Associations between claw lesions and reproductive performance of sows in three Greek herds

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ABSTRACT: Claw lesions, which are nowadays very common in sows, are associated with a high risk of early culling and compromised welfare. In this study, we investigated the associations between the severity of claw lesions and three of the most important reproductive indicators, the number of live-born and weaned piglets and the wean-to-first service interval in three Greek farrow-to-finish herds. All studied sows were individually housed during their previous gestations. Sows were examined for lesions, which were scored on a severity scale, on several anatomical sites of the claws, before farrowing. Data on the examined reproductive indicators were retrieved from productivity databases of the herds. Because scoring of lesions on several claw sites resulted in many correlated variables for each sow examined, we employed factor analysis to create a smaller set of uncorrelated variables (factors) which contained all the information in the original variables and produced the corresponding factor scores. The number of live-born and weaned piglets was associated with the produced factor scores in two multivariable linear regression models, whereas the possible associations between the wean-to-first service interval and the factor scores was modelled with the use of zero-inflated negative binomial regression. The number of live-born piglets was negatively associated with factor scores representing lesions on heel ($P \leq 0.001$) and sole of front feet ($P = 0.019$). The number of weaned piglets was also negatively associated with factor scores representing lesions on heel ($P = 0.003$) of any foot, on sole of front feet ($P = 0.001$) and on white line, sole and wall of rear feet ($P = 0.008$), while the wean-to-first service interval was associated with factor scores representing lesions on heel of any foot ($P = 0.02$), on sole of front feet ($P = 0.02$) and of dew claw length of front feet ($P = 0.009$). Our results indicate that combinations of lesions on the dorsal and ventral part of the claws, negatively affected the reproduction parameters considered, emphasising the importance of general improvement of feet health.

Keywords: sows; claw lesions; reproductive performance

Claw lesions, which are very common among sows (Pluym et al. 2011), have been associated with lameness (Anil et al. 2007; Lisgara et al. 2015). Lameness is an animal-based welfare indicator (Welfare Quality® consortium 2009) which reduces the productivity of a pig herd by reducing sow longevity and the number of pigs produced per sow per year due to increased involuntary culling rates of sows (Anil et al. 2005; Engblom et al. 2008). Some claw lesions were also associated with decreased litter weight, increased pre-weaning piglet mortal-

ity and higher odds of stillborn and crushed piglets (Fitzgerald et al. 2012; Pluym et al. 2013).

A commonly discussed parameter for determining breeding herd reproductive performance and a herd's overall efficiency is pigs weaned/female/ year. This parameter is principally influenced by the non-productive days/female/year, which is in-turn influenced by the wean-to-first service interval, the total number of piglets born and weaned and the lactation length (Polson et al. 1993; Almond et al. 2006). Evidently, if claw lesions negatively affect not

only sow longevity but also the important reproductive parameters which determine the breeding capacity of the herd and the profitability of the farm, every effort should be made to combat this problem. Thus, in this paper, we investigated the associations between the severity of claw lesions and the number of live-born and weaned piglets and the wean-to-first service interval in three Greek farrow-to-finish herds.

MATERIAL AND METHODS

Study population. The studied herds were, indoor, farrow-to-finish herds with 330 (A), 160 (B) and 800 (C) sows, respectively, with Danbred (A, B) and Hermitage (C) genetics. The only criterion for participation in the study was the written consent of the owners. Neither the health status of sow feet nor reproductive performance was considered for herd selection. The study was conducted during the first six months of 2013, before full compliance with the EU Directive (2001/88/EC), which requires that sows and gilts shall be kept in groups during a period starting from four weeks after service to one week before the expected time of farrowing. Therefore, all sows in the study population were individually housed during all their previous gestations.

Study design. Upon entry of sows into the lactation facilities, their hooves were examined for lesions and scored by three farm employees. The training of the employees to recognise, characterise and score feet lesions was done by two of the authors of this study (ML and LL). Training involved an initial session at the Clinics of the School of Veterinary Medicine of the University of Thessaly (Karditsa, Greece), where the different anatomical sites of the claws were identified and representative claw lesions collected in the slaughterhouse were characterised and scored. Training was repeated on each farm. For referencing, the employees were provided with a collection of pictures and a video of the training material. Each sow's feet data were recorded on specially developed sheets (paper data-capture forms) along with her parity, date of farrowing, number of live-born and weaned piglets and the wean-to-first service interval. Once a month the primary author visited all farms, collected the sheets and cross-checked the data of a random sample of 20 percent of the sheets by rescoring

sow claws together with the responsible farm employee. The medial and lateral toes of each foot were individually examined for lesions and scored when sows were lying down (the ventral surface) or standing up (the dorsal surface) in the farrowing crate before farrowing. Five claw anatomical sites were examined, the heel (soft keratinised epidermis on the ventral surface of the claw towards the posterior end, HL), the sole (hard keratinised epidermis anterior to the heel on the ventral surface of the claw including the junction between heel and sole, SL), the white line (junction between sole and wall, WL), the wall (hard keratinised epidermis on the dorsal surface of the claw, WA) and the coronary band (CB). The scoring system applied was based on "Zeugenklauwencheck", a scoring system developed in The Netherlands (Pluym et al. 2011) and the Zinpro Foot First method (Foot First Team 2010), with some modifications. Scoring of lesions of the epidermis involved a severity scale ranging from 0 to 2 where score 0 was given to claws with no lesions or very small superficial cracks of the epidermis ("score 1 or 2" in the Dutch scoring system or "mild" in the Foot First system), score 1 was assigned to serious lesions in the epidermis not extending into the corium ("score 3" in the Dutch scoring system or "moderate" in the Foot First system) and score 2 was assigned to severe lesions with serious and deep cracks extending into the corium or subcutis ("score 4" in the Dutch scoring system or "severe" in the Foot First system). For toe length (TL) and dew claw length (DCL), score 0 was assigned to toes and dew claws with normal length ("score 1 or 2" in the Dutch scoring system or "mild" in the Foot First system), score 1 to overgrown toes and dew claws touching the floor when the animal was standing ("score 3" in the Dutch scoring system or "moderate" in the Foot First system), and score 2 to overgrown and twisted or cracked toes and overgrown and twisted or crushed dew claws ("score 4" in the Dutch scoring system or "severe" in the Foot First system). For the coronary band (CB), lesion score was 0 when healthy ("score 1 or 2" in the Dutch scoring system) and 1 when any lesion was observed ("score 3 or 4" in the Dutch scoring system).

Statistical analysis. All statistical analyses were performed using Stata 13.1 (Stata Statistical Software. College Station, TX). The total score for the four feet for each anatomical site was obtained by adding the respective scores of all claws

and dew claws. Therefore, for all anatomical sites except the coronary band, the total score for the four feet could range from 0 to 16; for the coronary band, the total score varied between 0 and 8. The total score for each foot was obtained by adding the scores of each anatomical site considered. Therefore, the total score of each foot could range from 0 to 13. Initially the data were summarised by calculation of frequencies, medians, ranges and means ± SD. Analysis of variance (ANOVA) was used to compare the mean number of live-born and weaned piglets among the three herds, whereas the medians of the wean-to-first service interval were compared among the herds using the Kruskal-Wallis test (multiple comparisons were interpreted at Bonferroni adjusted *P*-values).

Scoring of lesions at the considered foot sites resulted in fifty six variables for each sow examined. The major problem to be dealt with in analysing this data set was multicollinearity, i.e., variables were closely related to each other (highly correlated) because they referred to the same animal and/or same foot and/or same claw. The first approach when dealing with multicollinearity involves reducing the number of independent variables prior to investigating associations with the outcome. This could be accomplished by screening for multicollinearity and selecting predictor variables, by creating scores or indexes combining data from several variables or by using multivariable methods (principal component analysis or factor analysis) to summarise the information contained in the original predictors into a smaller set of variables (Dohoo et al. 1997). The first alternative is limited by the arbitrary nature of selecting the level of correlation coefficient and which of the correlated variables to remove, while the second precludes the evaluation of the effects of the individual variables which make up the score or index in analyses of risk factors. Between the use of principal component and factor analysis, we opted to use the latter because principal components are merely mathematical constructs with no intrinsic meaning, whereas factor analysis is based on the assumption that a set of factors which do have an inherent meaning of their own can be computed as weighted sums of the original variables (Dohoo et al. 1997). Thus, through the use of factor analysis we created a smaller set of uncorrelated predictor variables (factors) which contained all the information in the original variables. The original variables were

assumed to be linear combinations of the factors with weights (factor loadings) plus an error term. Extraction of the factors was accomplished by using the method of principal components (Berghaus et al. 2005). The suitability of individual variables for use in the factor analysis was evaluated by using the Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy. Determination of the number of factors to keep for interpretation was a compromise between parsimony, interpretability, and the total amount of variation in the original variables that was explained by the factors in the model (Berghaus et al. 2005). Kaiser's criterion (initial eigenvalue ≥ 1), a Scree-test plot and the number of factors that are required to account for a given proportion of the variance observed in the original variables (Stevens 1996), were considered in the analysis to determine which factors to retain for interpretation. Orthogonal and oblique factor rotations were both evaluated, but ultimately an orthogonal rotation was selected for the final analysis because it resulted in a relatively simple and interpretable structure while maintaining factor independence (Berghaus et al. 2005). |Factor loadings| > 0.40 were used in the interpretation of rotated factors. Sixteen factors had an eigenvalue ≥ 1, suggesting that they should be kept for interpretation according to Kaiser's criterion, while use of the Scree method suggested that 13 or 14 factors should be retained. After consideration of the amount of variance explained, we retained 13 factors cumulatively accounting for almost 63 percent of the variance in the original variables. Then, for these 13 factors we produced standardised factor scores with the regression method (Berghaus et al. 2005).

The number of live-born and weaned piglets was associated with the produced factor scores in two multivariable linear regression models. However, the distribution of the observed days of wean-to-first service was over-dispersed (Lord et al. 2007). This was expected because most sows were inseminated within five days after weaning. Thus, we used a zero inflated negative binomial (ZINB) model to investigate the possible associations between the wean-to-first service interval and the factor scores (Carrel et al. 2010). The latter model fitted the data better than the Poisson or negative binomial regression models as dictated by two tests, namely the Vuong and the Countfit tests which are available in Stata 13.1. The ZINB model generates two separate models and then combines them; first, a logit

model was generated for sows which were serviced within five days after weaning and then, a negative binomial model was generated for sows which were serviced more than five days after weaning (Long and Freese 2006).

In all models, adjustment for the likely parity-effect was accomplished by forcing a dummy variable for "parity" (categorised in one of three categories comprising parities 1 or 2, 3 to 5, and ≥ 6) into the models. A dummy variable coding for "herd" was also forced into all models as it controlled for variation in the outcomes because of the different within-herd sampling frequency and other unmeasured herd level factors.

The model building procedure was similar for the linear regression and ZINB models. Initially, for each outcome, each factor score was screened separately, together with "parity" and "herd", in tri-variable models. A significance level of $P < 0.25$ was used as a screening criterion for possible inclusion in the initial full models (Hosmer and Lemeshow 1989). Then, the initial full models including all factor scores previously found significant at $P < 0.25$ along with "parity" and "herd" were fitted. Examination of the residuals of the multiple regression models for the number of live-born and weaned piglets did not reveal any notable deviation from normality and homoscedasticity. The full models were reduced by backwards elimination of factor scores with $P \geq 0.05$ (Mickey and Greenland 1989). When only significant factor scores remained in the models, a stepwise forward selection process was performed, offering to the models previously deleted factor scores one at a time. This ensured that any factor scores excluded earlier during backward elimination, but adding significantly to the final models, were included. Lastly, all possible two-way interactions between the remaining factor scores were created and tested for significance one-by-one.

RESULTS

A total of 804 sows were scored, of which 121 were in herd A, 126 in herd B, and 557 in herd C. In herd A, the most frequent and severe lesions were the TL 111/121 (91.7%), median 4 (range 0–14) and the DCL 110/121 (90.9%), median 3 (range 0–15); in herd B they were on the HL 113/126 (89.7%), median 2 (range 0–10) and the TL 97/126 (77%),

median 2 (range 0–7); and in herd C they were on the HL 502/557 (90.1%), median 6 (range 0–16) and the DCL 433/557 (77.7%), median 4 (range 0–16).

In herd A, the mean number of live-born and weaned piglets were 14.14 (± 3.00) and 12.60 (± 1.27); in herd B, they were 14.41 (± 2.80) and 11.11 (± 1.90); and in herd C they were 10.97 (± 2.70) and 10.16 (± 1.40), respectively. Means of live-born piglets were lower ($P < 0.01$) in herd C but did not differ between the other herds, whereas means of weaned piglets differed ($P < 0.01$) among herds. Some of the sows were culled at weaning; therefore, the wean-to-first service interval was available for 95, 109 and 500 sows in herds A, B and C, respectively. It had a median of six days (range 5–47 days) in herd A, five days (range 3–35 days) in herd B and five days (range 4–98 days) in herd C; the distributions of days from wean-to-first service differed ($P < 0.01$) among herds.

All variables examined were suitable for inclusion in the factor analysis, since their KMO values were > 0.5, suggesting an acceptable fit with the structure of the other variables. Most variables loaded high on only a single factor, the exception being factor 10. For this factor, three different groups of variables loaded: variables describing the severity of lesions on the white line, sole and wall of the rear feet. None of the examined interactions was significant. The final model for live-born piglets included factor scores 1, 2 and 4, the one for weaned piglets included factor scores 1, 2, 4 and 10 and the model for wean-to-first service interval included factor scores 1, 2, 4 and 7.

Factor score 1, representing the severity of HL lesions on front and rear feet.

Factor score 2, representing TL on front and rear feet.

Factor score 4, representing the severity of SL lesions on front feet.

Factor score 7, representing DCL on front feet.

Factor score 10, representing the severity of WL, SL and WA lesions on rear feet.

The number of live-born piglets was negatively associated with factor scores 1 ($P \leq 0.001$) and 4 ($P = 0.019$). Specifically, for one unit increase of the former or the latter, a sow farrowed on average 0.36 and 0.24 less piglets, respectively. In contrast, the number of live-born piglets was positively ($P \leq 0.001$) associated with factor score 2; for one unit increase of factor score 2 the number of live-born piglets increased by an average of 0.38 pig-

Table 1. Linear regression models for associations between the number of live-born and weaned piglets and claw lesions of 804 sows, adjusted for parity and herd effects, in three Greek herds, together with the negative binomial part of a zero-inflated negative binomial regression model for the association between the longer than five days after weaning-to-first service interval and claw lesions of 704 sows from the same herds, adjusted for parity and herd effects

Factor scores	Number of live-born piglets		Number of weaned piglets		Wean-to-first service interval	
	Coefficient (CI)	*P*-value	Coefficient (CI)	*P*-value	Coefficient (CI)	*P*-value
1[a]	−0.36 (−0.58, −0.16)	≤ 0.001	−0.17 (−0.28, −0.06)	0.003	0.27 (0.04, 0.50)	0.02
2[b]	0.38 (0.19, 0.60)	≤ 0.001	0.16 (0.05, 0.28)	0.004	−0.47 (−0.69, −0.25)	≤ 0.001
4[c]	−0.24 (−0.41, −0.01)	0.019	−0.17 (−0.28, −0.07)	0.001	0.26 (0.04, 0.47)	0.02
7[d]	–	–	–	–	0.28 (0.07, 0.48)	0.009
10[e]	–	–	−0.15 (−0.26, −0.04)	0.008	–	–

[a]factor score representing the severity of heel lesions on front and rear feet

[b]factor score representing the overgrowth of toes on front and rear feet

[c]factor score representing the severity of sole lesions on front feet

[d]factor score representing the overgrowth of dew claws on front feet

[e]factor score representing the severity of white line, sole and wall lesions on rear feet

lets (Table 1). The number of weaned piglets was negatively associated with factor scores 1 (*P* = 0.003), 4 (*P* = 0.001) and 10 (*P* = 0.008), and positively associated with factor score 2 (*P* = 0.004). On average, a sow weaned 0.17 piglets less for one unit increase of each of the first two factor scores and 0.15 piglets less for one unit increase of factor score 10; for a unit increase of factor score 2 the number of piglets weaned increased on average by 0.16 piglets (Table 1).

In the negative binomial part of the ZINB model, the wean-to-first service interval was associated with factor scores 1 (*P* = 0.02), 2 (*P* ≤ 0.001), 4 (*P* = 0.02) and 7 (*P* = 0.009). Therefore, for sows serviced more than five days from weaning, one unit increase of either of factor scores 1, 4 and 7 increased the wean-to-first service interval by a factor of 1.30. In contrast, for one unit increase of factor score 2 the wean-to-first service interval decreased by a factor of 0.60. In the logit part of the ZINB model, the wean-to-first service interval was not associated with any factor score.

DISCUSSION

In this study we scored lesions on five claw sites, namely, the heel, the sole, the white line, the wall and the coronary band, the toe and the dew claw length. Then, we investigated the associations between claw lesion scores and three main reproductive parameters, the number of live-born and weaned piglets and the duration of the wean-to-first service interval, in three Greek swine herds. We identified lesions located on six foot sites, namely the heel, sole, white line, wall and the overgrown toes and dew claws which were associated with reproductive performance parameters. With the sole exception of the overgrown toes, any increase in the severity score of lesions on the other foot sites had a negative effect on the reproductive parameters considered (Table 1).

Although the impact of claw lesions on sow longevity, lameness (Anil et al. 2007; Anil et al. 2009) and increased risk of culling (Engblom et al. 2008) is established, there are only sparse reports on their associations with reproduction efficiency parameters. Previous studies reported the association of heel lesions and wall cracks with decreased litter weight, increased pre-weaning piglet mortality and higher odds of stillborn piglets (Fitzgerald et al. 2012; Pluym et al. 2013). Our results indicate that combinations of lesions on the dorsal and ventral part of the claws, negatively affected the reproduction parameters considered. These lesions are extremely common (Anil et al. 2007; Pluym et al. 2011) with 56% of the sows, in our study population, having at least two lesions on the ventral part and 58% at least one lesion on the dorsal part of the claw of any foot.

According to our experience, lesions on the white line were frequently accompanied by lesions on the sole of the claw, since these two sites are adjoined. The heel bulb, mainly of the lateral claws, is a soft

tissue prone to injuries because it carries most of the sow's weight (Kroneman et al. 1993; Pluym et al. 2011). All lesions on the ventral or dorsal part of the claw may facilitate the invasion of bacteria into the corium resulting in inflammation and pain, causing, due to cytokine release, anorexia and lethargy (Kempson and Logue 1993; Johnson 1997). In our study, the great majority of the animals affected with severe lesions (lesion score 2) had, when culled and pathologically examined, evidence of laminitis (data not shown). Reduced feed consumption as a sequel of claw lesions could be either or both the result of an existing inflammatory process or an impaired locomotor ability. In addition, the postural behaviour of the sow may be influenced, with affected sows exhibiting higher relative frequency of lying and lower frequency of standing posture (Enokida et al. 2011), spending less time feeding and drinking. The amount of feed intake during lactation influences subsequent reproductive performance, such as wean-to-first service interval and subsequent litter size (Koketsu et al. 1996). An inadequate nutrient and energy intake is expected to result in extended wean-to-oestrus interval with a lower percentage of sows in oestrus within seven days of weaning, reduced pregnancy rate and reduced embryo survival (Quesnel et al. 1998; Aherne et al. 1999). Especially protein restriction during lactation can have a negative impact on post weaning ovulation rate (Mejia-Guadarrama et al. 2002), whereas a crucial body protein mass loss can rapidly reduce ovarian function (Clowes et al. 2003) and increase the time required for expression of oestrus after weaning (King and Dunkin 1986; Koketsu et al. 1996). In contrast to the above, we found that overgrown toes in front and rear feet were associated with more live-born and weaned piglets as well as with a shorter wean-to-first service interval. The mean claw horn growth rate in sows is higher than the mean wear rate per month (6.3 mm vs 5.1 mm) (Amstel et al. 2010); therefore, in higher parity sows, which are more prolific compared to younger ones (3–6 vs 1–2 parities) (Tantasuparuk et al. 2000), claw overgrowth may occur simply as a function of age.

The results of our study are limited to the extent that recording and scoring of lesions was based exclusively on farm personnel. Although there were training sessions for lesion characterisation by the personnel, and the validity of a subsample of the recordings was verified by one of us, there were differences among herds. These differences were not only due to the unavoidable imperfect validity and repeatability of personnel scorings but also to the existing variations in management, productivity and genetic lines of sows. We opted not to analyse the associations within each herd but rather model the data obtained from all herds because the former approach would have reduced the statistical power to detect significant associations among individual or combinations of claw lesions with the investigated reproductive parameters. Our analytical approach was able to identify groups of closely related claw lesions among a larger set of fifty six variables describing lesions on feet of each sow, without losing any important information, and minimising the possibility of finding associations 'due to chance alone' (Dohoo et al. 1997). We showed that sow reproduction ability was affected by different feet lesions, either having a combined effect on the examined reproductive parameters (factor score 10), or a discerned effect according to their location. Although generalisation of these results is dangerous, since the data originated from three herds, when combined with those of other studies (Fitzgerald et al. 2012; Pluym et al. 2013), they point to the importance of feet health and the need for general improvement in this area. Measures to improve feet health are expected to be of increased importance for both the longevity and productivity of sows in the modern swine industry, especially under the mandatory implementation of group housing (Anil et al. 2007; Fitzgerald et al. 2012) because claw lesions have a higher incidence of occurrence in loose compared to individually housed sows (Anil et al. 2007).

In conclusion, it is important to recognise that feet lesions, which are usually clinically unnoticed and therefore untreated, pose a constant challenge throughout a sow's life. Once a lesion is created the most probable outcome is its deterioration over time, thus explaining the overall negative impact on sow reproductive performance and longevity (Fitzgerald et al. 2012; Pluym et al. 2013). Claw lesions should not be regarded as independent injuries on specific sites, but rather as a complex, since they had a combined effect on the examined parameters. Claw lesions occur more frequently and severely in older sows (Dewey et al. 1993; Pluym et al. 2011; Fitzgerald et al. 2012), suggesting a time-related pattern of occurrence and likely a cumulative effect over time on the animal's reproductive performance.

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