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Report 335

The effect of optimized lighting conditions on feather pecking and production of laying hens

Het effect van geoptimaliseerd kunstlicht op verenpikken en productie van leghennen

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Abstract
Feather pecking is one of the major problems in commercially kept laying hens. The current research considers the relevance of colour of light in the feather pecking problem.

Keywords
Laying hens, ultraviolet light, feather pecking, fear, production

Reference
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ANIMAL SCIENCES GROUP
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Voorwoord

Voor u ligt de Engelstalige rapportage van het onderzoek naar het effect van licht op het gedrag en de productie van leghennen. Het onderzoek is uitgevoerd in opdracht van Philips Lighting en het Productschap Pluimvee en Eieren. Het is uitgevoerd door onderzoekers van Wageningen UR Livestock Research op twee proefaccommodaties in Lelystad.

Het onderzoek draagt bij aan de inspanningen die verricht worden om verenpikken bij leghennen tegen te gaan met het oog op het toekomstige verbod op snavelbehandelingen. Deze rapportage beschrijft de achtergrond, de methodes, resultaten en conclusies van drie opeenvolgende dierproeven, in de periode 2006-2008. Speciaal voor dit doel heeft Philips Lighting nieuwe lampen ontwikkeld. Exacte technische details en (kleur)eigenschappen van de nieuwe lampen waren niet bekend bij de onderzoekers en zijn vertrouwelijk.

We willen Philips Lighting en het Productschap Pluimvee en Eieren graag bedanken voor het toegezegde vertrouwen om het onderzoek door ons te laten uitvoeren.

Samenvatting

Achtergrond en hypothese

Van verenpikken is bekend dat het vaak te herleiden is naar een arme omgeving met weinig prikkels en mogelijkheden tot het uiten van natuurlijk gedrag. Wageningen UR Livestock Research onderzocht in opdracht van Philips Lighting en het Productschap Pluimvee en Eieren (PPE) in hoeverre verenpikken teruggedrongen kan worden door aanpassingen in lichtkleur, optimaal afgestemd op het kippenoog. De achterliggende gedachte was dat kippen meer kleuren kunnen onderscheiden dan mensen, en dat ze in tegenstelling tot mensen ook ultraviolet A (UV-A) licht kunnen zien. Het is bekend dat dit UV-A licht, aanwezig in daglicht een grote invloed heeft op het natuurlijke gedrag van kippen. Met UV-A licht zien kippen meer details in de omgeving en herkennen ze soortgenoten beter. Dit stimuleert natuurlijk gedrag zoals bodempikken, bodemkrabben en stofbaden en vermindert de intentie om naar elkaar te gaan pikken. Bij voorkeur zal een kip deze actieve gedragingen bij lichtsterktes boven de 50 lux willen uitvoeren.

Het belang van licht voor het natuurlijke gedrag en het kunnen zien van kippen is nauwelijks bekend in de praktijk. De verlichting in pluimveestallen - vaak witte TL-verlichting – bevat nauwelijks tot geen UV-A licht. Daarnaast worden in de praktijk relatief lage lichtsterktes gehanteerd, meestal tussen de 5 en 30 lux.

Drie dierproeven

In de periode 2006 – 2008 zijn drie opeenvolgende dierproeven uitgevoerd met Lohman Bruin (LB) en Lohman Selected Leghorn (LSL) leghennen. De snavels van de hennen bleven intact. De hennen werden als eendagskuikens in grondhokken geplaatst. Naast het gedrag is het gewicht van de hennen en de kwaliteit van het verenkleed nauwlettend gevolgd. Op basis van voortschrijdend inzicht werden in elke proef twee nieuw ontwikkelde lampen getest, en vergeleken met de resultaten onder standaard witte verlichting. De nieuwe lampen zijn ontwikkeld door Philips Lighting, en er is gebruik gemaakt van hoogfrequente PL lampen. In de nieuwe lampen is met name gevarieerd met de hoeveelheid en exacte golflengte van het UVA licht. De exacte technische details en (kleur)eigenschappen van de nieuwe lampen waren niet bekend bij de onderzoekers.

In proeven 1 en 2 werden de leghennen in groepjes van 10 gehuisvest, op bodems ingestrooid met houtkrullen. Beide proeven duurden tot het einde van de opfokperiode (17 weken). De lichtsterkte was 20 of 40 lux in proef 1, en 40 lux in proef 2.
In proef 3 werden de hennen gehuisvest in groepjes van 30, bij 40 lux. Er werd gestart met bodems zonder strooisel, om de omstandigheden minder optimaal te maken. Uiteindelijk kregen LSL hennen op een leeftijd van 6 weken en LB hennen op een leeftijd van 14 weken beschikking over strooisel. Strooisel werd verstrekt op het moment van uitbraken van verenpikken bij de respectievelijke merken. In deze proef werden de hennen ook in de legperiode gevolgd, tot een leeftijd van 50 weken, om ook een effect op technische kengetallen te bestuderen.

Pikgedrag

Zoals bleek in de eerste proef had lichtsterkte nauwelijks effect op de resultaten. Alleen waren de hennen bij 20 lux wat minder actief. Op verschillende momenten in de opfokperiode van proef 1 werd met een nieuwe lamp meer bodempikken en minder zacht verenpikken waargenomen, vergeleken met de standaard lamp. Dit was ook het geval in proef 2, maar alleen bij de testlamp met de hoogste UV-A output. Vermoedelijk is het beter is als er minder zacht verenpikken voorkomt, aangezien dit gedrag over kan gaan in beschadigend verenpikken. Genoemde positieve effecten waren overigens soms alleen bij één merk zichtbaar. Beschadigend verenpikken werd in proeven 1 en 2 niet waargenomen.

In de derde proef was het beeld beduidend anders. In de legperiode werd onder de testlampen bij LB hennen meer verenpikken gezien dan bij de standaard lamp en was de veerschade aan staart en rug op 50 weken aantoonbaar groter. Bij LSL hennen werd nauwelijks verenpikken waargenomen in de legperiode. Deze hennen hadden al in de vroege opfok strooisel gekregen, en dit verklaart wellicht het verschil.

Overig gedrag en technische resultaten

Als reactie op een persoon of op een onbekend voorwerp toonden leghennen van één of beide merken in alle proeven minder mijdingsgedrag bij één van beide testlampen. Dit was indicatief voor minder angst. Er is in de proeven 2 en 3 ook aantoonbaar meer comfortgedrag gezien, vergeleken met standaard verlichting, zoals stofbaden en poetsen.

Over het algemeen hadden de nieuwe lampen geen effect op de technische resultaten in de opfok- en legperiodes. Bij sommige testlampen was de uniformiteit lager. In de legperiode van proef 3 was de voerconversie hoger bij één van de testlampen. Bij de andere testlamp werden meer grondeieren gevonden. De oorzaak is onduidelijk.

Discussie en vervolg

De resultaten laten zien dat kunstlicht dat ook ultraviolet licht uitstraalt bij kan dragen aan het stimuleren van het gewenste pikgedrag. De hennen worden dan gestimuleerd om meer naar de bodem en minder naar elkaar te pikken. Vermoedelijk doorslaggevend in een positief effect van geoptimaliseerd licht is de tijdige aanwezigheid van voldoende prikkels en afleiding. Omgekeerd beredeneerd werkt een optimale verlichting van een kale omgeving verenpikken eerder in de hand. Dit geeft aan dat een goede verlichting alleen niet voldoende is om ongewenst pikgedrag tegen te gaan. Eenmaal aangeleerd ongewenst pikgedrag in de opfok lijkt overigens moeilijk af te leren, ook niet als de omstandigheden in de late opfok en legperiode beter zijn.

Gezien de samenhang met en afhankelijkheid van andere factoren, zoals strooisel en wellicht voer, zal Philips Lighting nog geen aangepaste lamp op de markt brengen. Als in de toekomst een lamp wordt aangeboden, zal dit gebeuren in combinatie met een strooisel- en voeradvies. Voor dit aan te bevelen "pakket" is nog vervolgonderzoek nodig. Dit onderzoek kan in de praktijk plaatsvinden.

Summary

Feather pecking is one of the major problems in commercially kept laying hens. The current research considers the relevance of colour of light in the feather pecking problem. Chickens have a well-developed colour vision, and even have the ability to “see” into the ultraviolet range (ultraviolet A). It is hypothesized that UV-A inclusion in light results in a better vision and consequently a richer environment for the hens, as hens receive more detailed information from their environment. Accordingly, they may become less interested in each other feathers.

The following research questions were addressed in the research:
1) Can UV supplementation reduce gentle and severe feather pecking in laying hens?
2) Can UV supplementation increase desired types of pecking, such as ground pecking?
3) can UV supplementation decrease fearfulness of the hens?
4) Are aspects of hen development and egg production affected by UV-A supplementation?

The effect of optimized lighting conditions on the behaviour and production of laying hens was tested experimentally with a white and a brown egg layer breed. This was done in three consecutive experiments. The first two experiments comprised the rearing period, whereas the third experiment also included the laying period until 50 weeks of age. In each experiment two adapted or optimized light sources were tested, and compared with standard white light. In all cases fluorescent tubes (PL) were used. Light intensities were either 20 or 40 lux in experiment 1 (factor), and was fixed around 40 lux (standardized brightness) in the other experiments.

The results of the three experiment indicate that with UV-A inclusion in light, gentle feather pecking at times can be reduced and ground pecking may be stimulated. This is possible at relatively high light intensities (around 40 lux), which is close to the desired light intensities by laying hens for their active behaviours. UV-A inclusion in light has fear-reducing properties. The most important egg production traits are not affected by UV-A inclusion, but uniformity in weight and proportion of eggs in nests may be at risk and require attention. In experiments 1 and 3, adapted light sources each had their specific (dis)advantages. In experiment 2, the most promising light source was E2-optimized-2, which had the highest UV-A output.

Adapted lighting in itself will not exclude or reduce injurious feather pecking, as clearly shown in experiment 3: LB hens developed high levels of injurious pecking. Other factors, such as suitable litter, may determine whether the effects of adapted light are either beneficial or detrimental. LB hens were relatively long kept without litter, in an environment lacking stimuli, and this may have led to an undesirable situation in which improved vision may have caused more interest in each other feathers and thus more feather pecking. Injurious feather pecking in LSL hens, on the other hand, was initially high but was much reduced following litter provision at a relatively young age. However, positive effects of adapted light in the longer term were only seen for gentle pecking, while severe pecking was not affected.

In practice, litter management for loose housed hens varies a lot. Moreover, many hens are kept in cages, which have a relatively barren environment with very limited litter provision. LB hens are the predominant breed kept for commercial purposes. This specific combination may pose a risk for development of feather pecking, as we may conclude from our results. Optimized light sources are therefore not ready for marketing at this point, without knowing more about the interaction of light with other factors. We expect the most from rich substrates and feed which have high reflective properties. Adapted light by UV inclusion then may have its beneficial effect.

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1 Introduction

Motives and background

Feather pecking is one of the major problems in commercially kept laying hens. Feather pecking varies from gentle feather pecking to severe feather pecking or feather pulling (Savory, 1995). Gentle feather pecking is a form of feather pecking without removal of feathers, and causes little or no feather damage and is often ignored by the recipient. Severe feather pecking on the other hand is much more forceful, and poses a major welfare risk for the hens. Severe feather pecking is the pecking at and pulling out of feathers of conspecifics. This causes feather damage and loss of feathers, and eventually leads to bald patches. Most damage by pecking is caused to the tail, rump and back regions (Bilcik and Keeling, 1999). It is also an economical burden for the farmer. Costs of egg production increase, as a loss of feathers leads to increased body heat loss, and consequently higher feed (energetic) requirements. Bald patches may attract skin or tissue pecking, which can escalate into wounding of the victim and cannibalism (i.e. consumption of flesh or food). Feather pecking is both observed in cages and in alternative systems. In alternative systems with large groups, however, the problem is more difficult to control, as feather pecking may spread by social transmission (Zeltner et al, 2000). In alternative housing, losses may be up to 15% of the birds per production cycle. Beak trimming as a remedial measure will be banned in the near future in The Netherlands.

Gentle and severe feather pecking are not clear-cut and may grade into each other (Savory, 1995). It is suggested that in adult laying hens gentle feather pecking by increasing intensity or severity may develop into severe feather pecking (McAdie and Keeling, 2002). If this is the case (other theories also exist, e.g. Newberry et al., 2007), gentle feather pecking early in life may be an indicator of severe pecking in adult laying hens. Feather pecking should not be confounded with aggressive pecking, which is used to maintain the dominance hierarchy. Aggressive pecking may lead to some damage to the head and neck region. There is an ongoing discussion on the causation of feather pecking. One of the most important single causal factors associated with feather pecking is the provision of a suitable floor substrate (litter). The two most influential theories on the causation of feather pecking are related to this factor: feather pecking is thought to be a form of redirected behaviour, developing either from ground pecking for foraging and feeding (Blokhuis, 1986) or pecking during dustbathing (Vestergaard, 1994), in the absence of a suitable substrate. However, as feather pecking is not fully eliminated by availability of suitable substrates, it is generally accepted that the development of feather pecking is multifactorial. Other single factors involved are nutrition (food form, dilution), group size and stocking density, rearing conditions, and light intensity and colour (Rodenburg, 2003). Large variation in performance of feather pecking also exists between strains of laying hens. Breeding programmes to solve the feather pecking problem seem possible, but so far the results on this factor are not consistent, and heritability estimates range substantially, e.g. from 0.04 to 0.56 (van Hierden, 2003).

The current research considers the relevance of colour of light in the feather pecking problem. Chickens have a well-developed colour vision, and even have the ability to “see” into the ultraviolet range (ultraviolet A: UV-A) (Prescott and Wathes, 1999a, Prescott et al., 2004; Wortel et al., 1987). To compare, the human eye is not able to perceive ultraviolet A radiation (Figure 1; UV-A ranges between 320 and 400 nm wavelenght). Colour assessment by humans is therefore an inadequate and mis-leading approach for the relevance of colour of light for hens. Hens have four photoreactive pigments (tetrachromatic) associated with the cone cells, compared with three (trichromatic) in humans. These four pigments are maximally sensitive at 415, 455, 508 and 571 nm wavelengths, compared with 419, 531 and 558 in humans (Prescott et al., 2004).

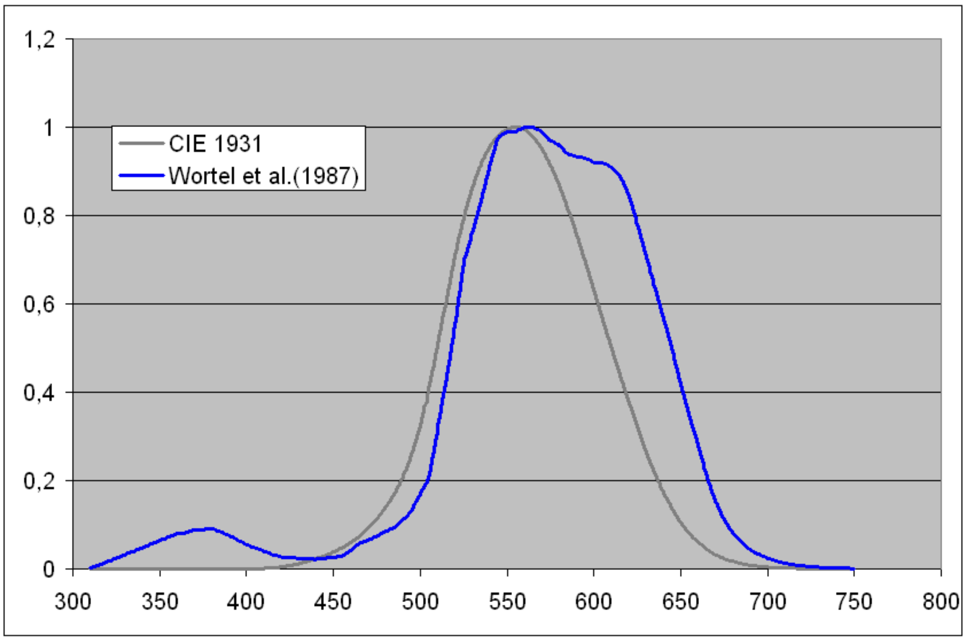


Figure 1. Spectral sensitivity (relative sensitivity: y-axis) of chickens (blue line) and humans (grey line) at different wavelengths (wavelength in nm: x-axis)

UV-A light is specifically relevant for poultry to obtain more information from the environment. Reflectance of UV-A light from feathers facilitates recognition, assessment of and communication between individuals. There is a variation between breeds in colour and the reflectivities of the feathers. Even in a flock of apparently white birds, each may have plumage of distinctive overall reflectivity, colour and pattern when viewed by a conspecific (Prescott and Wathes, 1999b). Reflection by surroundings improves recognition of resources, e.g substrates and feed (Prescott and Wathes, 1999b). Biological materials have similar reflective characteristics to feathers. Sawdust or straw bedding, eggshells, and wood all have a minimum reflectivity at 400 nm. However, artificial lighting used in poultry housing produce little, if any, UV-A radiation. This means that current light environments impose some sensory deprivation on laying hens, by impairing animal recognition and foraging behaviour (by impaired recognition of substrate and feed). Indeed, the consequences for animal recognition were shown in a study with broiler breeders: sexual selection and mating behaviour were improved with UV-A light inclusion (Jones at al, 2001). The impairment of foraging behaviour may be of relevance for the feather pecking problem. This impairment may lead to an increased risk for feather pecking. Interestingly, but the effect came along with other measures, injurious pecking behaviour of turkeys was found to be reduced with UV-A inclusion (Lewis et al., 2000b). Further evidence of the beneficial effects of UV light was provided by Maddocks et al. (2001). Basal corticosterone levels were higher, suggestive of chronic stress and fear, in chickens kept under UV-deficient rather than full-spectrum lighting. Fearfulness has also been associated with feather pecking, and may be initiated by fearful birds (Vestergaard et al., 1993). However, fearfulness may also be a consequence of feather pecking, induced by feather damage and pain. The effect of UV light on reproduction of laying hens is rather unknown. Results of Lewis et al. (2000a) suggest that UV light influences behavioural rather than reproductive responses. UV light had no effect on the timing of the ovulatory cycle, but did suppress food intake.

It has been suggested that the more sophisticated apparatus for colour vision means that hens have better vision in bright light than dim. In commercial poultry houses, however, the intensity of light is much lower than normal daylight. Hen houses may be lit between 5 and 30 lux. By comparison, on a sunny day illuminance outdoors can reach 100.000 lux while offices are usually lit to 300 lux. Reducing light intensity is employed by farmers to restrict or to prevent rising levels of feather pecking. Often, it is stated by farmers that higher light intensities increase the risk for feather pecking. This is, however, a wrong interpretation. Other factors may be associated with the occurrence of feather pecking, and then an effective measure is to dim light. The mechanism behind this is that with lower light intensities abnormalities in plumage like damage, baldness, and blood spots become less clear.

Accordingly, hens are less invited to peck at the feathers and skin of other hens. A similar effect is seen with red light, a strategy also often applied in practice when feather pecking occurs. Strategies of dim or red light do at first sight not negatively affect egg production. Laying hens are much more tolerant to low light intensities than earlier stocks (Renema et al., 2001). Specifically for red light, it must be emhasized that although numbers of eggs laid are not negatively affected, eggs may become smaller sized (Er et al., 2007; Pyrzak et al., 1987). Other advantages of dimming light are a reduction in energy costs and a higher food conversion efficiency. The latter is very probably due to a reduced hen activity. Indeed, it is known that hen activity is positively associated with light intensity. Hens do show preference for lower light intensities for performing certain behaviours such as resting and perching, but will move to brighter areas for more active behaviours such as feeding, drinking and foraging (Davis et al., 1999). When given a choice, hens prefer to employ active behaviour, such as eating, in 200 lux (Prescott and Wathes, 2002). Martin (1989) showed that activity in hens reduced at 50 lux or less. It may therefore be expected that a reduction in intensity will influence the wavelengths emitted by a light source and that at dim levels chickens are unable to employ their full repertoire of visual capabilities with potentially important consequences for their behaviour. Also, young birds were more fearful at 17-22 lux than at 55-80 lux (Hughes and Black, 1974). Very low intensities (<5 lux) even may cause eye abnormalities as the functional development of vision may be affected, especially when these conditions occur during rearing. At these very low light intensities, hens are also restricted in moving around the house, and to jump between horizontal perches (Taylor et al., 2003). Last but not least, dim conditions also negatively affect staff working conditions. A minimum intensity of 20 lux is recommended on grounds of animal welfare, staff working conditions and aesthetics. However, the cited results above on fear and activity threshold, might indicate that the minimum lux should be higher, i.e. between 50 and 100 lux. It must be emphasized that for poultry with different spectral sensitivities to the human, the lux unit is incorrect. For example, for typical fluorescent and incandescent luminaires illuminated to the same lux level and consequently isoluminant for humans, hens perceive the incandescent bulb as 20% brighter than the fluorescent tube (Prescott et al., 2004).

Aim of the research

The concern is that current light environments in hen houses impose some sensory deprivation on the hen. The effect of light colour and light intensity on behaviour and especially on the onset of injurious behaviour like feather pecking, merits further investigation. It is hypothesized that UV-A inclusion in light results in a better vision and consequently a richer environment for the hens, as hens receive more detailed information from their environment. Accordingly, they may become less interested in each other feathers. To test the potential of adapted lighting for laying hen behaviour, Philips Lighting asked the Animal Sciences Group of Wageningen University and Research Centre (Wageningen UR) to study this experimentally in small scale trials. In a time-span of three years, 3 experiments were performed. Promising adapted light sources were provided by Philips Lighting.

The following research questions were addressed in the research:
1) Can UV supplementation reduce gentle and severe feather pecking in laying hens?
2) Can UV supplementation increase desired types of pecking, such as ground pecking?
3) Can UV supplementation decrease fearfulness of the hens?
4) Are aspects of hen development and egg production affected by UV-A supplementation?

Underlying questions were:
a) Do white and brown egg layer breeds react differently to adapted light environments?
b) Is there an effect of light intensity in the range 20 to 40 lux?
c) Are general time budgets of other behaviours affected by adapted light environments, e.g those related to resting, feeding or comfort?

2 Materials and Methods

The effect of optimized lighting conditions on the behaviour and production of laying hens was tested experimentally with a white and a brown egg layer breed. This was done in three consecutive experiments. All procedures involving animal handling and testing were approved by the Animal Experimental Committee of the Animal Sciences Group of Wageningen University and Research Centre.

2.1 Experimental housing and animals

The two breeds used in the experiments were Lohman Brown (LB) hens and Lohman Selected Leghorns (LSL). These two breeds were obtained from a commercial hatchery (Verbeek, The Netherlands), and are known for their difference in behavioural traits and activity (LSL more active). Accordingly they were also expected to differ in propensity for feather pecking. The hens used for the experiments were not beak trimmed. Experiments 1 and 2 were performed at the experimental poultry facility 'Spelderholt' in Lelystad, The Netherlands. Experiment 3 was done in a climate controlled facility, also in Lelystad, The Netherlands.

Figure 2. Experimental poultry facility 'Spelderholt' (left) and the climate controlled facility (right), Lelystad, The Netherlands

In each experiment, birds arrived as day-old chicks. They were allocated at random to floor pens, as described in more detail under 2.2. Experimental design. The pens were built of wire and hens could not see their flock mates in other pens by additional wooden partitions between the pens. The pens used in experiments 1 and 2 measured 0.95 by 0.75 meter (height: 0.80 m) and were supplied with wood shavings as substrate on the floor from day 0 to week 6 of age. As floors were solid, the material on the floor gradually became a mixture of wood shavings, (dry) manure, and feathers. The pens in experiment 3 were variable in size and measured maximally 3.0 by 1.0 meter (variable height: maximum 1.5 meter). The hens were housed on fully slatted floors at the start of the experiment. Provision of substrate on a partly solid floor (1/3 of floor surface) was done at a later age (see also 2.2.3 experiment 3). The pens were provided with perches (15 cm/hen) and laying nests (5 hens per nest) when the hens were around 17 weeks of age. The laying nests were placed outside each pen.

The health status of the hens was monitored daily. The vaccination scheme applied in the rearing period was comparable to that in commercial hen farming. The hens had free access to feed and water. Feed was provided in feeding troughs (length of 0.75 meter) and water was available through nipple drinkers. From 0 to 3 weeks of age, the hens received a standard commercial starter diet. During the further rearing period (until the age of 17 weeks), two different standard commercial rearing (grower) diets were provided. From 17 weeks onwards (experiment 3), hens received a standard commercial layer diet.

The environmental temperature was lowered from 33 ^{0}C on day one to 20 ^{0}C at 6 weeks of age onwards. On days 1 and 2 of age the chicks received 24 hours of light. Between 2 and 7 days of age, light was on for 16 hours per day. From 7 days to 6 weeks of age onwards the light regime gradually decreased by one hour per week to a 9 hour light period. Until 17 weeks of age, this light regime stayed the same. From this age onwards (experiment 3), the light period was gradually extended by one hour per week to a 15 hour light period at 23 weeks of age. Light intensities varied according to experimental design and light source. All materials concerning the light installations and sources were supplied by Philips Lighting BV. In all cases fluorescent tubes (PL) were used.

2.2 Experimental design

2.2.1 Experiment 1

In experiment 1, a total of 240 LSL and 240 LB hens were used. The experiment was done in the rearing period only, i.e with young hens from birth to the age of 17 weeks. The hens were housed in two identical compartments. Each compartment was divided in 6 subcompartments (rows) and consisted of 4 pens. In each pen, hens were housed in groups of 10 (48 pens in total). Within each subcompartment, one light source was tested, together with the two breeds. Mingling of light between subcompartments was prevented by partitioning by fences on which black plastic was attached.

Groups of hens were allotted to 1 of the 12 treatments according to a 3 (light source) x 2 (light intensity) x 2 (breed) factorial arrangement, with 4 replicates per treatment:
Light source (code in italics):

1. *E1-Standard*: white light (Master PL-S 830/4P; 7 W).
2. *E1-optimized-1*: Combination white light (master PL-S 840/4P; 9W) and Blacklight Blue (PL-S 9W/08 2P).
3. *E1-optimized-2*: adapted light source developed by Philips (details unknown with experimenters).

Light intensity (the 3 light sources were illuminated to the same lux level) :

1. 20 lux (often recommended for commercial poultry farming)
2. 40 lux (more close to behavioural needs)

Breed:

1. Lohman Selected Leghorn (LSL)
2. Lohman Brown (LB)

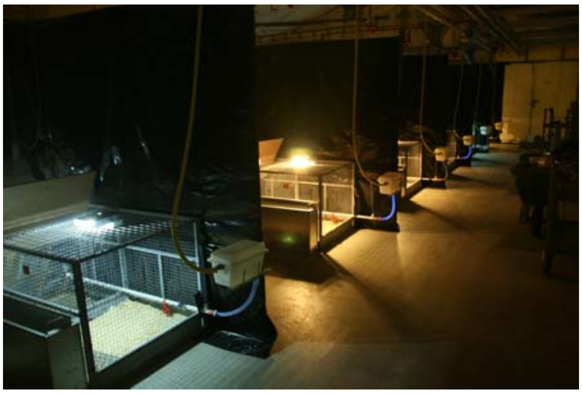


Figure 3. Experimental set-up Experiment 1: overview (left), E1-optimized-2 light (right)

2.2.2 Experiment 2

Experiment 2 was also done in the rearing period only. A total of 240 LSL and 240 LB hens were housed in the same two compartments as for experiment 1. Now each compartment was divided into 12 subcompartments. Each subcompartment consisted of 2 pens, in which one light source and the two breeds of laying hens were tested. Different lux levels were used to reach the same brightness of the light sources as perceived by the hens, with 40 lux for standard lighting as a reference. As for experiment 1, hens were housed in groups of 10 (48 pens in total). Compared to experiment 1, additional fences with black plastic were placed to prevent mingling of light between subcompartments.
Groups of hens were originally assigned to 1 of 12 treatments, according to a 6 (light source) x 2 (breed) factorial arrangement. However, it appeared during the experiment that light emission of some

light sources did not fully meet the set requirements. Other characteristics, on the basis of UV-A output, were therefore used for statistical analysis. The factorial setup therefore changed into a 3 (light source) x 2 arrangement.
Light source (code in italics):

1. *E2-Standard*: white light (Master PL-S 830/4P; 7 W); UV-A output: 0 to 7.5 (unit unknown with experimenters); 8 replicates.
2. *E2-optimized-1*: adapted light source developed by Philips; UV-A output 7.5 to 13 (details and unit unknown with experimenters); 34 replicates
3. *E2-optimized--2*: adapted light source developed by Philips; UV-A output 13 to 20 (details and unit unknown with experimenters); 6 replicates

Breed:

1. Lohman Selected Leghorn (LSL)
2. Lohman Brown (LB)


Figure 4. Experimental set-up Experiment 2: E2-standard light (left), adapted light source (right)

2.2.3 Experiment 3

A total of 270 LSL and 270 LB hens was studied until the age of 50 weeks. They were housed in 3 identical climate-controlled rooms. Each room consisted of 6 pens. These pens were stepwise enlarged in size according to age of the birds: 1 m2 between 0 and 4 weeks, 1.25 m2 between 4 and 7 weeks, 2 m2 between 7 and 17 weeks, and 3 m2 from 17 weeks of age onwards. Accordingly, the number of feed troughs also increased, from 1 between 0 and 7 weeks, 2 between 7-17 weeks, to 3 from 17 weeks onwards.
To stimulate feather pecking behaviour, substrate was not provided at the start of the experiment and floors were fully slatted. Moreover, group size was enhanced compared to experiments 1 and 2, to 30 hens per pen. However, due to an outbreak of severe feather pecking and cannibalism in LSL hens around 4 to 5 weeks of age, litter was provided at 6 weeks of age (mortality at the end of rearing: 8.5%). At that point, feather pecking among LB was much less, and litter was provided at 14 weeks of age (mortality at the end of rearing: 4.4%).

The groups of hens were allotted to 1 of 6 treatments, according to a 3 (light source) x 2 (breed) factorial design. In each room, all combinations were present, and each treatment had 3 replicates. Brightness of the light sources was standardized, with 40 lux for standard lighting as reference:
Light source (code in italics):

1. *E3-Standard*: white light (Master PL-S 830/4P; 7 W).
2. *E3-optimized-1*: adapted light source developed by Philips (code: green; details unknown with experimenters)
3. *E3-optimized-2*: adapted light source developed by Philips (code: red; details unknown with experimenters).

Breed:

1. Lohman Selected Leghorn (LSL)
2. Lohman Brown (LB)


Figure 5. Experimental set-up Experiment 3: E2-standard light (left), E3-optimized-1 light (right)

2.3 Observations

2.3.1 Pecking and general behaviour

To evaluate the effect of lighting conditions, pecking behaviour and general behaviour were observed every 4 weeks in the rearing period, i.e. at 4 (or 5), 8, 12 and 16 weeks of age. Additionally, in the laying period observations were done at 24, 32, 40 and 48 weeks of age (experiment 3). In an observation week, the behaviour of the hens was observed in the home pen. Observations were always performed between 08:30 a.m. and 05:00 p.m., by either two (experiment 3) or 3 observers (experiment 1 and 2). Observations were carried out on two days per test week, usually on Tuesday and Thursday. On one day, the behaviour of the hens in all pens was noted 8 times (in total 16 times per pen in one observation week). The occurrence of pecking behaviour (see Table 1; ethogram) was determined through one-minute scan samplings, following adaptation periods of one minute. Pecking behaviour was either scored as seen or not seen, independent of the number of animals engaged in the behaviour. Subsequently, at the end of the one-minute observations, general time budgets of various other behaviours was noted, by counting the number of hens performing a certain behaviour (see Table 1; ethogram).

Table 1. The ethogram used for observation of behaviour in the home pen

Label	Description
Pecking behaviours	
Gentle feather pecking	Mild or gentle pecking at feathers of other hens, generally performed in multiple bouts, no removal of feathers. No reaction of recipient.
Severe feather pecking	Severe or forceful pecking on or vigorous pulling the feathers of other hens. This may be single pecks or pulls. Can result in wounding the other bird. Often with reaction of recipient.
Aggressive pecking	Forceful pecks, directed at head or neck region.
Ground or litter pecking	Pecking at the floor or litter.
Other behaviours	
Walking	Walking, running, jumping or flying.
Scratching	Ground scratching, head usually in a lower position than the rump.
Eating and drinking	Eating from food trough or drinking from nipple drinkers/cups.
Resting	Sitting or standing inactive (no movement of the legs), perching.
Preening	Comfort behaviour: autopecking, nibbling, stroking, combing, head rubbing.
Dustbathing	Comfort behaviour: laying down on the floor or in substrate and trying to work dust or other loose material into the feathers.

2.3.2 Responses to human presence and novelty

As feather pecking is suggested to be associated with fearfulness, simple behavioural tests were done to assess fear for humans and general fear. Fear for humans was assessed by a human approach test. This test was performed three times in experiment 1 (at 5, 8 and 16 weeks of age) and once in experiments 2 (at 5 weeks of age) and 3 (at 15 weeks of age). From a distance of 1.5 meter, an experimenter walked straight forward to a pen, en then stood still at a distance of 0.5 meter from the front of the pen. Each pen was virtually divided in two equal sections: a back and a front section. The experimenter then noted the latency time for five hens to approach the experimenter by entering the front section of the pen. The test lasted maximally 2 minutes.
General fear was assessed in experiments 2 and 3 by introducing unfamiliar or novel objects into the pens (experiment 2: at 15 weeks; experiment 3: at 15 and 44 weeks). The novel objects were, respectively, a bottle of shampoo in experiment 2, and a piece of white paper (15 weeks) and a coloured stick (44 weeks) in experiment 3. Both objects were placed in the front section of the pens. In experiment 2, the latency time for the first hen to enter the front section of the pen was determined. In experiment 3, it was determined when the piece of paper was first pecked at. Again, maximum time of the test was set on 2 minutes. For the test with the coloured stick, during 2 minutes the number of hens within henlength of the stick was noted every 30 seconds (expressed in % of number of hens in a pen; cummulative score).

2.3.3 Plumage and skin condition scores

Plumage and skin condition were evaluated to assess the extent of problems associated with feather pecking. Damage to the feathers and skin of hens was assessed by a method slightly adapted from Bilcik and Keeling (1999). This method assesses feather and skin condition on 10 body parts. The scale was 0 (intact feathers) to 5 (completely bald) for feather condition, and 5 (intact skin; no injury) to 9 (severe wounds) for skin condition. Furthermore, an overall score was given for dirtiness: 0 (clean) to 3 (dirty). The condition scores were obtained at 6, 9, 13 and 17 weeks of age in experiments 1 and 2, and at 8 (only LSL hens) and 17 and 50 weeks of age in experiment 3. All hens were scored.

2.3.4 Body weight and uniformity

Development of the hens was determined by information on body gain and uniformity. The hens were weighed per pen at the start of all experiments and at 50 weeks of age in experiment 3. At 17 weeks of age, all hens were weighed individually. Information on individual weights was used to determine uniformity, ie the percentage of hens that was within 10% (+/- 10%) of average weight. The higher uniformity, the more hens are in the same stage of development, which is beneficial for efficient applying feeding and lighting schedules in the laying period.

2.3.5. Feed consumption and egg production

In experiment 3, feed consumption was recorded every 4 weeks, and egg production weekly, from 20 weeks of age onwards. Feed consumption was determined by weighing feed and feed troughs every 4 weeks, on a fixed day of the week. Eggs were collected each day, and floor eggs were kept separately. Once a week, also on a fixed week day, the number of eggs was counted to determine rate of lay and weight of the eggs. The proportion of second grade eggs and eggs with open breaks was determined. The information on egg weight and feed intake was also used to assess feed conversion, i.e. kg feed/kg egg.

2.4 Statistical analysis

Analyses were performed with Genstat 11.1 (2008, VSN International Ltd, GenStat Procedure Library Release PL19.1). Significance level was set at 0.05. Split-plot design were used for experiments 1 and 2, and a completely randomized block design was used for experiment 3.

In experiments 1 and 3, continuous data, e.g. responses to novel object, body weight, feed intake, egg weight, were analyzed with analysis of variance (ANOVA). In experiment 2, continuous data were analyzed by regression analysis (linear mixed model REML, fits a variance-components model by residual (or restricted) maximum likelihood). For determining differences between light sources and interactive effects the procedures PAIRTEST (performs t-tests for pairwise differences) en PPAIR (displays results of t-tests for pairwise differences) were used.

Percentages (close to 0), e.g for behaviours, mortality, floor eggs, second grade eggs, were analyzed with an IRREML procedure, which fits a deviance-components model by residual (or restricted) maximum likelihood). For determining differences between light sources and interactive effects the procedures RPAIR en PPAIR were used. RPAIR gives t-tests for all pairwise differences of means from a regression or GLM and PPAIR displays results of t-tests for pairwise differences.

Plumage and skin condition scores were analyzed by the threshold model of McCullagh or by logistic regression when the exterior scores were unequally divided.

3 Results

Behavioural activity time budgets and other characteristics often varied substantially between the two breeds. Therefore, it was decided to present the results separately for LSL and LB hens. In experiment 1, results for the two light intensities only occasionally differed significantly. Therefore, results for light intensity are not presented separately in tables or figures, but where applicable differences are mentioned.

3.1 Effect of optimization of lighting conditions on feather pecking behaviour

3.1.1 Gentle feather pecking

Rearing period
Results for gentle feather pecking in the rearing period are shown in Figure 6. Levels of gentle feather pecking with optimized lighting are presented in comparison with the results under standard lighting conditions (0-line). In the first experiment, at 5 weeks of age, the occurrence of gentle feather pecking was decreased with E1-optimized-1, compared to E1-standard lighting (significant main effect for the factor light source: $p<0.01$). In addition, but in the presence of both optimized light sources, gentle feather pecking was reduced at 8 weeks of age. This effect was only observed in Lohman Brown hens (significant interaction between the factors breed and light source: $p< 0.01$).
A decrease in gentle feather pecking, specifically for 8 weeks old LSL hens, was observed in experiment 2 with E2-optimized-2 lighting, when compared to E2-standard and E2-optimized-1 conditions (significant interaction between the factors breed and light source: $P<0.05$).
In experiment 3, high gentle feather pecking levels were observed. At 5 weeks of age, gentle feather pecking levels seemed lower in LSL hens with E3-optimized-1. The interaction between the factors light source and breed was, however, not significant.

Laying period
Figure 7 shows levels of gentle feather pecking during the laying period of experiment 3. At 24 weeks of age, gentle feather pecking was decreased in LSL hens and increased in LB hens with E3-optimized-1 light relative to the other two light sources. The interactive effect of light source and breed almost reached significance ($p=0.1$). At 40 weeks, gentle feather pecking tended to be lower with the two optimized light sources, but only in LSL hens (interaction between the factors breed and light source: $p=0.1$). Gentle pecking seemed to be decreased with the two adapted light sources at 48 weeks in LB hens, but effects were not near significance.

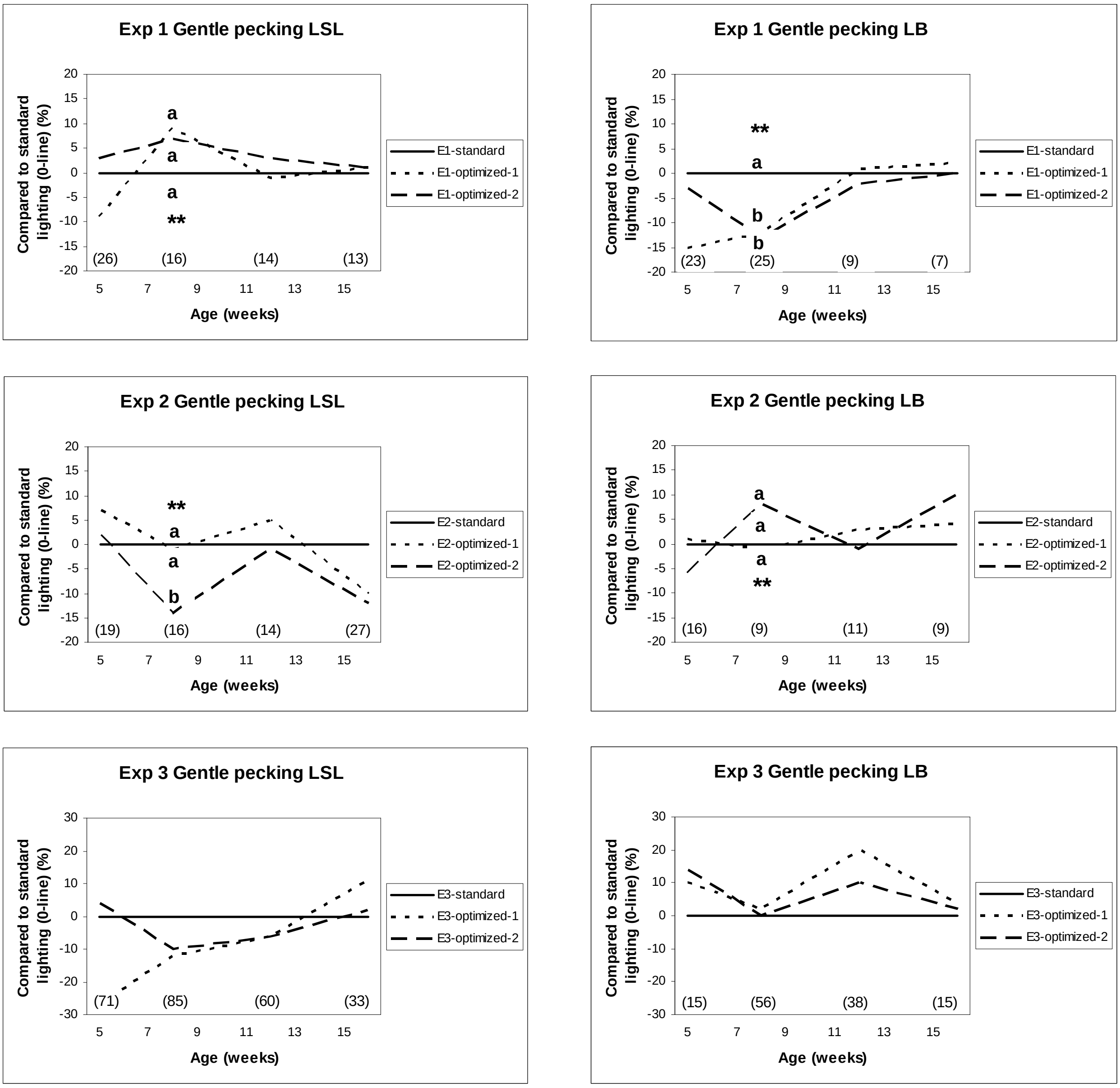
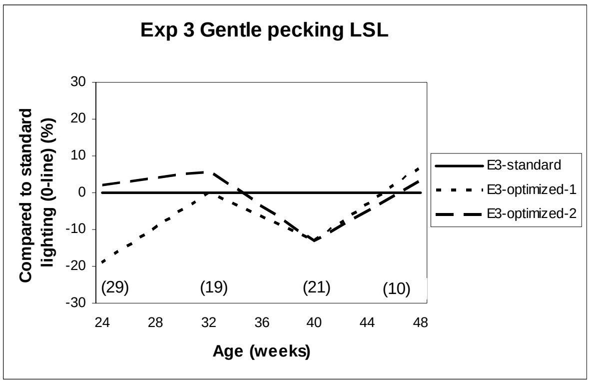


Figure 6. Gentle feather pecking in experiments 1 to 3: rearing period. The values between brackets represent absolute percentages with standard lighting. **When letters are presented, there is a (significant) interaction between the factors breed and light source; different letters present significant within breed-differences.



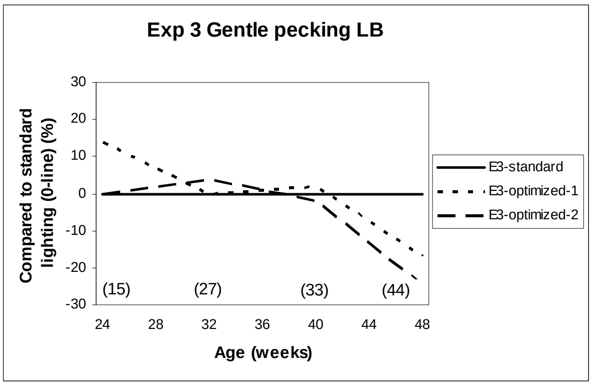


Figure 7. Gentle feather pecking in experiment 3: laying period. The values between brackets represent absolute percentages with standard lighting.

3.1.2 Severe feather pecking

Rearing period

In experiments 1 and 2, levels of severe feather pecking were rather low for all treatment groups, and no differences were observed between treatment groups (Figure 8).
Severe feather pecking in experiment 3, however, reached high levels at a rather young age, especially observed in LSL hens under standard lighting at 5 weeks of age (but no significant effect of light source). To control the outbreak of feather pecking among LSL hens, litter was provided at 6 weeks of age. At a later age, feather pecking also increased in Lohman Brown hens, and accordingly litter was provided at 14 weeks of age. As can be seen in Figure 8, optimized lighting conditions rather increased than suppressed severe feather pecking in Lohman Brown hens in the absence of litter, at 8 and 12 week of age (but no significant or nearly significant interactions).

Laying period

In accordance with the earlier observations of the hens in experiment 3 at 8 and 12 weeks of age, both optimized light sources apparently enhanced severe feather pecking in LB hens (at 40 and 48 weeks of age), but not in LSL hens (Figure 9). Differences between treatment groups did, however, not (nearly) reach significance, due to a high variation between replicates.

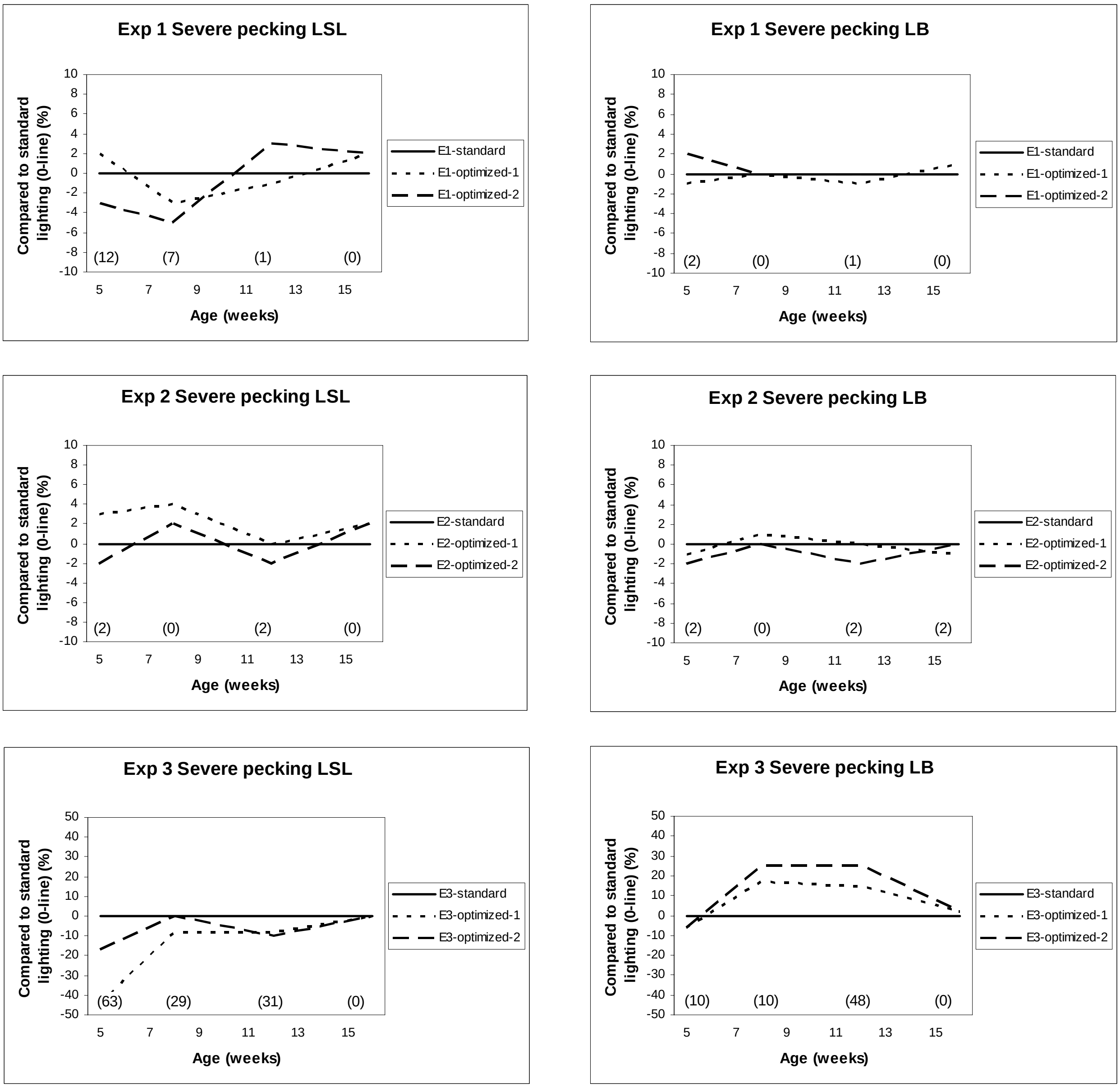


Figure 8. Severe feather pecking in experiments 1 to 3: rearing period. The values between brackets represent absolute percentages with standard lighting.

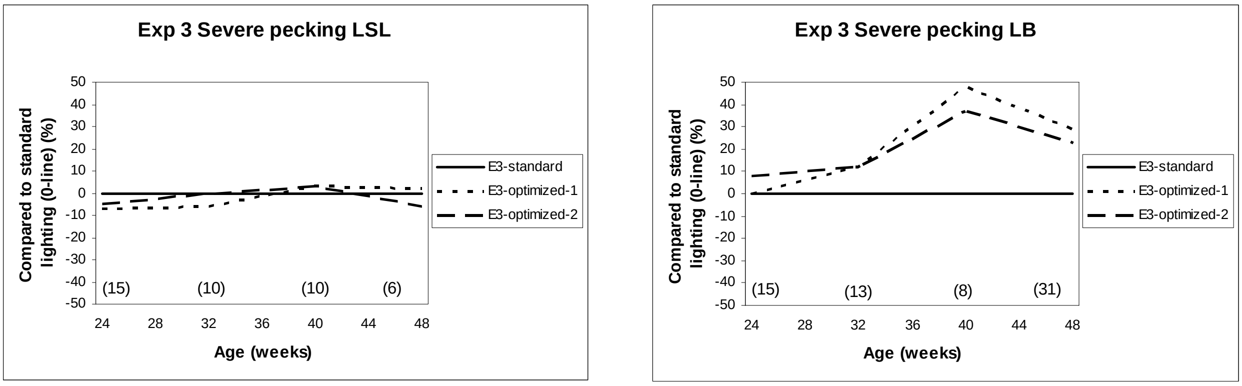


Figure 9. Severe feather pecking in experiment 3: laying period. The values between brackets represent absolute percentages with standard lighting.

3.1.3 Ground pecking

Rearing period

Figure 10 shows the results for ground pecking behaviour. In experiment 1, more ground pecking was observed with E1-optimized-2 at 5 weeks of age (83%), compared to the E1-standard and E1-optimized-1 light sources (respectively, 73 and 74%; significant main effect for the factor light source: $p<0.05$).

Experiment 2 showed significant effects of light source on ground pecking at several ages. At 8 weeks of age, ground pecking levels were generally higher with E2-optimized-2 (75%; 66 and 67%, for E2-standard lighting and E2-optimized-1, respectively; significant main effect for the factor light source: $p<0.05$). Compared to standard lighting, ground pecking was either more frequently (LB hens, 12 weeks) or less frequently observed (LSL hens, 16 weeks) under E2-optimized-2 lighting conditions (significant interactions between the factors breed and light source: $p<0.05$)

In experiment 3, ground pecking was stimulated by provision of litter from 6 weeks of age onwards in LSL, and from 14 weeks onwards in LB hens. At 12 weeks of age, LSL hens appeared to have more pecks directed to the litter with both optimized light sources, but the increases were not significant. Results for LB hens are not shown in Figure 10, as there was only one observation period, ie at 16 weeks of age. Ground pecking levels did not differ for LB hens at this age: 90, 85 and 88%, for E3-standard, E3-optimized-1, and E3-optimized-2, respectively.

Laying period

At 32 weeks of age, but not at the other ages and only observed with LB hens, ground pecking was increased with E3-optimized-1 (Figure 11; significant interaction between the factors breed and light source: $p=0.05$).

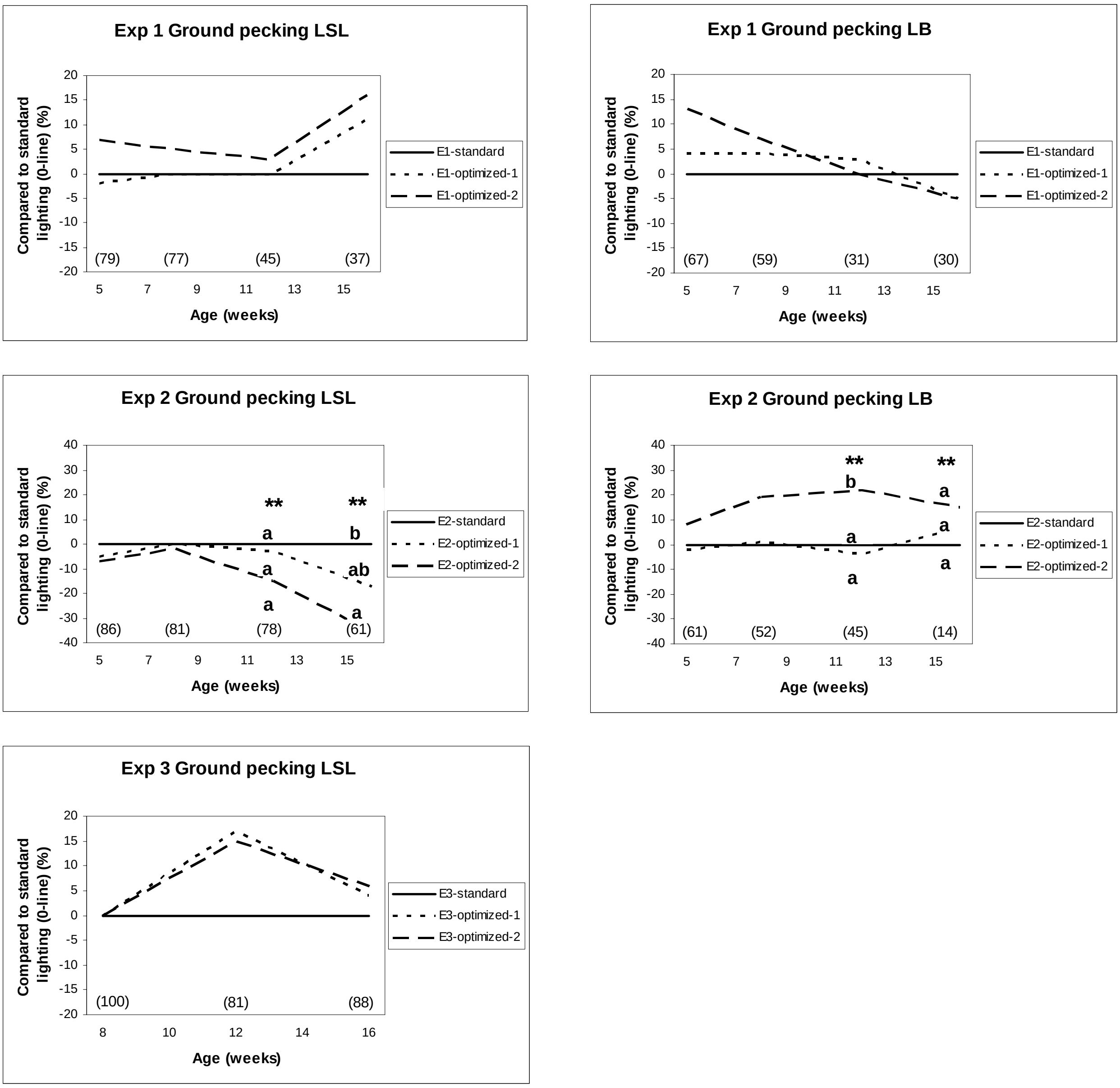


Figure 10. Ground pecking in experiments 1 to 3: rearing period. The values between brackets represent absolute percentages with standard lighting. **When letters are presented, there is a (significant) interaction between the factors breed and light source; different letters present significant within breed-differences.

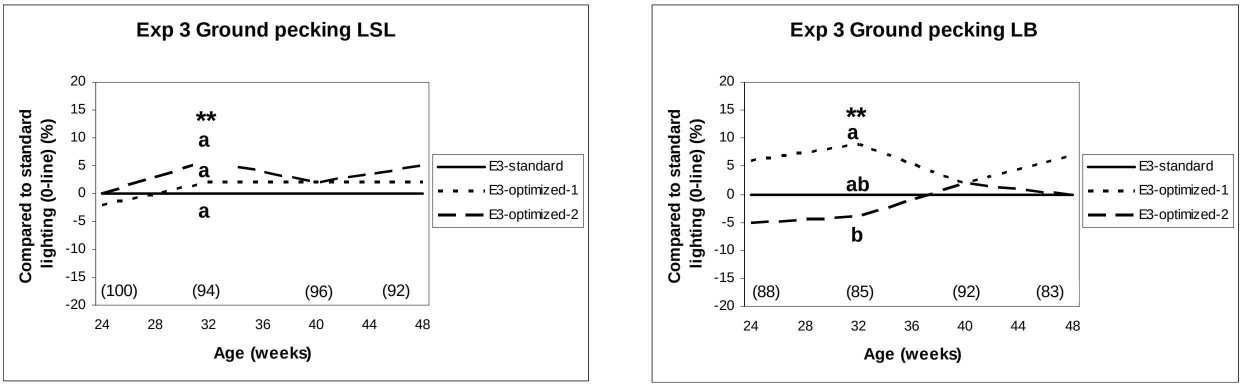


Figure 11. Ground pecking in experiment 3: laying period. The values between brackets represent absolute percentages with standard lighting. **When letters are presented, there is a (significant) interaction between the factors breed and light source; different letters present significant within breed-differences.

3.2 Effect of optimization of light on general behaviour

Very often, time spent in various other behaviours than those related to pecking, did not differ between treatment groups in the 3 experiments.

Rearing period

For resting and comfort behaviours, but never for walking, scratching and eating/drinking behaviours, some significant differences were found between treatment groups at specific ages. These are mentioned here.

In experiment 1, with E1-optimized-2, at 12 weeks of age more resting behaviour was observed at 20 lux (56%) compared to 40 lux (46%) (significant interaction between factors light source and light intensity: $p<0.05$).

In experiment 2, comfort behaviour was increased with E2-optimized-2 at two ages. At 8 weeks of age, more dustbathing was observed (1.4%), compared to the other two light sources (both 0.7%) (significant main effect for the factor light source: $p<0.01$). At 12 weeks of age, hens housed with E2-optimized-2 showed more preening (13%), and the main effect for light source tended to be signicant ($p=0.1$) (standard: 8%; E2-optimized-1: 6%).

In experiment 3, at 5 weeks of age, hens showed more comfort (preening) behaviour with both optimized light sources (E3-optimized-1: 4.4% ; E3-optimized-2: 4.6%) compared to E3-standard lighting (2.8%) (significant main effect for the factor light source: $p<0.05$). A similar effect (main effect light source: $p<0.05$) was observed at 16 weeks of age, but then an increase in preening was only seen in the presence of E3-optimized-1.

Laying period

General behaviour was not affected by light source.

3.3 Effect of optimization of light on fear for humans and general fear

Results are shown in Table 2 for both rearing (experiments 1 to 3) and laying periods (experiment 3). At 5 weeks of age in experiment 1, LB hens took longer to enter the front part of the cage in human presence with E1-standard lighting compared to E1-optimized-1 lighting.

Introduction of a novel object (bottle) in experiment 2 showed that it lasted longer for LSL hens to approach the object with E2-standard lighting compared to E2-optimized-2.

Findings in experiment 3 were comparable with those in experiment 2: hens with standard lighting generally tended to have a longer latency to peck at the novel object (piece of paper), compared to E3-optimized-2. At 44 weeks, the percentage of hens within henlength of a coloured stick did not differ between treatments.

Table 2. Behavioural responses to the human approach and novel object tests

	LSL				LB			
Human approach (latency to enter front part cage (s))	**Exp 1[1] 5 wk**	**Exp 2 5 wk**	**Exp 3 15 wk**		**Exp 1[1] 5 wk**	**Exp 2 5 wk**	**Exp 3 15 wk**	
Standard	*39 a*	61	0		*119 a*	120	2.7	
Optimized-1	*68 a*	72	0		*73 b*	111	0	
Optimized-2	*64 a*	63	0		*92 ab*	105	0	
Novel object (approach or contact latency) (s); (Exp. 3, 44 weeks: hens within hen-length (%))	**Exp 1**	**Exp 2[2] 15 wk**	**Exp3[3]**		**Exp 1**	**Exp 2[2] 15 wk**	**Exp3[3]**	
			15 wk	**44 wk**			**15 wk**	**44 wk**
Standard	*	*116 a*	67	4	*	*92 a*	107	10
Optimized-1	*	*81 ab*	40	12	*	*108 a*	128	8
Optimized-2	*	*67 b*	35	4	*	*120 a*	77	13

When letters are presented, there is a (significant) interaction between the factors breed and light source; different letters present significant within breed-differences.

[1]Exp. 1. Data only presented for the first human approach test at 5 weeks of age: tendency for an interaction for the factors breed and light source ($p<0.08$). No differences found at 8 and 16 weeks of age (data not presented).

[2]Exp. 2, novel object test at 15 weeks of age, significant interaction for the factors breed and light source ($p< 0.05$).

[3]Exp. 3, novel object test at 15 weeks of age, tendency for a main effect for the factor light source ($p=0.1$)

3.4 Effect of optimization of light on plumage and skin condition

The three experiments showed that feather damage predominantly occurred for the tail, back and wing feathers. Accordingly, condition scores for these body regions are presented in tables 3, 4 and 5, respectively.
In experiments 1 and 2, plumage condition was rather good, and most condition scores were maximally 1. Minor damages to the back feathers seemed predominantly related to optimized lighting conditions in experiments 1 and 2 (Table 4). Damage to the wing feathers was either somewhat higher (experiment 1 for E1-optimized-2) or lower (experiment 2), with optimized lighting compared to standard lighting.
By far, the worst feather condition was found in experiment 3, and average feather condition scores of more than 1 are presented in the tables. Due to the outbreak of severe feather pecking in LSL hens, an additional exterior score was obtained for these hens at 6 weeks of age. At this age, feather damage of the tails of LSL hens was severe, but no significant contrasts were seen between light sources. At 17 weeks of age, LB hens generally showed more damage of the back feathers than LSL hens, but effects of light source were not significant. However, the difference between breeds was much more pronounced at 50 weeks of age and also dependant on light source: tail and back feathers of LB hens were severely damaged with optimized lighting conditions.

Table 3. Damage to the tail feathers

Tail	**LSL**					**LB**				
Exp 1	**6 wk**	**9 wk**	**13 wk**	**17 wk**	**50 wk**	**6 wk**	**9 wk**	**13 wk**	**17 wk**	**50 wk**
Standard	11.3	0	0	1.3	*	0	0	0	0	*
Optimized-1	5.0	0	1.4	0	*	0	2.5	0	0	*
Optimized-2	8.8	0	0	1.3	*	0	0	0	1.3	*
Exp 2										
Standard	0	0	2.5	14.2	*	0	0	0	2.5	*
Optimized-1	0	3.9	7.1	12.0	*	0	0	0	1.8	*
Optimized-2	0	0	10	20.0	*	0	0	0	0	*
Exp 3[1]										
Standard	30.7	*	*	0	*69.7 a*	*	*	*	7.5	*45.1 a*
Optimized-1	23.5	*	*	5.9	*45.4 a*	*	*	*	2.4	*91.4 b*
Optimized-2	56.2	*	*	11.5	*69.0 a*	*	*	*	1.3	*82.0 ab*

Exp. 1 Incidence of score 1 (%)
Exp. 2 Incidence of score 1 or more (%)
Exp. 3 Incidence of score more than 1 (%)
When letters are presented, there is a significant interaction between the factors breed and light source; different letters present significant within breed-differences.
[1]Exp. 3, at 50 weeks of age, significant interaction for the factors breed and light source (p<0.01)

Table 4. Damage to the back feathers

Back	**LSL**					**LB**				
Exp 1[1]	**6 wk**	**9 wk**	**13 wk**	**17 wk**	**50 wk**	**6 wk**	**9 wk**	**13 wk**	**17 wk**	**50 wk**
Standard	2.5	*6.3 a*	0	0	*	5.5	*11.3a*	5	1.3	*
Optimized-1	0	*0 a*	2.8	8.3	*	3.8	*23.8b*	15	8.8	*
Optimized-2	0	*0 a*	0	0	*	0	*24.1b*	12.6	1.3	*
Exp 2 [2]										
Standard	0	0	0	*2.8 a*	*	0	2.5	0	*7.5 a*	
Optimized-1	0	0	0	*2.2 a*	*	1.2	2.4	2.4	*6.9 a*	
Optimized-2	0	0	0	*16.7 b*	*	0	0	0	*0 a*	
Exp 3[3]										
Standard	0	*	*	0	*33.3 a*	*	*	*	1.2	*38.2 a*
Optimized-1	0	*	*	0	*16.7 a*	*	*	*	5.7	*89 b*
Optimized-2	1.2	*	*	0	*63.1 a*	*	*	*	14.3	*82 ab*

Exp. 1 Incidence of score 1 (%)
Exp. 2 Incidence of score 1 or more (%)
Exp. 3 Incidence of score more than 1 (%)
When letters are presented, there is a significant interaction between the factors breed and light source; different letters present significant within breed-differences.
[1]Exp. 1, at 9 weeks of age, significant interaction for the factors breed and light source (p<0.05)
[2]Exp. 2, at 17 weeks of age, significant interaction for the factors breed and light source (p<0.05)
[3]Exp. 3, at 50 weeks of age, tendency for an interaction for the factors breed and light source (p=0.09)

Table 5. Damage to the wing feathers

Wing	LSL					LB				
Exp 1[1]	**6 wk**	**9 wk**	**13 wk**	**17 wk**	**50 wk**	**6 wk**	**9 wk**	**13 wk**	**17 wk**	**50 wk**
Standard	17.5	2.5	0	1.3	*	6.3	0	2.5	0	*
Optimized-1	14.3	1.3	0	13.5	*	10	0	7.5	1.3	*
Optimized-2	12.5	6.3	0	24.8	*	10.2	2.5	1.3	6.3	*
Exp 2[2]										
Standard	0	0	5	*5.6 a*	*	0	2.5	2.5	*0*	
Optimized-1	0	4.1	0	*0 b*	*	0	0	2.4	*1.3*	
Optimized-2	0	3.3	0	*0 b*	*	0	0	6.7	*3.7*	
Exp 3										
Standard	0	*	*	0	2.8	*	*	*	0	32.4
Optimized-1	1.2	*	*	0	3.7	*	*	*	0	32.0
Optimized-2	0	*	*	0	3.7	*	*	*	0	30.2

Exp. 1 Incidence of score 1 (%)
Exp. 2 Incidence of score 1 or more (%)
Exp. 3 Incidence of score more than 1 (%)

When letters are presented, there is a significant interaction between the factors breed and light source; different letters present significant within breed-differences.

[1]Exp. 1, at 17 weeks of age, significant main effect for the factor light source ($p<0.001$)

[2]Exp. 2, at 17 weeks of age, significant interaction for the factors breed and light source ($p<0.001$)

3.5 Effect of optimization of light on body weight and uniformity

Data are presented in Table 6. In experiment 1, no differences in weight and uniformity were observed between the treatment groups at the end of the rearing period (17 weeks of age).
In experiment 2, hens were more uniform in weight at 17 weeks of age with E2-optimized-1, compared to E2-optimized-2 (significant main effect for the factor light source: $p<0.01$).
In experiment 3, with E3-optimized-2 lighting conditions, LB hens were less uniform in weight at 17 weeks of age, an effect not seen with LSL hens (significant interaction for the factors breed and light source: $p<0.05$).

Table 6. Body weight and uniformity

	LSL				LB			
Weight (g)	**Exp 1**	**Exp 2**	**Exp 3**		**Exp 1**	**Exp 2**	**Exp 3**	
			17	**50**			**17**	**50**
Standard	1290	1113	1267	1817	1609	1329	1562	2131
Optimized-1	1288	1109	1250	1879	1555	1341	1565	2119
Optimized-2	1299	1051	1269	1757	1583	1278	1536	2095
Uniformity (%)	**Exp 1**	**Exp 2**[1]	**Exp 3**[2]		**Exp 1**	**Exp 2**[1]	**Exp 3**[2]	
Standard	84	80.3	*82 a*		89	62.5	*83 a*	
Optimized-1	89	82.5	*84 a*		83	82.2	*84 a*	
Optimized-2	87	72.2	*87 a*		86	60.0	*63 b*	

When letters are presented, there is a significant interaction between the factors breed and light source; different letters present significant within breed-differences.

[1]Exp. 2, Uniformity: significant main effect for the factor light source ($p<0.01$)

[2]Exp. 3, Uniformity: significant interaction for the factors breed and light source ($p<0.05$).

3.6 Effect of optimization of light on feed intake and egg production

Table 7 shows feed intake and egg production traits for the period between 20 and 50 weeks of age in experiment 3.
With E3-optimized-1 light, feed efficiency of LB hens (kg feed per kg egg) was worse compared to the other two light sources (interaction between the factors breed and light source: p<0.05). With E3-optimized-2 lighting, more eggs were found on the floor and feed intake (gram/hen/day) was lowest (main effect for the factor light source, respectively, p<0.05 and p<0.10).

Table 7. Feed intake and egg production traits between 20 and 50 weeks of age in experiment 3

Results 20-50 weeks of age	**LSL**			**LB**		
	Standard	**Optimized-1**	**Optimized-2**	**Standard**	**Optimized-1**	**Optimized-2**
Number of eggs per average hen	184.2	188.7	185.3	171.6	168.1	165.1
Percentage of lay	90.7	93.0	91.3	84.5	82.8	81.4
Egg weight (g)	61.7	62.2	62.1	63.2	63.3	62.9
Egg mass (g/h/d)	56.0	57.9	56.7	53.4	52.4	51.2
Feed intake (g/h/d) [1]	122.8	124.5	120.4	117.1	123.2	114.5
Kg feed/kg egg[2]	*2.19 a*	*2.15 a*	*2.12 a*	*2.20a*	*2.35b*	*2.24a*
Mortality (%)	18.9	14.8	26.7	12.5	8.2	31.4
Number of eggs per hen housed	168.8	175.2	163.7	160.7	163.9	148.0
Kg egg per hen housed	10.41	10.91	10.20	10.16	10.37	9.31
Feed intake (kg/hen housed)	22.85	23.43	21.65	22.23	24.38	20.78
Floor eggs (%)[1]	0.1	0.1	0.2	2.6	3.4	8.3
Open breaks (%)	0.1	0.2	0.3	1.1	0.6	1.2
Second grade eggs (%)	10.0	9.6	9.8	4.3	4.2	4.4

When letters are presented, there is a significant interaction between the factors breed and light source; different letters present significant within breed-differences.

[1]Feed intake, floor eggs (%): (significant) main effect for the factor light source, respectively, p<0.10 and p<0.05.

[2]Kg feed/kg egg: interaction for the factors breed and light source: p<0.10

4 Discussion and conclusions

Properties of light sources are not known in detail with experimenters.

The research questions addressed in the introduction are being answered and discussed here:

1) Can UV-A supplementation reduce gentle and severe feather pecking in laying hens?

In experiments 1 and 2, feather pecking behaviour mainly consisted of gentle feather pecking and almost no severe feather pecking. The first 2 experiments, however, only comprised the rearing period, and severe pecking may have occurred at a later age in the laying period. Gentle feather may grade into severe pecking at a later age (Savory, 1995). In those cases when gentle feather pecking properties significantly differed from standard lighting, gentle pecking levels were always lower. This points to a beneficial effect of adapted light conditions. In experiment 1, the positive effect was seen with E1-optimized-1 lighting (combination white light and Blacklight Blue) at two ages, i.e. 5 and 8 weeks (Figure 6). At the latter age, the effect was only observed with LB hens. E1-optimized-2 lighting had a similar positive effect at 8 weeks of age. In the second experiment, LSL hens performed less gentle feather pecking with E2-optimized-2 lighting, at 8 weeks of age. Plumage condition of the hens was rather good. The slight damages observed for tails and wings might also be due to more abrasion caused to more activity. However, our behavioural observations did not substantiate that.

The two breeds at times reacted differently to the light sources, as mentioned above. This may be due to differences in colour and reflective properties of the feathers, possibly in combination with the behavioural traits (genetic predisposition) of each breed. Generally, LSL hens performed more feather pecking than LB hens. In experiment 3, an outbreak of severe feather pecking occurred among very young (4-5 weeks of age) LSL hens. Damage to the tails of LSL hens was severe (Table 3). At that age, gentle and severe pecking reached the highest levels with standard lighting, especially when compared with E3-optimized-1. Measures were taken to reduce feather pecking levels in LSL hens, i.e provision of litter at 6 weeks of age. Subsequently, feather pecking levels were much reduced. A contrast between light sources became visible again at 24 weeks of age (E3-optimized-1) and at 40 weeks (both optimized light sources), with adapted light sources having suppressed levels of gentle feather pecking (near significance).

In experiment 3, LB hens more gradually developed high levels of feather pecking. It was decided to provide litter at 14 weeks. At the two observation periods prior to litter provision, feather pecking levels were rather increased than suppressed with optimized lighting conditions (Figure 8). Following litter provision, severe feather pecking was much reduced, but this was seen for all light sources. Despite this reduction, back feather damage at 17 weeks still seemed (not significant) more pronounced with E3-optimized-2 light (Table 4). Around 40 weeks, severe feather pecking seemed to increase again with the adapted light sources (Figure 9). This resulted in a severely damaged tail and back feathers, as monitored at the end of the experiment, at 50 weeks of age.

Although the latter differences were not significant, we speculate that the presence of litter is important in a beneficial effect of light. When lighting conditions are improved, leading to a better vision, but the environment lacks stimuli to peck at such as floor substrate, hens may theoretically get more interest in each others feathers. Our results may thus indicate that it is beneficial to improve vision of hens, but in combination with (suitable) environmental enrichment, e.g. substrate on the floor. Neither light nor litter as single factors can fully eliminate feather pecking. Currently, research takes place investigating the effect of early provision of litter (1 versus 21 days of age) and two types of litter (sand or woodshavings) (De Jong et al., experiment still running, confidential).
Results are not statistically analyzed yet. So far, feather pecking levels are low. The impression is that at 40 weeks of age, feather pecking levels were somewhat lower when woodshavings were provided on day 1. Differences in ground pecking seem not to exist after 4 weeks of age. The reason for not seeing profound differences in feather pecking behaviour, besides low general levels not allowing contrasts, may be the relatively young age of litter provision. Stimulation by litter provision at 21 days still seems early enough for hens to learn normal pecking behaviour. In our research, litter provision not earlier than at 6 weeks of age, had no negative consequences for feather pecking behaviour of LSL hens in the long term. However, 14 weeks seems too late, as severe pecking in LB could only temporarily be reduced by provision of litter.

Interestingly, no effects of light intensity, i.e. 20 versus 40 lux, on feather pecking levels were found (experiment 1). As stated before, higher light intensities, i.e. between 50 and 100 lux, are beneficial for the welfare of hens, as long as it does not provoke more feather pecking. We did observe that resting behaviour with 20 lux may increase compared to 40 lux. This may indicate that 20 lux is perceived as dimmer by the birds, and that the birds may be less invited to employ active behaviours at the lower light intensity.

2) Can UV-A supplementation increase desired types of pecking, such as ground pecking?

In each experiment, a beneficial effect was observed of (at least) one of the adapted light sources on ground pecking levels. Ground pecking for foraging and feeding or during dustbathing represents the normal pecking behaviour of chickens. In experiment 1, most ground pecking occurred with E1-optimized-2 lighting at 5 weeks of age (Figure 10). In experiment 2, the lighting conditions with the highest UV-A output (E2-optimized-2) stimulated more ground pecking in LB hens at two ages (8 and 12 weeks of age). LSL hens, on the other hand, displayed less ground pecking behaviour with E2-optimized-2 at 16 weeks. At this timepoint, however, pecking levels generally seemed to be decreased.
In experiment 3, LSL hens appeared (not significant) to have more pecks directed to the litter with both optimized light sources, but only at 12 weeks of age. In the laying period, LB hens pecked more often to the litter with E3-optimized-1 light (Figure 11). This was only seen at 32 weeks of age, but not at 40 and 48 weeks of age when severe feather in LB hens was found to be increased again. This may represent a redirection of pecking behaviour, possible caused by the late provision of litter.

In experiments 2 and 3 highest levels of comfort behaviours were observed with some type of optimized lighting. In experiment 2, more dustbathing (at 8 weeks of age) and preening behaviours (at 12 weeks of age) were observed with E2-optimized- 2 lighting. In experiment 3, more preening was either associated with both optimized light sources (at the age of 5 weeks) or with E3-optimized-1 (at the age of 16 weeks). An increase in comfort behaviour may be regarded as positive for the welfare of the hen.

3) Can UV-A supplementation decrease fearfulness of the hens?

Fearfulness has also been associated with feather pecking, either being a cause or a consequence. In our experiments, simple tests were performed to assess fearfulness, i.e. general fearfulness and specific fearfulness for humans. The tests showed positive effect of adapted lighting conditions, for specific combinations of breed and age (Table 2). Under standard lighting conditions, it took longer for LB hens to come closer to a person (experiment 1, compared to E1-optimized-1), it lasted longer for LSL hens to approach an unfamiliar object (experiment 2, compared to E2-optimized-2), and for both breeds a longer latency was observed for the first peck at an unfamiliar object (experiment 3, compared to E3-optimized-2).

4) Are aspects of hen development and egg production affected by UV-A supplementation?

The results of experiments 2 and 3 showed that adapted lighting conditions might result in a lower uniformity in weight at the end of the rearing period (Table 6). This is a disadvantage in commercial farming, as less hens are in the same stage of development. In experiment 2, this was observed for E2-optimized-2 lighting, despite the positive effects of this light source on gentle feather pecking, ground pecking and fear. It may be hypothesized that the relatively high UV-A output may have stimulated active behaviours, such as foraging behaviours. Our behavioural observations, however, could not substantiate this. In experiment 3, LB hens were less uniform in weight with E3-optimized-2 lighting conditions. This may be caused by feather pecking, as LB hens kept under E3-optimized-2 lighting conditions suffered a lot from this. Between 20 and 50 weeks of age, important production traits like egg numbers, rate of lay, egg weight, but also mortality, did not differ between treatment groups (Table 7). Egg production thus seems not to be much affected by UV-A supplementation. However, with E3-optimized-2 lighting more eggs were found on the floor and feed intake was lowest. The latter is in agreement with earlier findings of a suppressed feed intake with UV light (Lewis et al., 2000a). E3-optimized-1 lighting was associated with a reduced feed efficiency in LB hens.

5 Conclusions

The results of the three experiment indicate that with UV-A inclusion in light, gentle feather pecking at times can be reduced and ground pecking may be stimulated. This is possible at relatively high light intensities (around 40 lux), which is close to the desired light intensities by laying hens for their active behaviours. UV-A inclusion in light has fear-reducing properties. The most important egg production traits are not affected by UV-A inclusion, but uniformity in weight and proportion of eggs in nests may be at risk and require attention. In experiments 1 and 3, adapted light sources each had their specific (dis)advantages, and it is difficult to indicate which one is the most beneficial (Table 8). In experiment 2, the most promising light source was E2-optimized-2, which had the highest UV-A output.

Table 8. Overview of positive (+) and negative (-) effects of adapted light sources, as compared with standard white lighting.

Parameter	Experiment 1		Experiment 2		Experiment 3	
	Opt-1 White/ bla.blue	Opt-2	Opt-1 UV-A 7.5-13	Opt-2 UV-A 13-20	Opt-1 Code green	Opt-2 Code red
Ground pecking	0	+	0	+ LB	+LB (+LSL)	(+ LSL)
Gentle feather pecking	+	+ LB	0	+ LSL	- LB + LSL	+ LSL
Severe feather pecking	0	0	0	0	(- LB +LSL)	(- LB)
Major feather damage	0	0	0	0	- LB	(- LB)
Comfort behaviour	0	0	0	+	+	+
Fear for humans	+ LB	0	0	0	0	0
General fear	*	*	0	+ LSL	0	+
Uniformity	0	0	0	(-)	0	- LB
Floor eggs	*	*	*	*	0	-
Feed intake	*	*	*	*	0	-
Feed efficiency	*	*	*	*	- LB	0

When put between brackets, effects are apparent, but not statistically substantiated.

However, adapted lighting in itself will not exclude or reduce injurious feather pecking, as clearly shown in experiment 3: LB hens developed high levels of injurious pecking. Other factors, such as suitable litter, may determine whether the effects of adapted light are either beneficial or detrimental. LB hens were relatively long kept without litter, in an environment lacking stimuli, and this may have led to an undesirable situation in which improved vision may have caused more interest in each other feathers and thus more feather pecking. Injurious feather pecking in LSL hens, on the other hand, was initially high but was much reduced following litter provision at a relatively young age. However, positive effects of adapted light in the longer term were only seen for gentle pecking, while severe pecking was not affected.

In practice, litter management for loose housed hens varies a lot. Moreover, many hens are kept in cages, which have a relatively barren environment with very limited litter provision. LB hens are the predominant breed kept for commercial purposes. This specific combination may pose a risk for development of feather pecking, as we may conclude from our results. Optimized light sources are therefore not ready for marketing at this point, without knowing more about the interaction of light with other factors. We expect the most from rich substrates and feed which have high reflective properties. Adapted light by UV inclusion then may have its beneficial effect.

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