Plumage colour and feather pecking in laying hens, a chicken perspective?

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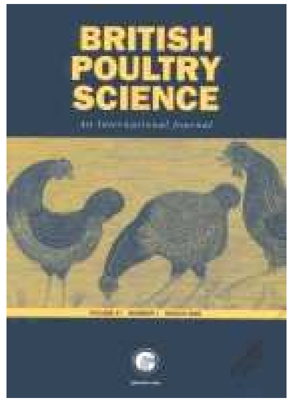

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Short title: PLUMAGE COLOUR AND FEATHER PECKING

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Abstract. 1. This study investigated whether feather damage due to feather pecking and bird behaviour were influenced by plumage colour in Oakham Blue laying hens (black, white, grey colour variants). The reflectance properties of feathers and spectral composition of light environments experienced by the hens were also examined.

2. Nine hundred and seventy nine birds were inspected and scored for feather damage; 10.5 h of video recordings were examined to record feather pecking and bird behaviour. Feathers and light environments were measured using a USB-2000 spectrometer and DH-2000-CAL-DTH lamp.

3. Oakham Blue birds with white plumage had less feather damage due to feather pecking than black or grey birds. There was more severe feather pecking in the mornings than in the afternoon. White birds feather pecked severely more than black or grey birds, although there were no other behavioural differences between plumage colours.

4. White feathers reflected at a higher intensity than black or grey feathers. However, black and grey feather spectra were relatively flat and the contribution of UV wavelengths to plumage reflection was proportionally greater than that for white feathers.

5. Light intensity inside a poultry house was 100 x (UW/cm^2/nm) less than on the range and there was low or no UV reflectance. Under the dim, artificial lights inside a poultry house, Oakham Blue hens with black and grey feathers may be less visible to conspecifics than white birds because their plumage reflects at a lower intensity. Furthermore, the lack of available UV light inside versus outside and the higher contribution of UV reflectance to black and grey plumage, may make black and grey birds appear more different inside the house than white birds. It is possible that this

novel/unusual appearance may make black or grey Oakham Blue hens more susceptible to feather pecking.

INTRODUCTION

Feather pecking is a type of abnormal behaviour in poultry that consists of pecking at, and or, pulling out the feathers of conspecifics (Savory, 1995). Feather pecking may result in poor quality plumage, patches of feather loss and damage to the skin. Feather pecking is a welfare problem because pulling out feathers causes pain (Gentle and Hunter, 1990), and damaged birds may be cannibalised (Allen and Perry, 1975). Feather pecking is also an economic problem; it can lead to lowered egg production (Johnsen *et al.,* 1998; El-Lethey *et al.,* 2000), and higher food consumption because birds with little feather cover have poor thermoregulation and consequently greater energy demands than unaffected birds (Leeson and Morrison, 1978; Tauson and Svensson, 1980; Tullett *et al.*, 1980; Peguri and Coon, 1993). Understanding the causal basis of feather pecking is a major priority for the egg-producing industry (Jones *et al.*, 2004; Rodenburg *et al.*, 2004).

Feather pecking is usually regarded as redirected foraging (Blokhuis, 1989; Blokhuis and van der Haar, 1989), or dust-bathing behaviour (Vestergaard *et al.*, 1993; Vestergaard and Lisborg, 1993). The redirection of pecking towards other birds is influenced by many management, environment, genetic and behavioural factors (Hughes and Duncan, 1972; Huber-Eicher and Audige, 1999; Green *et al.,* 2000; Nicol *et al.*, 2003; Sedlackova *et al.,* 2004). It is generally accepted that the development of feather pecking within a flock represents a multifactorial process (Jensen *et al.*, 2005).

Commercial laying producers frequently comment that white birds are better feathered than brown or black birds (personal communications). In experimental studies also, birds with white plumage frequently have less plumage damage due to feather pecking than pigmented birds (Ambrosen and Petersen, 1997; Savory *et al.,* 1999; Kjaer and Sørensen, 2002). The effects of plumage colour on variation in plumage damage due to feather pecking, has been difficult to quantify because different coloured birds are usually from a different strain and/or flock. Recently, Keeling *et al.,* (2004) found that in an F2 White leghorn and Red jungle fowl cross, victims of feather pecking were partly pre-disposed when the colour of their plumage was due to the expression of a wild recessive allele at a gene that controls plumage melanisation; pigmented birds ran a higher risk of being feather pecked and were more vulnerable to feather pecking when they were relatively more common than non-pigmented birds. However, the propensity to peck feathers was independent of the assailant's plumage genotype (cited in Keeling *et al.*, 2004)) and in a subsequent study on the same cross Jensen *et al.*, (2005), found few behavioural differences between feather pecking victims and non-victims.

The first aim of this study was to investigate plumage colouration effects on plumage damage due to feather pecking in three commercial flocks of Oakham Blue laying hens. The second aim was to determine whether the propensity to feather pecking or the behaviour of feather pecked victims and assailants varied with plumage colouration. Oakham Blue hens lay characteristic blue/green eggs, and there are three plumage colour morphs (white, black and grey). Because the birds within a single flock are of the same age and breed, and experience the same management and husbandry practices, **it was** possible to separate the effects of colour and strain/management/husbandry on feather pecking.

Vision is a dominant sense in domestic fowl, and they use plumage colour and pattern to gain information about conspecifics (see reviews in Espmark *et al.*, 2000). Changes to plumage appearance (for example, due to light environment or visual background (Savory and Mann, 1999)) or ratio of differently coloured birds in a flock (Keeling *et al.*, 2004) may also inhibit or stimulate feather pecking. Galliformes are behaviourally sensitive to UV radiation (Prescott and Wathes, 1999*b*; Jones *et al.*, 2001), and feathers of both traditional and modern breeds of domestic fowl reflect UVA light with an efficiency similar to that at longer wavelengths (Prescott and Wathes, 1999***a***). The artificial light provided in commercial poultry houses is usually at a low intensity and without UV radiation (Prescott and Wathes, 1999*a*)). The ability of domestic fowl to use their visual system to its full extent may be handicapped in this artificial light environment. For example, hens may find it difficult to discriminate between familiar and unfamiliar flock mates at low light intensities (D'Eath and Stone, 1999). Furthermore, limited UV and low light intensities might present the birds with a foraging environment they perceive to be inappropriate and cause them to redirect pecking to the feathers of their flock mates. This might be particularly important for free-range flocks which move between artificial and natural light environments. Thus, the third and final aim of this study was to investigate the spectral properties of white, black and grey Oakham Blue feathers, and the spectral properties of the typical light environments experienced by the Oakham Blue hens.

METHODS

Animals and housing

Three commercial free-range flocks of Oakham Blue laying hens were studied. The first flock (A, 4 200 hens) was at FAI farms Wytham, Oxfordshire, UK. The birds were housed in 4 mobile arks (126.84 m^2 each), with daily access to 1 ha of wood chip on which to range (09.00 h – dusk). During the day, birds were free to move between houses. Commercial grade layer mash was provided *ad libitum* in pan feeders (4.6 cm per hen) and water by nipple drinkers (146 per house). Lighting was supplied by natural light and Sollatek Lumina 12 V compact fluorescent bulbs (Tafelberg Marina Ltd) on a 15L:9D cycle (07.00 – 22.00 h). The houses also had skylights, which provided natural light. The nest boxes were open from 04.00 – 16.00 h each day.

The second (B, 2 590 hens), and third flocks (C, 3 000 hens) were at Dean's Foods Ltd, Walesby, Lincolnshire, UK. The birds were housed in static barns (~60% slat ~30% litter (chopped straw): 349.27 m^2), with daily access to 6 ha of grass, and gravel on which to range (09.30 h– dusk). Commercial grade layer mash was provided *ad libitum* in flat chain feeders (10 cm per hen) and water by bell drinkers (30 per house). Lighting was supplied by tungsten bulbs (60 W, various brands) on a 14L:10D cycle (06.30 – 20.30 h). The nest boxes were open from 04.30 – 19.30 h each day.

Feather score

Three hundred and fifteen birds from flock A (73 weeks old), 400 birds from flock B (25 weeks old) and 264 birds from flock C (68 weeks) were inspected for feather damage. A coordinate grid map of the houses and the range area and random numbers were used to select birds for inspection. If there was more than one bird at a coordinate location the observer used a clear sheet of A4 acetate with 5 cm^2 marked squares. The observer stood a few metres back and held up the acetate grid so that it covered most of the section, and selected the bird closest to the square indicated by a pre-determined random number. For all birds, the body was divided (Bilćik and Keeling, 1999) into 5 different regions: neck, back, rump, tail and wing. The neck, back and rump were scored on a 0 (best) to 4 (worst) scale adapted from Allen and Perry, (1975) (see Bright *et al.,* 2006). Slightly different criteria were used for scoring flight feathers (tail and wing primaries), because of the different types of feathers and damage. I did not attempt to score the underside of the neck or the breast as feather damage from these regions may be attributed to abrasion from the feeders and unrelated to damage from other birds (Bilćik and Keeling, 1999), see also Bright *et al.,* (2006) for more information on feather scoring method. Bird colour was classified as 'white', 'black' or 'grey'.

Feather pecking behaviour

For flock A, a camera (wide angle CCTV, B. Bundenburg Oxfordshire, UK) and video recorder (Sanyo TLS-4024P, Sanyo Electric Co., Ltd, Japan) with 12V battery (Yuasa battery Ltd, Swindon, UK) were set up in one of the 4 houses when the birds were between 69 and 72 weeks of age (three recordings from House 2, one recording from House 1). Video recordings (1-3 h) of the birds were collected in the mornings (05.00-12.00 h) or afternoon (13.00-20.00 h). A total of 5 h video was collected (from inside the houses only). For flock B, a camera and video recorder was set up at a random location along the eastern wall of the barn when the birds were 17, 25, 29 and 39 weeks of age. Video recordings (0.45-2 h) of the birds were collected in the morning (10.00-12.00 h) or in the afternoon (13.00-16.00 h). A total of 5.5 h of video tape was collected. No video recordings of flock C were collected.

From the video recordings, the number of severe and gentle pecks given by birds to conspecifics was determined. This was later converted to pecks/10 min/30 birds because approximately 30 birds within a video frame could be reliably watched for pecking at any one time. Bird colour was classified as 'white', 'black' or 'grey'.

Using the same videos, the behaviour and plumage colour of 'feather peckers' and feather peck 'receivers' at the time of a pecking incident (severe or gentle) was recorded. Only bouts of pecking between different pairs of birds were used.

Statistical analysis

The statistical software used was Minitab for Windows, Release 14 (MINITAB® Inc) General linear model (GLM) procedures were used to test for the effects of flock (A, B, C) and plumage colour (white, black, grey) on total, rump, tail and wing feather score (N = 979). To meet the assumptions of parametric tests, the total feather score data set was square-root transformed, the rump, tail and wing feather score data sets were $\log_{10}$ transformed. Flock was entered as a random factor and first in the model followed by plumage colour (nested in flock). Thus, effects due to flock were taken into account before calculating the *F*-ratio and associated *P* value for plumage colour. Model fit was checked by visual examination of residual plots and the adjusted R^2 values. *F*-ratios and associated values were calculated using sequential sums of squares (Grafen and Hails, 2002). Because of a high frequency of 'zero' plumage damage scores for the neck and back body regions, data could not be transformed to meet the assumptions of normality and homogeneity of variance. Non-parametric Kruskall-Wallis *H* tests were therefore carried out to test for effects of flock and plumage colour on neck and back scores. Multiple comparison tests *sensu* Siegel and Castellan, (1988) were used when *H* tests were significant at $\alpha < 0.05$.

GLM procedures were used to test for effects of week, flock (A, B), time of day (morning, afternoon), plumage colour (white, black, grey) and week by flock effects on the number of severe and gentle feather pecks/10 mins/30 birds. (N = 21). To meet the assumptions of parametric tests, the severe and gentle feather pecking data sets were $\log_{10}$ transformed. In the GLM model, week was declared as a covariate, flock was entered as a random factor, time of day and plumage colour were nested within flock. Thus, effects due to flock and age (week) on feather score were taken into account before calculating the *F*-ratio and associated *P* value for time of day and plumage colour.

Chi-square analysis was carried out to test whether feather peckers and receivers performed different behaviours (N= 538) and whether feather peckers and receivers of different plumage colours performed different behaviours (N = 252).

Plumage reflectance

Feathers of white, black and grey birds from the neck, back, rump, tail and wing were collected from birds of flock B. Between 6 and 11 feathers for each region were collected depending on feather cover of the individual birds captured. Feathers were cut from the appropriate region and placed into labelled envelopes and returned to the lab for later measurement. The reflectance spectrum from each individual feather was measured using a USB 2000 spectrometer with an R200-7 probe and DH2000 Balance Deuterium Tungsten Halogen light source (Ocean Optics Inc, Florida, USA). Measurements were taken at a 90˚ angle to, and 5 mm from the feather using a probe holder. A white reference (WS-1 Diffuse Reflection Standard, Ocean Optics Inc, Florida, USA) and dark measurement were taken before each sample. Spectra were averaged from 5 scans with a smoothing scale of 3 (OOIIrrad-C Software, Ocean Optics Inc, Florida, USA).

Light measurements

Light measurements of random locations at flock A (using a co-ordinate grid map and random numbers) on the range, under trees, in verandas and the houses were taken in the morning (10.00 – 12.00 h) and afternoon (14.00 – 16.00 h) with < 50% and ≥ 50% cloud cover with a USB 2000 spectrometer (UV2/OFLV-4 detector and L2 lens, Ocean Optics Inc. Florida USA) and a cosine-corrected sensor (CC-3-UV, Ocean Optics Inc. Florida USA), custom-calibrated with a DH-2000-CAL deuterium tungsten halogen lamp (Ocean Optics Inc. Florida USA). Measurements were taken at a point approx 30 cm above the ground (chicken height) by pointing a 600 um fibre end (QP600 2-UV-BX) perpendicular to the sun or, nearest light source (houses only). Dark references were taken for each measurement. Spectra were averaged from 5 scans, with smoothing scale of three and an appropriate integration time (Ocean Optics Inc, 2005). All measurements were taken in 2005 between April 6 and May 17 on 7 separate days.

RESULTS

Feather scores

Flock had no significant effects on total, rump, tail or wing feather damage scores ($F_{2, 6.03} > 4.25$, $P > 0.05$ for all).

There were significant plumage colour effects on total feather damage score ($F_{6, 970} = 26.27$; $P < 0.001$). Birds with white plumage had lower total feather scores (lower scores, less damage) than black or grey birds in all three flocks (Figure 1a).

There was a significant difference between flocks for neck and back feather scores ($H_2 = 152.90$, $P < 0.001$; $H_2 = 88.87$, $P < 0.001$ respectively), and for plumage colour ($H_2 = 13.92$, $P < 0.001$; $H_2 = 27.80$, $P < 0.001$). White birds had lower neck and back feather scores than birds with black plumage (Figure 1b and c).

There were significant plumage colour effects on rump ($F_{6, 970} = 47.99$, $P < 0.001$), tail ($F_{6, 970} = 19.08$, $P < 0.001$), and wing ($F_{6, 970} = 12.04$, $P < 0.001$) feather damage scores. White birds had less plumage damage than black or grey birds (Figure 1d-1f).

Feather pecking behaviour

There were significant, flock, time of day, plumage colour and week by flock effects on the number of severe feather pecks/10 mins/30 birds (Table 1). Flock A feather pecked severely at a higher rate than Flock B (Figure 2a and b), there was more severe feather pecking in the morning (Figure 2a) and white birds feather pecked severely more than black or grey birds (Figure 2b). There was a negative relationship between severe feather pecking and week for Flock A (50.82 - 0.717 x week) and a positive relationship between severe feather pecking and week for Flock B (-2.66 + 3.279 x week). There was no effect of week, flock, time of day, plumage colour or week by flock on the number of gentle feather pecks/10mins/30birds (Table 1).

There was a difference between behaviour of feather peckers and receivers ($\chi^2 = 115.13$, df = 7, $P = < 0.001$). Receivers were more likely to be dust bathing, feeding or sitting when being feather pecked. Feather peckers were more likely to be standing or walking when feather pecking (Figure 3).There was no difference between the proportion of black white or grey receivers of feather pecking and the plumage colour of their feather peckers ($\chi^2 = 1.57$, df = 4 , $P = 0.815$). There was no difference between the behaviour of black, white or grey receivers ($\chi^2 = 16.94$, df = 14, $P = 0.259$) or, the behaviour of black white or grey feather peckers ($\chi^2 = 20.35$, df = 14, $P = 0.119$).

Plumage reflectance

Reflectance spectra for white, black and grey feathers were averaged for each body region. The reflectance from all three plumage colours showed similar patterns, irrespective of body region (Figure 4a-e). White feathers showed ~ 20% reflectance in the UV at 300 nm, increasing steadily to ~80% reflectance at 450 nm then levelling off (Figure 4a-e). Black feathers had low reflectance and showed very little variation across the bird visible spectrum (~300-700 nm). Grey feathers showed ~30% reflectance in the UV at 300 nm, increasingly sharply to ~40% at 350 nm then levelling off. Because the black and grey feather spectra were relatively flat, the contribution of UV wavelengths to plumage reflection, was proportionally greater than that for white feathers (Figure 4a-e).

Light spectra

On the range, light intensity was higher with < 50% cloud cover than ≥ 50% cloud cover, and there was a pronounced peak in light intensity at ~450 nm. There was little difference between morning and afternoon spectra (Figure 5a). Under trees, light intensity was also higher with < 50% cloud cover than ≥ 50% cloud cover, there was a pronounced peak at ~450 nm and dip at ~550nm (Figure 5b). However, light intensity in the morning at < 50% cloud cover was lower than light intensity in the afternoon at < 50% (Figure 5b). In verandas, light intensity was higher in the afternoon at < 50% cloud cover than in the morning at < 50%, morning ≥ 50% and afternoon ≥ 50% cloud cover (Figure 5c). This was probably due to positioning of the houses, which catch the afternoon sun.

The light intensity inside the house is less than on the range or under trees but comparable to that in veranda with ≥ 50% cloud cover (Figure 5d). The light spectra from inside the house had low or no reflectance between 300-400 nm (UVA), while the range, under trees and veranda spectra show varying amounts (Figure 5d). Finally, the house spectra peaks and troughs in different regions of the spectrum to that of natural light (Figure 5d). The shape of this house light spectra is typical of fluorescent light sources (Prescott and Wathes, 1999***a***).

DISCUSSION

This study investigated plumage colouration effects on plumage damage due to feather pecking in three commercial flocks of Oakham Blue laying hens. Plumage colour effects on feather pecking have previously been demonstrated (Ambrosen and Petersen, 1997; Savory and Mann, 1999; Kjaer and Sørensen, 2002), although these may have been confounded by bird strain. Here, significant effects of plumage colour on plumage damage due to feather pecking were found within a single strain of bird: birds with white plumage had lower feather scores (less plumage damage due to feather pecking) than black or grey birds in all three flocks (Figure 1a-f). There were also significant flock effects: variation in flock age, management and husbandry practices are known to influence feather pecking (Hughes and Duncan, 1972; Green *et al*., 2000; Bestman and Wagenaar, 2003; Nicol *et al.*, 2003).

Why might black or grey birds suffer more plumage damage due to feather pecking than white birds? It has recently been proposed (Keeling *et al.*, 2004), that the genes which determine plumage pigmentation in chickens may predispose birds to becoming victims of feather pecking. In Oakham Blue laying hens, genes determining plumage colour may also be important in predisposing birds to becoming feather pecking victims. There are also likely to be behavioural and environmental interactions/factors that stimulate or inhibit feather pecking.

Plumage colour and behaviour

In mammals, coat colour is related to level of activity, reaction intensity and environmental awareness (Hemmer, 1990). Selection of certain coat colours can produce a behavioural change with a corresponding change in the stress system (Hemmer, 1990). In chickens, the alpha melanocyte stimulating hormone (MSH) controls pigment regulation and is directly related to energy homeostasis (Takeuchi *et al.,* 2003). It is feasible that plumage colour and behaviour are associated in laying hens as in mammals (Takeuchi et al., 2003)). In this study, there was more severe feather pecking in the morning than in the afternoon (Table 1, Figure 2a). Diurnal variation in feather pecking behaviour has previously been established in laying hens (Kjaer, 2000). White birds produced more severe feather pecks than black or grey birds (Table 1, Figure 2b) (there was no significant difference between plumage colours for gentle feather pecks (Table 1)). Severe feather pecking is generally considered to cause the majority of feather pecking damage (Vestergaard *et al*., 1993; Bilćik and Keeling, 1999). However, there was no difference between the proportions of white, black or grey receivers of feather pecks and the plumage colour of their feather peckers or, evidence that the behaviour of feather peckers and receivers varied with plumage colouration. White birds might have delivered more severe feather pecks, but they did not specifically target, or behave differently to, pigmented birds. A wide array of behavioural and developmental traits are genetically linked to feather pecking behaviour, (Keeling *et al.*, 2004; Jensen *et al.*, 2005). It is possible that there are behavioural/developmental differences between Oakham Blue white and pigmented birds that were not detected in this study.

In contrast, there was a behavioural difference between feather peckers and receivers (regardless of plumage colour) during pecking incidents: Feather peckers were more likely to be standing or walking, while receivers were more likely to be dust bathing, feeding or sitting (Figure 4). Behavioural differences between feather and non-feather-pecking birds have been demonstrated in other studies of single strain laying hens (Jensen *et al.,* 2005; (Nätt *et al.,* 2006) and may be indicative of personality type/coping strategy (van Hierden *et al*., 2002; Korte, *et al*., 1997; 1999).

Plumage colour and environment

Fowl are visually-dominant animals with a visual system that is well adapted to collecting spectral information; they have 4 cone visual pigments with wavelengths of maximum sensitivities at 408 nm (Ödeen and Håstad, 2003), 455 nm, 507 nm and 569 nm (Bowmaker *et al.*, 1997). Recent studies on sexual selection (Bennett *et al*., 1996; Andersson and Amundsen, 1997; Hunt *et al.*, 1997), and foraging behaviour in birds (Viitala *et al.*, 1995; Church *et al.*, 1998) have emphasised the need to interpret signals on the basis of the visual system perceiving them. Human eyes do not have oil droplets and only three classes of cone visual pigments, and are likely to perceive colours in different ways from birds. It is important to interpret feather reflectance and light composition data from a ‘chicken perspective’. Under the dim, artificial lights inside a poultry house, birds with black and grey feathers may be less visible to conspecifics than white birds because their plumage reflects at a lower intensity (Figure 5a-e). Furthermore, the lack of available UV light inside versus outside and the higher contribution of UV reflectance to black and grey plumage, than to white plumage, may make black and grey birds appear more different inside the house than white birds. It is possible that this novel/unusual appearance may make black or grey Oakham Blue hens more susceptible to feather pecking. For example, in turkeys (*Meleagris gallopovo*), which have similar cone visual pigment sensitivities as chickens (Hart *et al.*, 1999), the age at which UV-visible markings were first observed on the wings and tail corresponded closely with the age at which injuries to these sites were first caused by pecking (Sherwin and Devereux, 1999). Behavioural (Jones *et al.*, 2001) and physiological (Rosiak and Zawilska, 2005) sensitivity to UV wavelengths has been demonstrated in chickens. However, little is known about how UV reflectance from feathers affects recognition/communication in laying hens, or whether the absence of UV wavelengths during rearing affects perception of UV signals in adulthood. Experimental studies are necessary to establish just how important factors such as UV reflectance and reflectance intensity are, in stimulating and inhibiting feather pecking in comparison to other factors such as dust particles/ litter substrate being more visible on darker birds and encouraging pecking (Savory *et al.,* 1999). Given the importance of vision and plumage/integument cues for communication in fowl, and the light environment on behaviour, further investigation into plumage colour and visual environment on feather pecking is warranted.

In conclusion, Oakham Blue laying hens with white plumage had significantly less plumage damage due to feather pecking than black or grey birds**.** White birds severe feather pecked severely more than black or grey birds, but there were no other behavioural differences between black, white and grey birds observed in this study. The reflectance intensity and spectra shape of black, white and grey feathers varied over the bird visible range (~300nm-700nm). Furthermore, there were marked differences between the artificial light provided inside a commercial poultry house and the natural light available outside on the range. This variation in plumage reflectance and ambient light environment may affect bird recognition/perception of conspecifics and influence feather pecking behaviour.

The development of feather pecking is multifactorial in nature and there are likely to be genetic and environmental interactions that influence the occurrence of outbreaks in a flock. Vision is the dominant sense in fowl, researchers and commercial producers should be aware of the way in which chickens perceive their environment if we are to better understand the behaviour and improve the welfare of commercially-housed flocks.

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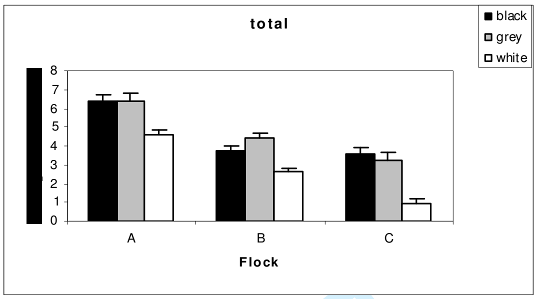
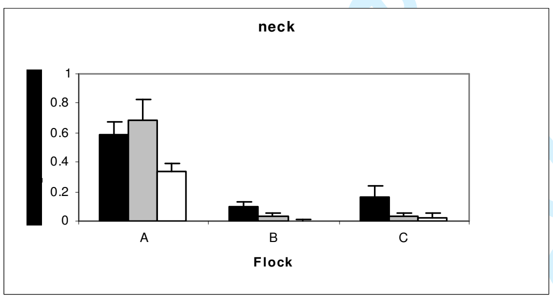
FIGURE 1. *Total (a), neck (b), back (c) rump (d), tail (e) and wing (e) plumage damage feather score (mean ± SE) by flock. Lower score indicates less damage.*

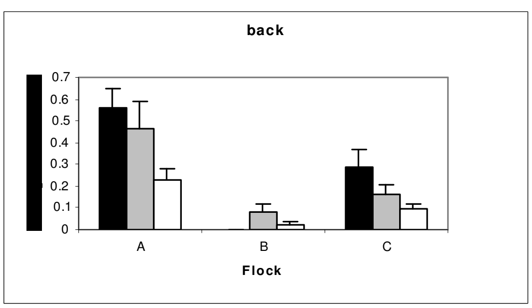
(a) total



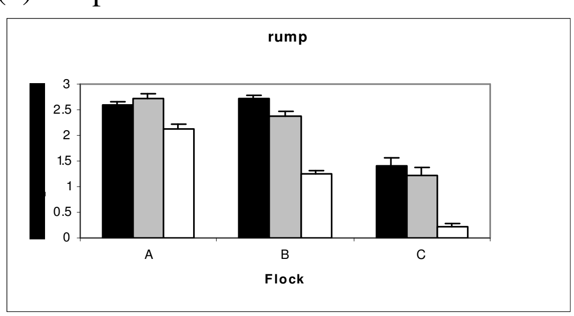
(b) neck



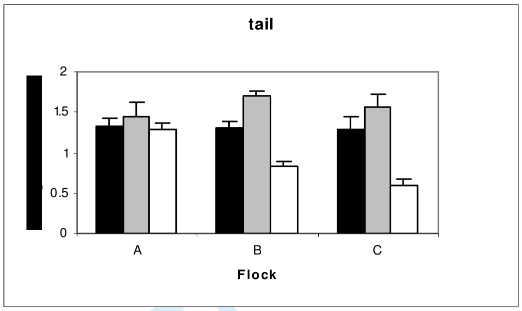
(c) back



(d) rump



(e) tail


tail
[redacted]
2
1.5
1
0.5
0
A
B
C
Flock

(f) wing

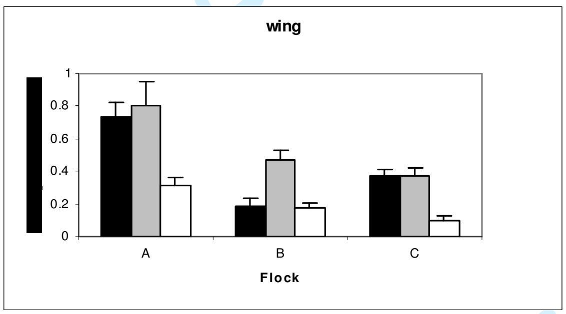
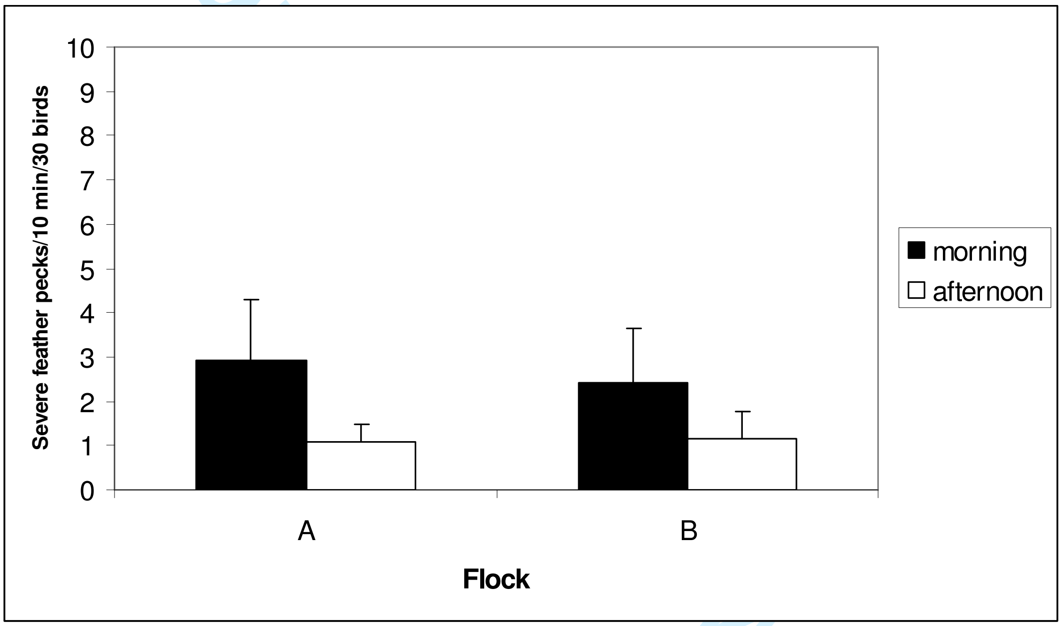

wing
[redacted]
1
0.8
0.6
0.4
0.2
0
A
B
C
Flock

FIGURE 2. *Severe feather pecks/10 birds/30 min (mean ± SE) by flock for, Time of day (a) and Plumage colour (b).*

(a) time of day



(b) plumage colour

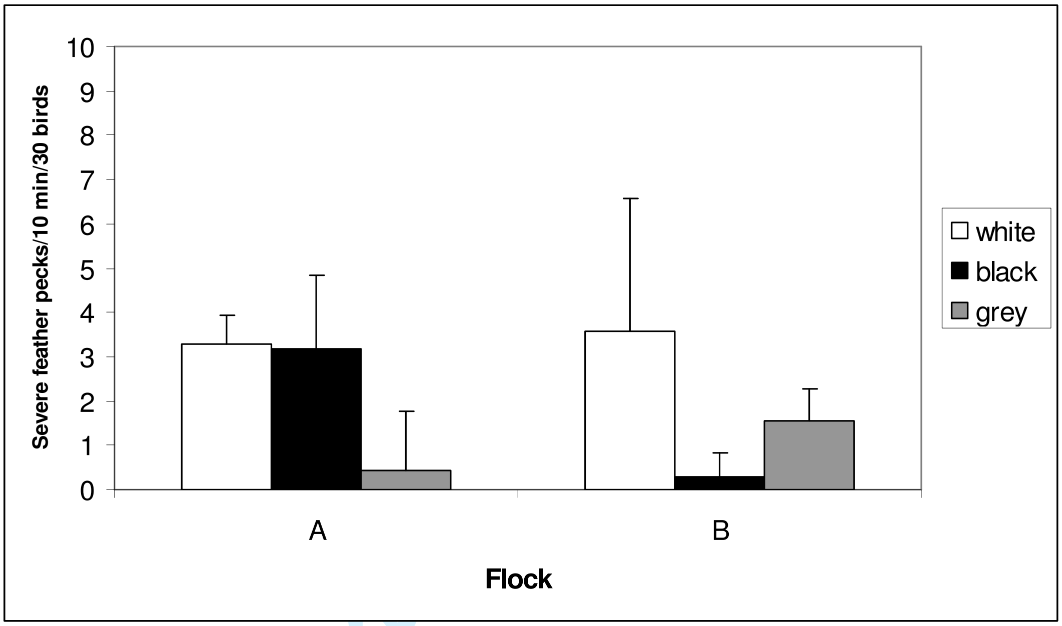


FIGURE 3. *Behaviours performed by feather peckers and feather peck 'receivers' during feather pecking incidents.*

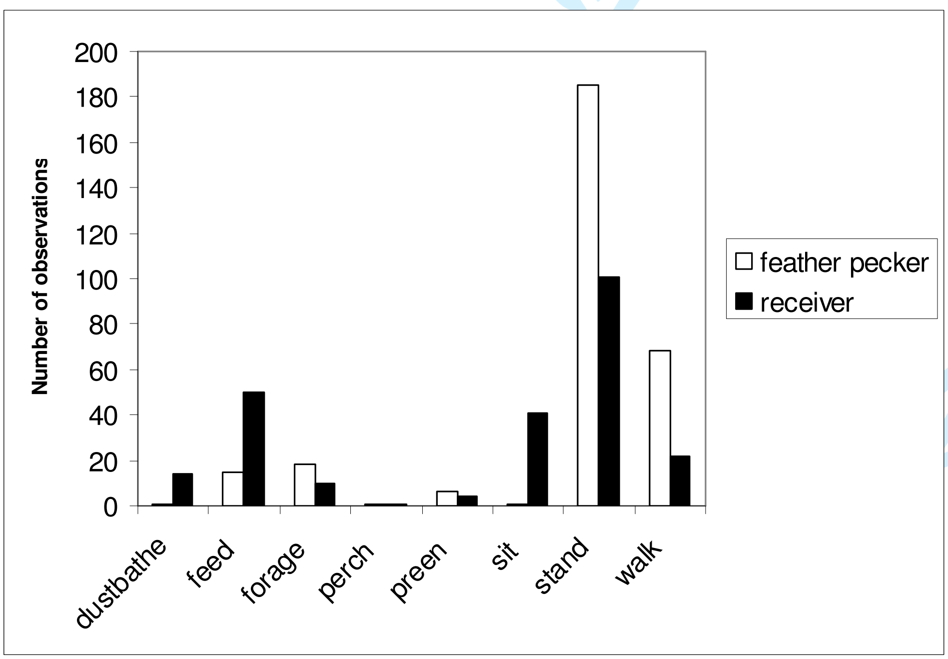
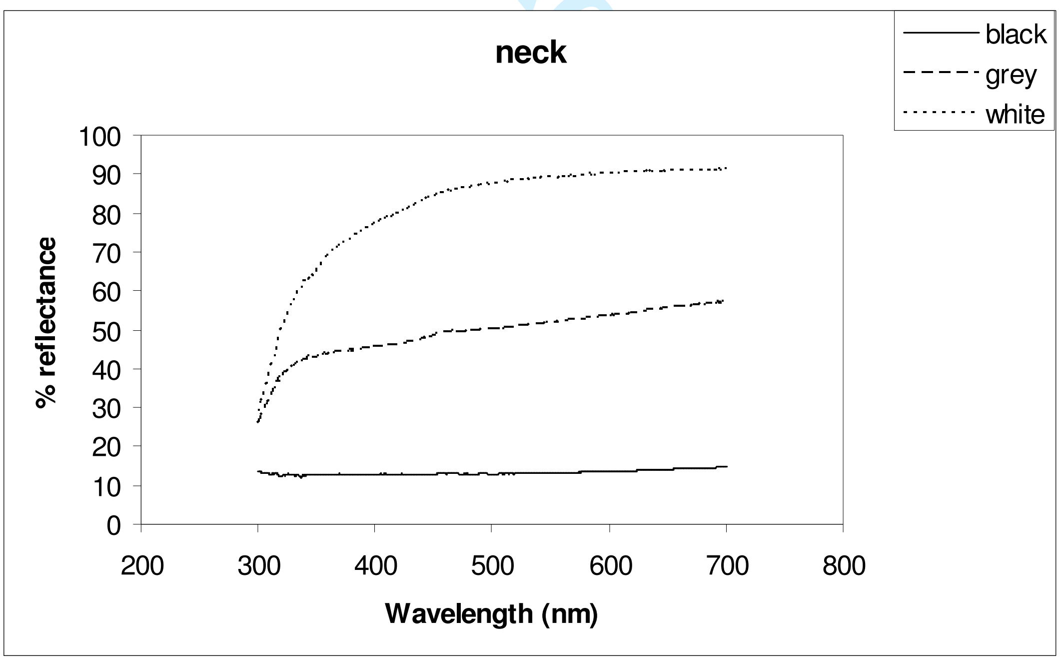
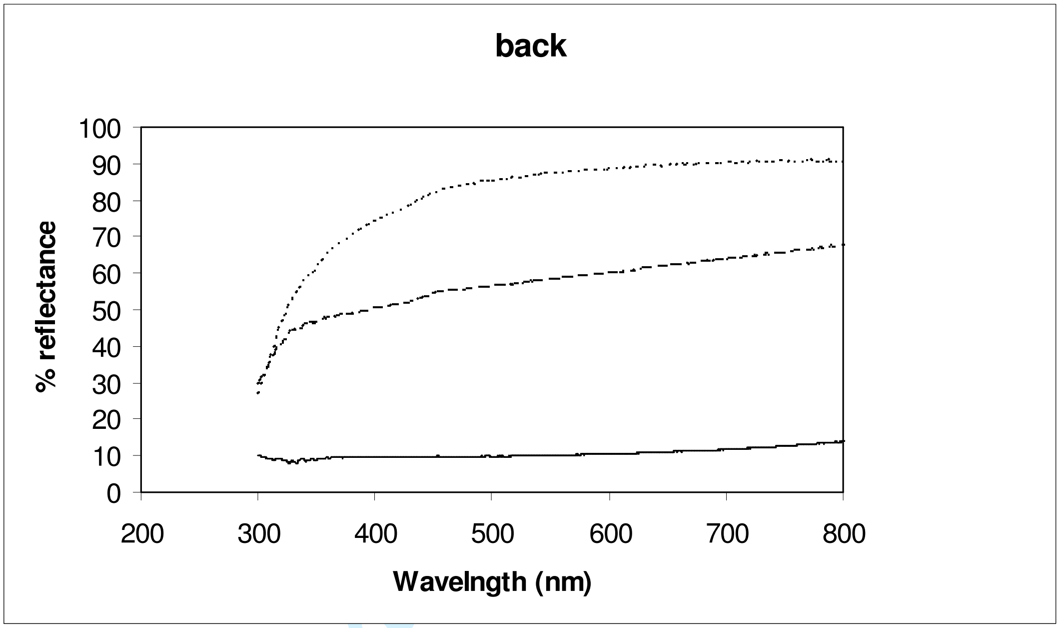


FIGURE 4. *Reflectance spectra of black, grey and white feathers from the neck (a), back (b), rump (c), tail (d) and wing (e). Between 6 and 11 feathers from each region were measured using a USB 2000 spectrometer with an R200-7 probe and DH2000 Balance Deuterium Tungsten Halogen light source (Ocean Optics Inc, Florida, USA). Measurements were taken at a 90˚angle to, and 5 mm from the feather using a probe holder. A white reference (WS-1 Diffuse Reflection Standard, Ocean Optics Inc, Florida, USA) and dark measurement were taken before each sample. Spectra were averaged from 5 scans with a smoothing scale of 3 (OOIIrrad-C Software, Ocean Optics Inc, Florida, USA).*

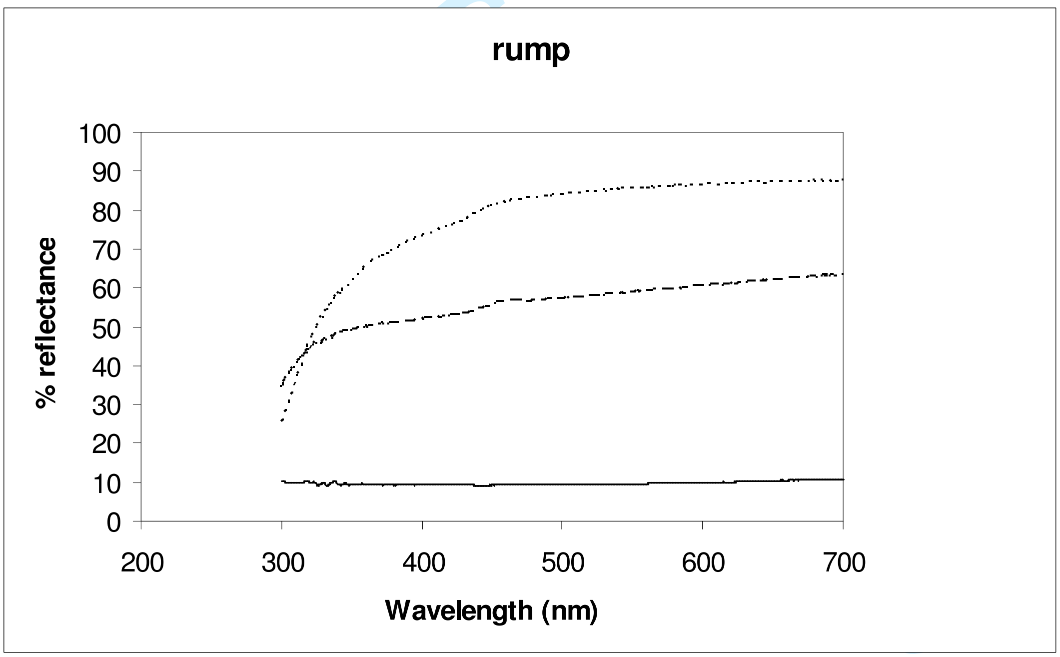
(a) neck



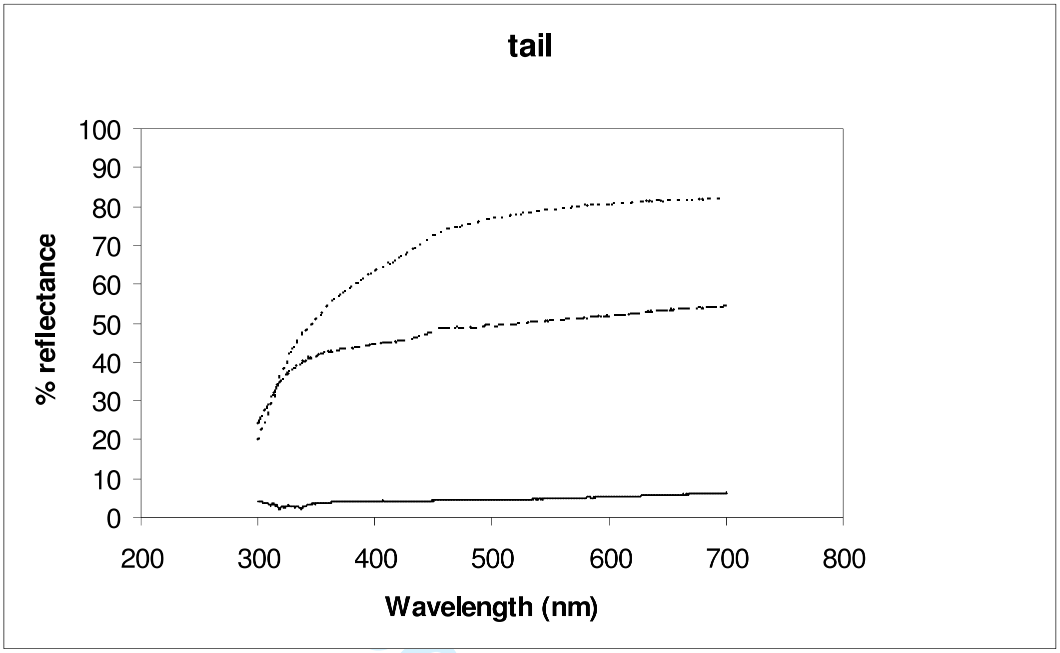
(b) back


back
100
90
80
70
60
50
40
30
20
10
0
% reflectance
200
300
400
500
600
700
800
Wavelngth (nm)

(c) rump


rump
100
90
80
70
60
50
40
30
20
10
0
% reflectance
200
300
400
500
600
700
Wavelength (nm)

(d) tail



(e) wing

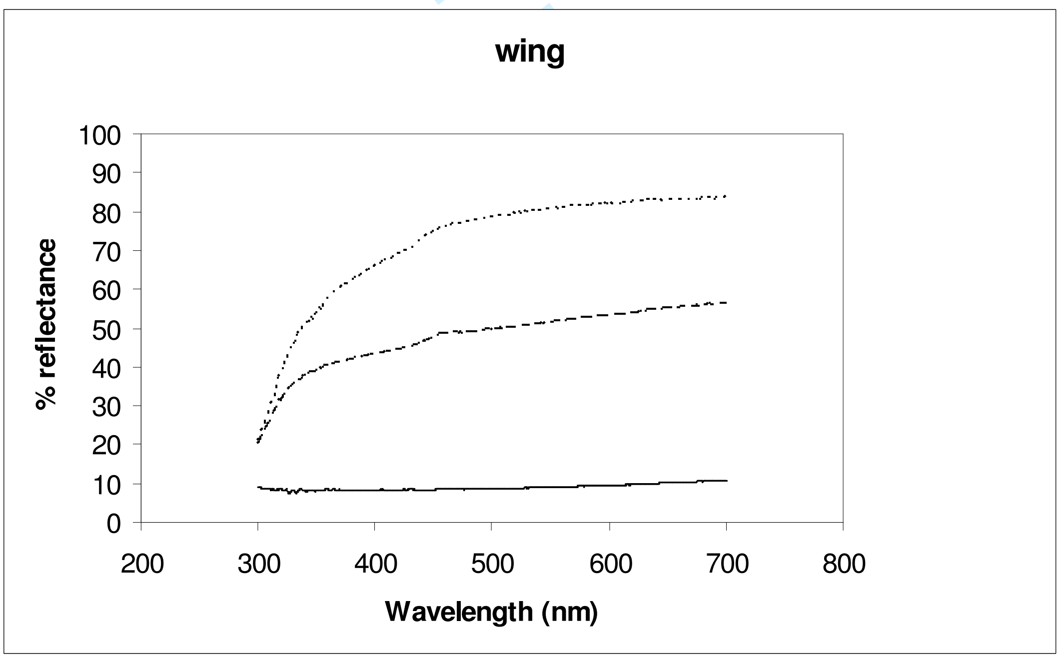
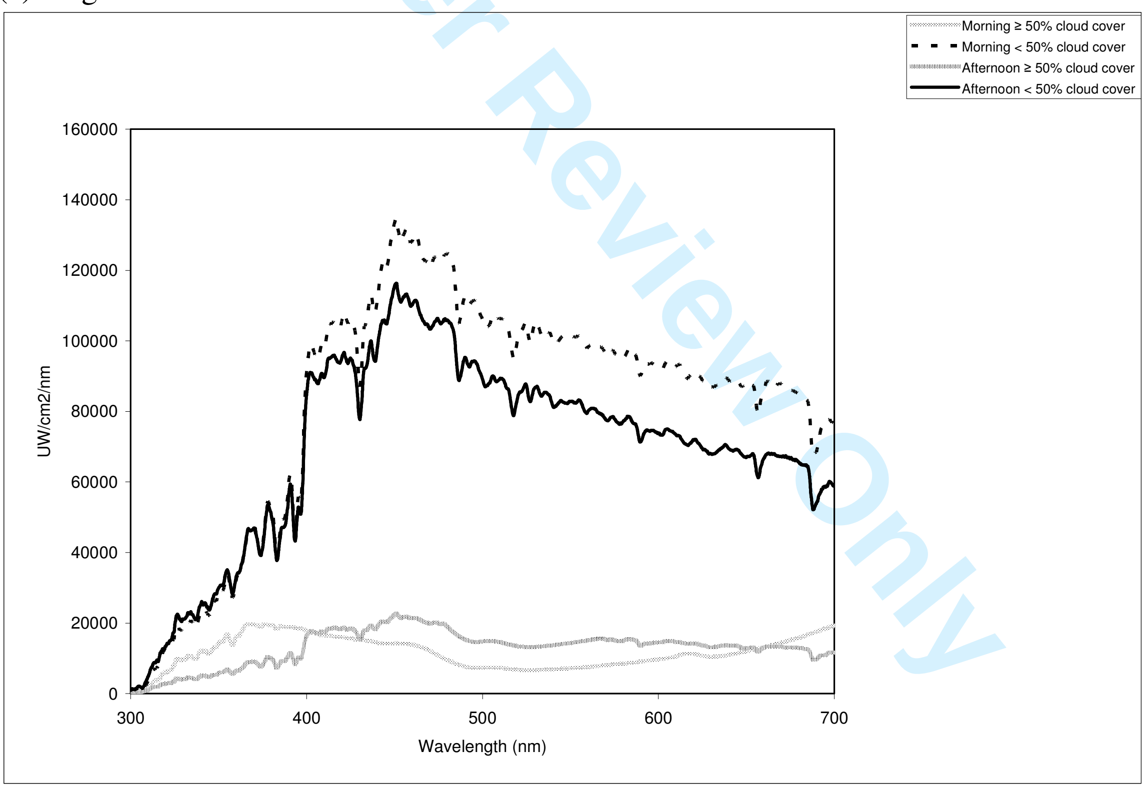


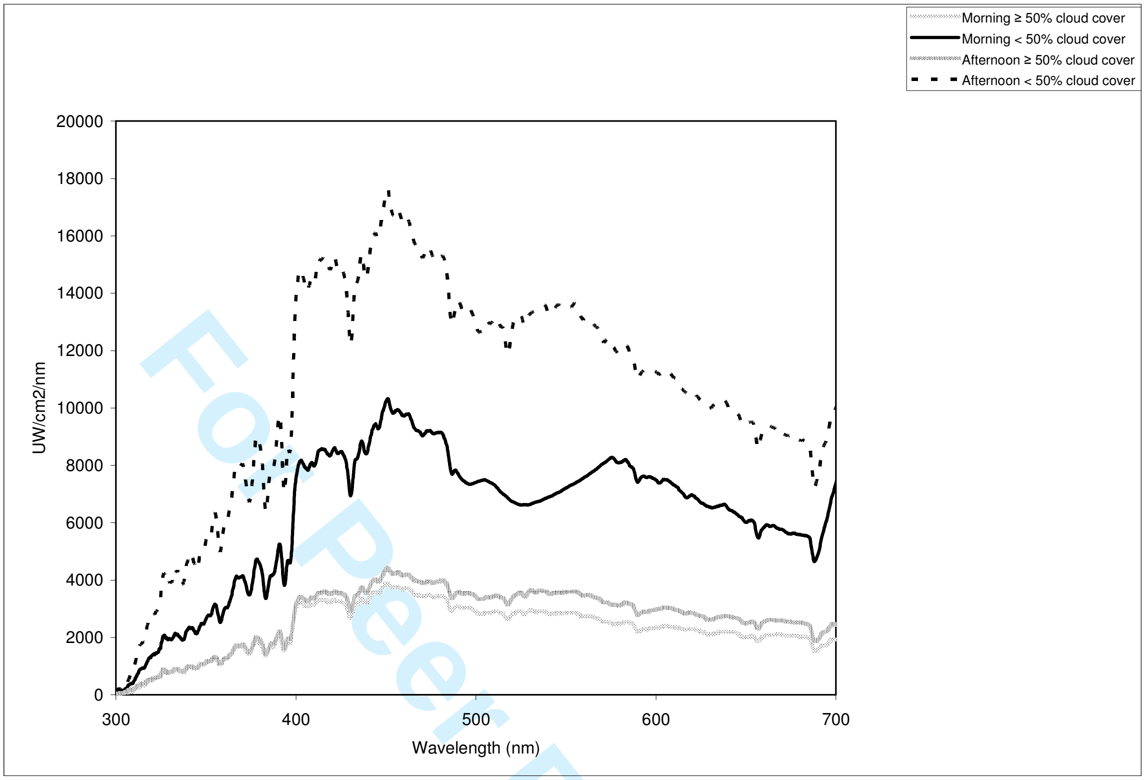
FIGURE 5. *Typical light spectra at the FAI farm, Wytham, Oxford in the morning and afternoon with < and ≥ 50% cloud cover on the open range (a), under trees (b), veranda (c) and house (d). Measurements were taken using a USB 2000 spectrometer*

(UV2/OFLV-4 detector and L2 lens, Ocean Optics Inc. Florida USA) and a cosine-corrected sensor (CC-3-UV, Ocean Optics Inc. Florida USA), custom-calibrated with a DH-2000-CAL deuterium tungsten halogen lamp (Ocean Optics Inc. Florida USA). Measurements were taken at a point approx 30 cm above the ground (chicken height) by pointing a 600 μm fibre end (QP600 2-UV-BX) perpendicular to the sun or, nearest light source (houses only). Dark references were taken for each measurement. Spectra were averaged from 5 scans, with smoothing scale of 3 and an appropriate integration time.

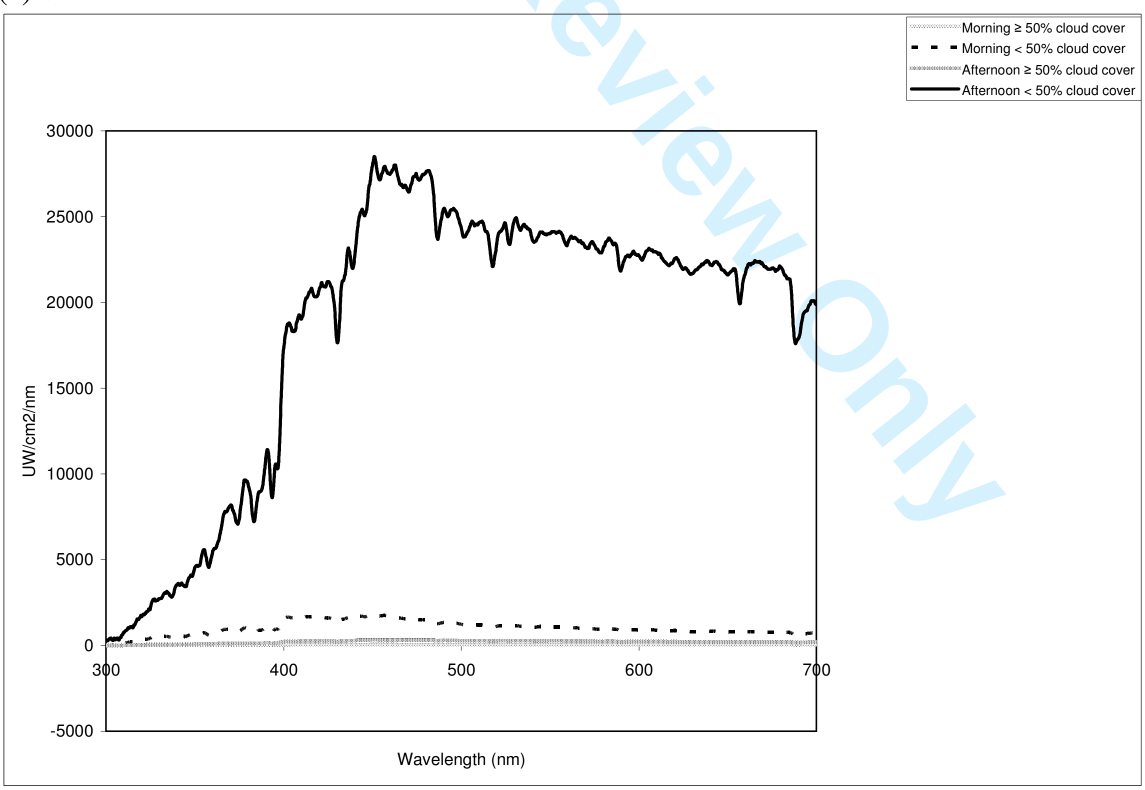
(a) range



(b) trees



(c) veranda



(d) house

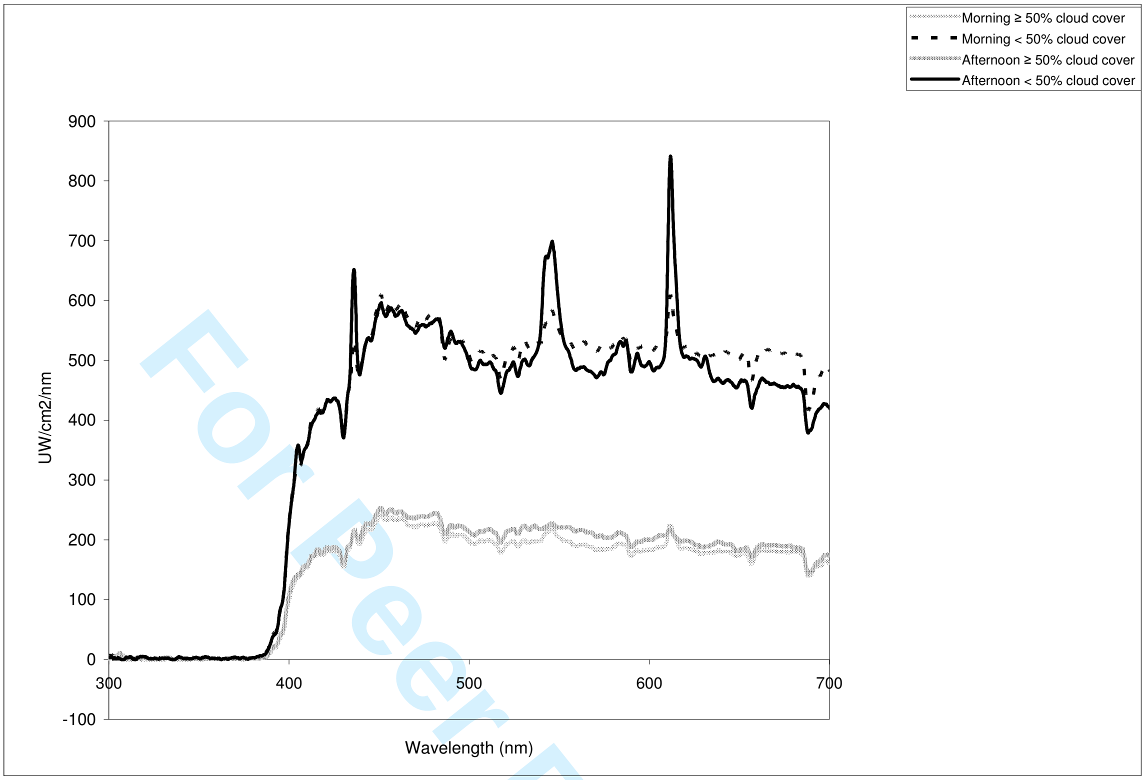


TABLE. *F-ratio and associated P values for GLM on the effects of week, flock (A-C), time of day (morning, afternoon), plumage colour (white, black, grey) and week by flock interaction on severe and gentle feather pecks/10 mins/30 birds. Week was included as a covariate in the model, flock as a random effect. Time of day and plumage colour were nested within flock. N = 21.*

	Severe	*P*	Gentle	*P*
Week	$F_{1, 11} = 3.37$	0.094	$F_{1, 11} = 0.29$	0.602
Flock	$F_{1, 11} = 4.95$	0.048	$F_{1, 11} = 0.26$	0.620
Time of day (flock)	$F_{2, 11} = 8.75$	0.005	$F_{2, 11} = 0.67$	0.532
Plumage colour (flock)	$F_{4, 11} = 4.83$	0.017	$F_{4, 11} = 1.83$	0.193
Week*Flock	$F_{1,11} = 5.65$	0.037	$F_{1,11} = 0.25$	0.625

1