra-retinal photoreceptors on the pineal gland and hypothalamus (Akyuz & Onbasilar, 2018).

The anatomy of the avian eye and its sensitivity to the visible light spectrum can influence the physiology, behaviour, and growth, making the source, spectrum and intensity of artificial lighting in commercial poultry houses a key factor in determining poultry welfare (Archer, 2015; Campbell et al., 2015; House, Sobotik, Nelson, & Archer, 2020a).

There are, however, slight differences between the species which will be addressed in the respective chapters.

2.2 Circadian system

The circadian system of poultry has the potential to modulate bird physiology and behaviour, which can consequently influence growth performance and welfare. In modern poultry production, artificially controlled photoperiod is an environmental factor used to manipulate the circadian rhythm of poultry, thus providing ideal conditions (Malleau, Duncan, Widowski, & Atkinson, 2007).

In industrial practice not occurring in Norway, chickens are usually kept in large groups on continuous bright light and this practice can influence sleep and rest. Under continuous bright light it might be difficult for chickens to get adequate sleep and rest because of the constant movement of the birds to and from feeders and drinkers which will disturb those chickens trying to sleep or rest. In addition to the physical disturbance, hens have shown that when they rest in the light period, they show EEG patterns typical of quiet sleep, whereas when they rest in the dark period, they show EEG patterns typical of both active and quiet sleep (Ookawa & Gotoh, 1964). As both forms of sleep are required for proper body function, the practice of continuous light given to young chicks and the continuous or almost continuous light usually given to broilers may result in sleep deprivation and influence animal welfare (Malleau et al., 2007).

2.3 Lighting

Historically, incandescent and sodium vapour lighting were used as a source of artificial light on poultry farms but have been replaced by fluorescent light sources. The need for more sustainable production has led to the use of light emitting diodes (LED) and compact fluorescent light (CFL) in poultry production and the research is increasingly looking into effects those types of lighting have on animal welfare. The LED give monochromatic light from different wavelengths and have several advantages over conventional illuminants, including high energy efficiency, long life, high reliability, and low maintenance costs.

Different light sources have different physical properties regarding wavelengths, notably the absence of UV spectrum in LED lighting (Md. Sohel Rana & Campbell, 2021). The UV light spectrum can be divided into three different parts: UVA (315–400 nm), UVB (280–315 nm), and UVC (100–280 nm). It is suggested that UVA light might have a positive impact on reducing fear and stress responses, but some studies have found an increase in feather pecking as a result of exposure to UVA light. UVB light is found to improve skeletal health due to its role in the production of D_3 vitamin, but exposure needs to be optimised due to its negative effect on vitamin A in the skin. The UVC part of the spectrum is harmful for both humans and poultry and is used in sanitisation only (Md. Sohel Rana & Campbell, 2021).

In addition, in commercial egg production it is difficult to provide uniform lighting, especially in tier cages. Cannibalism was observed in layers living in the upper cage tier which may be due to the high light intensity in the upper cage tier. This problem might be less pronounced in alternative production systems if birds can move freely (Tunaydin & Yilmaz Dikmen, 2019).

2.4 Domestic fowl

2.4.1 Layers

2.4.1.1 Light sources, photoperiod, and wavelength

Four different light sources were compared to investigate their effect on welfare of layers; incandescent, (IN), fluorescent (FL), sodium vapor (SV) and mercury vapor (MV) (Tavares, Pereira, Bueno, & Silva, 2015). The study was undertaken in a tropical climate with a dry season during winter and mean annual temperature above 22 ºC. Seventy 52-week-old Dekalb laying hens were kept in scaled-down housing under the same environmental and feeding conditions and exposed to light (16L:8D) of approximately the same calculated/mean luminance; MV 265/243 lux; SV 240/225; IN 246/277 and FL 249/247 lux. Wavelength for the lighting was ±400 - ±700 for MV, SV and FL while IN hade wavelength of ±400 - ±4000 with a long tail between 2000 and 4000. The occurrence of natural behaviour like floor-scratching and pecking was recorded and used as a measure of welfare. Based on the results the authors concluded that the lamp sources emitting longer waves caused layers to be more active (Tavares et al., 2015).

The effects of LED and CFL and cage tier on welfare parameters like feather score, body and comb wounds, bumble foot and footpad dermatitis, beak damage, keel bone deformity, toe damage, aggressive pecking behaviour, and behaviour in the avoidance distance test (ADT) was investigated in laying hens reared in an enriched cage system with food access ad libitum and 14 L:10 D photoperiod (Tunaydin & Yilmaz Dikmen, 2019). Light sources used were CFL cool daylight, 6500 K and LED lamp white 6000–6500 K. A total of 400 Nick Chick White Egg layers were used to determine the welfare traits at 25 and 45 weeks of age. The authors concluded that the birds reared in the LED light performed better in terms of some welfare parameters such as feather score, comb wound, finger damage, aggressive pecking behaviour, and avoidance distance and dust accumulation rate. The effect of cage tier on some welfare parameters was generally significant at 45 weeks of age, and the difference between cage tiers varied according to the age of the hens (Tunaydin & Yilmaz Dikmen, 2019).

A more recent study (Raziq, Hussain, Mahmud, & Javed, 2021) compared the effect of IN, FL and LED on the productivity and welfare of commercial layers of LSL lite strain at the age of 16 and 32 weeks. The study was conducted in a hot and humid tropical climate and the birds were housed in 3-tiered laying cages. The authors concluded that LED bulbs improved the productive performance and welfare aspects in laying hens being an economical as well as animal-friendly source of light in commercial laying hens (Raziq et al., 2021).

Huber-Eicher et al. (2013) examined the effects of white, red, and green LED on behaviour and production parameters of 600 Brown Nick laying hens obtained at 16 weeks of age. Light intensities in the 3 treatments were adjusted to be perceived by hens as equal. Groups of 25 laying hens were kept in identical compartments equipped with a litter area, raised perches, feed and drinking facilities, and nest boxes. Initially, they were kept under white LED for a 2-weeks adaptation followed by 4 weeks in 8 randomly chosen compartments lit with red LED (640 nm) and 8 others with green LED (520 nm). Behaviour was monitored during the last 2 weeks of the trial. The results showed minor effects of green light on explorative behaviour, while red light reduced aggressiveness compared with white light. The observed effects were ascribed to the specific wavelength because the luminance perceived by hens was controlled as to be similar in all treatments (Huber-Eicher et al., 2013).

Natural mating colony cages for layer breeders are in use in some countries but they promote unwanted behaviour like feather pecking (FP) and cannibalism (Shi et al., 2019). The effects of four LED light colours: WL (491 nm), RL (641 nm), yellow-orange: YO (600 nm), blue-green: BG (479 nm) with two light intensities for each colour (higher tier cage 25 lux - high light intensity HLI; and the lower tier was 10 lux low light intensity LLI), on FP, plumage condition, cannibalism, fear, and stress was investigated. Results showed that hens treated with RL, and low light intensity showed a lower frequency of severe FP, less damaged plumage, were less fearful, had lower physiological indicators of stress, and had reduced mortality from cannibalism (Shi et al., 2019).

2.4.1.2 Supplemental UV light

The study by Liu et al. (2018) found that the hen laying chicks spent significantly higher proportion of time (61.3% vs. 38.7%) and consumed significantly more feed (60.5% vs. 39.5%) under LED+15 % UVA than under LED without UVA supplementation thus demonstrated the attracting effect of UVA light at 15% inclusion rate under LED illumination. However, the chick groups in the study were small and large-scale studies might be needed to further confirm those findings.

When individually tested, 108 ISA Brown laying hens of 44 weeks of age preferred a medium intensity of UVA light, and both low and medium intensity of the light containing UVA plus UVB wavelengths (UVA/B) over the standard indoor LED white lighting (M.S. Rana, Cohen-Barnhouse, Lee, & Campbell, 2021).

White laying hens of the hybrid Bovans Robust were tested for preference and behaviour in the study that compared light closely resembling natural daylight (with UV), light found in forest understory in Southeast Asia (ancestral habitat of jungle fowl, with UV) and control light (commercial standard without UV). The results indicated that birds preferred either daylight or forest light over control light, but no preference between daylight and forest light was observed. This might indicate that these effects were owing to the presence of UV light, which is known to be important for visual performance in birds. However, the differences were relatively small, which might point to sufficient light intensity and other quality factors in the housing environment being more important in maintaining high welfare than the specific spectral composition (Wichman, Groot, Håstad, Wall, & Rubene, 2021).

White Leghorn hens were used in a study determining stress susceptibility and fear response (Sobotik, Nelson, & Archer, 2020). The results indicated layers reared without UV supplementation were more stressed and grew more asymmetrically in response to longer term stress than layers reared with UV supplementation. In addition, layers reared without UV supplementation showed stronger fear response compared to layers reared with UV supplementation. The following result may imply that commonly used commercial UV-deficient light sources, may be detrimental to layers' welfare.

The spectrum and intensities preferences were tested in a study of lighting that approximated sunlight as close as logistically possible based on commercially available pet reptile light bulbs. The results showed that hens without substantial prior experience of daylight had significant preferences to spend more time under the different types of treatment lights over standard indoor lighting. The hens preferred the high intensity of the visual spectrum light and a trend toward the high intensity of the UVA but did not prefer the high UVA/B wavelengths (M.S. Rana et al., 2021).

2.4.1.3 Summary layers

Literature review shows that change to more sustainable source of lighting like LED, might improve animal welfare in layers. There have not been enough studies to conclude firmly on a preference for a colour although some positive results have been observed for RL and GL. The data available in the literature suggest positive effects of supplementation of the LED with UVA and UVB spectrum for layers. One study has shown positive impact of lower light intensity (10 lx), this was however conducted in mating cage system.

2.4.2 Broilers

2.4.2.1 Light sources, photoperiod, and wavelength

The change in sources of lighting in broiler production necessitated the need to evaluate the effect of the new sources on the welfare of the birds. Female ROSS 308 broiler chicks were tested for light preferences for four different light sources (three fluorescent and one incandescent) and illuminances (5 and 100 clux; perceived illuminance of the different light sources from the spectral sensitivity of chickens) at 16L:8D photoperiodic regime. Age and time-of-day affected most behaviours recorded while light sources and illuminance didn't affect the time budgets to a great extent. The birds spent 61% of their time resting in the litter at 6 weeks of age but resting was not significantly affected by light source or illuminance. However, feather-pecking was less pronounced in warm-white rather than Biolux light while foraging behaviour was more noticeable in dim rather than bright light intensities (Kristensen et al., 2007). Comparison of IL, CFL and LED with lighting regime 23L:1D at 20 lx for 16 days followed by 20L:4D at 5 lx for 31 days showed that birds kept under LED were less fearful and stressed than birds kept under IL or CFL lights (Archer, 2015).

Research was conducted to evaluate the behaviour and welfare of broiler chickens under different light colours and illuminance by LED. Comparison of warm LED light (2700 K) and cool LED (5000 K) showed that cool light reduced stress and fear responses while increasing weight gains (Archer, 2018). Similar result was shown investigating light preferences and welfare impact on broilers when kept under neutral-white (4,100 K) and cold-white (6,065 K). Birds have shown a preference for cold-white, however, no difference was registered in any of the welfare parameters between the different light treatments (Riber, 2015).

Lucena et. al (2020) compared the effect of white band (400-760 nm) and blue/green band (470-525 nm) with luminescences of 5 lx, 20 lx, 150 lx and 5-20 lx (5 lx in the 1st, 2nd and 6th weeks and 20 lx in the 3rd, 4th and 5th weeks) on 384 one-day-old chicks (mixed batch) of Cobb 500 strain. A continuous lighting program was used, 18L:6D. Broilers subjected to wavelengths in the blue/green range and illuminance of 20 lx and 5-20 lx showed more significant comfort behaviours, demonstrating better welfare. This was in accordance with a previously reported study conducted by Kim et al. (2014), showing that broilers subjected to blue/green lighting were calmer and had a higher frequency of comfort and natural movement behaviours, as well as better welfare. Similarly, Mohamed et al. (2020) showed that monochromatic GL, BL and GLxBL at low intensity (5 lx) have a potential to improve broiler welfare. Studies of use of RL in broiler production showed that, while some welfare parameters might be improved (Senaratna, Samarakone, & Gunawardena, 2016) more active behaviour like greater walking, flying, head movement, litter scratching, body shaking, wing flapping, wing/leg stretching, feather pecking, and aggression were also observed (Hesham, El Shereen, & Enas, 2018).

Olanrewaju et al. (2014) investigated the effect of strain on the preference for the light intensity. The results of the study of Ross x Ross 308 and Ross x Ross 708 strains showed no effect of strain and light intensity on ocular indices, immune response, plasma corticosterone levels, and mortality.

Literature shows that the welfare improved with increasing light intensity as the data support 5 lx as a minimum light intensity in broiler production (Deep, Raginski, Schwean-Lardner, Fancher, & Classen, 2013). The studies of the effect of different light intensities (5lx, 50 lx and 200 lx) showed that the 200 lx birds spent significantly more time sleeping during the scotophase and spent significantly more time preening during the overall photoperiod than the 5 lx broilers who showed more even distribution of activities. The authors concluded that providing a more distinct photoperiod could improve the welfare of broiler chickens (Alvino, Archer, & Mench, 2009; Blatchford et al., 2009).

Few studies have investigated the welfare implications of varying light intensity. Rault et al. (2017) investigated the effects of providing 5 or 20 lux light intensity on broiler behaviour, welfare and productivity. Treatments began on d 8 with one of 2 light intensity levels: 5 lux or 20 lux, using LED lights on a 16L:8D photoperiod with 30 min sunrise and sunset periods. The results showed that keeping broilers at 20 lux stimulated behavioural activity, reduced weight gain, and reduced eye weight compared to keeping broilers at 5 lux. However, there was no clear evidence that keeping broilers at 5 lux is detrimental to broiler welfare based on measures of biological functioning, with no significant differences in mortality and culls, plasma corticosterone concentrations, or latency to lie reflective of leg strength (Rault et al., 2017).

In the study by Fidan et al. (2017) photoperiod length had no significant effect on corticosterone concentration which is considered an important indicator of stress while light intensity had no significant affect, except for triglyceride level, on any of blood parameters measured. This result is in accordance with the findings of Olanrewaju et al. (2013), in which the serum glucose and corticosterone concentrations were not affected by lighting program or light intensity.

However, the 16L:8D photoschedule increased activity and comfort behaviours and decreased resting and sleeping during the observations made in the morning and afternoon scan sampling times as shown in a study conducted by Bayram et al. (2010). Although the authors did not observe broiler behaviour throughout the whole day, the greater activity behaviours (eating, drinking, walking-standing) and less resting and sleeping behaviours in the 16L:8D group were more apparent during the morning observations, which could be attributed to more natural daily rhythms (Bayram & Ozkan, 2010).

The question of possible differences in reactions to light intensities between different strains of chicken was addressed in a study by Olanrewaju et al. (2014). The results showed no effect of strain and light intensity on plasma corticosterone levels.

2.4.2.2 Supplemental UV light

In birds, UVA light is a part of a visible spectre and may facilitate social interactions. UVB wavelengths promote endogenous vitamin D synthesis, which could support the rapid skeletal development of broilers. Supplementation of the white LED with UVA and UVA+UVB light was studied in day-old Ross 308 birds reared under commercially representative conditions. Birds in the UVA treatment had shorter tonic immobility durations compared to the controls, suggesting lower fearfulness. Broilers reared in UVA and UVA+UVB had better Bristol Gait Scores compared to the control. Together these results suggest UV may be beneficial for broiler chicken welfare (James, Asher, Herborn, & Wiseman, 2018). This was further confirmed in the study by House et al. (House et al., 2020a) where UV birds righted quicker during tonic immobility and had less intense wing flapping compared with the control. UV birds also had lower physical asymmetry, plasma corticosterone, and heterophil-to-lymphocyte ratios than the control birds. Treatments did not differ in humoral immunity. These results suggest broilers reared under ultraviolet light have lower stress susceptibility and fear responses maximizing broiler welfare.

2.4.2.3 Summary broilers

Literature review shows that change to more sustainable source of lighting like LED, does not represent a threat to animal welfare in broiler production and might actually improve it as studies have shown. The birds have shown a preference for neutral to colder part of the LED spectrum (4100 K – 6065 K) and improved welfare at 5000K. There were also improvements in the welfare of the birds reared under blue/green band (i.e., 470-525 nm), however, there is still uncertainty about the welfare consequences of the colours of the light as some improvements were shown for RL as well although those might be offset by unwanted aggressive behaviours.

The studies on photoperiod lengths and light intensities show that blood parameters relevant to stress are not affected by different photoperiods or light intensities. However, photoperiods resembling more natural daily rhythm (i.e., 16L:8D) with dusk and dawn periods encourage more activity and comfort behaviours in broilers. There was no clear evidence in the literature of great differences in welfare under different light intensities, although lighting providing more distinct difference between photo- and scotophase (50-200 lx) could improve welfare through encouraging more activity during photophase and more resting during scotophase.

LED light is often devoid of UV spectre and the data show the beneficial effects of supplementation of LED lighting with UVA and UVB part of the spectrum.

2.4.3 Turkey

The literature search identified no relevant articles for lighting in turkey rearing.

2.4.4 Ducks

Ducks that forage underwater have relatively few red R-type oil droplets in their cone photoreceptors compared to chickens and other poultry, possibly due to the rapid absorbance of long wavelengths which occurs on the surface of water (Hart & Hunt, 2007).

Ducks may therefore use this dense population of short wavelength-sensitive cones in a similar way to how chickens and other poultry use long-wavelength-sensitive cones to perceive their environment and conspecifics (Campbell et al., 2015).

2.4.4.1 Light sources, photoperiod, and wavelength

Research has shown that rearing in different wave lengths can improve growth and decrease aggressive behaviours in chickens and turkeys. However, the spectral sensitivity of ducks is different from other poultry species (Barber et al., 2006), suggesting the effects on the performance and welfare of Pekin ducks can't be directly extrapolated.

Campbell et al. (2015) investigated the effects of different lights on Pekin ducks. The study followed 110-day-old Pekin ducks until processing age of 35 days, raised under conditions similar to standard commercial barns and kept in RL (approximately 625 nm), BL (approximately 425 nm), and WL, with light sources standardized to produce a peak energy at 1.6×10^3 μM photons/m^2/s at the level of the ducks' heads. The photo cycle was 18L:6D and access to water and commercial duck diet was ad libitum. Their results showed that ducks housed under BL showed a higher level of anxiety compared to ducks housed under RL or WL suggesting that BL may be inappropriate for raising Pekin ducks (*Anas platyrhynchos* domestica) in a commercial setting. Furthermore, the findings of the study conducted by House et al. (2021a) investigating the effects of white/red (WR) or white/ blue (WB) LED light spectra on duck production, stress and fear responses indicate that rearing ducks under WR caused less stress susceptibility and fear responses compared to ducks under WB. Pekin duck welfare seemed to be compromised by blue LED light exposure, even at supplemental levels utilised in commercial poultry lighting (House et al., 2021a).

The effects of monochromatic light on fear reactions, physiological responses to stress and welfare behaviour of Mulard ducks (*Anas platyrhynchos*) were investigated with 108 newly hatched Mulard ducks housed in either blue light (BL), green light (GL), red light (RL) or white light (WL) for 12 weeks (R. A. Mohamed, Abou-Ismail, & Shukry, 2017). Ducks were exposed to a light/dark schedule of 23L:1D, and food and water were provided ad libitum.

Their results, contrary to studies on Pekin ducks, showed that birds exposed to RL or WL displayed higher levels of behavioural indicators of fear and higher levels of physiological indicators of stress when compared to birds exposed to either BL or GL. Rearing Mulard ducks in BL or GL appeared to enhance their ability to cope with the environment and may therefore improve their welfare (R. A. Mohamed et al., 2017).

Even though previous report recommended rearing meat ducks under a continuous photoperiod (Erdem, Onbaşılar, & Gücüyener Hacan, 2015) to increase body weight gain and carcass development, providing hours of darkness may be necessary to improve stress related welfare factors (Malleau et al., 2007). Modern duck housing systems must therefore use artificial lighting photoperiods to maximize production and welfare. The study by House et al. (2021b) was investigated the effects of two photoperiods on Pekin ducks – 20L:4D and 16L:8D - on the growth, stress, and fear responses of 384 Pekin ducks during the grow-out period. The 20L:4D ducks were less stressed, as indicated by reduced plasma corticosterone concentration, heterophil to lymphocyte ratio, and composite asymmetry score ($P < 0.02$), and elevated humoral immune response to a Newcastle Disease Virus vaccine ($P = 0.035$) compared to 16L:8D ducks. These results indicated ducks reared under the 20L:4D photoperiod had decreased stress and the effects of stress compared to the 16L:8D photoperiod group. However, fear response data from the study were not conclusive indicating future studies are still needed to clarify the effects of various photoperiods on the fear response of Pekin ducks (House et al., 2021b).

The results emphasize the need for appropriate, species-specific artificial photoperiods in modern grow-out facilities to maximize the production of Pekin ducks while also reducing stress.

2.4.4.2 Supplemental UV light

Effects of UV supplementation on Pekin duck production, behaviour, and welfare were studied with ducks reared for 35 days under either LED bulbs with supplemental UV light (Agrishift® HL-UVA, Once Innovations, Plymouth, MN, USA; UV) or just LED bulbs (Agrishift® MLB, Once Innovations, Plymouth, MN, USA; control). While there were no differences in production parameters the results of the study suggest that Pekin ducks reared under an environment with supplemental UV light have decreased stress and fear responses, indicating better welfare than ducks reared under only LED bulbs, which are deficient in UV light (House, Sobotik, Nelson, & Archer, 2020b).

2.4.4.3 Summary ducks

Studies investigating impacts of lightning on duck welfare are more recent and we have mostly found results for Pekin ducks. They show that there might be differences in the effect of the colour of the light between the Pekin and Mulard ducks with the BL negatively affecting the former and positively the latter. The data on photoperiod beneficial for welfare of ducks are scarce but point to the possibility of improved welfare with the use of 20L:4D program. There were no new studies on light intensities.

2.4.5 Geese

The literature search retrieved no relevant articles for lighting in geese rearing.

2.4.6 Quail

2.4.6.1 Light sources, photoperiod, and wavelength

Different light intensities have an impact on behaviour, welfare, and performance of Japanese quails (*Coturnix japonica)*. The study by Nasr et al. (2019) investigated the effect of low (10 lux), moderate (50 lux) and high light intensity (250 lux), generated by incandescent bulbs and with sudden changes in lighting (no dawn/dusk) in a randomized way, on 1-day-old Japanese quail chicks. Birds kept under low light intensity had lowest H/L ratio and corticosterone level suggesting low light intensity is improving quail's welfare as well as performance and reproduction as shown by heaviest body weight and best feed conversion ratio. Results also showed detrimental effects of high light intensity on both welfare and performance (Nasr et al., 2019).

Aggressive behaviour of birds can affect both animal welfare and productivity and different photoperiods are introduced at different stages of rearing to prevent those behaviours. A study by Caliva et al. (2017) intended to characterize the aggressive responsiveness of photostimulated (14L:10D photoperiod) adult Japanese quail when interacting with a photocastrated (6L:18D photoperiod) assumed that photocastrated birds, reared in male-female pairs, will not actively provoke an aggressive confrontation. The unexpected finding was that 37% and 32% of photocastrated males and females, respectively, performed aggressions toward their photostimulated counterparts, and initiated the aggressive interactions in a similar proportion than photostimulated males. In addition, aggressive photocastrated males did not perform reproductive-type behaviours like grabs and mounts. Their aggressiveness was attributed to their social experience prior to photocastration. To test that assumption the study investigated in a second experiment encounters between a photostimulated male or female and a naive photocastrated male where photocastration started at 4 weeks of age, prior to sexual development. Photocastrated males performed no aggressions toward their photostimulated counterparts (Caliva et al., 2017) confirming that early introduction of photoperiod can reduce aggressive behaviour thus having a potential to improve bird welfare.

2.4.6.2 Supplemental UV light

Quails possess brilliant full-colour vision that enables them to see under UV lighting circumstances which may play a role in their colour vision mediating behaviour, such as intraspecific signalling and foraging. Study by (Smith, Greenwood, Goldsmith, & Cuthill,

2005) investigated the effect of lack of UV light and switching from UV containing light to UV deficient light and vice versa on welfare of Japanese quails. Welfare was assessed monitoring behaviour, body mass, tarsus and feather length, fluctuating asymmetry and plasma corticosterone levels. The results showed no significant impact on the welfare of birds, as measured using above mentioned indicators (Smith et al., 2005).

2.4.6.3 Summary quails

The data on light intensities were scarce but show better animal welfare results for lower light intensity of 10 lx. Photoperiod 14L:10D are also shown to have a potential to improve welfare of quails by reducing aggressiveness, particularly if introduced early. Unlike other birds, quails did not show significant effect of the supplementation with UV spectrum. There were no specific studies of the effects of LED lighting on quails.

3 Restrictive feeding and fibrous feed

3.1 The digestive system in poultry

The digestive system in birds is different from the digestive system of mammals. The digestive system in birds consists of beak, oral cavity, oesophagus, crop, proventriculus, gizzard, small intestine (jejunum), cecum, large intestine (colon), rectum, cloaca. To understand the effects of restrictive feeding and fibrous feed in poultry it is important to understand how the digestive system works and how the different parts of the gut cooperate to utilize the energy, protein, minerals and vitamins necessary to provide a growth that can exceed 20 % a day during the early life of a broiler chicken. (Svihus, 2016).

The anterior segment of the digestive tract is characterized by an enlargement of the oesophagus, called the crop. The crop is used as a food storage organ and filling of the crop inhibits food intake (Richardson, 1970). It may well be that the fibre fraction of the feed is important to the sensation of satiety, as the quality of ingested fibres affects the rate of entry and time of retention in the crop (Vergara, Ferrando, Jimenez, Fernandez, & Gonalons, 1989).

Ingested items are either retained in the crop or passed down directly to the next segment of the digestive tract. The anterior compartment of this segment is called the glandular stomach, or proventriculus, and constitutes the site for hydrochloric acid and pepsinogen secretion. The posterior compartment is named the ventriculus, or more commonly, the gizzard. In the gizzard, the particle size of ingesta is reduced by means of grinding, while the chyme is mixed with the secretions of the proventriculus. To function properly, however, the gizzard requires mechanical stimulation. Here, the excitatory effect of fibrous materials on the gizzard is well documented (Hetland, Svihus, & Choct, 2005; Rogel & Watkins, 1987; Steenfeldt, Kjaer, & Engberg, 2007).

Once ingested items have been ground to a critical size the particles are moved into the small intestine. The size of the fowl intestine has been adapted to flight and is therefore comparatively short. To compensate for this reduction in digestive capacity, poultry reflux digesta between various locations of the alimentary canal (Duke, Kimmel, Chaplin, Hunt, & Pollock, 1988; Sklan & Budowski, 1978). Although data are somewhat limited, ingested fibres were shown to influence peristalsis in man (Cherbut et al., 1994) and fibres present in the feed are believed to influence the gastroduodenal reflux of digesta in poultry (Hetland, Svihus, & Krogdahl, 2003).

Nutrients are digested and absorbed along the small intestine; but as previously indicated, poultry cannot degrade the fibre fraction of the feed. Instead, completely or partly undigested fractions of water soluble digesta particles, including fibres, are moved by means of anti-peristalsis into the pair of caeca. Coarser fractions of digesta are prevented from entering the caeca by a filter-like meshwork of villi stretching into the lumen (Bjornhag, 1989). The caeca harbour large numbers of bacteria with the capacity to use the energy present in the fibres. Some metabolic end products from this fermentation, such as short chain fatty acids, can finally be absorbed and utilized by the bird.

3.2 Restrictive feeding

Restrictive feeding means an actual reduction of nutrient intake below the minimum requirements of the birds. The genetics of the birds requires appetite feeding to reach its potential. In most cases this is wanted by the farmer (efficient egg production and meat production), but sometimes the need for feed restriction is wanted to regulate the feed for certain purposes. Examples of these are moulting of layers to stop egg production, or restrictive feeding of broiler and meat type duck parents to limit their growth with stabilizing fertility as the final goal. Though restrictive feeding is common in broiler and meat type duck breeders to restrict growth, restrictive feeding is usually not considered appropriate in layer breeders of domestic fowl or in breeders of meat type turkeys.

3.2.1 Layer breeders

Layer breeders, as for other layers, are fed ad libitum (Steinsland, 2022). Lu et al. (2021) describes restrictive feeding of layers in relation to sexual maturity, but no welfare parameters are measured. There is though a lot of literature that describes the reaction of layers to restrictive feeding, because it is a common practice in USA and some other regions, to actively moult layers to stop egg production (not legal in Norway or the EU) to force the animals to a new production period. Literature describing moulting in layers is probably the right source of information on the effect of hunger in poultry. Koelkebeck and Anderson (2007) describe the responses to moulting and thereby the responses of hunger in this way:

Moulting is a major event in the annual life cycle of most avian species, both wild and domestic. In laying hens, this type of research has been ongoing for more than 100 years (Anderson, Davis, Jenkins, & Carroll, 2004; Davis, Anderson, & Carroll, 2000; King &

Trollope, 1934; Rice, 1904; Rice, Nixon, & Rogers, 1908). Stevens (1996) commented, "There are times when birds in the wild do not eat in spite of having food readily available, e.g. during moulting, breeding, and egg incubation." . This quote indicates the importance birds place upon seasonal breeding and other activities. Stevens (1996) indicated that fasting is especially pronounced in geese that may be anorexic for 2.5 months and king penguins that fast for 4 to 6 months. During a moulting event, the metabolic rate and protein synthesis increases, along with a loss of adipose tissue, bone mass, and humoral immune system suppression (Kuenzel, 2003; Mumma, Thaxton, Vizzier-Thaxton, & Dodson, 2006) also results in an alteration of the hormonal system of the hen (Davis et al., 2000). Hormonal changes are typically associated with moulting and broodiness in the wild, seasonal changes resulting in limited food supply, and the husbandry practice of moulting in the commercial egg and breeder industries. The hen is capable of coping with and compensating for changing conditions in its environment to maintain physiological homeostasis (Clarenburg, 1986; Freeman, 1987). The hen responds by using physical, chemical, anatomical, and physiological mechanisms at its disposal to maintain this status. The hen has functions that are constitutive or always functioning and others that are adaptive, i.e., come into being as the need arises to maintain the homeostatic state. The following are some of the physiological mechanisms, both constitutive and adaptive, to limited or total restriction of food that occur postprandial, between meals, and during a fast, and it is arbitrary in determining at which point one starts and the other begins (Clarenburg, 1986). The metabolism of the chicken readily moves between these processes throughout the course of a regular day. Upon prolonged abstention of food, other essential nutrients are used up, for example, vitamins, minerals, essential amino and fatty acids, lipotropic factors, and carbohydrates, which can create a life-threatening situation. Starvation triggers a collapse of homeostasis, the basal metabolic rate declines, and simultaneously the body economizes on all energy expenditures to extend the survival of the animal; however, this response does not occur in the moulting programs associated with poultry husbandry practices.

Moulting of layers to give them another laying period is not considered a good practice in Norway, but the literature may be a good source of describing how the restrictive feeding has on the body related to welfare. In the review by Koelkebeck and Anderson (2007) it was concluded that "The behaviour patterns displayed during a moult program appear consistent with the response to physiological changes that layers experience and do not appear to compromise the welfare status of the hens."

It is shown that the corticosteroid level rises and therefore the immune response is reduced in the feed restricted hens. Many articles e.g. the articles by Dunkley at al. (2008) uses an alfalfa diet to reduce these negative consequences of moulting.

3.2.2 Broilers

Restrictive feeding of broiler chickens is seldom employed but has been used to grow broilers to extended age and weight. Nielsen et al. (2003) studied the effects of qualitative and quantitative feed restrictions in fast growing broilers. They discovered that quantitative feed restrictions were found to stimulate activity, which is positive for their leg health. The magnitude of the imposed feed restriction gave although high level of hunger which severely compromised the welfare of the birds. They recommended that production systems that require extended growth period should make use of slow growing strains/ hybrids.

It is common practice to control the feed consumption, and therefore the energy intake, of the parents of commercial broilers and ducks but not turkeys. Genetic selection for high rates of body weight gain results in correlated increases in ovulation rate and disrupted production of eggs with sound shells suitable for hatching. Feed restriction controls multiple ovulations in broiler breeders and ducks but not turkeys. In the publication: Biology of breeding poultry (Hocking, 2009) there is a thorough review of the use of feed restriction in broiler, turkey and duck breeders.

Due to a genetic selection for high growth rate of the progeny, broiler breeders need to be feed restricted to prevent health and reproduction problems at a later stage. Restricted fed broiler breeders show behavioural abnormalities that are indicative of hunger and frustration of the feeding motivation, like hyperactivity and abnormal oral behaviour (stereotyped object pecking and over drinking). Different strategies are tested to be able to reduce growth and keep fertility without compromising the bird's welfare. Carneiro et al. (2019) suggest different feeding strategies in the rearing period and suggest that the breeders should be fed restricted 4/3 (four days of feeding and 3 consecutive fasting days). Arrazola et al. (2019) draw the same conclusion. De Jong et al. (2005) studied the effects of scattered feeding and feeding twice a day on indicators of hunger and frustrations. They discovered that scattered feeding and meal feeding do not significantly improve broiler breeders' welfare during rearing. Scattered feeding reduced the time spent object pecking, but it was uncertain if the welfare was improved. Arrazola and Turrey (2019) included calcium propionate in the feed as an appetite suppressant but concluded that this appetite suppressant caused an avoidance response rather than satiety. The broiler parent paradox is almost impossible to solve if the breeding companies only breed for high egg production and growth, but Arrazola and Turrey (2021) suggest a solution to this imperative. They suggest that slower growing broiler breeders is the solution and though slower growing broiler breeders still require some degree of feed restriction to control growth, strains with lower feed restriction exhibit lower signs of feeding frustration and high body weight uniformity in this study.

3.2.3 Turkeys

The literature on restrictive feeding of turkeys is sparse, but Hocking (2009) concludes that control of body weight by protein inclusion is more feasible than feed restriction. Hocking summarizes the results of experiments with different lines of turkey breeders and suggest that controlling body weight by a substantial reduction in feed intake may decrease the prevalence of multiple ovulations in commercial female lines and increase shell quality and hatchability during early lay. However, overall productivity in medium and heavy female turkeys is unlikely to be better than conventional ad libitum -fed birds because maximum rate and persistency of lay are relatively poor. Breeding companies may recommend body weight targets for turkey breeder hens that are slightly less (5–10%) than their maximum potential to maintain fitness and mobility, a practice that also controls feed costs. These objectives are generally achieved by feeding a low protein diet rather than by limiting feed intake quantitatively. The Poultry site (thepoultrysite.com) describes the following: "It is accepted that bodyweight control of turkey hens during rearing is essential for optimising egg production, but physical restriction of hens as practised in broiler breeders is not an accepted option." Thus, there is a need for studies whose objective is to control body weight in replacement hens via ad libitum, controlled feeding of low nutrient density diets. Domestic hybrids of turkey are fed by weight control and thereby restrictive feeding. A good description of this is given in Avian breeder manual https://www.aviagenturkeys.us/uploads/2015/12/21/Aviagen%20Breeder%20Guide%202015.pdf.

3.2.4 Duck breeders

Commercial duck breeders are larger and have more paired ovarian follicles than unselected birds. In contrast to turkey breeders, but like broiler breeders, feed restriction decreases the occurrence of multiple follicles and enhances egg production. In spite of the very different growth pattern of ducks compared with chickens, the responses to feed restriction are therefore similar to broiler breeders and very different from turkey breeders (Hocking, 2009).

3.2.5 Hunger

During our literature review, which was restricted to literature after 2001, there was no matches for hunger. A google search with the search terms hunger and poultry had a few matches for old literature, e.g. the article by Bierer et al. (1965). Radical welfare consequences of feed and water deprivations in domestic fowl and turkeys are described in this study. These kinds of studies are illegal to perform today, but they show how animals of different age groups react to removal of feed and water. Layers reacted with moulting and decreased egg weight and shell strength while young animals had a sleepy attitude. Kidney failure and reduced muscle mass before dying were the major pathological findings. Cannibalism as a reaction to starvation was not seen in poultry.

Hocking (2009) propose a genetic solution to the broiler breeder paradox: "Genetic selection for high rates of body weight gain is associated with a correlated increase in the prevalence of multiple ovulations and results in the need for feed restriction in broiler and duck breeders, whereas in turkey breeders the producer has to accept relatively low productivity compared with ovarian potential, particularly in male lines of turkeys. Genetic selection to decrease the propensity for multiple ovulation would, in the long term, lead to the possibility of increasing target body weights to optimize the welfare of broiler breeders while maximizing the production of hatching eggs. Genetic selection against multiple ovulation is not possible at the present time because egg production does not reliably reflect ovarian activity and birds have to be killed to estimate follicle numbers. Marker-assisted selection using DNA markers or whole--genome selection would make such selection possible and is the objective of the author's current research. As broilers become larger, and target body weights become smaller as a proportion of the birds' potential weight (Renema, Robinson, & Zuidhof, 2007), the search for genetic solutions to the welfare issue will become more pressing. Fortunately, the modern genetic tools make this approach feasible and will have the added benefit of contributing to higher rates of lay, which may more than offset the costs of extra feed."

3.2.5.1 Summary restrictive feeding

Restrictive feeding is not known to be a common practice in layer breeders of domestic fowl and turkey breeders but is a common practice for duck breeders.

Radical welfare consequences of feed and water deprivations in domestic fowl and turkeys include layers reacting with moulting and decreased egg weight and shell strength while young animals had a sleepy attitude. Kidney failure and reduced muscle mass before dying were the major pathological findings. Cannibalism as a reaction to starvation was not seen in poultry.

3.3 Fibrous feed

In our literature search there were only two matches for "fibrous feed". In the first Johansson et al. (2016)) fed barley silage to layers in furnished cages. Birds fed silage spent less time expressing aggressive and feather-pecking behaviours and in nest boxes, and more time feeding than control birds. Egg production, egg quality and bird weight were not affected by treatment; yolk colour was darker for the silage treatment. Feathering quality was improved in silage-fed birds compared to control birds.

The second match was a review by Krautwald-Junghanns et al. (2021). The use of straw bales served as both a source for fibres and occupational material. It is important that the access to straw bales and hay is followed by the access to appropriable sized grit to prevent obstipation of the gastrointestinal tract.

In the doctoral thesis of Robin Kalmendal at the Swedish agricultural university "Fibrous feed for functional fowls" (Kalmendal, 2012), he describes the different effects of fibrous feed for poultry. This thesis was not found in the previous literature search but was found in a following Google-search.

The fibre fraction of poultry diets was long considered of diluting or even anti-nutritive nature, as reviewed by Mateos et al. (2012). Thus, it has commonly been used as a negative coefficient in prediction equations of the nutritive value of feeds (Larbier & Leclerq, 1994). Today, following the development of more sophisticated methods of fibre determination, it is known that different fibre fractions have different properties and should consequently be viewed differently (Krautwald-Junghanns et al., 2021).

The solubility is an important feature of fibres as it largely determines their effect on production performance (Choct, 2002). More specifically this effect is primarily mediated by the actions of the fibres in the digestive tract.

The detrimental effects of soluble-NSP (non-starch polysaccharides) in the feed are largely alleviated by the routine use of fibre-degrading enzymes in the feed. The efficacy of many mono- and multicomponent enzyme products is well documented, but their mode of action has been a matter of debate. In essence, the question has resolved around whether the benefits of the enzymes should be attributed their capacity to reduce the viscosity of the digesta, or their capacity to release nutrients encapsulated in the fibre matrix of the grain cell walls, or both (Bedford, 2002).

Kalmendal (2012) concluded that the significance of fibres in poultry nutrition largely depends on the quality of fibres. Whereas soluble fibres primarily acted detrimentally on the functionality of the birds, insoluble fibres tended to act in the opposite direction. In poultry nutrition experiments, however, it remains difficult to separate the effects of increasing amounts of fibrous feedstuffs from those of simultaneous dietary fat supplementation, nutrient dilution, or ingestion of fibrous materials such as litter. Animal density and stocking density

4 Animal and stocking density

4.1 Norwegian and EU regulations addressing animal density and stocking density

For laying hens, the maximum animal density is nine laying hens per m^2 usable area both in the European and Norwegian regulations. Further, for chickens kept for meat production the maximum stocking density is 33 kg/m^2 according to the European regulation. However, the maximum stocking density can be increased up to 39 kg/m^2 by way of derogation if the keeper complies with certain requirements. Further, if the criteria in Annex 5 in the regulations are fulfilled, Member States may allow to increase the maximum stocking density to 42 kg/m^2.

In the Norwegian regulations the standard stocking density is 25 kg/m^2. If the owner/keeper commits to an animal welfare program, the stocking density can be increased to maximum 34 kg/m^2.

The European regulations have no specific demands for animal density concerning turkeys, pullets and breeders. According to Norwegian legislation (LOVDATA, 2001) the stocking densities for turkeys kept for meat production should not exceed 38 kg liveweight/m^2 when the animals' liveweight is below 7 kg. When the mean liveweight exceeds 7 kg, the stocking density shall not exceed 44 kg/m^2.

In the following chapters animal density and stocking density will be described according to the requirements in legislation.

4.2 Stocking density turkeys

In 2016 a scientific committee under VKM made a risk assessment on welfare in turkeys (VKM, 2016). The committee points out among others that the standard requirements for stocking density vary between the Scandinavian countries (Denmark 58 kg/m^2, Sweden 30 kg/m^2, but 45 kg/m^2 for herds that participate in an official control program) and hence that experts disagree on the importance of this factor for animal welfare.

Since this committee completed their work, very few scientific data on stocking density on turkeys have been published. In 2017 Erasmus published a review on the effects of stocking density on turkey behaviour, welfare and productivity (Erasmus, 2017). Erasmus concludes that the majority of scientific studies were conducted over a decade ago with genetic lines of turkeys that may differ from modern genetic lines. However, based on the insight provided by the data in the review, in general higher stocking densities (> 29.3 kg/m^2) are associated with reduced body weight, reduced feed efficiency and increased mortality rate. The list of references in this review article (Erasmus, 2017) does not include other articles than in the report from the VKM committee.

Unfortunately, it seems that there is no additional scientific data produced over the last two decades that provides additional information beyond the VKM report (VKM, 2016).

4.3 Animal density for laying hens

The EU-regulations (Council Directive 1999/74/EC) defines "Usable area" as an area of at least 30 cm wide with a floor slope not exceeding 14 %, with headroom of at least 45 cm. Nesting area should not be regarded as usable areas. The Norwegian regulations (LOVDATA, 2001) uses mainly the same definition. Another term used in the EU-regulations is "alternative systems". According to Ferrante (2009), the category alternative systems comprise a wide variety of different types of systems, from very simple single level systems to multi-level aviaries with or without free-range facilities. The term "alternative systems" is used in the industry to indicate systems which are not conventional cages or any non-cage system.

In a review article, Ferrante (2009) writes that there is no clear scientific evidence for the maximum animal density of 9 birds/m^2 because large-scale replicated studies are few.

In an experiment with laying hens housed in enriched colony cages with either 20 birds per cage (973 cm^2 per bird) or 30 birds per cage (648 cm^2 per bird), Gast et al. (2016) found that increased space influenced the susceptibility of hens to Salmonella Enteritidis. However, in a later, similar experiment (Gast et al., 2017) found no effect of animal density.

In a cross-sectional study of 107 organic flocks of laying hens in eight European countries, the stocking density varied from 4.5 to 6.9 hens per m^2 usable area (Jung et al., 2019). There was however no significant effect on keel bone damage.

To summarize, there is apparently no scientific data made available over the two last decades which provides that basis for a change in the Norwegian regulation for animal density for laying hens.

4.4 Animal density and stocking density for chickens for meat production

Several studies have look at the effect of stocking density on welfare and performance because this is of vital importance for the production economy. Here is presented a selection of studies.

A Canadian study (Bergeron, Pouliot, & Doyon, 2020) included observations on 2.2 million male broilers and 2.3 million female broilers from 37 commercial production sites with a stocking density ranging from 20.5 kg/m^2 to 41,2 kg/m^2. Linear regression models showed that, for both male and female broilers, stocking density had little impact on mortality and meat quality, but average daily gain actually increased with stocking density significantly. This of course contrast with previous published results.

A Brazilian study (Federici et al., 2016) on 11 commercial broiler farms found that the mean stocking density was 28.5 kg/m^2 (22.4 – 31.3). Even if the mean stocking density was lower than recommended in many other countries, the authors conclude that when using the Welfare Quality protocol and looking at behavioural activities, the birds would benefit from even lower stocking densities.

Interestingly, in an Italian study (Iannetti, Romagnoli, Cotturone, & Vulpiani, 2021) with 14 batches of broiler chickens from 6 different farms found that even if the stocking density was higher in the antibiotic-free batches (36.4 kg/m^2 vs. 34.1 kg/m^2), the absence of antibiotics did not have an impact on the good-health principle (hock burns, food pad dermatitis and lameness).

Meluzzi et al. (2008) did a survey on 5 different Italian farms and checked nearly 300 000 chickens. They found no significant relationship between stocking density and lesion incidence or mortality rate.

Tsiouris et al. (2015)) studied 260 broiler chicks at different animal densities (not stocking densities) and conclude that high stocking density affects unfavourably the welfare and gut health of the broiler chicks.

Yanai et al. (2018) studied Cobb 500 broiler chicks at 10, 15 and 29 birds/m^2, and found that higher stocking density negatively affected final body weight as well as cumulative body weight gain. The higher density was also associated with decreased crouching, walking, preening, body care behaviour, and ingestive behaviour.

Also breed can have an influence on welfare and production and Weimar et al. (2020) found that chickens from slow-growing strains among others had the lowest prevalence of hock burns and the highest prevalence of toe damage. The authors highlight the importance of tailoring management to the strain of broiler raised.

In a study in 20 commercial broiler houses in UK (Collins & Sumpter, 2007), birds were tracked in order to look at social environment at different stocking densities. However, the study concludes that stocking density per se seems to have little effect on individual behaviours of the focal animals.

All the studies referenced here seem to be of good scientific quality, but still provide quite different results concerning the effect of density on animal welfare and hence do not provide an unambiguous basis for a change in the regulation for stocking density for chickens kept for meat production. This is in compliance with Dawkins et al. (Dawkins, Donnelly, & Jones, 2004) who concludes that "the difference among producers in the environment they provide have more impact on welfare than stocking density itself". It should be noted that EFSA (EFSA question Q-2020-00479) also later will assess space allowance for broiler chickens.

4.5 Environmental complexity for chickens for meat production

In the last years several articles have been published that focus on environmental complexity for broiler chickens. Bergmann et al. (2017) tested out increased environmental complexity such as perches, straw bales, pecking stones and access to roofed outside runs. They found that the enrichment was well accepted and used and that the birds were more active. Tahamtani et a. (2020) using Ross 308 chicks tested different types of environmental complexity. One of the conclusions from this study was that elevated platforms have to be further studied since footpad health was positively affected but walking ability was impaired.

In a recent study (Anderson et al., 2021) tested the effect of environmental complexity by training birds to approach ambiguous cues and conclude that environmental complexity improves broilers' affective states implying animal welfare benefits.

In a review on environmental enrichment for broiler chickens (Riber, van de Weerd, de Jong, & Steenfeldt, 2018) the authors conclude that many of the ideas for environmental enrichments for broilers need to be further developed, preferably in commercial trials.

Another important factor to improve animal welfare can be the type of breed. Rayner at al. (2020) conclude that significant animal welfare improvements can be achieved by utilizing slow-growing breeds.

The studies presented here imply that providing environmental complexity is positive for the animal welfare but should be further investigated. The introduction of slow growing breeds is promising.

4.6 Stocking density for breeders for chickens for meat production

There seem to be no studies that have looked at the effect on animal welfare of different stocking densities for breeders.

5 Uncertainties

5.1 Lighting

Main source of uncertainties in evaluating the results of the literature review for lighting stems from the small number of studies, in particular for poultry other than broilers. In addition, the studies found in the literature were of very different designs, not always related to either conditions or strains of poultry used in Norwegian production. There was also a great disparity in specification of details of material and methods, especially regarding specifying wavelengths and luminescence.

5.2 Restrictive feeding and fibrous feed

There is very limited literature concerning the welfare effects of restrictive feeding of turkey breeders.

The positive effects of feeding insoluble fibres to poultry with regard to gut health and gut function are well known, but the effect of these fibres on satiety are not thoroughly examined. The effects of soluble fibres on satiety is also uncertain. Positive effects were discovered in reference only.

5.3 Animal density and stocking density

The uncertainties in evaluating the animal and stocking density for turkeys is that there unfortunately seem to be no new, up to date studies looking at density. The same goes for laying hens. For chickens for meat production there are uncertainties both regarding the density/environmental complexity interaction and also the consequences of introducing more slow growing breeds.

6 Conclusions (with answers to the terms of reference)

6.1 Light

6.1.1 Welfare consequences of various artificial lighting systems used in poultry production

Artificial lighting systems are used in poultry production to improve both production and welfare of the birds. From a welfare point of view, it is important to emphasise that the lighting beneficial to production is not always beneficial for the welfare and some trade-offs might be needed. For example, the lower lighting intensities might be beneficial for production as they reduce birds' activity which, on the other hand, is not beneficial for their welfare. There are also consequences of the lighting systems with long or continuous photoperiods which do not allow for enough resting time for birds and behaviour natural for the species. Thus, the lighting systems imitating as close as possible natural day rhythm might reduce the impact of the intensive rearing.

6.1.2 Lighting parameters of paramount importance in avoiding risks to the bird's welfare

Risk to animal welfare stems from inadequate lighting that prevents normal activity of birds but also from unwanted behaviour like aggressiveness. Lighting parameters that influence the risks to bird welfare depending on the species that is considered include:

- the colour of the light (in the case of the WL also the warmth of the light),
- UV supplementation in the case of LED without UV spectrum,
- light intensity and
- photoperiod

6.1.3 Appropriate limits for the different lighting parameters

Table 6-1. Guidelines for limits for the relevant for different lighting parameters where available (more details in 2.4). Limits are subject to uncertainty described in 5.1.

<table>
<tr><th></th><th>Colour</th><th>UV suppl.</th><th>Light intensity</th><th>Photoperiod</th></tr>
<tr><td>Layers</td><td>red LED (640 nm)</td><td rowspan="2">UVA and UVB</td><td rowspan="2">20 lx</td><td rowspan="2">10L:114D</td></tr>
<tr><td></td><td>WL 5000-6500 K</td></tr>
<tr><td>Broilers</td><td>WL 4100K-6065K</td><td rowspan="2">UVA and UVB</td><td rowspan="2">50-200 lx</td><td rowspan="2">16L:8D</td></tr>
<tr><td></td><td>Blue-green (470-525 nm)</td></tr>
<tr><td>Ducks</td><td>BL (425 nm)*</td><td>UVA and UVB</td><td></td><td>20L:4D</td></tr>
</table>

	Colour	UV suppl.	Light intensity	Photoperiod
	RL (625 nm)**			
Quails	No data	No effect	10 lx	14L:10D

*Pekin duck

** Mulard duck (Muscovy duck hybrid)

6.2 Restrictive feeding and fibrous feed

6.2.1 Welfare consequences of diets and feeding systems for layer breeders of domestic fowl

Restrictive feeding is not known to be a common practice in layer breeders of domestic fowl. These birds, as for regular layers, are fed *ad libitum*.

6.2.2 Welfare consequences of restrictive feeding of turkey breeders (if it is common practice to restrictively feed any of the other species' breeders, please perform the assessment also for those species.)

There is very limited literature available concerning the welfare consequences of different methods of feeding turkey breeders. Restrictive feeding of turkey breeders is not a common practice because of negative effects of restrictive feeding on the animal's reproductive ability. Feeding adapted to the birds' growth is a major issue in the feeding protocols for turkey pullets and is used to manage their growth rate relative to recommendations.

Restrictive feeding of duck breeders is a common practice because they respond in a similar way to broiler breeders with regard to reproductive ability but very differently than turkey breeders.

6.2.3 Welfare consequences of hunger for the poultry species concerned

The welfare consequences of hunger are thoroughly discussed in the articles concerning feed restriction in broiler pullets and in the literature describing different moulting procedures. Restrictively fed broiler breeders show behavioural abnormalities that are indicative of hunger and frustration of the feeding motivation, like hyperactivity and abnormal oral behaviour (stereotyped object pecking and over-drinking), rise in heterophil to lymphocyte ratio and elevated plasma circulating corticosterone.

Radical welfare consequences of feed and water deprivations in domestic fowl and turkeys include layers reacting with moulting and decreased egg weight and shell strength. Kidney failure and reduced muscle mass before dying were the major pathological findings. Young animals had a sleepy attitude when exposed to extreme feed restriction. Cannibalism as a reaction to starvation was not seen in poultry.

6.2.4 Welfare consequences of use of fibrous feed and specifically its effect in mitigating hunger, reducing abnormal behaviours such as feather pecking or stimulating the birds to increased activity and in performing comfort behaviours

Fibres are not digested by fowls, but their impact on digestive physiology, nutrient metabolism and intestinal microflora can be substantial. It was concluded that the significance of fibres in poultry nutrition largely depends on the quality of fibres. Whereas soluble fibres primarily acted detrimentally on the functionality of the birds, insoluble fibres tend to act in the opposite direction. In poultry nutrition experiments, however, it remains difficult to separate the effects of increasing amounts of fibrous feedstuffs from those of simultaneous dietary fat supplementation, nutrient dilution or ingestion of fibrous materials such as litter.

6.3 Animal density and stocking density

6.3.1 Welfare consequences for domestic fowl and turkeys of abiding by the animal and stocking density rules cf. the poultry regulation sections 25, 29, 30 – 34, 35a and 36, in general and in particular its impact both on bird behaviour and the living environment such as air quality, bedding, and litter.

Both for turkeys and laying hens there seem to be no up to date/recent studies indicating that animal welfare is impaired when abiding to the Norwegian poultry regulation for animal density and stocking density.

For chickens for meat production there is no recent data indicating that animal welfare is impaired when abiding to the Norwegian poultry regulation for animal density and stocking density. However, more recent studies point out a possible positive effect of environmental enrichment on animal welfare.

Our literature search has been concentrated on animal density and hence we cannot provide data on the effect on animal welfare on air quality and litter/bedding.

6.3.2 Appropriate limits for both animal and stocking densities for both species and the different stages of the production cycle. Where relevant, appropriate limits for hybrids farmed in Norway.

Both for turkeys and laying hens there seem to be no up to date/recent studies on the effect of animal density and stocking density on animal welfare that would make it possible or reasonable to suggest new and appropriate limits for animal density and stocking density.

For chickens for meat production different results concerning the effect of density on animal welfare are published and hence do not provide an unambiguous basis for a change in the regulation for stocking density for chickens kept for meat production. However, more recent studies with chickens for meat production have indicated positive effects on animal welfare both of using slow-growing breeds and the provision of environmental enrichment.

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8 Appendix I - Literature search

8.1 Literature search strategy

Searches were performed in primary literature and keywords were adapted to the individual question in the mandate from the Norwegian Food Safety Authority and divided into animal welfare factors:

- Light * or spectre or wavelength or lux or brightness or natural light and broiler or breeder or layer or duck or geese or quail
- Feeding systems and welfare and layers or breeders or gallus
- Restrictive feeding and welfare and breeders or turkey
- Fibrous feed and welfare or health and breeders or turkey or duck or geese or quail
- Hunger and welfare and turkey or poultry or gallus
- Animal density or stocking or space allowance and consequences or welfare and poultry or gallus or breeders or layers or broilers or turkey

8.2 Light

https://www.webofscience.com/wos/woscc/summary/e7f11cf8-e184-4679-9489-8bff7b395ee1-1e57a37e/relevance/1 - light broiler, 139 articles retrieved

https://www.webofscience.com/wos/woscc/summary/59e0cd38-5cb9-4cde-90b1-fb074c3afdab-1e587956/relevance/1 - light breeder, 31 articles retrieved

https://www.webofscience.com/wos/woscc/summary/d35c5141-fcd8-4f65-9f21-cfa981906a79-1e589257/relevance/1 - light layer, 40 articles retrieved

https://www.webofscience.com/wos/woscc/summary/6f653c7f-ef48-40c0-99ee-ae33298e55c8-1e58a795/relevance/1 - light duck, 9 articles retrieved

https://www.webofscience.com/wos/woscc/summary/7e5d5f55-9576-426a-bfb5-7a9a7ac7869b-1e58b9f3/relevance/1 - light geese, 1 article retrieved

https://www.webofscience.com/wos/woscc/summary/aa73c350-a523-4e76-b3b7-8bd73240545f-1e58c906/relevance/1 - light quail, 9 articles retrieved

https://www.webofscience.com/wos/woscc/summary/bea5f9bf-95c7-4af4-853d-ca8a6bd4e594-1e58d757/relevance/1 - light combined, 211 articles retrieved, 77 relevant

8.3 Feeding

https://www.webofscience.com/wos/woscc/summary/9334bc0f-ac7d-4caf-8a4c-5a1da8212b07-1e5966a9/relevance/1 - feeding layers, 88 articles retrieved

https://www.webofscience.com/wos/woscc/summary/4cccecd9-5499-4c8b-8be8-ae85fa4865e3-1e599114/relevance/1 - feeding breeders, 107 articles retrieved

https://www.webofscience.com/wos/woscc/summary/8b935ab2-0a1a-4c51-b9f9-aa25e2bca423-1e59a6c6/relevance/1 - feeding gallus, 12 articles retrieved

https://www.webofscience.com/wos/woscc/summary/ab5d6193-5911-4ad3-a5cd-eb414fb7f35a-1e59b754/relevance/1 - feeding combined, 200 articles retrieved, 27 relevant

https://www.webofscience.com/wos/woscc/summary/1db226e5-878c-48f2-b481-0887c67d949f-1e59e12d/relevance/1 - restricted feeding breeders, 34 articles retrieved

https://www.webofscience.com/wos/woscc/summary/03c507c6-4f35-412d-901c-899f44bd2d74-1e5a031d/relevance/1 - restricted feeding turkey, 1 article retrieved

https://www.webofscience.com/wos/woscc/summary/ed67dbab-1554-4f64-9ef5-f77b56d2db79-1e5b4a69/relevance/1 - fibrous feed turkey, 0 articles retrieved

https://www.webofscience.com/wos/woscc/summary/8405e309-9d7e-41e5-878f-ff0f5f04a2ed-1e5b58b4/relevance/1 - fibrous feed duck, 0 articles retrieved

https://www.webofscience.com/wos/woscc/summary/54f6bab2-cf2c-4d1a-a351-0f3b81212bae-1e5b5b4a/relevance/1 - fibrous feed geese, 0 articles retrieved

https://www.webofscience.com/wos/woscc/summary/bad2aac4-8a90-4c0e-aee7-494d7031d6e3-1e5b5cdf/relevance/1 - fibrous feed quail, 0 articles retrieved

https://www.webofscience.com/wos/woscc/summary/53a0b629-cf5b-43e3-9cd1-f9c20c296e0e-1e5b6e52/relevance/1 - hunger turkey, 2 articles retrieved

https://www.webofscience.com/wos/woscc/summary/596f59bd-cccb-48a4-9eb0-9f90b730bc5e-1e5b7993/relevance/1 - hunger poultry, 14 articles retrieved

https://www.webofscience.com/wos/woscc/summary/b8cb30c9-bb0a-4255-9be7-90f690dc2f13-1e5b9b7b/relevance/1 - hunger gallus, 1 article retrieved

8.4 Animal density and stocking density

https://www.webofscience.com/wos/woscc/summary/2da29351-8c4e-4892-9605-95bf01a16b71-1e5bbab1/relevance/1 - animal density poultry, 81 articles retrieved https://www.webofscience.com/wos/woscc/summary/152ec850-7277-473f-be60-83483df943ba-1e5bddca/relevance/1 - animal density gallus, 2 articles retrieved

https://www.webofscience.com/wos/woscc/summary/d7e54221-faf3-40c4-95e1-6148a9520218-1e5bf307/relevance/1 - animal density breeders, 26 articles retrieved

https://www.webofscience.com/wos/woscc/summary/d3d55317-d3aa-433b-9a9d-c55ee3c39765-1e5c04b2/relevance/1 - animal density layers, 32 articles retrieved

https://www.webofscience.com/wos/woscc/summary/de3708a8-1792-4200-ba22-8fd42b4781ab-1e5c3384/relevance/1 - animal density broilers, 167 articles retrieved

https://www.webofscience.com/wos/woscc/summary/ea2c481d-0b4e-4f1a-bf7b-ff2cfc238b14-1e5c4f7d/relevance/1 - animal density turkey, 20 articles retrieved

https://www.webofscience.com/wos/woscc/summary/f0e5c903-0b04-410f-8001-678a539f2e0c-1e5c622c/relevance/1 - animal density combined, 259 articles retrieved, 35 relevant