Temporal changes and risk factors for foot-pad dermatitis in Danish broilers

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ABSTRACT Foot-pad dermatitis is a major welfare concern of broilers caused by ammonia irritation from the bedding material. In Denmark, an action plan to control the condition was implemented in 2002 with monitoring through a foot scoring system at slaughter and with predefined limits that trigger sanctions. The objective of the present study was to study time trends and to identify predisposing factors on the flock lesion scores. The analysis was carried out on a database created by merging abattoir lesion data with antemortem evaluation data, and the flock productivity database managed by the farmers' association. The database had a record for each flock and variables containing information on both flock foot-pad scores and a range of management factors. We observed a dramatic decline in flock lesion scores between the years 2002 and 2005 followed by a minimal decline hereafter. Mean flock lesion scores differed between abattoirs, and subsequent analysis was performed in a mixed effect model where abattoir was considered a random effect. The analysis showed that flock lesion scores increased when the litter quality was evaluated as poor during the on-site antemortem evaluation. Other significant risk factors were winter season as opposed to summer, low daily weight gain, straw as bedding material in contrast to wood shavings and sphagnum peat, and high age at slaughter. Stocking density was only weakly associated with flock lesion scores.

Key words: foot-pad dermatitis, broiler, welfare, risk factor

2013 Poultry Science 92:26–32
http://dx.doi.org/10.3382/ps.2012-02433

INTRODUCTION

Foot-pad dermatitis (**FPD**) is an important aspect of welfare in broiler and turkey production (Berg 2004; Shepherd and Fairchild, 2010). It is a contact dermatitis that starts as a discoloration of the skin followed by hyperkeratosis and necrosis of the epidermis. In more severe cases, the changes lead to a pododermatitis characterized by ulcerations and inflammation of the subcutaneous tissue. The lesions may develop in less than a week (Greene et al., 1985; Ekstrand et al., 1997). The lesions are not primarily caused by infection but may serve as an entry point for pathogenic bacteria.

The problem is often referred to as ammonia burns and is believed to be caused by a combination of moist litter and chemical irritation of the skin due to a high ammonia content of the litter (Berg, 2004). The chain of events leading to hyperkeratosis and pododermatitis is not fully known. In the extra-animal environment, organic nitrogen from, for example, feces and urine will be converted to ammonia under anaerobic conditions and to nitrate under aerobic conditions (Madigan et al., 2000). A high moisture content in the bedding material may therefore lead to a humid environment, attachment of litter to the feet, and formation of irritating ammonia due to the anaerobic conditions.

Legislation to control the condition was first implemented in Sweden and later in Denmark. In Denmark, the postmortem scoring system has been in use since 2002 as described in the Departmental Order on Broiler Husbandry and Production of Hatching Eggs (Ministry of Food, Agriculture and Fisheries of Denmark, 2001). The implementation of the Order has led to inclusion of specific recommendations in the producer management guidelines (Poultry Advisory Board, 2003). These include recommendations on the type of heating, bedding material, ventilation of the poultry house, and control of water spillage.

Previous studies have analyzed the association between potential risk factors and the prevalence of FPD. Ekstrand et al. (1997) found that wet litter quality and a thickness of the bedding material above 5 cm both were predisposing factors. Differences between drinking systems were also found; fewer lesions were observed when water nipples were used compared with small cups. The importance of ambient temperature and humidity has been studied by Martrenchar et al. (2002),

Received April 26, 2012.
Accepted August 27, 2012.
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who found an association between FPD and poor fan ventilation, and by Ekstrand and Carpenter (1998a), who found a higher frequency of FPD in the winter season compared with the summer season.

Animal factors may also play an important role. Thus, Kjaer et al. (2006) demonstrated differences in susceptibility according to the genetic background of the birds. These differences could be detected between genetic lines and between sire groups within one of the lines with a heritability estimate of 0.31 ± 0.12.

The objective of the present study was to investigate the development of FPD and its risk factors in Danish broiler flocks slaughtered between 2002 and 2008. By merging the meat-inspection data with flock data from the farm efficacy recording system and with antemortem control data, we were able to analyze the association between the occurrence of FPD and potential predisposing factors on a national level and over several years.

MATERIALS AND METHODS

Legislation and Broiler Management Practices

Since 2002, Danish broiler production has been subject to the Departmental Order on Broiler Husbandry and Production of Hatching Eggs (Ministry of Food, Agriculture and Fisheries of Denmark, 2001). Rules for surveillance and control of FPD are part of the Order. With reference to the Order, the Association of Poultry Producers (*Det Danske Fjerkræråd*) published a set of guidelines on good production practices (Poultry Advisory Board, 2003). These guidelines included a recommendation on temperature and humidity in the houses from before the introduction of the day-old chicks to slaughter. It is, for example, recommended that the poultry house should be heated for 2 d prior to the application of the bedding material to avoid condensation due to insufficient heating of the floor. A section on the water system gives recommendations on how to avoid water spillage.

Slaughter Data

As prescribed by the Departmental Order (Ministry of Food, Agriculture and Fisheries of Denmark, 2001), the veterinary inspection at the abattoirs scores a random sample of 100 birds from each flock after slaughter with regard to foot-pad lesions. One foot is examined per bird and scored as no lesions = 0, few and limited lesions = 1, several or serious lesions = 2. The flock score is in turn calculated from the formula below, leading to values between 0 and 200:

$$\text{flock lesion score} = 1 \times (\text{number of feet with score 1}) + 2 \times (\text{number of feet with score 2}).$$

The Departmental Order refers to 3 categories of flock scores. A flock lesion score below or equal to 40 is considered acceptable. If the score is between 41 and 80, the farmer is notified with a request to improve management, whereas a flock lesion score above 80 also leads to notification of the veterinary authorities.

Antemortem Data

The antemortem data were collected as part of a compulsory control of the flocks before slaughter. Originally the inspection was carried out by a veterinarian, but since 2001 the information is reported by the farmers to the abattoir. The evaluation is carried out around 5 d before slaughter, the form is sent to the abattoir and should be received "not later than 3 d before slaughter" (Poultry Advisory Board, 2003). The data contain information on bedding quality and skin/feather conditions. Information on the type of bedding material is available in the database from 2004 onward.

Flock Efficacy Monitoring Data

The flock efficacy control database ("e-kontrol") is a management tool involving all broiler flocks. The database contains information on stocking density, feeding, and growth as well as several variables not related to the present study.

Data Handling and Statistical Analysis

Data of foot-pad lesion flock scores were merged with antemortem and efficacy control data on the basis of the unique combination of farm identification number (so-called CHR number), within-farm house number, and within-house yearly rotation number. The initial database represented 27,208 flocks slaughtered from 2002 to 2008. Hereof, correctly recorded lesion scores were available from 24,164 flocks. The information from the antemortem database was available from 2004, and the statistical analysis of risk factors in the period 2004 to 2008 included 15,945 flocks with complete information.

The association between predisposing factors and flock foot-pad lesion scores was analyzed in a mixed-effect model (PROC MIXED, SAS version 9.1, SAS Institute Inc., Cary, NC). To improve the modeling assumptions (of normal distribution and variance homogeneity), the flock score was square-root transformed. The explanatory variables included in the final model were bedding material (straw, wood shavings, other), bedding quality assessed by antemortem assessment (considered good if no remarks were made and poor if the bedding was assessed as wet, crusty, or a combination thereof), quarter (winter, spring, summer, autumn), date of slaughter (continuous variable with d 0 = January 1, 2002), density (defined as high if peak stocking density was >40 kg/m^2, otherwise defined as

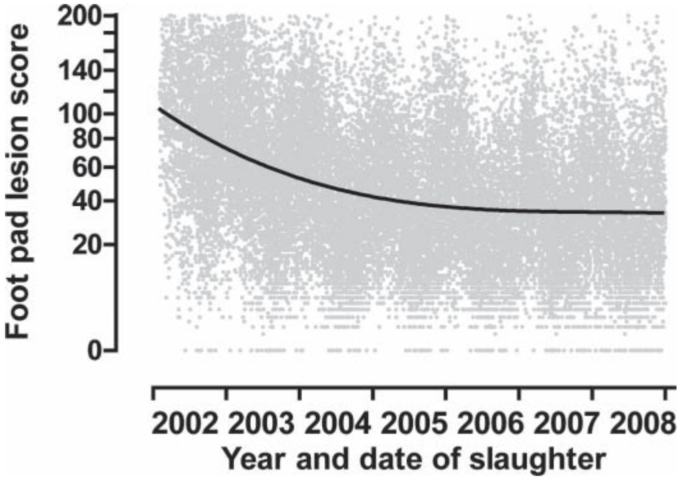

Figure 1. Individual flock foot-pad lesion scores (gray dots) in relation to the slaughter date in the period 2002 to 2008. The values are square-root transformed, whereas the labels on the vertical axis indicate the original nontransformed values. The solid line represents a cubic regression of the square-root-transformed data.

low), weight gain (defined as high if mean daily BW gain >56 g, otherwise as low) and age at slaughter (divided in 4 levels: <36, 36–38, 38–40, and >40 d, respectively). The bedding material category named other consisted mainly of flocks raised on sphagnum peat.

The initial statistical analysis showed significant differences in flock scores between slaughter houses and this factor was subsequently included in the final multivariate mixed effect model as a random effect. Slaughter houses that had slaughtered less than 1,000 flocks were excluded from the final analysis. Within-farm correlations were taken into account by specifying repeated measures on the farm level in the model.

A logistic regression model (PROC GENMOD, SAS version 9.1) was formulated for analysis of the effect of the risk factors specified above on the bedding quality assessed in the antemortem control. Bedding quality was considered good if the bedding was evaluated as dry, whereas the remaining categories of wet, crusted, and combinations thereof were merged to the new category poor. The reason to merge these categories was that there were relatively few observations in some of the original categories.

RESULTS

When analyzing the data for time trends, we observed a curvilinear decline in flock lesion scores (Figure 1). Initially, the mean flock score was above 80 (i.e., the limit for notification to the veterinary authorities). Thereafter, a rapid decline in flock lesion scores was observed in the period 2002 to 2005. This was followed by a minimal decline until 2008 with mean flock lesion scores stabilizing around 40. Marked seasonal oscillations were also observed.

With regard to background production data, the flocks were slaughtered at a mean age of 37.6 d (±2.1 d). The mean BW at slaughter was 2,118 g (±208 g). The mean daily weight gain calculated as the BW at slaughter divided by the age at slaughter was 56.3 g (±4.1 g). The mean flock density at slaughter was 40.1 kg/m^2 (±3.4 kg/m^2).

Data on type and quality of bedding material are presented in Table 1. It is seen that the farmers' choice of bedding material changed in the period 2004 to 2008. Whereas they mainly used straw for bedding in 2004, they gradually substituted this material with wood shavings and the category other, which mainly consisted of sphagnum peat. The bedding quality as assessed in the antemortem evaluation differed between years, but there was no overall positive or negative trend.

The mean flock lesion scores differed substantially according to the antemortem assessment of the bedding quality (Table 2). Because there were few observations in some of the categories, further analysis was based on only 2 categories of bedding quality (Table 3). The logistic regression of the effect of risk factors for poor bedding quality showed statistically significant effects of season ($P < 0.0001$) with the lowest risk in the second and third quarter as well as of low weight gain ($P < 0.0001$). The effects of bedding material, age at slaughter, and stocking density did not have any significant effect on bedding quality.

Table 1. Number of flocks raised on different types of bedding material and antemortem assessment of bedding quality by year[1]

	Type of bedding material				Quality	
Year	Straw	Wood shavings	Straw and wood shavings	Other (mainly sphagnum peat)	Good	Poor
2004	2,142	1,399	127	41	2,586	1,059
2005	1,520	2,030	157	66	2,654	1,069
2006	990	2,252	143	39	2,537	824
2007	634	2,069	133	538	2,371	899
2008	434	1,727	282	720	2,135	919

[1]Type and quality of bedding material data were available in the database from 2004. For the antemortem quality assessment, the category good was evaluated as dry in the original farm reporting form, whereas the category poor was reported as either dry but crusted, partially wet and crusted, partially wet but without crust formation, crusted, wet and crusted, or as wet.

Table 2. Mean flock foot-pad lesion scores according to the different categories of antemortem assessment of bedding quality[1]

Bedding quality	Flock lesion score			n
	Mean	Lower 95% CI	Upper 95% CI	
Good				
Dry	32.5	32.0	32.9	11,384
Poor				
Dry but crusted	47.2	45.8	48.6	2,660
Partially wet, crusted	51.4	47.5	55.5	309
Partially wet, no crusts	62.1	57.8	66.6	297
Crusted	70.2	66.9	73.6	597
Wet and crusted	84.8	76.6	93.5	116
Wet	88.9	80.1	98.2	112

[1]The means and CI are calculated on basis of the square-root transformed data and back-transformed to the original scale. The rows are presented in order of ascending foot-pad lesion scores.

The multivariate statistical model of the effect of risk factors on flock foot-pad lesion scores showed that flock lesion scores were highly associated with the quality of the bedding material ($P < 0.0001$, Table 4). Thus the category considered poor had a mean lesion score of 55.5 compared with 36.3 in the category considered good.

The analysis showed significant effects of the type of bedding material on flock lesion scores ($P < 0.0001$). The lesion scores of flocks raised on straw were significantly higher than those of flocks that were raised on wood shavings. The category other showed lower flock lesion scores than the flocks raised on straw bedding.

Season was among the most important predictors of high flock lesion scores ($P < 0.0001$). Thus, flocks slaughtered in the first and fourth quarters showed significantly higher lesion scores than flocks slaughtered in the second and third quarter (Table 4). This pattern is also reflected in the regular oscillations in flock lesion scores, which can be observed in Figure 1.

Low BW gain ($P < 0.0001$) and high age at slaughter ($P = 0.0136$) were both associated with higher lesion scores. The first of these factors was among those that contributed most to the between-flock variation, whereas the effect of age was more limited (Table 4).

The linear regression component for the effect of time in the statistical model showed no effect of time per se in the period from 2004 to 2008. However, the flock lesion scores increased in the wood shavings flocks ($\beta = 0.124$ square-root transformed scores per 365 d, $P < 0.0001$), whereas the flock lesion scores remained stable in the straw flocks ($\beta = 0.034$, $P = 0.221$) and the other flocks ($\beta = -0.022$, $P = 0.769$) and declining in the straw and wood shavings group ($\beta = -0.177$, $P = 0.026$). In the same period, there was a strong shift in choice of bedding material from straw to wood shavings (Table 1).

The effect of stocking density as a main effect was relatively small increase with increasing density ($P = 0.0303$). There was, however, a significant interaction between stocking density and quarter in the sense that a higher stocking density led to higher lesion scores in the summer quarters (Q2 and Q3) but had a slightly protective effect in the winter quarters (Table 4).

The estimates for the covariance of slaughter house (specified as a random effect in the statistical model) and farm (repeated observation on farm level, also modeled as a random effect) were 0.1222 and 1.3062, respectively (residual variance 4.321, values on the square-root transformed scale). The within-farm covariance thus exceeded the within-abattoir covariance. With regard to differences between slaughter houses, one abattoir showed considerably higher lesion scores than the others.

Table 3. Risk factors for poor bedding quality assessed by logistic regression[1]

Item	Odds ratio	Lower 95% CI	Higher 95% CI	P-value
Bedding material				= 0.8477
Quarter				<0.0001
1	1.1730	1.0434	1.3188	
2	0.7223	0.6437	0.8106	
3	0.7085	0.6356	0.7897	
4	1			
Weight gain				<0.0001
High	0.7838	0.7070	0.8689	
Low	1			
Stocking density				= 0.2103
Age				= 0.3496

[1]The quality of the bedding material was assessed as either poor or good (see Table 2 for details). The explanatory variables are extracted from Table 4.

Table 4. Results of the ANOVA for flock lesion score[1]

Item	Estimate	95% CI limits Lower	95% CI limits Higher	*P*-value
Overall mean	40.7	35.8	45.9	
Bedding quality				<0.0001
Good	36.3	32.5	40.3	
Poor	55.5	50.7	60.5	
Bedding material				<0.0001
Other (mainly sphagnum peat)	40.1	35.2	45.3	
Straw with wood shavings	47.1	42.3	52.2	
Wood shavings	37.3	33.5	41.3	
Straw	58.3	53.4	63.4	
Quarter				<0.0001
1	57.5	52.6	62.5	
2	41.9	37.7	46.2	
3	36.1	32.3	40.2	
4	47.3	42.9	51.9	
Weight gain				<0.0001
High (DBWG[2] > 56 g)	42.1	37.9	46.4	
Low	48.7	44.3	53.4	
Age				= 0.0136
Age $\leq$ 36 d	43.6	39.3	48.1	
36 < age $\leq$ 38 d	45.0	40.7	49.5	
38 < age $\leq$ 40 d	46.1	41.7	50.7	
Age > 40 d	46.7	42.2	51.5	
Stocking density				= 0.0303
Low ($\leq$40 kg/m^2)	44.8	40.5	49.3	
High	45.9	41.6	50.4	
Quarter (Q) $\times$ density				<0.0001
Q1, density low	58.0	53.0	63.2	
Q1, density high	57.0	52.0	62.1	
Q2, density low	40.4	36.2	44.8	
Q2, density high	43.3	39.0	47.8	
Q3, density low	34.7	30.9	38.8	
Q3, density high	37.6	33.6	41.8	
Q4, density low	47.7	43.1	52.4	
Q4, density high	46.9	42.4	51.6	

[1]The *P*-values and calculation of least-square estimates are based on the square-root transformed data, whereas the values stated in the table are back-transformed to the original scale.

[2]DBWG = daily mean BW gain.

DISCUSSION

The Danish program for control of FPD led to an impressive decline in flock foot-pad lesion scores in the period 2002 to 2005 followed by a minimal decline in the following years. The present study determined that poor bedding quality, flocks raised in the cold seasons, straw as bedding material rather than wood shavings and sphagnum peat, low weight gain, and high age at slaughter were significant predisposing factors for high flock lesion scores in the period 2004 to 2008. Unfortunately, not all predicting variables were available for 2002 and 2003, the years with the most dramatic decline, but we attribute this decline to the producers paying attention to the problem by change of practices such as better control of water spillage and thorough heating of the poultry houses before application of bedding material and reception of the day-old chicks. The implementation of the program also led to more emphasis on proper ventilation from the farmers' side. This was mainly in the form of optimization of existing systems rather than by substitution of equipment (C. Fisker, SKOV A/S, Roslev, Denmark, personal communication).

The lesion score system is based on visual examination of the feet, and it was therefore not a surprise to observe differences in the flock scores between slaughter houses. In our analysis, we handled these differences by including random effect of slaughter house in the statistical model. In previous studies, observer bias has been handled either by using the same observer for all observations (Ekstrand et al., 1997) or by analyzing the data set for observer differences (Martrenchar et al., 2002). Under routine conditions, it will be more difficult for the inspecting veterinarians and technicians always to reach the same results.

Our study stressed the importance of bedding quality on the development of FPD because bedding quality was the most important predictor for high lesion scores (Table 4). The bedding quality was assessed during the antemortem evaluation approximately 5 d before slaughter and was shown to depend on low BW gain and season, with the highest risk for poor bedding quality in the 2 winter quarters (Table 3).

We observed very marked seasonal variation in the occurrence of FPD. Thus, the highest lesion scores were found in the winter quarters (October to March) compared with the summer quarters (April to September).

During winter months, ventilation is reduced or the outdoor air drawn in through the ventilation system is colder than during summer months. The RH is therefore increased, leading to a higher moisture content of the bedding material. These findings are in agreement with Bruce et al. (1990), who found a higher incidence of contact dermatitis in the winter and with Ekstrand and Carpenter (1998a), who found a higher incidence of FPD in the winter.

Higher lesion scores were associated with using straw as bedding material rather than wood shavings and sphagnum peat. This is consistent with a study from Sweden (Ekstrand et al., 1997), which likewise found higher lesion scores when the birds were reared on straw compared with wood shavings. The difference observed in the Swedish study was, however, not statistically significant, possibly due to a limited number of flocks in their study. Also, a study from Alabama showed that the prevalence of food pad dermatitis varied significantly between 8 types of bedding material and the prevalence was associated with high litter moisture and caking scores (Bilgili et al., 2009). The type of bedding material did in our study not have a significant influence on the risk for development of poor bedding quality, meaning that the type of bedding material also may exert an effect on foot-pad lesion development, which is not directly visible in the antemortem assessment of bedding quality.

Farmers' choice of bedding material changed in the period 2004 to 2008. Whereas farmers mainly used straw for bedding in 2004, they gradually substituted this material with wood shavings and sphagnum peat. The observed decline in flock lesion scores in the period 2004 to 2008 may therefore largely be attributed to a gradual change in the choice of bedding material from straw to wood shavings. As farms with high foot-pad lesion scores may be more likely to change the type of bedding from straw to wood shavings, the latter category will receive the problem farms, and this may explain the apparent increase in flock scores in wood shavings group with time.

Stocking density was only moderately associated with higher lesion scores. There was, however, a significant interaction between stocking density and quarter, in the sense that a higher stocking density led to slightly higher lesion scores in the summer but higher stocking densities had a minor protective effect on the high scores found in the winter months. The underlying mechanism could be a beneficial effect of higher heat production on the bedding quality in the winter months. This finding is in line with the results of Martrenchar et al. (2002). However, stocking density only varied over a relatively narrow range in both the mentioned study and our study.

Higher BW gains were associated with lower flock lesion scores. The causal direction of this statistical association may be complex. First, foot-pad lesions are painful and may thus reduce feed-intake and lead to poorer production results. Second, higher BW gain may lead to shorter production time, better feed conversion, less nitrogen loss with the droppings, and thereby less risk of bedding problems. A lower nitrogen loss is also associated with lower urinary flow and thereby a lower water excretion (Ward et al., 1975). A third possibility is that the focus on bedding quality could have led to a reduced incidence of diseases such as coccidiosis and necrotic enteritis, thereby improving both productivity and foot health at the same time.

The results obtained in the Danish FPD program have shown that it is possible to reduce this welfare problem considerably. The findings also indicate that is may be difficult to obtain a complete elimination of the problem with the current interventions due to, for example, seasonal variations. Although it may be possible to control air quality completely by ventilation combined with heating, such a strategy will be very costly in terms of energy for heating. Additional strategies are therefore needed to obtain further reduction in FPD. One possibility might be to control the binding of nitrogen to the bedding material, as the ammonia production is linked to anaerobic conditions (Madigan et al., 2000) and the balance between ammonium and volatile ammonia depend on the pH of the bedding (Tasistro et al., 2008). Control approaches aiming at reducing the viscosity and water-holding capacity of the feces by adding feed enzymes cleaving nonstarch polysaccharides have so far been unsuccessful (Nagaraj et al., 2007). A promising complementary possibility may be to increase host resistance through selection of the birds (Kjaer et al., 2006). Most likely, further improvement will depend on the implementation of a range of different technologies.

ACKNOWLEDGMENTS

The databases were kindly extracted from the original sources by Jacob Bo Christensen (Danish Agriculture and Food Council, Copenhagen, Denmark).

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