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Case control study on environmental, nutritional and management-based risk factors for tail-biting in long-tailed pigs

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Abstract

*A case control study with a questionnaire was carried out to compare feeding practices, diet composition, housing and management in 78 herds with or without a history of tail-biting in undocked pigs (*Sus scrofa*) in Finland. Tail-biting was measured as the mean annual prevalence score of tail-biting damage (TBD) for a farm. Logistic regression parameters were calculated separately for risk factors present in piglet (lactation), weaner, and finishing units. Risk factors found in piglet units for TBD were slatted floors and area of slats. In the weaner units, slatted floors, area of slats, use of whey or wheat in the diet, and use of purchased compound feeds were associated with a risk of TBD. In the finishing units, slatted floors, area of slats, increasing number of finisher pigs at the farm, absence of bedding, liquid feeding, several meals per day, specialised production type and a group size greater than nine pigs were found as risk factors for TBD. Increased farm size was connected to risk for TBD in the overall dataset. The nutritional risk factors seem to operate together with other risk factors, but with relatively lower odds. The risk factors of undocked herds in this study seem to be similar to the risk factors from earlier studies of docked pigs. This study provides information which can be used to refine decision-support tools for management of the potentially higher risk for tail-biting among long-tailed pigs, thus aiding compliance with EU law and enhancing pig welfare.*

Keywords: *animal welfare, environment, feeding, pig, risk factor, tail-biting*

Introduction

Tail-biting is a behaviour that gives rise to serious animal welfare and economic problems in modern pig (*Sus scrofa*) production. Many environmental, feed-related or animal-based risk factors increase the likelihood of onset of tail-biting (for a review, see Taylor *et al* 2010). From an ethological point of view, tail-biting has been associated with a redirection of normal foraging or exploratory behaviour linked to other pigs' tails (eg Schrøder-Petersen & Simonsen 2001). The absence of suitable foraging material — feed, bedding or enrichment — is shown to make pigs redirect their exploratory behaviour from the ground to other pen items and pen-mates (Averos *et al* 2010), behaviours that appear in conjunction with an increased level of tail-biting behaviour (Day *et al* 2002). Solutions that satisfy pigs' needs for exploration, rooting and foraging are preferred in order to decrease the risk of tail-biting, but are not always practical from a farmers' point of view (D´Eath *et al* 2014).

Whilst there are many anecdotal reports of nutritional risk factors for tail-biting, both quantitative and qualitative in nature, there has been little research carried out on this subject using an epidemiological approach. Results which associate tail wounds or tail-biting behaviour with limited feeding space (Botermans & Svendsen 2000; Hunter *et al* 2001; Moinard *et al* 2003; Smulders *et al* 2008; Taylor *et al* 2012), feeding frequency (Botermans & Svendsen 2000; Hessel *et al* 2006; Taylor *et al* 2012; Temple *et al* 2012), deficits in diet quality or quantity (Fraser 1987; McIntyre & Edwards 2002; Beattie *et al* 2005; Temple *et al* 2012), form of the feed (Hunter *et al* 2001; Moinard *et al* 2003; Holmgren & Lundeheim 2004; Smulders *et al* 2008; Taylor *et al* 2012) or dysfunction of the feeder system (Paul *et al* 2007; Taylor *et al* 2012) do exist. In many cases these come from experimental studies, and there is limited evidence of their importance under practical farming conditions, where multiple risk factors are present simultaneously (Smulders *et al* 2008). The combined effect of environmental and nutritional limitations at farm level requires special attention for the risk of tail-biting to be comprehensively measured.

Most of the epidemiological investigations originate from short-tailed pigs, as tail-docking is widely carried out in the majority of European countries. A few epidemiological studies explore the relationship between tail-biting behaviour, or tail damage, and housing and feeding in long-tailed pigs (Hunter *et al* 2001; Moinard *et al* 2003; Holmgren & Lundeheim 2004). It is seldom mentioned whether the pigs were tail-docked or not, but many studies are carried out in countries where docking predominates, and only Holmgren and Lundeheim (2004) used farms with long-tailed pigs as the sole source in their study. Furthermore, Hunter *et al* (2001) and Moinard *et al* (2003) compared docked and undocked pigs. In these studies, it is likely that a variety of confounded factors influenced the risk of tail-biting. Farms with high-risk systems are more likely to be the ones that decide to dock, and thus Moinard *et al* (2003) found tail-docking to be associated with the magnitude of tail-biting risk.

Since the European Union has a stated objective of encouraging countries to reduce tail-docking (European Commission 2013), the requirement for knowledge on how to manage long-tailed pigs is growing. Although decreasing the probability of tail-biting, tail-docking in itself has negative implications for pig welfare through the experience of short- and possibly longer-term pain (eg Sutherland & Tucker 2011; Herskin *et al* 2015). Furthermore, tail-docking does not guarantee pigs safety from tail-biting. In Finland, tail-docking is forbidden, but pigs are raised predominantly in a way similar to the majority of pig-farming in the EU, contrary to countries, such as Sweden, Norway and Switzerland which have a more restrictive legislation regarding both tail-docking and pig housing and management. Finland, therefore, makes an interesting model country for studying risk factors for tail-biting in long-tailed pigs.

This study aims to measure the magnitude of risk of tail-biting damage associated with feeding practices, environmental factors and management, and diet composition concentrating on undocked pigs. The study method is a case-control questionnaire between herds with or without a history of tail-biting, in which logistic regression was used to estimate the effect of the studied factors on the risk of tail-biting wounds. Based on the generally accepted theory of a varied motivational background for tail-biting (Taylor *et al* 2010), it is hypothesised that most of the environmental and nutritional risk factors for tail-biting may still be identical to those in docked pig populations.

Materials and methods

Study design

This study was designed to identify risk factors for tail-biting using observed tail-biting damage as a measure of the magnitude of tail-biting at a farm. Based on this, farms were classified as case farms (more than average tail-biting damage) or control farms (no tail-biting damage). The study was separated into two sub-studies (later called the housing study and diet study), which both had their own questionnaires about potential risk factors for tail-biting. The housing study questionnaire had questions about feeding practices, environmental factors and management, and the diet study questionnaire had questions about the diet composition. Farms in the diet study are a subset of the farms in the housing study.

Selection of the farms

The farms were selected from the Finnish pig health register, called Sikava (run by Animal Health ETT, PL 221, 60101 SEINÄJOKI; www.sikava.fi), where a total of 1,954 farms were included. Sikava requires quarterly veterinary healthcare visits with estimation of the frequency of tail-biting damage (TBD). Tail-biting was diagnosed as the prevalence of pigs scored as having tail damage during these farm inspections.

Some farms had been visited by the healthcare veterinarian more, and some less, than four times a year (median 3; min 1; max 13). TBD was originally recorded using a five-point scale describing the amount of TBD: 0 = data missing; 1 = none; 2 = some TBD (1–5% of the pigs); 3 = plenty (6–19% of the pigs); and 4 = lots (over 20% of the pigs). Farms with missing TBD recordings were excluded. TBD was estimated using only one score per farm covering all age groups. There was no possibility of knowing the prevalence of TBD separately in piglet (lactation), weaner or finishing units. We used TBD data from a 12-month period: year one (Y1 from 1st May 2008 until 30th April 2009) or year two (Y2 from 1st October 2009 to 30th September 2010) to calculate a TBD mean value for each farm as the average of the yearly evaluations. TBD mean (± SD) of all farms was 1.84 (± 0.49) in Y1 (n = 1,954 farms) and 1.82 (± 0.48) in Y2 (n = 1,801 farms). The median of all observations was 2.00 within both studies.

For this study, a case farm was defined as a farm with TBD mean value of > 2.6 (Y1) or > 2.1 (Y2) and a control farm had a TBD mean value of 1. The criteria for a case farm of TBD mean above 2.6 in Y1 was chosen because this was the 95% percentile of all farms. The lower TBD limit for case farms was used for Y2 because there were not enough farms with a TBD mean above 2.6 in Y2. If the farm fulfilled the criterion in both years, but had participated in the study already in Y1, it was not re-invited to the Y2 study. The Y2 study with new farms was conducted only after it was determined that there were not enough farms participating in the study in Y1 for statistically reliable analyses. Since the Y2 study was carried out a year later than Y1, we needed to choose the Y2 farms by using their TBD data for the new corresponding period.

Invitation of herds for the housing study

Altogether, 289 case and 326 control farms fulfilled the criteria and were invited by letter to participate in the housing study. In Y1, a first reminder was sent by letter and a second by phone. No reminders were used in Y2 because here the purpose was not to achieve a specific number of farms but to increase the overall sample size from Y1.

Invitation of herds for the diet study

All invitations for the diet study were sent by letter in 2011, at the same time as Y2 farms were asked to join the housing study. Farms already participating in the housing study in Y1 were asked, at this point, to supplement their participation with the web-based diet questionnaire. No reminders were sent. In total, 350 Y2 farms and 49 Y1 farms were invited to the diet study. Altogether, 210 of them were case and 189 control farms.

Data collection

Housing study

An internet-based questionnaire (QuestBack™) was used to collect the data, unless the farm had asked specifically for an identical paper version. Seven farms were provided with the possibility of completing a pilot version of the questionnaire, after which final modifications were made for the main study. Questions were divided into the following categories (not shown to the respondents): general questions (farm-related), environmental questions (pen environment and enrichment use), feeding-related questions (feeds and feeding technique), and other questions. All questions were asked separately for the piglet unit (pigs from birth to weaning, approximately 0–10 kg), weaner unit (pigs after weaning but before finishing, approximately 10–25 kg) and finishing unit (pigs from approximately 25 kg to slaughter). A complete list of the original questions and options accompanying the questionnaire (before any combination of options for the analyses) can be seen in the Appendix (in the supplementary material to papers published in *Animal Welfare* on the UFAW website: https://www.ufaw.org.uk/the-ufaw-journal/supplementary-material). There were primary questions that every farm answered. Additionally, detailed sub-category questions were visible or invisible, depending on the farmers' answers to the primary questions. Where the sample size was insufficient for meaningful interpretation (power of 80%), these sub-category questions were not further analysed. The farmers' opinion about the tail-biting status of their farm was requested and compared with the TBD mean. Farmers did not report any major health problems in their herds at the time of the study.

Diet study

In the diet study, the questions were asked as a part of the internet-based questionnaire used in the housing study for Y2 farms, or a separate paper version for Y1 farms, both at the same time (2011). Information regarding the use of certain products were requested separately for piglet, grower and finishing units: barley, oats, wheat, rye, corn, other grains, soya bean, rape or turnip rape, peas, barley protein concentrate, whey (wet or dry), protein concentrate, limestone, feed phosphate, salt (NaCl), mineral mixture, vitamin mixture, amino acid mixture, or purchased compound feed (PCF). For PCF, we sought to identify the manufacturer, name of the product and production period. The recipes for PCF were then provided by feed manufacturers (Hankkija Agriculture Ltd, Raisioagro Ltd, A-rehu Ltd, Finland). For all type of feeds, statistical analyses were carried out using only the utilisation or otherwise of ingredients and not the accurate percentage of these in specific recipes.

Data management and statistical analysis

Within the housing study, the total response rate was 19% in Y1 and 12% in Y2 giving a total of 90 farms. Within the diet study, the total response rate was 13%. Eight herds were excluded as a result of changes in management and feeding practices during the time-period in which data recordings were collected. Four farms were removed for other reasons, such as inconsistency of answers or responding twice. Furthermore, if the questionnaire was completed incorrectly, the farm's answers for that particular production stage (piglet, grower or finishing stage) were removed from the study (n = 2, 9, 9 per stage, respectively), but the farm as whole was not excluded. The final housing study data consisted of a total of 78 farms from which farms included in the diet study are a subset (n = 50). The distribution of case to control farms in the final data set was 38 to 40 and 26 to 24 within the housing and diet studies, respectively. Within the housing study, 46 farms raised piglets (15 cases, 31 controls), 39 raised growers (14 cases, 25 controls) and 61 raised finishers (36 cases, 25 controls). Within the diet study, 24 farms raised piglets (nine cases, 15 controls), 29 raised weaners (ten cases, 19 controls) and 44 raised finishers (24 cases, 20 controls). Sample size calculations were carried out beforehand (only the housing study) and again afterwards (both the studies). Intended power was 80 and confidence of 95%. After completing data collection and excluding farms according to criteria listed above, the ratio between case and control farms was approximately 1:1 as intended beforehand within both studies.

General category questions including the number of adult animals (sows, finishers and boars) or finisher pigs on the farm, as the overall measurements of the size of the farm, were tested from the complete data set (n = 78 farms) against TBD status of the farm. After that, the data were divided into three separate data tables: answers to piglet unit questions; answers to weaner unit questions; and answers to finishing unit questions. An individual farm could answer regarding one or more unit questions, depending on their type of production (integrated or separated). The 'number of sows on farm' was tested as part of the piglet and weaner unit questions and the 'number of finisher pigs on farm' as part of the finishing unit questions, indicating the size of the specified unit. If there were no data given on number of animals on farm, imputation was made using the mean of all farms (Allison 2002). The same TBD status of the farm (case or control) was used as an outcome score in all the units' questions. Therefore, TBD status describes the whole farm situation regarding tail-biting, not the level of tail-biting observed within any separate unit.

Explanatory variables (questions) were first analysed against TBD (case-control) status using cross-tabulation to determine whether enough observations in each class were obtained, and see if there was an association between the exposure (variable) and outcome (TBD status). Answer choices within a question were combined into new groups if this was needed in order to obtain enough observations within cells (eg in the questions 'Do you have slatted floors' and 'How large is the slatted area' the original answer choices were 'less than 50%', '50%', 'more than 50%' and '100%', which were combined in the final data set into new groups of '1–49%' and '50–100%' compared to the option of '0%' as having no slatted floors). Only the final combined categories for each variable are presented within the results. Pearson Chi-square was used for categorical

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variables with only two levels, the likelihood ratio Chi-square test for variables with more than two levels and one-way ANOVA for continuous variables. After this, univariate logistic regression was applied to obtain unadjusted odds ratios (OR) and 95% confidence intervals (CI) for those variables significantly associated with TBD status ($P < 0.05$). The reference category, equal to odds ratio of 1.0, was defined as the answer choice (presence or absence of the exposure at farm) that was connected with a higher proportion of farms having control status. The model fit of each univariate model was tested using the hit ratio (% of observations estimated correctly) and the model coefficient of determination by Cox & Snell's R^2.

All significant variables' multicollinearity and the type of association was tested within the finisher unit risk factors. Possible nested structure of data was taken into account by using stratification. A confounding effect was defined, when both the variables associated with the outcome variable (tested with stratified bivariate cross-tabulation with status as outcome variable) and with each other (tested with Pearson Chi-square test without the outcome variable), if crude OR was outside the limits of the stratified ORs, and if the difference between the crude OR and Mantel-Haenszel OR was more than 10%. An interaction effect was defined, if crude OR was inside the limits of the stratified ORs. In the case of confounding effect, Mantel-Haenszel OR is reported, and in the case of interaction both the stratified ORs are presented in the *Results*.

Multivariate logistic regression could not be done, because the sample size for including interaction terms in the multi-variate model was too low. Moreover, factors with multi-collinearity were equal regarding their biological relevance but might not have mirrored the same biological mechanism, so no variable could be excluded from the model before another one without, at the same time, increasing the risk for incorrect choice. Otherwise, we might end up highlighting only some risk factors at the expense of others equally important in a biological sense.

SPSS 18.0 was used for all statistical analyses excluding sample size estimates and detailed variable multi-collinearity. Variable interaction and confounding were tested with Epi Info™ 7.1.0.6 (Centers for Disease Control and Prevention, USA) using StatCalc and 2 × 2 tables programmes, and with PS – Power and Sample Size Calculation (Dupont & Plummer 1990).

Results

Housing study

General information about farms is given in Table 1. Table 2 shows the univariate contingency table of the variables found to have a significant association with TBD status of the farm (case or control). For all the other variables, there was no association with TBD status ($P > 0.05$ for all), and these are not shown in Tables 2 or 3. In all the units, the risk factors were fully or partly slatted pen floor (SlattedF) compared to solid floor and the area of slatted floor (ASF) which was further divided into three categories (1–49 or 50–100% slats compared to solid floor). In addition, the following risk factors for TBD case status were found only in the finishing units: > 10 pigs compared to < 10 pigs in a pen (NpigsP), use of liquid feeding compared to dry feeding (LiquidF), absence of bedding material compared to presence of it (BeddingM), and type of production that had only finishing pigs compared to integrated units (TypeP). There was no significant difference in TBD status when comparing 'feeding in meals' and 'feed present all the time' *per se*. However, after recoding the variables, feeding *ad libitum* incurred an equal risk to one or two meals a day, resulting in 'more than two meals offered a day compared to one or two meals or *ad libitum* feeding without separate meals' (Nmeals) as a risk factor. Table 3 presents measures of the magnitude of the risk (odds ratios with confidence intervals), predictions of the model fit and model-derived significances for each individual risk factor for piglet, weaner and finisher units from univariate logistic regression.

An increasing number of adult pigs, and finisher pigs, on the farm was associated with a risk of TBD in the complete data set (n = 78 farms) prior to separating the data into categories according to the units present on the farm. In the piglet or grower units the number of sows was not associated with the risk for TBD ($P > 0.1$ for both, n = 46 and 39, respectively). In the finishing unit, the number of finisher pigs was associated with the risk for TBD (n = 61 farms).

The following variables (risk factors) in the finishing unit were observed to have multicollinearity with each other in the presence of TBD status as the outcome variable: SlattedF to LiquidF, SlattedF to BeddingM, SlattedF to Nmeals, Nmeals to LiquidF, Nmeals to BeddingM, Nmeals to TypeP, TypeP to NpigsP, and TypeP to LiquidF. In the piglet and grower units, there were no additional risk factor interactions to be examined.

In the finisher unit, having slatted floors increased the risk for TBD. Multicollinearity of SlattedF to BeddingM, Nmeals and LiquidF was found. After adjusting SlattedF for BeddingM, the risk of TBD caused by slatted flooring was reduced in farms using bedding (OR = 6.5, CI 1.5–28.8; $\chi^2 = 6.74$; $P < 0.05$; n = 41) whereas no change in OR was seen in farms not using bedding (OR = 8.0; CI 0.3–184.4; $\chi^2 = 2.14$; $P > 0.1$; n = 20) compared to all farms having slatted floors. After adjusting SlattedF to Nmeals, farms with '1 or 2 meals or *ad libitum* feeding' tended to have lowered risk of TBD associated with SlattedF (OR = 4.4, CI 0.8–23.6; $\chi^2 = 3.24$; $P < 0.1$; n = 27) in contrast to farms having 'more than two meals' where OR increased (OR = 9.2, CI 1.3–64.9; $\chi^2 = 6.05$; $P < 0.05$; n = 34) compared to all farms having slatted floors. Furthermore, SlattedF was found to be confounded with LiquidF. Therefore, having liquid feeding in the finisher unit turned out to reflect the risk for TBD instead of presence or absence of slatted floors (M-H OR = 6.1, CI 1.7–21.9; $\chi^2 = 7.9$; $P < 0.01$; n = 61). In farms not having liquid feeding, the risk of TBD was still associated with SlattedF but reduced compared to all farms having slatted floors (OR = 7.3, CI 1.5–36.7; $\chi^2 = 6.5$; $P < 0.05$).

Table 1 General descriptors about the whole farm and of separate units of those farms, based on questionnaire answers by the farmers.

		Units[1]		
	Farm	**Piglet**	**Weaner**	**Finishing**
Number of farms	78	46	39	61
Mean (± SD) number of adult animals at farm[2]	469 (± 650)	272 (± 490)	323 (± 569)	575 (± 698)
Mean (± SD) number of sows at farm	63 (± 205)	107 (± 265)	98 (± 282)	64 (± 230)
Mean (± SD) number of finishers at farm	398 (± 582)	152 (± 238)	212 (± 326)	502 (± 620)
Breed of the pigs (%)[3]				
Landrace	26.9			
2-crossbred	50.0			
3-crossbred	46.2			
Other	3.8			
Analysis of feeds or raw materials available (%)[4]				
Yes	74.4			
No	19.2			
How often are feeds or raw materials analysed (%)				
From every new material fed	11.5			
Yearly from every harvest	61.5			
More seldom than mentioned above	3.8			
Either no analysis or usage of full concentrates	23.1			
Who makes the feeding recipes (%)[4]				
Farmer	29.5			
Feeding company	37.2			
Farmer and feeding company together	28.2			
Advisor	3.8			
Someone else	1.3			
Production type (%)				
From birth to slaughter	46.2			
Specialised single type of production	53.8			
Is feeding automated (%)[4]				
Completely	38.5			
Partly	30.8			
Not at all	26.9			
What kind of tail-biting is there at farm (%)[5]				
Continuous	1.3			
From time-to-time	61.5			
No tail-biting at any time	33.3			
What proportion of pens have tail-biting incidents (%)[5]				
Less than half of the pens	100.0			
More than half of the pens	0.0			
How many pigs have been bitten in the pens (%)[5]				
A few pigs	91.8			
Half of the pigs	4.1			
Almost all pigs	4.1			

[1] Units in this study represent farms with a certain production phase, but might also have other phases;
[2] Adult animals includes sows, finisher pigs and boars;
[3] Farm can have more than one breed of pigs;
[4] The missing proportion are farms with no data available;
[5] Includes only those farms which have tail-biting.

Table 2 Distribution of farms and statistical significance within risk factors found to have association with tail-biting damage (TBD) status in the housing study, univariate analysis.

Factors	Categories	Cases/animals (n)	%	Controls/animals (n)	%	Statistical significance χ^2/G/F	df	P-value
General questions		n = 38		n = 40				
Number of adult pigs at the farm†	Mean (± SD)	742 (± 674)		208 (± 507)		15.8	1; 76	***
Number of finisher pigs at the farm	Mean (± SD)	693 (± 691)		117 (± 225)		25.0	1; 76	***
Piglet unit (0–10 kg)		n = 15		n = 31				
Slatted pen floor (fully or partly)	No	3	20.0	24	58.7	13.7	1	***
	Yes	12	80.0	7	22.6			
Area of slatted floor	0%	3	20.0	24	77.4	14.4	2	**
	1–49%	8	53.3	4	12.9			
	50–100%	4	26.7	3	9.7			
Weaner unit (11–30 kg)		n = 14		n = 25				
Slatted pen floor (fully or partly)	No	1	7.1	13	52.0	7.8	1	**
	Yes	13	92.9	12	48.0			
Area of slatted floor	0%	1	7.1	12	52.0	11.2	2	**
	1–49%	9	64.3	11	44.0			
	50–100%	4	28.6	1	4.0			
Finisher unit (31–110 kg)		n = 36		n = 25				
Slatted pen floor (fully or partly)	No	5	13.9	14	56.0	12.2	1	***
	Yes	31	86.1	11	44.0			
Area of slatted floor	0%	5	13.9	14	56.0	12.5	2	**
	1–49%	26	72.2	10	40.0			
	50–100%	5	13.9	1	4.0			
Pigs in one pen	Less than ten	14	38.9	17	68.0	5.0	1	*
	Ten or more	22	61.1	8	32.0			
Liquid feeding	No	14	38.9	18	72.0	6.5	1	*
	Yes	22	61.1	7	28.0			
Meals offered per day	1 to 2 or to appetite	11	30.6	16	64.0	6.7	1	*
	> 2 but not to appetite	25	69.4	9	36.0			
Presence of bedding	Yes	18	50.0	23	92.0	11.8	1	*
	No	18	50.0	2	8.0			
Number of finisher pigs at the farm	Mean (± SD)	729 (± 692)		174 (± 268)		14.5	1; 59	***
Type of production	From birth to slaughter	16	44.4	18	72.0	4.5	1	*
	Only finishers	20	55.6	7	28.0			

† Including sows, boars and finisher pigs;
*** $P < 0.001$; ** $P < 0.01$; * $P < 0.05$.

Absence of bedding material in the finishing unit was associated with increased risk for TBD, although BeddingM had an interaction effect with SlattedF. In farms with slatted floors, there was a decreased risk for TBD in the absence of BeddingM (OR = 10.7, CI 1.21–93.7; $\chi^2 = 6.1$; $P < 0.05$; n = 42) compared to all farms with the absence of BeddingM. In finisher units with solid floors, there only tended to be an effect of absence of bedding material on the risk for TBD (OR = 8.7, CI 0.58–130.1; $\chi^2 = 3.0$; $P < 0.1$; n = 19).

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Table 3 Univariate logistic regression, magnitude of the risk expressed as odds ratios (OR) and model statistics of the risk factors found for tail-biting damage (TBD) status from the housing study in case (n = 38) and control (n = 40) farms.

Factors	Categories	Ref[1]	Unadjusted (crude) OR	CI (95%)	Hit ratio (%)	Cox & Snell (R^2)	*P*-value
General questions							
Number of adult pigs at the farm[2]			1.003	1.001–1.005	78.2	23.6	**
Number of finisher pigs at the farm			1.006	1.002–1.009	79.6	35.5	***
Piglet unit (0–10 kg)							
Slatted pen floor (fully or partly)	No	†	1.0				
	Yes		13.7	3.0–62.7	78.3	26.6	**
Area of slatted floor	0%	†	1.0		78.3	26.9	
	1–49%		16.0	2.9–87.4			**
	50–100%		10.7	1.6–72.7			*
Weaner unit (11–30 kg)							
Slatted pen floor (fully or partly)	No	†	1.0				
	Yes		14.1	1.6–124.6	66.7	20.8	*
Area of slatted floor	0%	†	1.0		71.8	24.9	
	1–49%		10.6	1.2–97.6			*
	50–100%		52.0	2.6–1,033.8			*
Finisher unit (31–110 kg)							
Slatted pen floor (fully or partly)	No	†	1.0				
	Yes		7.9	2.3–27.0	73.8	18.3	**
Area of slatted floor	0%	†	1.0		73.8	18.8	
	1–49%		7.3	2.1–25.5			**
	50–100%		14.0	1.3–150.9			*
Pigs in one pen	Less than ten	†	1.0				
	Ten or more		3.3	1.1–9.8	63.9	8.0	*
Liquid feeding	No		1.0				
	Yes		4.0	1.3–12.1	65.6	10.3	*
Meals offered per day	1 to 2 or to appetite	†	1.0				
	> 2 but not to appetite		4.0	1.4–11.9	67.2	10.5	*
Use of bedding	Presence	†	1.0				
	Absence		11.5	2.4–56.2	67.2	19.6	**
Number of finisher pigs at the farm			1.004	1.002–1.007	78.7	30.4	**
Type of production	From birth to slaughter	†	1.0				
	Only finishers		3.2	1.1–9.6	62.3	7.3	*

[1] Reference category, identified as †;
[2] Including sows, boars and finisher pigs;
*** $P < 0.001$; ** $P < 0.01$; * $P < 0.05$.

Number of meals (Nmeals) in the finishing unit had a significant effect on TBD. *Ad libitum* feeding was described as 'having free access to feeds all the time' and meal feeding as restricted feeding where 'feed was not present all the time' even though the individual meal size could have been calculated according to the appetite of the pigs. Nmeals showed multicollinearity to LiquidF, BeddingM, TypeP and SlattedF. After adjusting Nmeals to LiquidF, farms with liquid feeding tended to have increased risk for TBD if pigs were fed more than twice a day at the same time (OR = 8.4,

Table 4 Distribution of farms and statistical significance within risk factors found to have association with tail-biting damage (TBD) status in the diet study, univariate analysis.

Factors	Categories	Cases (n)	%	Controls (n)	%	Statistical significance		
						χ^2/G/F	df	*P*-value
Piglet unit (0–10 kg)[2]	Total farms (n)	n = 9		n = 15				
Weaner unit (11–30 kg)	Total farms (n)	n = 10		n = 19				
Use of purchased compound feed	No	2	20.0	12	63.2	4.89	1	*
	Yes	8	80.0	7	36.8			
Use of wet or concentrated whey[1]	No	3	37.5	10	83.3	4.43	1	*
	Yes	5	63.5	2	16.7			
Use of wheat	No	0	0.0	6	31.6	3.98	1	*
	Yes	10	100.0	13	68.4			
Finisher unit (31–110 kg)[2]	Total farms (n)	n = 24		n = 20				

[1] Farms that used unknown concentrated protein source were not included, n = 9;
[2] No statistically significant risk factors were found;
* $P < 0.05$; [ns] $P > 0.05$.

CI 0.63–112.1; $\chi^2 = 3.3$; $P < 0.1$; n = 29). There was no interaction effect in farms not having liquid feeding (OR = 1.4, CI 0.3–7.0; $\chi^2 = 0.17$; $P > 0.1$; n = 32) compared to all pigs being fed more than twice a day. When Nmeals was adjusted to BeddingM, in farms with absence of bedding material, the association with Nmeals to TBD could not be calculated because of a low number of observations (OR = undefined; $\chi^2 = 0.74$; $P > 0.1$; n = 20) but in farms with presence of bedding material there was a protective effect against TBD of BeddingM in 'more than twice fed pigs' (OR = 4.6, CI 1.2–17.2; $\chi^2 = 5.33$; $P < 0.05$; n = 41). Having all age categories of pigs present in the herd seemed to be confounded with number of meals so that the true risk for TBD was caused by the TypeP, not NMeals (M-H OR = 3.0, CI 0.9–10.0; $\chi^2 = 3.3$; $P < 0.1$; n = 61). SlattedF was also confounded with NMeals, so that having slatted floors caused the true risk for TBD (M-H OR = 2.7, CI 0.8–8.9; $\chi^2 = 2.8$; $P < 0.1$; n = 61).

Type of production (TypeP) in the finishing unit analysis was associated with TBD. However, TypeP had an interaction with LiquidF and NpigsP. After adjusting TypeP to NpigsP, if having 'less than 10 pigs per pen' the risk for TBD caused by having only finisher pigs was increased (OR = 12.0, CI 1.2–117.4; $\chi^2 = 6.0$; $P < 0.05$; n = 31), compared to all finisher farms independently of NpigsP. In farms having '10 or more pigs per pen' there was no interaction effect observed with TypeP on the risk of TBD (OR = 0.6, CI 0.1–3.6; $\chi^2 = 0.34$; $P > 0.1$; n = 30). Adjustment of TypeP to LiquidF tended to increase the risk for TBD in finishing farms with no liquid feeding (OR = 4.4, CI 0.7–27.8; $\chi^2 = 2.79$; $P < 0.1$; n = 32) compared to all finishing farms. There was no interaction effect of TypeP and LiquidF in finishing farms using liquid feeding on the risk of TBD (OR = 0.9, CI 0.1–5.6; $\chi^2 = 0.03$; $P > 0.1$; n = 29).

Use of liquid feeding in the finisher stage was significantly associated with TBD. LiquidF had interaction with NM and TypeP. There tended to be increased risk for TBD in farms with liquid feeding and more than two feeding times (OR = 4.2, CI 0.8–22.9; $\chi^2 = 2.98$; $P < 0.1$; n = 34) compared to all liquid-fed pigs. In farms having '1 or 2 meals or *ad libitum* feeding' we found no interaction with LiquidF (OR = 0.7, CI 0.1–8.8; $\chi^2 = 0.08$; $P > 0.1$; n = 27). Within the interaction of LiquidF and TypeP, having all age of pigs at a farm where finisher pigs were fed with liquid feed increased the risk for TBD (OR = 6.2, CI 1.1–36.6; $\chi^2 = 4.64$; $P < 0.05$; n = 34) compared to all farms having liquid feeding. In farms having only finisher pigs there was no interaction with LiquidF in the finisher unit (OR = 1.2, CI 0.2–8.2; $\chi^2 = 0.03$; $P > 0.1$; n = 27).

The number of pigs in one finisher pen (NpigsP) was associated with the risk of TBD, when 'less than ten pigs', '10 to 19 pigs' and '20 or more pigs' per pen were used as variable categories in the raw data (the questionnaire). The prevalence of having more than 20 pigs per pen turned out to be only five per cent. However, there was an interaction between NpigsP and TypeP. The risk for TBD caused by larger group size (10–19) was higher in farms having pigs of all age (OR = 8.0, CI 1.4–46.8; $\chi^2 = 6.17$; $P < 0.05$; n = 34) compared to all production types. In farms with only finisher pigs there was no interaction effect with NpigsP on the risk for TBD (OR = 0.4, CI 0.0–4.0; $\chi^2 = 0.67$; $P > 0.1$; n = 27) compared to all production types.

Diet study

No association was found in piglet and finishing units between TBD status of the farm (case or control) and use of different feed ingredients ($P > 0.05$). Within the grower unit we found use of purchased compound feed (PCF), whey and wheat to be associated with TBD status (Table 4). The use

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Table 5 Univariate logistic regression, magnitude of the risk expressed as odds ratios (OR) and model statistics of the risk factors found for tail-biting damage (TBD) status from the diet study in case (n = 26) and control (n = 24) farms.

Factors	Categories	Ref[1]	Unadjusted crude OR	CI (95%)	Hit ratio (%)	Cox & Snell (R^2)	*P*-value
Piglet unit (0–10 kg)							ns
Weaner unit (11–30 kg)							
Use of purchased compound feed	No	†	1.0				
	Yes		6.9	1.1–41.8	69.0	16.3	*
Use of wet or concentrated whey[2]	No	†	1.0				
	Yes		8.3	1.03–67.1	75.0	20.1	*
Use of wheat	No	†	1.0				
	Yes		im	im	im	im	im
Finisher unit (31–110 kg)							ns

[1] Reference category, identified with †;
[2] Farms that used unknown concentrated protein source were not included, n = 9;
im: impossible to measure;
* $P < 0.05$.

of whey and presence of liquid feeding was investigated because farms that have liquid feeding often use industrial by-products, such as wet whey as an ingredient of the liquid feed mixture. There were only two farms having liquid feeding in the grower unit and neither of them used whey, so no apparent confounding connection could be found. The interaction between use of PCF and use of whey or wheat in the grower unit seemed to be likely, but this was impossible to test statistically due to too few farms divided according to use of PCF. In farms using PCF, 46 and 93% had whey or wheat in the grower diet, respectively. From those farms, whey was used in four out of seven case farms and in two out of six control farms. Wheat was used in seven out of seven case farms and in six out of seven control farms. The odds ratios of statistically significant diet-related risk factors for TBD are reported in Table 5.

Discussion

In this study, we used the Finnish pig health register 'Sikava' to select case farms that had more than average tail-biting damage (TBD), and control farms with no observed tail-biting damage. Making use of an internet questionnaire, farm management factors related to feeding, environment and diet choices for pigs of different age categories were elucidated. The aim was to identify and quantify risk factors that might be the potential source of tail-biting at these farms. The level of tail-biting could only be defined at whole farm level; thus, each farm only had one value of TBD as tail-biting present (case) or absent (control) on-farm. The risk factors were analysed at production stage level (piglet, weaner or finishing unit), independently of the unit in which TBD was observed.

We found environment-related (slatted floors, the slatted area, absence of bedding, moderate to large group size), management-based (type of production, number of finisher pigs at farm) and feeding-related (liquid feeding, number of separate meals, use of whey or wheat or PCF for grower pigs) risk factors of TBD, located mostly in the finisher unit. The magnitude of the risk for TBD seemed to be higher within the first category (environment), measured by the univariate crude odds ratios, but several interaction effects between these different categories complicated interpretation of the findings.

Risk factors for tail-biting from the housing study

Environmental risk factors

Slatted floors within each production stage were found to be associated with increased risk for TBD in this study. Completely solid floors were rare (7–20%) within the case farms, whereas they were relatively common (52–77%) within all the control farms in each production stage. Solid floors have been shown to decrease time spent expressing negative social behaviours (Averos *et al* 2010). In weaner and finishing pigs, the risk of TBD associated with slatted floors also increased as the area of slats increased, although the confidence intervals of odds ratios for slatted areas were wide. Fully slatted floors were reported to increase tail-biting in contrast to partly slatted floors by Ruiterkamp (1985). In contrast, we found that in piglets, during lactation, having 1–49% slats in the pen area increased the risk for TBD more than having at least half-slatted floors compared to solid floors. This observation cannot be easily explained, but may result from only a few farms having a slatted area of more than 49%. In contrast to our results, Moinard *et al* (2003) found a significant difference only in the comparison between presence and absence of slats, not in the area of slats.

We found absence of bedding material in the finishing unit to be a risk for TBD, corresponding well to previous studies (Beattie *et al* 1995; Hunter *et al* 2001; Moinard *et al* 2003). In this study, 'presence of bedding' was clarified in the questionnaire as 'having bedding material put on the pen floor suitable to absorb the moisture; not only for enrichment or to play with'. None of the studies cited above defined the amount of bedding provided to pigs. Even moderate bedding decreased the tail lesion index of undocked finisher pigs in the study of Munsterhjelm *et al* (2009).

In the report from EFSA (2007), risk caused by slatted floors was not reported individually but in connection with use of straw, which might be of practical relevance. These types of feeding- and environment-related relationships between multiple factors affecting tail-biting behaviour are well described in the review by D´Eath *et al* (2014). In our study, there were many interaction effects between floor type, use of bedding material and management of feeding, adjusting the odds of single risk factors for TBD. The risk for TBD associated with slatted flooring increased in magnitude when pigs were fed more than twice a day. When pigs are fed in many separate, small meals, they might experience post-meal hunger resulting in increased expression of foraging behaviour. In an environment with slatted floors, lack of a sufficient amount of chewing material is common and pigs are unable to fulfil their need to forage and explore, leading them to redirect their appetitive and exploratory behaviours from the ground to other animals (Averos *et al* 2010). This attentional shift increases the risk for two-stage tail-biting behaviour (Taylor *et al* 2010). In addition, escalated competition at feeders (possibly multiple times a day), is a potential source of sudden, forceful tail-biting (see Taylor *et al* 2010). In a situation where there is competition for feed, edible bedding materials as a source of non-nutritional fibre can also work as a buffer against digestive tract discomfort (Taylor *et al* 2010) and provide satiety for the pigs (Bolhuis *et al* 2010). This might explain the additive effect of the number of meals and slatted floors, and protective effect of bedding in pens with slats, on the risk for TBD.

Moderate to large group size in pens was associated with increased risk of TBD, although the majority of farms (95%) reported having group size below twenty pigs. Holmgren and Lundeheim (2004), who found that an increase of one pig to the group increased the prevalence of tail-biting by +0.2% with long-tailed pigs, suggested that this was a consequence of an increase in the number of potential victim pigs. Crowding and large group sizes increases the exposure of one pig to other pigs' bodies and tails (Fraser 1987; D'Eath *et al* 2014), and makes the copying of biting behaviour more likely (Fraser 1987). Furthermore, pathogens spread more rapidly with multiple animals close to one another, and tail-biting has been shown to be associated with general health problems (Schrøder-Petersen & Simonsen 2001; Moinard *et al* 2003; Niemi *et al* 2011), increased respiratory diseases (Moinard *et al* 2003; Sihvo *et al* 2012; Munsterhjelm *et al* 2013) and mortality (Moinard *et al* 2003). Large group sizes are suggested to induce fear, stress and damaging behaviour in animals that would naturally live in smaller groups (Rodenburg & Koene 2007).

It should be borne in mind that the found risk factor of moderate to large group size is discussed here only in connection to the number of animals in a certain restricted space, although other factors may be influenced by this. The potential risk of large group size increasing tail-biting behaviour might be linked to limitations in feeder space or the amount of supplied manipulable materials in the pen or to increased stocking density (Moinard *et al* 2003; D´Eath *et al* 2014). The first of these (feeder space) was not identified as a risk factor in our study. Of the finishing farms, 78% used feed troughs and the great majority of them (92%) reported that finisher pigs were able to eat simultaneously for the whole finishing period. However, Schmolke *et al* (2003) found no effect of group sizes between ten and eighty pigs on TBD or feed intake even if there was only one feeder for every ten pigs. The second factor (manipulable material quantity) and the last one (stocking density) were not investigated in the questionnaire. Farms with higher group size might also have higher stocking density, which is often mentioned as a source of tail-biting (Jericho & Church 1972; Moinard *et al* 2003; Taylor *et al* 2012). However, farms might have varying stocking densities due to other environmental issues, such as pen layout, feeder type, availability of the feeding space, or in accordance with the weight of the pigs. In order to keep the questionnaire as simple and easy-to-answer as possible, and without needing to visit farms personally, these sorts of complex variables were not included. However, farms were expected to follow the Finnish legislation of having a minimum of 0.40 m^2 floor space (piglet and grower stage, 0–30 kg) or 0.60–1.00 m^2 floor space (fattening stage, 31–130 kg) per pig (Finlex 2012).

Feeding-related risk factors

Although this study was aimed at identifying potential feeding-related risk factors for TBD using detailed questions about feeding technique, type of feed and manufacturing of the feed mixtures, only two feeding-related risk factors were found: the use of liquid feed and offering more than two meals a day in the finishing unit. Feeding-related risk factors were not found in the piglet or grower units.

Jericho and Church (1972) were the first to report that *ad libitum* feeding reduces tail-biting. In our study, meal feeding with more than two meals a day in the finisher unit was observed to increase risk for TBD. We suggest that our result might be a consequence of dividing the same amount of feed into several small portions, resulting perhaps in pigs remaining hungry after a meal, as described earlier in the *Discussion*. Increasing the number of meals has also been connected with growing competition at the feeder, antagonistic behaviour and increased skin lesions (Hessel *et al* 2006). Temple *et al* (2012) found time-restricted feeding systems to be associated more with severe wounds than *ad libitum* feeding systems. Furthermore, an increase in the frequency of feeding from two to four times a day induced larger relative risk of tail-biting compared to feeding only once or twice a day (Temple *et al* 2012). This strengthens the conclusion that multiple, time-restricted feeding might increase the risk of tail-biting in our study case farms.

Similarly to our findings, liquid feeding was recognised as predisposing to tail-biting in studies by Bracke *et al* (2004) and Temple *et al* (2012), although contradictory results also exist (Hunter *et al* 2001; Moinard *et al* 2003; Smulders *et al*

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2008). Liquid feeding might, despite its beneficial effects on growth, nutrient utilisation and gastrointestinal tract health (for a review, see Scholten *et al* 1999), be a potential source of tail-biting because synthetic amino acids may be degraded during storage of fermented feed (Pedersen *et al* 2002), and a lack of protein or amino acids is associated with being attracted to the taste of blood (Fraser *et al* 1991; McIntyre & Edwards 2002) and tail-biting (Jericho & Church 1972). Diet nutrient content is also more variable with liquid feeding, due to the availability of industrial by-products, which is known to induce tail-biting behaviour (Fraser 1987). Managing the liquid feeding system requires more engineering skills from the farmer and there is a source of error in managing the mixing process and delivering homogenous feed to all the pens in the building (de Lange *et al* 2006). Decreased dry matter content of feed provided in some pens can prevent satiety after a meal, which can increase restlessness and aggressive behaviour (Bolhuis *et al* 2010), both of which are behaviours observed in tail-biting pens (Zonderland *et al* 2011).

The risk for TBD caused by the use of liquid feeding tended to increase further when the daily ration of feed was divided into several small meals, and in addition the risk for TBD caused by having more than two meals tended to increase in liquid-fed pigs. This might also be the result of the relationship between these two factors under practical farm conditions: liquid feeding is automated whereas dry feeding is mostly organised without any, or only some, automation (bearing in mind that the majority of farms had feed troughs, not one- or multi-space feeders). The number of working hours required by the farmer to feed by-hand is likely to limit the number of meals offered. Altogether, 90% of finisher farms using liquid feeding had more than two meals a day, whereas 75% of farms feeding the pigs with dry feeds had meals only once or twice a day, or feed present at all times, which explains the additive effect of the risk factors observed within our data. Furthermore, having these two risk factors present at the same time, combines two potential sources of stress to the pigs, if liquid feeding and having many small meals causes lack of satiety (low-density diet) and competition at feeders several times during the day.

The risk of TBD connected to use of liquid feeding at the finisher stage (25–110 kg) was pronounced in integrated farms. When only finishing pigs were present the risk was not significantly connected to TBD at all. One reason for this interaction could be that piglets experience a change from dry to liquid feeding at the time of the transition into the finishing unit, as sudden changes in diet are known to induce tail-biting (Day *et al* 2002). This was tested statistically, but there was no effect of the change in feed type on TBD (data not shown). However, it is possible that the interaction and its effect on TBD was more affected by the size of the farm (measured as the number of pigs) than by type of production itself. This might be because liquid feeding is known to be more common in large farms, and an increased number of finisher pigs was connected to the risk for TBD in our study. These were all recognised as risk factors for tail-biting by Moinard *et al* (2003).

Management-related risk factors

The total number of adult pigs (sows, boars and finisher pigs) as well as the number of finisher pigs on-farm were connected to the risk for TBD in the overall data of farms (n = 78). Increasing farm size by 100 pigs was associated with a 0.3 or 0.6% increase in odds of TBD, respectively. In addition, the number of finisher pigs on-farm was associated with a 0.4% increase in the odds of TBD in farms having a finishing unit. Farm size, even though a significant risk factor for tail-biting, had a relatively small practical influence. This is in accordance with Moinard *et al* (2003), who found a 1.01-fold increase in the risk of tail-biting as the number of pigs slaughtered weekly increased by one. Increased number of pigs and pens per stockman is another risk factor for tail-biting connected with larger farms (Moinard *et al* 2003). Since number of sows was not associated with risk of TBD in the piglet or weaner unit analyses, it may be speculated that the size of the finishing unit better describes the farm situation with tail-biting than the size of the piglet or weaner units. Severe tail-biting is observed more often among weaned piglets and finishers (Bracke *et al* 2004) than in young suckling piglets, but this is suggested, in part, to result from the fact that pre-weaning tail-biting behaviour may not cause clearly visible wounds and therefore not perceived problematic (Ursinus *et al* 2014). There is a possibility that the TBD status of the farm (case or control) in this study was most clearly — or even completely — an outcome of the amount of tail-biting present at the finishing stage. There were only two TBD status case farms that had no finishing unit at all, compared to 13 case farms with both piglet and finishing units. However, as it has been hypothesised that early life experiences affect injurious behaviours such as tail-biting later in life (Schrøder-Petersen & Simonsen 2001; Moinard *et al* 2003; Munsterhjelm *et al* 2009), the effect of piglet or weaner unit environment or feeding should not be excluded completely when evaluating the reasons for tail-biting problems at the same farm in later stages.

Farms raising only finishers were associated with a greater risk of TBD in the finisher unit compared to integrated farms. The reason for the greater risk of TBD in farms raising only finishers might be simultaneous changes in environment, diet, human contact and social grouping when pigs are delivered from one farm to another according to their age — even three times in a lifespan. The pigs originating from the same farm might not experience stress associated with these changes. Transportation of pigs by truck from elsewhere, compared to pigs being walked within the farm, at the beginning of the weaning-finishing period was observed as a risk factor for tail-biting in Moinard *et al* (2003). The interaction between type of production and use of liquid feeding or number of meals, as described earlier, might demonstrate the overall effect of stable environmental- and feeding-related solutions to work against general stress factors as potential triggers for tail-biting behaviour.

The link between a further elevated risk for TBD and larger group size in integrated farms is difficult to explain. It was shown that farms with units for all ages of pigs tended to show smaller group sizes (less than ten pigs) in the finisher pens, whereas farms having only finisher pigs had moderate to large group sizes (ten pigs or more) in the finisher pens. There might have been a third, unknown factor causing this effect, such as diverse technical-, environmental- or feeding-related management solutions in farms having one of the two production types. These type of three dimensional interactions remained unsolved because there were too few farms for statistical analysis and therefore no regression models covering all the risk factors could be used. Taylor *et al* (2012) observed that even farms with good management practices regarding prevention of tail-biting might have deficiencies in other areas influencing the overall risk of tail-biting on the farm.

Risk factors for TBD from the diet study

In this study, purchased compound feeds (PCF) fed in the weaner unit were associated with increased risk for TBD. Giving PCF to pigs at the weaner stage might be due to the practicality, or an attempt to increase diet quality or digestibility, aiming at achieving the optimal daily growth potential. However, Berrocoso *et al* (2012) questioned the benefit of complexity of feeds in the starter phase. PCF are usually supplemented with pure amino acids and minerals as pre-mix, which makes them more nutrient dense feeds than farm-made mixtures. Weaner pigs are suggested to suffer from endotoxin stress if fed high-energy dense diets, causing them to become more predisposed to become tail-bitten (Jäger 2013). Moreover, PCF are usually pelleted, a form of feed that has been connected with increasing risk for tail-biting in long-tailed pigs (Hunter *et al* 2001), although pelleted feeds were not found as a risk factor in our study.

Use of wheat and use of PCF were interconnected because wheat was included in almost all PCF for its higher energy value and digestibility in young animals compared to barley and oats, which are the most common grains used in farm-made feed mixtures. Use of wheat for weaner pigs was found to be a risk factor for TBD although, whereas all case farms had it included in the diet, this was also true for two-thirds of the control farms. Wheat has been associated with possible tail-biting-predisposing gut disorders, such as gastric ulcers and nutrition-induced colitis (Nielsen & Ingvartsen 2000; Thomson 2009). However, it is possible that finding use of wheat as a risk factor for TBD may be a confounding effect of usage of ground and pelleted wheat in PFC, not necessarily a true risk associated with provision of the separate ingredient by itself.

There is a suggestion, in the literature, of an association between liquid whey in feeds and tail-biting (Holmgren & Lundeheim 2004). In our study, whey was reported to be used only as dry condensed powder, mostly as an ingredient of PCF or protein concentrate. It was not used with liquid feeding, so there was no interaction between liquid feeding and whey in determining the risk of TBD. Dry whey increased the risk for TBD in dry feeding systems among weaner pigs. Although whey is shown to have beneficial effects on growth after weaning (de Lange *et al* 2006), possibly due to its high lactose content helping the shift from maternal milk to external feed source (Berrocoso *et al* 2012), whey could be a risk factor for tail-biting because it has been reported to have varying sodium and potassium content and might induce salt poisoning if water supply is limited (de Lange *et al* 2006), which was not reported by our farms. A variable level of NaCl in the diet is suggested to be associated with tail-biting behaviour (Fraser 1987). An interaction between PCF and whey seems likely, but remains unknown because we had too few observations for further analyses.

Animal welfare implications

EU Commission Directive (EC 2001/93, article 8 of the annex) states, that tail-docking should not be routinely applied but inappropriate environmental conditions or management systems must first be avoided. This study gives farmers further information to manage the potentially greater risk for tail-biting among the long-tailed pigs in order to better conform to EU legislation. It indicates that the sources of risk for tail-biting that the farmers need to concentrate on will not differ greatly if the tails are left undocked in the future. Tail-biting has been considered a problem for decades, and most of the risk factors, by now, are well known so there may be no need for new instructions and, instead, time, work, and resources are required to promote further observation and avoidance of these risks under farm conditions. Minimising these risks might at the same time improve the welfare of pigs by allowing them to fulfil their behavioural and nutritional needs that, if compromised, might lead to various undesirable behaviours.

Conclusion

In light of our results, and how closely they resemble those from epidemiological studies published earlier, there appears to be great similarity between tail-biting risk factors for both short- and long-tailed pigs. The nutritional risk factors for tail-biting damage operate through interactions with environmental- and management-based risk factors, but with relatively lower odds. Interactions of multiple risk factors were apparent. The diet that pigs ate after weaning, but before the finishing stage, was found to include components that increased the risk for tail-biting damage at farm level.

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