OPEN ACCESS

Paper

Early warning of footpad dermatitis and hockburn in broiler chicken flocks using optical flow, bodyweight and water consumption

M. S. Dawkins, S. J. Roberts, R. J. Cain, T. Nickson, C. A. Donnelly

Footpad dermatitis and hockburn are serious welfare and economic issues for the production of broiler (meat) chickens. The authors here describe the use of an inexpensive camera system that monitors the movements of broiler flocks throughout their lives and suggest that it is possible to predict, even in young birds, the cross-sectional prevalence at slaughter of footpad dermatitis and hockburn before external signs are visible. The skew and kurtosis calculated from the authors' camera-based optical flow system had considerably more power to predict these outcomes in the 50 flocks reported here than water consumption, bodyweight or mortality and therefore have the potential to inform improved flock management through giving farmers early warning of welfare issues. Further trials are underway to establish the generality of the results.

Introduction

Footpad dermatitis (ulcerated lesions of the pad of the foot) and hockburn (discoloration and lesions of the hocks) are serious welfare and economic issues in the production of broiler (meat) chickens (Bessei 2006, Haslam and others 2007, Meluzzi and others 2008, Shepherd and Fairchild 2010, de Jong and others 2012, Kyvsgaard and others 2013, Elson 2015), but currently there are few reliable ways of easily assessing these while the birds are still alive and interventions are still possible. Chickens reared for meat frequently live for only 33–42 days and as measures of welfare, producers use either *postmortem* measures of the cross-sectional prevalence of footpad dermatitis, hockburn and breast blisters recorded at slaughter (SCAHAW 2000, Haslam and others, 2007, Allain and others 2009, Hepworth and others 2010) or labour-intensive methods such as manually sampling birds (Ekstrand and others 1998, de Jong and others 2012, de Jong and others 2016) that give only a snapshot of the state of a flock at a particular time.

Average bodyweight of birds at 14 days of age has been suggested as a possible indicator of flocks at high risk of later developing a high prevalence of hockburn (Hepworth and others 2010, 2011). The amount of water consumed by the growing birds is also widely recommended as means of assessing welfare (Defra 2013, RSPCA 2013, Red Tractor Assurance 2014, OIE 2016), since both increases and decreases in water consumption can indicate health problems (Butcher and others 1999). However, although the total amount of water consumed over the lifetime of a flock is positively correlated with the prevalence of footpad dermatitis assessed at the slaughter plant (Manning and others 2007), day-to-day changes in estimated water consumption do not appear to be particularly accurate as a welfare indicator (Manning and others 2007) because such changes can be caused by many factors such as leakages, inaccuracy of meters, variation in temperature, drinker type, ventilation rate, the mineral content of the water and diet (SCAHAW 2000, Lott and others 2003).

In this paper, the authors compare the usefulness of both bodyweight and water consumption with that of an alternative automated welfare assessment system that monitors the behaviour of chicken flocks using 'optical flow' data derived from inexpensive cameras (Dawkins and others, 2009; Dawkins and others 2012). Optical flow yields measures of behaviour at flock rather than individual level, such as overall levels of flock activity and whether the flock is behaving uniformly or is showing unusual behaviour (Dawkins and others, 2013). Changes in behaviour are increasingly recognised as precursors of clinical signs of disease or other problems (Toscano and others 2010, Lee and others 2011) so that changes in optical flow have the potential to give early warning of disease at the very earliest stages. For example, optical flow patterns observed in chicken flocks as young as three days old have already been shown to predict hockburn prevalence at slaughter (Roberts and others 2012). Similarly, optical flow patterns in chicken flocks of less than seven days old have been shown to predict *Campylobacter* prevalence at slaughter (Colles and others 2016). Needing only simple cameras, optical flow analysis measures the rate of change over time of brightness within different parts of a moving visual image (Beauchemin and Barron 1995, Fleet and Weiss 2005) and thus provides information about tens or hundreds of individuals at once. Using a sample of 50 commercial broiler flocks, the authors show that optical flow can potentially provide farmers with an inexpensive and easy-to-use early warning system for flocks at increased risk of developing footpad dermatitis and hockburn.

Veterinary Record (2017) doi: 10.1136/vr.104066

M. S. Dawkins, BA, DPhil,
R. J. Cain, BSc, PhD,
Department of Zoology, University of Oxford, Oxford, UK
S. J. Roberts, BSc, PhD,
T. Nickson, BA, DPhil,
Department of Engineering Science, University of Oxford, Oxford, UK
C. A. Donnelly, BA, MSc, ScD,
Department of Infectious Disease Epidemiology, MRC Centre for Outbreak Analysis and Modelling, School of Public Health, Imperial College, London, UK

E-mail for correspondence: marian.dawkins@zoo.ox.ac.uk

Provenance: Not commissioned; externally peer reviewed

Accepted February 3, 2017

Methods

Flocks and housing

The aim of the project was to obtain optical flow, production, water use and welfare records from commercial flocks of broiler chickens and to cover all seasons of the year. Since differences between companies, farms, time of year and management practices are known to have major effects on the health and welfare of birds (Dawkins and others, 2004), the study was designed to minimise the effects of these potentially confounding variables by using 50 flocks from a single farm, and thus standardising the flocks as far as possible, including having the same farm manager throughout, the same set of breeder farms from which the chicks were derived and the same slaughterhouse. The farm chosen had six identical houses. Twenty-four flocks (i.e. four successive crops from the six houses) were studied between October 2010 and June 2011. A further 29 flocks were studied between May 2014 and January 2015. Due to camera failure, optical flow records were obtained from only 50 flocks.

The six identical houses had metal sides and a floor area of 1670 m^2. Each house contained 488 feed pans and 1735 water nipples. Ventilation was standard roof extraction and the houses had windows and perches. Chicks were placed ‘as hatched’ (mixed sex) as day-olds (33,000–35,000 per house) and grown to 33–35 days of age with a target stocking density of 34 kg/m^2. In some cases, early removal of a proportion of birds (‘thinning’) occurred, but this was unpredictable in both timing and proportion of the flock removed (both these factors were dependent on growth rate and supermarket demand). To avoid the disruption caused by thinning (de Jong and others, 2012), optical flow data were collected only up until 30 days of age, before thinning occurred in any of the flocks.

Hockburn and footpad dermatitis

Slaughterhouse measurements of hockburn and footpad dermatitis are used by producers to set targets for the health and welfare of flocks. The outcome measures used in this study were therefore the same as those used by the farmers themselves—namely data on hockburn and footpad dermatitis on each flock collected by the producer company at slaughter following routine producer procedures. These were recorded as the cross-sectional prevalence of any signs of hockburn or footpad dermatitis, expressed as per cent of that flock.

Estimated water consumption

Estimated daily water consumption was routinely recorded from house-specific meters by the farm staff and converted to consumption in litres/1000 birds. The data were recorded by the farm staff on flock sheets in each house.

Bodyweight and daily mortality

Producers supplied daily measurements of bird weights and cumulative mortality (dead plus all culls) for each flock as part of their own routine monitoring. Chickens were routinely weighed by fully automated electronic scales linked to a Fancom FWBU.e agri-computer (http://www.fancom.com/en/broilers/biometrics).

Cameras and recording equipment

Flock behaviour was recorded using custom-built C120 web cameras connected (two cameras/unit) to a small form-factor industrial PC (Fit-PC2, Anders Electronics, London, UK) enclosed in a protective waterproof housing. In each house, two units (four cameras) were installed, one on each side of a house at a height of 2.0±0.1 m and pointing towards the ground at an angle of 70°. Cameras were positioned so that the field of view contained less than 10 per cent of static objects such as feeders, drinkers, house uprights and connected to a mains power supply. To avoid disturbing the chicks, cameras were installed before the chicks arrived. To avoid possible disturbance caused by thinning (removal of a portion of the flock), data were collected for days 1–30 only (before any thinning occurred).

Optical flow

Optical flow analysis involves detecting the rate of change of brightness within different areas of a moving visual image both temporally and spatially. These changes are combined to give an estimate of local velocity vectors (Beauchemin and Barron 1995, Fleet and Weiss 2005). Each image frame on a video file was divided into 320×240 pixel images grouped into 1200 (i.e. 40×30) 8-by-8 pixel blocks and optical flow statistics (mean, variance, skew, kurtosis) were calculated following methods described in (Dawkins and others 2012, Roberts and others 2012), at 4 Hz between 08.00 and 20.00, when the lights were on. For each flock, daily means for each statistic were calculated for days 1–30.

Statistical analysis

The cross-sectional prevalence of hockburn and footpad dermatitis was analysed using multivariable linear regression models. Logistic regression models could not be fitted to the estimated prevalence data because the sample size (n) used at the slaughter plant to estimate the prevalence was not recorded.

For each day’s data, all possible univariable and multivariable linear regression models were fitted to the data with between 1 and 7 of the potential predictors. For each day, the best of these models was selected on the basis that it maximised the adjusted R^2 statistic. Once this model had been chosen, it was refitted to data from flocks with complete data for the model predictors (not just those flocks with complete data for all seven predictors for that day), non-significant predictors ($P>0.05$) were dropped and the reduced model refitted until all of the remaining predictors were significant.

The authors analysed data up to 15 days of age to investigate the basis for an early warning system for farmers. Some data were missing due to cameras not working. Data from days 1, 2 and 3 were not analysed because only eight flocks had optical flow data from day 1, only 36 flocks had data from day 2 and only 38 flocks had data from day 3. The number of flocks (observations) used for the analysis is shown in Tables 1 and 2.

TABLE 1: Best adjusted R^2 models for each age of birds as predictors of footpad dermatitis prevalence

Age (days)	Obs. used	Best adjusted R^2 (%)	Model
1	(8)		
2	(36)		
3	(38)		
4	**43**	**31.8**	**Water4 Weight4 CumulMort4 OFVar4 OFSkew4 OFKurt4**
5	43	24.3	Water5 CumulMort5 OFVar5 OFSkew5 OFKurt5
6	45	23.6	Water6 CumulMort6 OFMean6 OFSkew6 OFKurt6
7	45	30.7	Water7 CumulMort7 OFSkew7 OFKurt7
8	47	21.9	Water8 CumulMort8 OFVar8 OFSkew8 OFKurt8
9	47	21.2	Water9 CumulMort9 OFVar9 OFSkew9 OFKurt9
10	48	20.7	Water10 CumulMort10 OFVar10 OFSkew10 OFKurt10
11	50	17.9	Water11 CumulMort11 OFVar11 OFSkew11 OFKurt11
12	49	16.6	Water12 CumulMort12 OFVar12 OFSkew12 OFKurt12
13	49	16.4	CumulMort13 OFSkew13 OFKurt13
14	49	21.7	CumulMort14 OFSkew14 OFKurt14
15	49	19.3	Water15 OFVar15

Best fit model in bold.
The variable names are as follows: estimated water consumption (Water), average weight (Weight), cumulative mortality (CumulMort), and optical flow statistics: mean (OFMean), variance (OFVar), skew (OFSkew) and kurtosis (OFKurtosis). The number at the end of the name reflects the age in days to which each predictor related

TABLE 2: Best adjusted R^2 models for each age of birds as predictors of hockburn prevalence (variable names as in Table 1)

Age (days)	Obs. used	Best adjusted R^2 (%)	Model
1	(8)		
2	(36)		
3	(38)		
4	**43**	**29.8**	**OFMean4 OFSkew4 OFKurt4**
5	43	23.8	OFSkew5 OFKurt5
6	45	27.6	Weight6 OFSkew6 OFKurt6
7	45	22.7	Weight7 OFMean7 OFVar7 OFSkew7 OFKurt7
8	47	24.3	Weight8 OFMean8 OFVar8 OFSkew8 OFKurt8
9	47	21.0	Weight9 OFSkew9 OFKurt9
10	48	21.2	Weight10 OFSkew10 OFKurt10
11	50	25.3	Weight11 OFMean11 OFVar11 OFSkew11 OFKurt11
12	49	25.2	Weight12 OFMean12 OFSkew12 OFKurt12
13	49	25.7	Weight13 OFMean13 OFVar13 OFSkew13 OFKurt13
14	49	29.0	Weight14 OFMean14 OFSkew14 OFKurt14
15	49	25.6	Weight15 OFSkew15 OFKurt15

Best fit model in bold.

Results

The mean prevalence of footpad dermatitis in the 53 flocks was 51.6 per cent (sd 23.4) and of hockburn 20.5 per cent (sd 16.4 per cent). There was a positive correlation between footpad dermatitis and hockburn (Pearson r=0.53, n=50, P<0.01). The mean cumulative mortality to 30 days was 3.4 per cent (sd 1.07). The mean 30-day bodyweight was 1.6 kg (sd 0.09). Data and number of flocks recorded for each age for daily means for water consumption, bodyweight, cumulative mortality and the four optical flow variables (mean, variance, skew and kurtosis) are given in online Supplementary Table S1.

The best adjusted R^2 models for the prevalence of footpad dermatitis and hockburn are shown by age in Tables 1 and 2, respectively. The data at four days of age produced the best models (in terms of adjusted R^2) for both footpad dermatitis and hockburn. Table 3 and Fig 1a show the best fit linear regression model for the prevalence of footpad dermatitis, that is, it includes only those predictors (out of the possible seven) that reached significance at P<0.05. This shows that as early as day 4 of life both skew and kurtosis of optical flow are highly significant predictors of future (as measured at slaughter) footpad damage. Bodyweight, estimated water consumption and cumulative mortality appear as part of the highest adjusted R2 model, but did not reach significance as predictors in the multivariable model for four days of age. Table 4 and Fig 1b show the corresponding best fit linear regression model for the prevalence of hockburn. The importance of optical flow predictors is again apparent. Estimated water consumption and bodyweight did not reach significance as predictors in the multivariable model for four days of age, nor did the mean or variance of optical flow.

TABLE 3: Parameter estimates for the best fit multivariable linear regression model for the prevalence of footpad dermatitis (variable names as in Table 1)

Variable	Estimate	se	T	P value
Intercept	94.58	14.78	6.40	<0.0001
OFSkew4	−31.88	8.46	−3.77	0.0005
OFKurtosis4	2.81	0.73	3.85	0.0004

Adjusted R^2=23.0%; n=44. If fixed effects are added for the six houses, the estimates are very similar: OFSkew4: −31.14, se=9.79, t=−3.18, P=0.0030; OFKurtosis4: 2.75, se=0.83, t=3.32, P=0.0021

Discussion

A particular strength of this study is the objective manner in which the predictors (estimated water consumption, bodyweight, cumulative mortality as well as optical flow) were collected prospectively, that is, before the levels of hockburn and footpad dermatitis had been determined. Furthermore, the assessments of hockburn and footpad dermatitis were made using routine company practices, avoiding biases that could arise due to bespoke study-specific methods of assessment. Optical flow data were collected from standard camera positions but not analysed until after the flocks had been cleared.

Hockburn and footpad dermatitis were correlated here as has been found previously (Haslam and others 2007). Both conditions have a genetic component (Bizeray and others 2000, Haslam and others 2007, Ask, 2010, Shepherd and Fairchild 2010) and are also affected by environmental factors, particularly poor quality litter (Eichner and others 2007, Haslam and others 2007, Martins and others 2013).

Chicken flocks where some individuals have hockburn or footpad dermatitis can be seen as 'mixed ability' flocks—that is, they contain a mixture of birds with healthy and unhealthy legs and feet. Optical flow analysis of the movements of such flocks detects this as changes in both the skew and the kurtosis of flock movement, in comparison with healthier flocks, which are more homogeneously healthy and more uniform in their movement. The skew and kurtosis of optical flow were, together, highly predictive of footpad dermatitis and hockburn at slaughter, but each detected a different measure of the heterogeneity in the movement of a flock. The skew values reported here (range 1.0–6.7, Fig 1) suggest that there are some flocks with an increase in asymmetry in the movement distribution, indicating a flock in which the most common kind of movement (the mode) is displaced from the mean or average movement.

The kurtosis describes a different feature of the flock behaviour, which is the extent to which the balance between the centre and the 'tails' of the distribution deviates from what is expected in a normal population. The high kurtosis reported here for some flocks implies that there is a deviation in the direction of 'fat tails'—in other words, an unusually high number of birds moving very much faster or slower than the mean. Although it seems counterintuitive to say that the presence of a few fast-moving birds is a sign of an 'at risk' or poor welfare flock, the flock that is in real trouble is the one where fast movement has become relatively rare. Healthy flocks have uniformly high levels of movement, with few outliers and therefore low kurtosis.

Lower skew (for a given level of kurtosis) and higher kurtosis (for a given level of skew) are thus indicative of heterogeneity in flock movement that is predictive of two key welfare outcomes, footpad dermatitis and hockburn. Optical flow can thus provide early warning of these key welfare issues, enabling farmers to make interventions (such as extra litter) to prevent signs becoming more serious.

However, it is still not clear exactly how the correlations between optical flow, hockburn and pododermatitis arise (Dawkins and others, 2013). One possible connection could be that flocks with a tendency to sit for long periods of time spend more time with their legs in contact with litter and so are more likely to develop hockburn. But other routes, such as infections that make the birds both less active and more prone to gut disorders that then lead to poorer quality litter that in turn affects their legs and feet also need to be investigated.

The best fit multivariable linear regression model showed that skew and kurtosis of optical flow had more predictive power than estimated water consumption, bodyweight or cumulative mortality, thus confirming the value of optical flow as a flock management tool.

The next step will be to repeat similar studies in additional farms, in particular those run by other companies to explore the generality of the results.

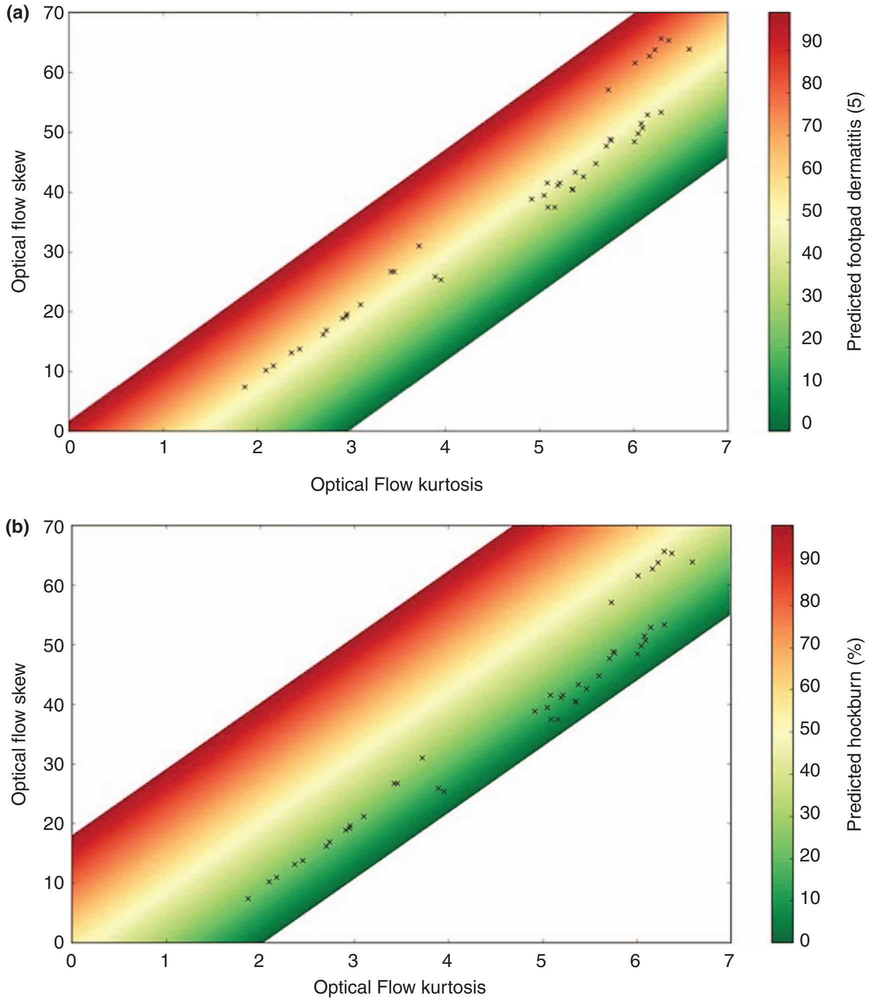

FIG 1: Plots of the best fit regression models for (a) the prevalence of footpad dermatitis and (b) the prevalence of hockburn as a function of the optical flow skew and kurtosis at four days of age (see Tables 3 and 4 for the parameter estimates). The observed data are overlaid over the regression model predictions

TABLE 4: Parameter estimates for the best fit multivariable linear regression model for the prevalence of hockburn (variable names as in Table 1)

Variable	Estimate	se	t Value	P value
Intercept	55.14	11.13	4.96	<0.0001
OFSkew4	−27.15	6.37	−4.26	0.0001
OFKurtosis4	2.45	0.55	4.42	<0.0001

Adjusted R^2=30.29%; n=44. If fixed effects are added for the six houses, the estimates are very similar: OFSkew4: −28.45, se=7.31, t=−3.89, P=0.004; OFKurtosis4: 2.50, se=0.62, t=4.04, P=0.0003

Ethics

This study used broiler flocks that were reared commercially by industry partners, in line with standard industry practice. The authors performed non-invasive, non-intrusive camera observations of birds, and thus the need for approval under the Animals (Scientific Procedures) Act of 1986 was waived. All prevailing local, national and international regulations and conventions and normal scientific ethical practices have been respected.

Acknowledgements

This work was funded by the Biotechnology and Biological Science Research Council (grant no. BB/K001388). The authors are very grateful for in-kind support from Cargill Meats (Europe) and would like to thank Andrew Morris for his essential help with this project.

Contributors M.S.D. designed and organised the study, collated the results and drafted the paper. S.J.R. and T.N. developed the optical flow algorithms and R.J.C. ran the trials and drew the figures. C.A.D. performed the statistical analysis.

References

ALLAIN, V., MIRABITO, L., ARNOULD, C., COLAS, M., LE BOUQUIN, S., LUPO, C. & MICHEL, V. (2009) Skin lesions in broiler chickens measured at the slaughterhouse: relationships between lesions and between their prevalence and rearing factors. *British Poultry Science* **50**, 407–417

ASK, B. (2010) Genetic variation of contact dermatitis in broilers. *Poultry Science* **89**, 866–875

BEAUCHEMIN, S. S. & BARRON, J. L. (1995) The computation of optical flow. *ACM Computational Surveys* **27**, 433–466

BESSEI, W. (2006) Welfare of broilers: a review. *World's Poultry Science Journal* **62**, 455–466

BIZERAY, D., LETERRIER, C., CONSTANTIN, P., PICARD, M. & FAURE, J. M. (2000) Early locomotor behaviour in genetic stocks of chickens with different growth rates. *Applied Animal Behaviour Science* **68**, 231–242

BUTCHER, G. D., JACOB, J. F. & MATHER, E. R. (1999) *Common poultry diseases*. Fact Sheet PS-47. University of Florida

COLLES, F. M., CAIN, R. J., NICKSON, T., SMITH, A. L., ROBERTS, S. J., MAIDEN, M. C. J., LUNN, D. & DAWKINS, M. S. (2016) Monitoring chicken flock behaviour provides early warning of infection by human pathogen *Campylobacter*. *Proceedings of the Royal Society of London* **283**, 20152323

DAWKINS, M. S., CAIN, R. & ROBERTS, S. J. (2012) Optical flow, flock behaviour and chicken welfare. *Animal Behaviour* **84**, 219–223

DAWKINS, M. S., CAIN, R., MERELIE, K. & ROBERTS S. J. (2013) In search of the behavioural correlates of optical flow patterns in the automated assessment of broiler chicken welfare. *Applied Animal Behaviour Science* **145**, 44–50

DAWKINS, M. S., DONNELLY, C. A. & JONES, T. A. (2004) Chicken welfare is influenced more by housing conditions than by stocking density. *Nature* **427**, 342–344
DAWKINS, M. S., LEE, H. J., WAITT, C. D. & ROBERTS, S. J. (2009) Optical flow patterns in broiler chicken flocks as automated measures of behaviour and gait. *Applied Animal Behaviour Science* **119**, 203–209
DE JONG, I. C., VAN HARN, J., GUNNINK, H., LOURENS, A. & VAN RIEL, J. W. (2012) Measuring foot-pad lesions in commercial broiler houses. Some aspects of methodology. *Animal Welfare* **21**, 325–330
DE JONG, I. C., HINDLE, V. A., BUTTERWORTH, A., ENGEL, B., FERRARI, P., GUNNINK, H., PEREZ MOYA, T., TUYTTENS, F. A. & VAN REENEN, C. G. (2016) Simplifying the Welfare Quality® assessment protocol for broiler chicken welfare. *Animal* **10**, 117–127
DEFRA (2013) https://www.gov.uk/guidance/welfare-for-meat-chickens-and-breeding-chickens. Accessed January 1, 2016
EICHNER, G., VIEIRA, S. L., TORRES, C. A., CONEGLIAN, J. L., FREITAS, D. M. & OYARZABAL, O. A. (2007) Litter moisture and footpad dermatitis as affected by diets formulated on an all-vegetable basis or having the inclusion of poultry by-product. *The Journal of Applied Poultry Research* **16**, 344–350
EKSTRAND, C., CARPENTER, T. E., ANDERSSON, I. & ALGERS, B. (1998) Prevalence and control of foot-pad dermatitis in broilers in Sweden. *British Poultry Science* **39**, 318–324
ELSON, H. A. (2015) Poultry welfare in intensive and extensive production systems. *World's Poultry Science Journal* **71**, 449–460
FLEET, D. J. & WEISS, Y. (2005) Optimal flow estimation. In *Mathematical Models for Computer Vision*. Eds N. PARAGIOS, Y. CHEN & O. FAUGERAS. New York: Springer. pp 239–258
HASLAM, S. M., KNOWLES, T. G., BROWN, S. N., WILKINS, L. J., KESTIN, S. C., WARRISS, P. D. & NICOL, C. J. (2007) Factors affecting the prevalence of foot pad dermatitis, hock burn and breast burn in broiler chicken. *British Poultry Science* **48**, 264–275
HEPWORTH, P. J., NEFEDOV, A. V., MUCHNIK, I. B. & MORGAN, K. L. (2010) Early warning indicators for hock burn in broiler flocks. *Avian Pathology* **39**, 405–409
HEPWORTH, P. J., NEFEDOV, A. V., MUCHNIK, I. B. & MORGAN, K. L. (2011) Hock burn: an indicator of broiler flock health. *Veterinary Record* **168**, 303
KYVSGAARD, N. C., JENSEN, H. B., AMBROSEN, T. & TOFT, N. (2013) Temporal changes and risk factors for foot-pad dermatitis in Danish broilers. *Poultry Science* **92**, 26–32
LEE, H. J., ROBERTS, S. J., DRAKE, K. A. & DAWKINS, M. S. (2011) Prediction of feather damage in laying hens using optical flows and Markov models. *Journal of the Royal Society Interface* **8**, 489–499
LOTT, B. D., DOZIER, W. A., SIMMONS, J. D. & ROUSH, W. B. (2003) Water flow rates in commercial broiler houses. *Poultry Science* **82**(Suppl. 1), 102
MANNING, L., CHADD, S. A. & BAINES, R. N. (2007) Water consumption in broiler chicken: a welfare indicator. *World's Poultry Science Journal* **63**, 63–71
MARTINS, R., HÖTZEL, M. J. & POLETTO, R. (2013) Influence of in-house composting of reused litter on litter quality, ammonia volatilization and incidence of broiler foot pad dermatitis. *British Poultry Science* **54**, 669–676
MELUZZI, A., FABBRI, C., FOLEGATTI, E. & SIRRI, F. (2008) Survey of chicken rearing conditions in Italy: effects of litter quality and stocking density on productivity, foot dermatitis and carcase injuries. *British Poultry Science* **49**, 257–264
OIE (2016) World Organisation for Animal Health. Terrestrial Animal Health Code. Chap. 7. *Animal Welfare and Broiler Chicken Production Systems*. OIE. pp 1–7. http://www.oie.int/index.php?id=169&L=0&htmfile=chapitre_aw_broiler_chicken.htm. Accessed 08/07/2016
RED TRACTOR ASSURANCE SCHEME (2014) *Chicken standards: broilers and poussin*. http://assurance.redtractor.org.uk/contentfiles/Farmers-5616.pdf. Accessed 05/07/2016
ROBERTS, S. J., CAIN, R. & DAWKINS, M. S. (2012) Prediction of welfare outcomes for broiler chickens using Bayesian regression on continuous optical flow data. *Royal Society Journal Interface* **9**, 3436–3443
RSPCA (2013) *Welfare Standards for Chickens*. Horsham, W. Susse: RSPCA
SCAHAW (Scientific Committee on Animal Health and Animal Welfare) (2000). *The Welfare of Chickens Kept for Meat Production (Broilers)*. Report to the European Commission. http://ec.europa.eu/food/animals/docs/aw_arch_2005_broilers_scientific_opinion_en.pdf. Accessed 08/07/2016
SHEPHERD, E. & FAIRCHILD, B. (2010) Footpad dermatitis in poultry. *Poultry Science* **89**, 2043–2051
TOSCANO, M. J., SAIT, L., JØRGENSEN, F., NICOL, C. J., POWERS, C., SMITH, A. L., BAILEY, M. & HUMPHREY, T. J. (2010) Sub-clinical infection with *Salmonella* in chickens differentially affects behaviour and welfare in three inbred strains. *British Poultry Science* **51**, 703–713

CrossMark

Veterinary Record

Early warning of footpad dermatitis and hockburn in broiler chicken flocks using optical flow, bodyweight and water consumption

M. S. Dawkins, S. J. Roberts, R. J. Cain, T. Nickson and C. A. Donnelly

Veterinary Record published online February 27, 2017