明治大学大学院農学研究科

2019 年度

博士学位請求論文

疫学的アプローチ: 欧州生産農場での
母豚の行動と四肢障害または子宮脱による
母豚の淘汰・死亡

Epidemiological approach: sow behavior and removal due to lameness or prolapse in European commercial herds

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EPIDEMIOLOGICAL APPROACH: SOW BEHAVIOR AND REMOVAL DUE TO LAMENESS OR PROLAPSE IN EUROPEAN COMMERCIAL HERDS

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ACKNOWLEDGEMENTS

I would like to take this opportunity to express my grateful appreciation to all the people who have helped me to complete this dissertation.

First and foremost, I would like to express my deeply gratitude to my advisor Dr. Yuzo Koketsu for his guidance, wonderful discussion, support and acceptance to work under his supervision at Meiji University. I am also grateful to Drs. Iain McTaggart, Yasushi Mizoguchi and Maiko Kawaguchi for their critical reviews of this dissertation. Additionally, my thanks go to all members of our Animal Production Laboratory for their friendship and assistance.

I owe special gratitude to my parents, Takehiko and Junko Iida for their understanding and encouragement, and my brothers, Kenta and Rikuto for their unfailing support. I also thank my grandmother, Ayako Sato who has been always encouraging.

Finally, I am grateful to thank the swine producers for their cooperation in providing their valuable data for use in this dissertation, and also the staff at PigCHAMP Pro Europa S.L. (Segovia, Spain) for their technical assistance. This work was supported by the Meiji University Giken-B-2019 Project Grant.

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ABSTRACT

Since January 2013, group housing for mid to late gestating sows has been mandatory in the European Union (EU). One of the options which producers can choose is an electronic sow feeder (ESF) system. The system records how much feed has been dispensed and how long each sow stays in the feeding station. However, such eating behavior is not well characterized. Furthermore, no studies have reported the associations between the eating behavior and subsequent performance of sows.

Prolapses in sows are an emerging concern in pig production. Meanwhile, lameness in sows is an important health problem and welfare concern in the swine industry. However, there has been few research quantifying those removal incidences and reporting their related factors.

Therefore, the overall aims of this dissertation were 1) to characterize eating behavior for sows fed in an ESF and their subsequent performance, and 2) to identify the factors associated with the incidence of sow removal due to prolapses and lameness.

This dissertation comprises three chapters. In the first chapter, the associations were quantified between eating behavior and either displacement hazard or subsequent performance for sows were fed in an ESF. Data included eating records and reproductive performance records of 685 sows in a herd in Spain. The eating behavior comprised weekly

averages of daily feed dispensed (ADFD) and daily total time spent in the feeding stations (TTSF). A displacement sow was defined as a sow removed from her group for health reasons. Generalized mixed effects models were fitted to the records. Inter-quartile ranges of ADFD and TTSF were 2.1-2.8 kg and 7.5-10.8 min, respectively. Parity 0 sows had less ADFD than parity 1 or higher sows during gestational weeks 5-13 ($P < 0.05$), but there was no difference in TTSF between parity 0 and parity 1 or higher sows in gestational weeks 5-8 and 11-13 ($P > 0.05$). Sows that were entered into the ESF system during summer had less ADFD, and shorter TTSF in gestational weeks 5-12 than those entered during the other seasons ($P < 0.05$). The TTSF varied between two genotypes during gestational weeks 5-7 ($P < 0.05$). Also, a higher displacement hazard was associated with less ADFD ($P < 0.01$). A higher hazard of pregnancy loss was associated with shorter TTSF ($P < 0.01$).

In Chapter 2, the study estimated the incidence rate of prolapses and determined risk factors associated with prolapse occurrences. Data included 905,089 service records of 155,238 sows from 144 herds in Spain. A one-to-four matched case-control study was carried out to investigate prolapse risk factors, and piecewise exponential models were applied to the data. Almost 1% of sows (0.8%) were removed due to prolapses, and the annualized incidence rate for all prolapse cases was 3.8 cases per 1000 sow-years. Significant factors were the 16th week after service, being in parity 3 or higher, re-service, shorter gestational length, fewer piglets born and more stillborn piglets ($P \leq 0.04$). For example, the prolapse incidence was 30.6 times higher at 16 weeks after service than during the first 14 weeks ($P < 0.01$). Also, 60.9% of 1198 prolapses occurred during the first 0 to 4 weeks after farrowing. The prolapse incidence was 1.5-1.8 times higher in parity 3 or higher sows than in parity 0 sows (*P* < 0.01), and 1.3 times higher in re-serviced sows than in first serviced sows (*P* = 0.02). It was also 1.3-1.5 times higher in sows with a prior gestational length of 113 days or less than in sows with 114 days or more gestational length (*P* < 0.01). Lastly, the prolapse incidence rate was 1.2 times higher in sows with 11 or fewer piglets born than in sows with 12-16 piglets born (*P* = 0.04), and was also 1.4 times higher in sows with two or more stillborn piglets than in sows with no stillborn piglets (*P* < 0.01).

In the final chapter, the incidence rate of lameness removal was estimated, and the longevity and reproductive performance were investigated for sows removed due to lameness. Poisson models were applied to a cohort dataset of 165,918 sows in 148 herds in Spain. The Wilcoxon rank sum test was used to compare the performance of sows removed due to lameness and their controls in one-to-two matched case-control datasets. Removal due to lameness accounted for 4.3% of all sows, and the incidence rate for lameness removal was 19.9 cases per 1000 sow-years. The majority (72.6%) of these removal cases were farrowed sows, whereas only 27.4% were serviced sows. In farrowed sows, a higher incidence of lameness removal was associated with weeks 4-8 after farrowing, higher parity and winter farrowing (*P* < 0.01). The removal incidence was 32.6-39.9 times higher in weeks 4-8 after farrowing than during the first week after farrowing. It was also 1.3-1.7 times higher in parity 4-5 than in parity 1, and 1.3 times higher in winter farrowing than summer farrowing (*P* < 0.01). In contrast, with serviced sows, the factors associated with lameness removal were weeks 4-5 after service and being re-serviced (*P* < 0.01). For example, the removal incidence was 5.0 times higher in weeks 4-5 after servicing than during the first 2 weeks after servicing ($P < 0.01$). Also, it was 2.1 times higher in re-serviced sows than in first serviced sows ($P < 0.01$). In case-control datasets, in comparison with control sows, sows that were removed due to lameness had higher weaning-to-first-mating interval (means: 6.5 vs. 5.8 days), fewer piglets born alive (11.7 vs. 12.5 piglets) and lower parity at removal (3.4 vs. 4.9; $P < 0.01$).

In conclusion, I recommend that both ADFD and TTSF should be measured in ESF systems to help identity sows having problems. Also, producers should pay more attention to sows exposed to high risks, while trying to identify prolapse cases at an early stage and to check sows' subclinical lameness. I recommend making a quick decision to cull a sow at risk in order to decrease the welfare concern.

CONTENTS

CHAPTER 1

BEHAVIOR, DISPLACEMENT AND PREGNANCY LOSS IN PIGS UNDER AN ELECTRONIC SOW FEEDER

ABSTRACT

Our objective was to characterize eating behavior associated with displacement hazard and subsequent performance for pigs were fed in static groups by an electronic sow feeder (ESF). Data included weekly eating records and subsequent farrowing records of 685 pigs. The eating behavior comprised weekly averages of daily feed dispensed (ADFD) and daily total time spent in the feeding stations (TTSF). A displacement female was defined as a pig removed from her group for health reasons. A multivariate model and piecewise exponential models were fitted to the records. Means (inter-quartile ranges) of ADFD and TTSF were 2.4 kg (2.1-2.8 kg) and 9.3 min (7.5-10.8 min), respectively. Gilts had less ADFD than sows during gestational weeks 5-13 ($P < 0.05$), but there was no difference in TTSF between gilts and sows in gestational weeks 5-8 and 11-13 ($P > 0.05$). Also, gilts had higher displacement hazard than parity 2 or higher sows in gestational weeks 8-10 ($P < 0.05$). Pigs that were entered into the ESF system during summer had less ADFD, and shorter TTSF from gestational weeks 5 to 12 than those entered during the other seasons ($P < 0.05$). The TTSF varied between two genotypes during gestational weeks 5-7 ($P < 0.05$). Also, a higher displacement hazard was associated with less ADFD ($P < 0.01$). A higher hazard of pregnancy loss was associated with shorter TTSF ($P < 0.01$). In conclusion, we recommend that both ADFD and TTSF should be measured in ESF systems to help identity females having problems.

Keywords: eating behavior; electronic sow feeder; multivariate analysis; repeated measures

1. Introduction

The European swine industry is moving towards group housing because the use of gestation stalls has been banned for mid- and late gestation in all member states of the European Union (EU) since 2013. One of the options which EU producers can choose is an electronic sow feeder (ESF) system (Olsson et al., 2011; Bench et al., 2013a, b; Levis, 2013). The ESF system enables producers to control the amount of feed for each pregnant pig in group housing, and it also records how much feed has been dispensed and how long each pig stays in the feeding station, i.e. its eating behavior. Such eating behavior of mid to late gestation pregnant pigs in ESF systems is not yet well characterized in commercial herds. Records of eating behavior can include weekly average daily feed dispensed (ADFD) and daily total time spent in the feeding stations (TTSF). Appropriate housing of pregnant pigs during mid to late gestation helps ensure they have enough nutrition to develop mammary glands, and adequate placental, fetal and maternal growth (Kraeling and Webel, 2015). Increased nutrients and energy are needed, especially in late gestation when fetuses are growing rapidly. However, some pregnant pigs do not adapt to the ESF system, and such pigs have to be displaced from the group to a hospital pen or a stall (Chapinal et al., 2010a; Bench et al., 2013b). Despite this, no studies have reported on the displacement hazard of gilts and sows in static groups in commercial herds, nor the association between eating behavior (i.e. ADFD and TTSF) and the displacement hazard or subsequent reproductive performance of sows under the ESF system. Therefore, the objectives of the present study were 1) to characterize the two types of eating behavior (ADFD and TTSF), 2) to assess the displacement hazard for pregnant pigs under an ESF system, and 3) to determine the associations between the pregnant pigs' eating behavior and the displacement hazard, pregnancy loss, and subsequent farrowing and weaning performance in a breeding herd.

2. Materials and methods

2.1. Herd with an electronic sow feeder system

This observational study was conducted on a farrow-to-wean commercial farm housing 500 sows (Segovia, Spain). There was mechanical ventilation in the herd's farrowing, breeding and gestation barns. Every 3 weeks, sows were weaned and then moved to individual stalls for insemination and pregnancy diagnosis. Breeding was conducted using artificial insemination during an estrus period, and a pregnancy was confirmed by real-time ultrasound at 28-35 days after insemination. Lactational and gestational diets were formulated using cereals (barley, wheat and corn) and soybean meal. Replacement gilts in the herds were purchased from the three breeding companies: PIC (PIC España, S. Cugat del Vallés, ES), ACMC (Pure Pig Genetics Ltd, Driffield, UK) and DanBred (DanAvl, Copenhagen, Denmark).

After pregnancy confirmation, pregnant pigs were placed into the ESF system. The group housing pens consist of a 50% concrete slatted floor and no bedding. The ESF system (GERIONTE, Salamanca, Spain) has four feeding stations for pregnant gilts and sows and was installed in 2014. Under the ESF system, a radio frequency identification (RFID) is attached to each pregnant pig. Each pregnant gilt or sow in the ESF receives 1.8-2.5 kg of feed each day depending on their body condition. Then, for the last 3 weeks of gestation, the amount of feed is increased to 2.0-3.0 kg per day. The dispensed feed amount is estimated on a volumetric basis, with a calibration between volumetric and actual feed weights performed every month. The size of the static groups was approximately 60 sows per group, including both gilts and sows, with a space allowance of 2 m^2 per pig.

2.2. Data and exclusion criteria

Eating records for females that entered the ESF system between January 2014 and October 2015 were extracted from the system, including data on daily feed dispensed and daily total time spent in the feeding stations. The initial dataset contained 100,724 daily eating records in 1568 pregnancy records of 688 female pigs.

Eating records of pigs' first and last days in the ESF system were excluded (3132 records). Records on or after the date of pregnancy loss were also excluded (42 records). Daily records showing zero kg feed dispensed were considered as missing records (9949 records; 10.2% of 97,550 records), and these were also excluded because ADFD and TTSF would be underestimated. Further records were excluded, if either gestational days at entry was greater than 76 days (7 records), or if total time in the system was greater than 79 days (3048 records). Finally, records showing daily total time spent in the feeding station was 18 min (the mean + 3SD) or longer were considered as extreme and excluded (511 records). Hence, the final dataset included 84,035 daily eating records in 1513 pregnancy records of 685 females. Additionally, the 14,322 records for both ADFD and TTSF were calculated from the daily eating records. These eating records were coordinated with respective reproductive performance data from the PigCHAMP recording system.

Records used in the analysis of eating behaviour were restricted to weeks 5-15 of gestation because there were only 61 records for weeks 3, 4 and 16 of gestation. Also, records of pregnancy loss females were not used in the analysis of displacement hazard.

2.3. Definitions

A gilt is defined as a female pig that has entered a herd but has not yet farrowed, and a sow is a female pig that has farrowed at least once. Parity was defined as the number of farrowing, and the number of parities were retained for female pigs with pregnancy loss. In this study, gestation days and gestation weeks were the respective numbers of days and weeks from the date of entry into the system (day 0 and week 0). Also, displaced females were defined as females removed from the group for health reasons.

The following measurements were examined: whether or not a pig had pregnancy loss, whether or not a pig had assistance at farrowing, number of piglets born alive, number of stillborn piglets, number of mummified piglets, number of piglets that died less than 24 hours after farrowing, number of piglets that died 24-48 hours after farrowing, number of piglets that died during lactation and the number of weaned piglets.

2.4. Categories

Female pigs were categorized into three parity groups: 0 (gilt), 1 and 2 or higher. Entry months were categorized into four quarterly groups (Jan. to Mar., Apr. to Jun., Jul. to Sep. and Oct. to Dec.). Also, genotypes were grouped into the three groups (A, B and C).

2.5. Statistical analysis

Descriptive statistics were performed using SAS University Edition (SAS Institute Inc., Cary, NC, USA). All the models mentioned below included entry year and a block of feeding station.

2.5.1. Models for eating behavior and displacement hazard

A multivariate longitudinal model was fitted to the weekly eating records by using the GLIMMIX procedure in order to compare eating behavior for different parities, month of entry into the system and genotype (Gao et al., 2006). Response variables were ADFD and TTSF, which were assumed to follow normal distribution. This model included the following variables as fixed effects: gestational week, parity groups nested within gestational week, entry month groups nested within gestational week, and genotype groups nested within gestational week. The main effects of parity, entry month and genotype groups were not included in the model because the main effects were not of interest; our research interest for this specific model was only the effects of these variables within each gestational week. Random female effects were also included in the model to allow two intercept terms (one for ADFD and one for TTSF) to vary randomly across female pigs. A separate set of regression coefficients was fitted for each response variable to examine the correlation between these random effects. Two random intercepts were fitted using a RANDOM statement. Also, another RANDOM statement specified that the variances of measurement errors were different for different response variables by using the GROUP option and RESIDUAL option. The TYPE=AR(1) covariance structure was fitted to the repeated measures data. Weekly eating records of females with pregnancy loss were not used in the analysis of eating behavior (107 records). To check the adequacy of the model assumptions, the normality of the random effects and the residuals were evaluated by visual inspection of the normal-probability plots.

A piecewise exponential model was also fitted to the data by using the GLIMMIX procedure in order to estimate displacement hazards for each parity group in each gestational week (Allison, 2010). Parity, entry month and genotype groups were added to the model. Also, the baseline hazard was fitted by a step function (Yang and Goldstein, 2003). Furthermore, ADFD and TTSF were added separately to different versions of this model as a time-varying variable to examine the association between the respective two types of eating behavior and displacement hazards.

A two-step testing procedure was implemented to test mean differences between groups in each gestational week. In the first step, a global test was performed for the null hypothesis that the expected means of all groups were equal. If this global null hypothesis could be rejected, then in the second step, all pairwise multiple comparisons were made using the Tukey-Kramer method. All significance levels were set at 0.05.

2.5.2. Matched case-control study

A matched case-control study was designed to examine the associations between either ADFD or TTSF and subsequent farrowing performance. One to two case-control matchings were performed to minimize confounding by randomly selecting controls using the SURVEYSELECT procedure (Diseker and Permanente, 2004). The case and control groups for the number of piglets born alive, the number of piglets that died during lactation and the number of weaned piglets were categorized into two groups based on the 75th percentile of the respective performances (Table 1). The 10 case groups selected were groups of female pigs that experienced pregnancy loss, sows with assisted farrowing, sows with 14 or more piglets born alive, sows with one or more stillborn piglets, sows with one or more mummified piglets, sows with one or more piglets that died less than 24 hours after farrowing, sows with one or more piglets that died 24-48 hours after farrowing, sows with 3 or more piglets that died during lactation and sows with 11 or more weaned piglets. The control groups were matched to the case groups based on parity, entry month and genotype group.

Two piecewise exponential models were fitted to the hazard of pregnancy loss. The ADFD and TTSF were treated as time-varying variables. Parity, entry month and genotype group were also added to the model. Records for pigs displaced from the ESF system were treated as censorings, although records for pigs with pregnancy loss less than one week after displacement were treated as an event. Thus, 24 pregnancy loss records were analyzed as events.

Reverse temporal models (multivariate longitudinal models) were applied using GLIMMIX procedure (Chen et al., 2015) to contrast trajectories of eating behavior in matched-pair groups for farrowing and weaning performance. This model included the following variables as fixed effects: gestational week, matched-pair groups nested within gestational week, parity, entry month and genotype group. A separate set of regression coefficients was fitted for each eating behavior. A two-step testing procedure was implemented to test mean differences between cases and controls during the time the pigs were in the ESF system. In the first step, a global test was performed for the null hypothesis that all the differences between the groups are zero in each gestational week. If this null hypothesis was rejected, then in the second step, the differences were checked for each gestational week by using pairwise comparisons.

3. Results

Descriptive statistics for measurements are shown in Table 1. Means (inter-quartile ranges) of ADFD and TTSF were 2.4 kg (2.1-2.8 kg) and 9.3 min (7.5-10.8 min), respectively.

Both ADFD and TTSF were associated with parity, entry month and genotype. Fig. 1 shows the eating behaviors of the three parity groups across gestational weeks. There were significant differences in ADFD between parity groups throughout the period in the ESF system ($P < 0.01$). For example, gilts had 0.13-0.24 kg less ADFD than sows during weeks 5-13 of gestation ($P < 0.05$). However, there were only significant differences between parity groups in TTSF during weeks 9-10 and 14-15 of gestation ($P \leq 0.03$); there were no differences in weeks 5-8 and 11-13 of gestation ($P > 0.05$). Also, there were no differences between parity 1 and parity 2 or higher sows for ADFD in weeks 5-7 and 10-13 of gestation, nor for TTSF during weeks 5-13 of gestation ($P > 0.05$).

Fig. 2 shows the eating behavior of the entry month groups across gestational weeks. There were significant differences in both ADFD and TTSF between seasons throughout the time in the ESF system ($P < 0.01$). For example, pigs that were entered during summer had 0.12-0.28 kg less ADFD, and had 0.28-2.71 min shorter TTSF during weeks 5 to 12 of gestation than those entered during the other seasons ($P < 0.05$).

Fig. 3 shows the eating behavior of genotype groups across gestational weeks. There were significant differences in ADFD between genotypes in weeks 8-11 and 13 of gestation ($P < 0.05$). Also, there were significant differences in TTSF between genotypes in weeks 5-8, 10-11 and 13 of gestation ($P \leq 0.03$). For example, genotype A pigs had 1.02-1.34 min shorter TTSF than genotype B pigs in weeks 7-8 of gestation ($P < 0.05$). However, during this period there was no such difference in ADFD between genotypes A and B pigs ($P > 0.05$). Also, even though genotype A pigs had 0.43-0.90 min shorter TTSF than genotype C pigs during weeks 5-7 of gestation ($P < 0.05$) there was no similar difference in ADFD at the same time between these genotypes ($P > 0.05$). Additionally, in the analysis of eating behavior, the model estimated that the correlation between ADFD and TTSF within a female pig was 0.68.

The frequency distribution (%) of displaced females at different weeks of gestation by the 3 parity groups are shown in Fig. 4. The percentages of records for gilts, parity 1 and parity 2 or higher sows that were displaced from the ESF system up to week 13 of gestation were 10.8, 5.3 and 2.6%, respectively. Gilts had 6.2-19.1 times higher displacement hazards than parity 2 or higher sows in weeks 8-10 of gestation ($P < 0.01$; Table 2). Furthermore, a higher displacement hazard was associated with less ADFD (hazard ratio and 95% CI: 0.750 [0.620-0.907]; $P < 0.01$), but not with TTSF (0.981 [0.947-1.016]; $P = 0.29$). Hence, the displacement hazard was estimated to rise by 2.5% for each 100 g decrease in ADFD.

Pregnancy loss occurred in 1.8% of pregnancy records between days 3 and 68 after entry into the system (Table 1). Gilts accounted for 20 of 27 pregnancy loss records (74.1%). A higher pregnancy loss hazard was associated with shorter TTSF (0.644 [0.486-0.852]; $P < 0.01$; Table 3), but not with the ADFD (hazard ratio and 95% CI: 0.504 [0.079-3.223]; $P = 0.47$).

Analysis of the trajectories of eating behavior showed that sows having one or more mummified piglets were associated with increased ADFD ($P < 0.01$), but not with TTSF ($P = 0.16$; Table 4). Sows with one or more mummified piglets had 0.04-0.05 kg more ADFD than those with no mummified piglets in weeks 11 and 15 of gestation ($P < 0.05$). However, there were no associations between such eating behavior and any of the other farrowing and weaning performance measures; sows having farrowing assistance ($P \geq$

0.45), sows having 14 or more piglets born alive ($P \geq 0.72$), sows having one or more stillborn piglets ($P \geq 0.49$), sows having one or more piglets that died less than 24 hours after farrowing ($P \geq 0.36$), sows having one or more piglets that died 24-48 hours after farrowing ($P \geq 0.65$), sows having 3 or more piglets that died during lactation ($P \geq 0.49$) or sows having 11 or more weaned piglets ($P \geq 0.32$).

4. Discussion

To the authors' knowledge, this is the first study that has quantified the weekly hazard of gestating gilts and sows in static groups being displaced from an ESF system. Gilts had a higher risk of displacement than parity 2 or higher sows in weeks 8-10 of gestation. Also, over 10% of gilts had been displaced from a group before the expected farrowing date. These results suggest that some gilts cannot adjust to the ESF or cannot get along with other pigs in the ESF system, and have to be removed from the pen. Gilts are generally subordinate to sows, and would be likely to receive more aggression and injuries compared with sows (Levis, 2013). Therefore, gilts under ESF systems would have more adaptation failure than sows, and it has been recommended that gilts are housed separately from sows (Li et al., 2012; Levis, 2013). Also, difficulties in adapting to ESF systems could be eased by training the pigs before they are introduced into such a system (Chapinal et al., 2010b).

In the present study, the fact that gilts had lower ADFD than sows, but had similar TTSF can be readily explained by the fact that gilts take longer to eat than sows (Levis, 2013). Therefore, it is necessary to provide gilts with sufficient amounts of feed in the feeding station to maintain their body reserves of protein and fat and to enable them to keep growing. However, there were no differences between parity 1 and parity 2 or higher sows between either type of eating behavior. So, it would not be a problem to house parity 1 sows with parity 2 or higher sows due to their similar eating behavior.

Our study has clearly shown that pregnant pigs were entered into the ESF during summer had the lowest ADFD and TTSF, compared with sows entered in the other seasons. This is most probably due to the increased environmental temperatures during summer leading to a reduction in feed intake by both the gilts and sows (Koketsu et al., 1996; Lewis and Bunter, 2011; Bergsma and Hermesch, 2012; Cabezón et al., 2016). Therefore, it would certainly be recommended that cooling systems (e.g., evaporative cooling systems) are introduced during gestation to help ensure the intake of necessary nutrients and energy by each female.

Genotype differences between the two types of eating behavior suggest that eating speed differs between genotypes. Large variation in eating speed has been reported for dry feed in group housed sows (Boe and Cronin, 2015). A part of large such variation may be explained by fear or stress related to received aggression in group housing (Kongsted, 2006). Although no research has yet reported any association between eating speed and genotype, it is definitely possible that mixing different genotypes may increase problems in aggression and eating behavior between females.

In this study, a higher displacement hazard was associated with less ADFD. This association could be because female pigs with less ADFD could have more health problems might result in them being removed from the group. Furthermore, our study implies that females that had pregnancy loss have different eating behavior from healthy pregnant pigs. Pregnancy loss females could have been infected by some diseases such as parvovirus or PRRS (Almond et al., 2006). Therefore, measuring ADFD and TTSF may help producers predict females that have a health problem in the ESF system, or females that are likely to have a problem of pregnancy loss.

There were no direct associations between either type of eating behavior during the 5-15 week mid- to late gestation periods and subsequent farrowing or weaning performance measurements. For example, the number of pigs weaned has been shown to be primarily affected by preweaning mortality, and the number of pigs born alive is mainly associated with insemination timing, management or care during breeding and early gestation phases (Dial et al., 1992; Knox, 2016). Also, the number of stillborn piglets is mostly influenced by the total number of pigs born and care in the peri-farrowing phase (Dial et al., 1992; Vanderhaeghe et al., 2013). The lack of any association between eating behavior and farrowing performance is consistent with the findings of earlier studies that showed no association between pigs born alive and different feeding or energy patterns experimentally imposed in gestation (Wang et al., 2016; Ren et al., 2017). However, our study did indicate that increased ADFD in late gestation was associated with having a mummified piglet at farrowing. Mummified piglets are defined as having died during mid and late gestation after bone mineralization (Almond et al., 2006). However, it is hard to distinguish whether large mummified piglets died in late gestation or healthy piglets died during farrowing.

Also, there is no known biological explanation for an association between increased ADFD in late pregnancy and having mummies.

In conclusion, producers could improve the care of gilts and sows in ESF systems if they consider the eating behavior of each pig based on parity, entry month and genotype. Therefore, we recommend that both ADFD and TTSF should be measured in ESF systems as part of daily practice, to help identify females having an eating problem.

There is a limitation with our study, because approximately 10% of the daily records in pregnant pigs were recorded as 0 kg. We could not confirm whether this 0 kg means that the pigs did not eat anything on that day or that the EFS systems had mechanical problems. However, even with such a limitation, our study provides unique information on two types of eating behavior in pregnant pigs under an ESF.

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Table 1

Descriptive statistics for measurements of pigs under an ESF system and their farrowing performance.

Measurements	N	Mean ± SE	Median	IQR
Weekly eating records				
Average daily feed dispensed, kg	14,322	2.4 ± 0.003	2.2	2.1-2.8
Average daily total time spent in the feeding stations, min	14,322	9.3 ± 0.02	9.6	7.5-10.8
Pregnancy records				
Number of parities	1513	2.3 ± 0.05	2.0	1-4
Gestational days at entry into the system	1513	43.4 ± 0.26	38.0	36-54
Gestational days at exit from the system	1513	104.7 ± 0.28	108.0	106-108
Total days fed in the system	1513	61.3 ± 0.38	69.0	51-71
Pregnancy loss, %	1513	1.8 ± 0.34	-	-
Days from entry into the system to pregnancy loss	27	28.3 ± 4.42	22.0	6-47
Assisted farrowing, %	1486	5.5 ± 0.59	-	-
Number of piglets born alive	1486	12.1 ± 0.08	12.0	11-14
Number of stillborn piglets	1486	0.6 ± 0.03	0.0	0-1
Number of mummified piglets	1486	0.2 ± 0.02	0.0	0-0
Number of piglets dying < 24 hours after farrowing	1486	0.6 ± 0.03	0.0	0-1
Number of piglets dying 24-48 hours after farrowing	1486	0.2 ± 0.02	0.0	0-0
Number of piglets dying during lactation	1486	1.7 ± 0.05	1.0	0-3
Number of weaned piglets[a]	1430	10.1 ± 0.07	10.0	9-11

ESF: electronic sow feeder; SE: standard error; IQR: inter-quartile range.

[a]56 records were regarded as missing records.

Table 2

Comparisons between parties for displacement hazards (cases/pig-week) of pigs entered into the ESF system[c].

Gestational	Parity		
week	Gilts	1	2 or higher
5	0.007 (0.0010-0.0533)	0.000 (0.0000- $e^{200.85}$)	0.002 (0.0002-0.0125)
6	0.013 (0.0033-0.0526)	0.005 (0.0007-0.0371)	0.010 (0.0046-0.0233)
7	0.016 (0.0061-0.0434)	0.000 (0.0000- $e^{193.65}$)	0.003 (0.0008-0.0131)
8	0.025 (0.0117-0.0517)[a]	0.004 (0.0006-0.0286)[ab]	0.001 (0.0002-0.0092)[b]
9	0.030 (0.0156-0.0582)[a]	0.000 (0.0000- $e^{166.71}$)[ab]	0.003 (0.0006-0.0102)[b]
10	0.024 (0.0114-0.0504)[a]	0.004 (0.0005-0.0275)[ab]	0.004 (0.0012-0.0119)[b]
11	0.010 (0.0034-0.0324)	0.019 (0.0080-0.0473)	0.004 (0.0012-0.0120)
12	0.004 (0.0005-0.0249)	0.020 (0.0082-0.0481)	0.004 (0.0012-0.0120)
13	0.007 (0.0018-0.0282)	0.008 (0.0020-0.0323)	0.003 (0.0006-0.0103)
14	0.281 (0.2200-0.3593)[a]	0.088 (0.0563-0.1380)[b]	0.051 (0.0361-0.0725)[b]
15	1.938 (1.6573-2.2672)	2.120 (1.7650-2.5464)	2.165 (1.8340-2.5559)

ESF: electronic sow feeder.

[ab]Estimates within a group with different letters are different ($P < 0.05$).

[c]Hazards and 95% confidence intervals were estimated by using the model.

Table 3

Estimates of fixed effects included in the proportional hazards model for pregnancy outcome.

Fixed effects[a]	Model 1		Model 2	
	Estimate (± SE)	*P*-value	Estimate (± SE)	*P*-value
Daily feed dispensed	-0.686 (0.945)	0.47	-	
Daily total time in feeding station	-		-0.440 (0.143)	< 0.01
Parity		0.48		0.51
Gilts	0.689 (0.623)		0.621 (0.629)	
Parity 1	0.774 (1.395)		0.848 (1.408)	
Entry month		0.60		0.48
January to March	0.424 (0.934)		-0.598 (1.010)	
April to June	1.106 (0.822)		0.850 (0.805)	
July to September	0.405 (0.588)		-0.139 (0.648)	
Genotype		0.30		0.43
A	1.320 (1.048)		0.975 (1.089)	
B	1.648 (1.321)		1.548 (1.333)	
Entry year		0.90		0.55
2014	0.13 (1.073)		-0.716 (1.193)	

SE: standard error.

[a]Intercepts and coefficients of the step function and for the feeding station block are not shown in the Table.

Table 4

P-values in global tests for association between two types of eating behavior and reproductive performance[a].

Reproductive performance	Daily feed dispensed	Daily total time staying in the feeding stations
Farrowing assistance	0.48	0.45
Piglets born alive	0.77	0.72
Stillborn piglets	0.69	0.49
Mummified piglets	< 0.01	0.16
Piglets dying < 24 hours after farrowing	0.50	0.36
Piglets died dying 24-48 hours after farrowing	0.66	0.65
Piglets dying during lactation	0.91	0.49
Weaned piglets	0.32	0.43

[a]Global test's null hypothesis is that all the differences are zero between cases and controls for eating behavior in each gestational week.

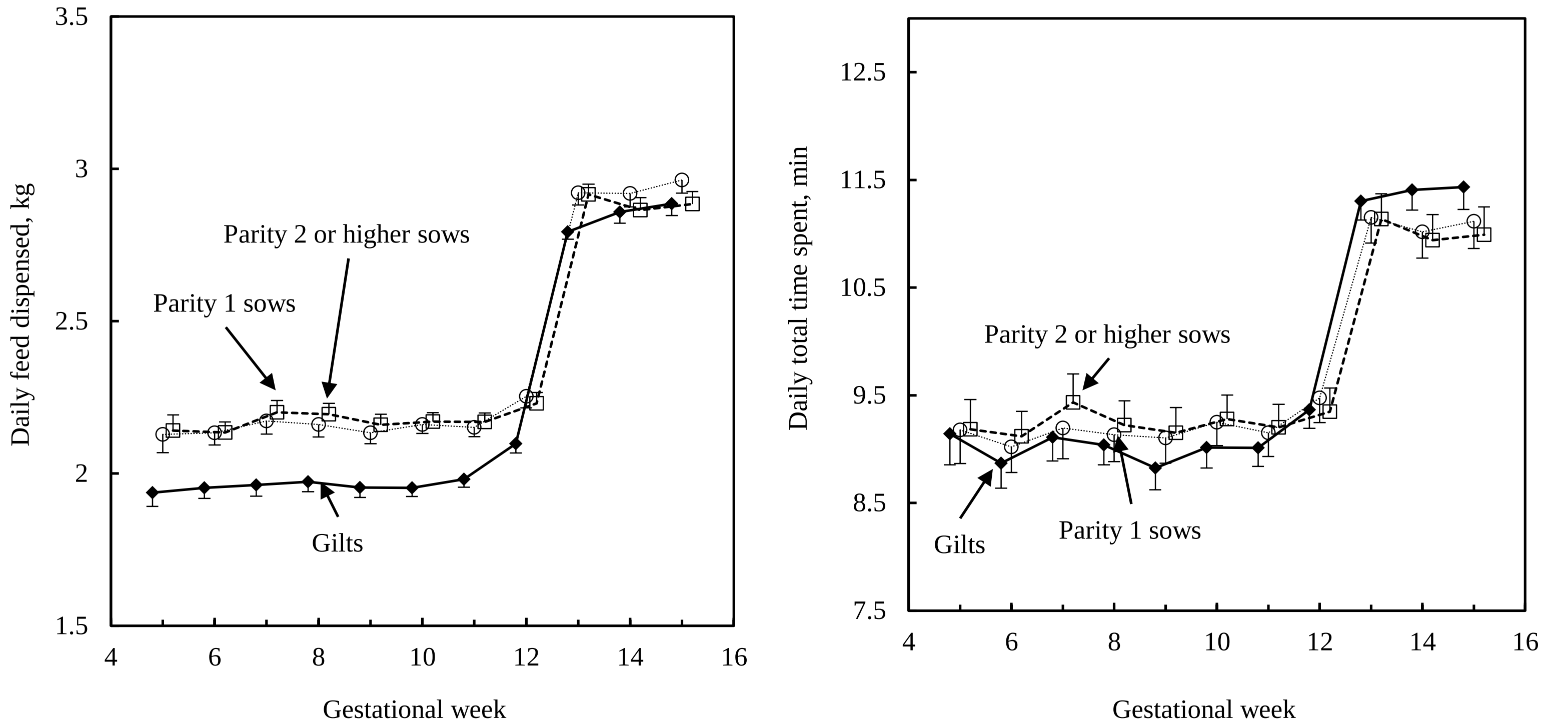

Fig. 1. Daily feed dispensed in the electronic sow feeder (ESF) system and daily total time spent in the feeding stations for different parity groups. Means and 95% confidence intervals were estimated by using the model.

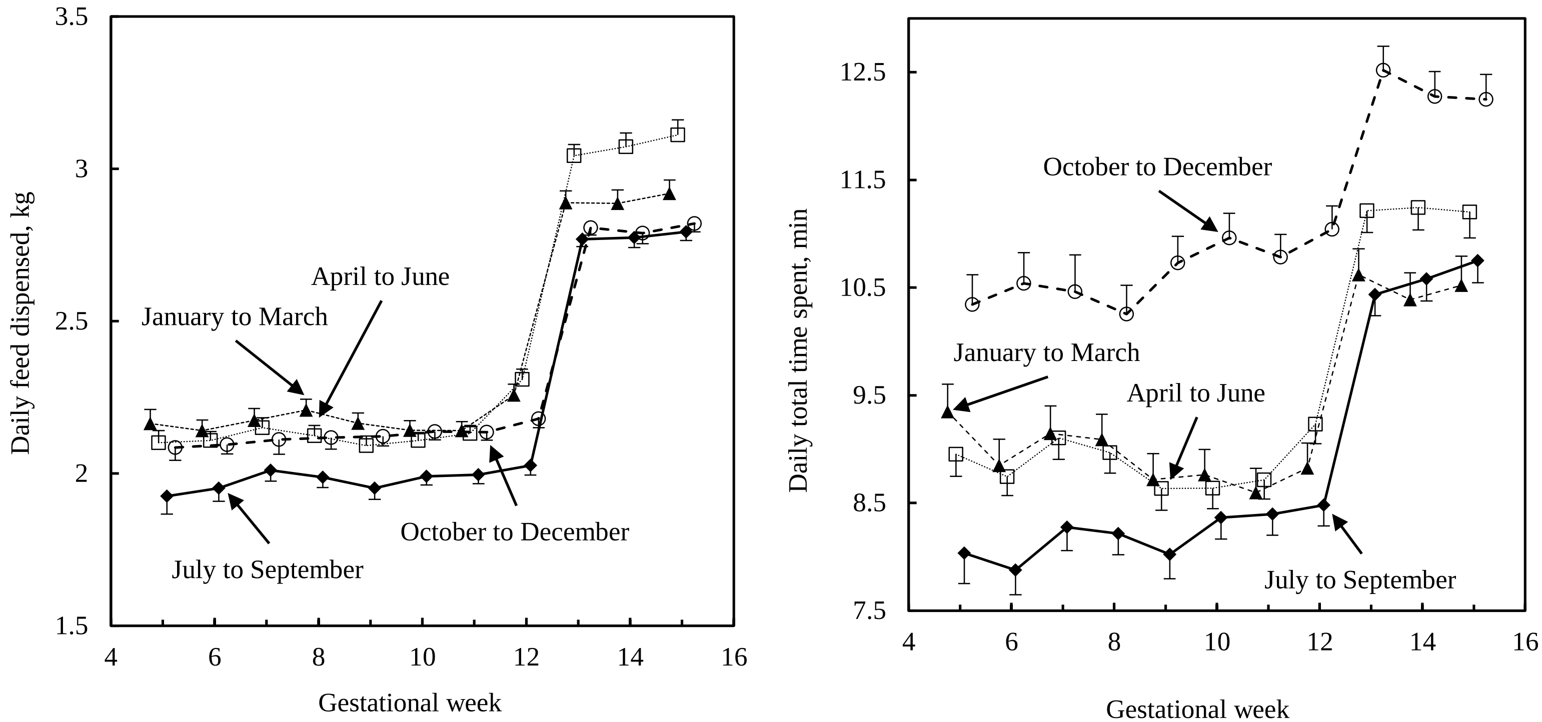

Fig. 2. Daily feed dispensed in the electronic sow feeder system (ESF) and daily total time spent in the feeding stations for different seasonal groups. Means and 95% confidence intervals were estimated by using the model.

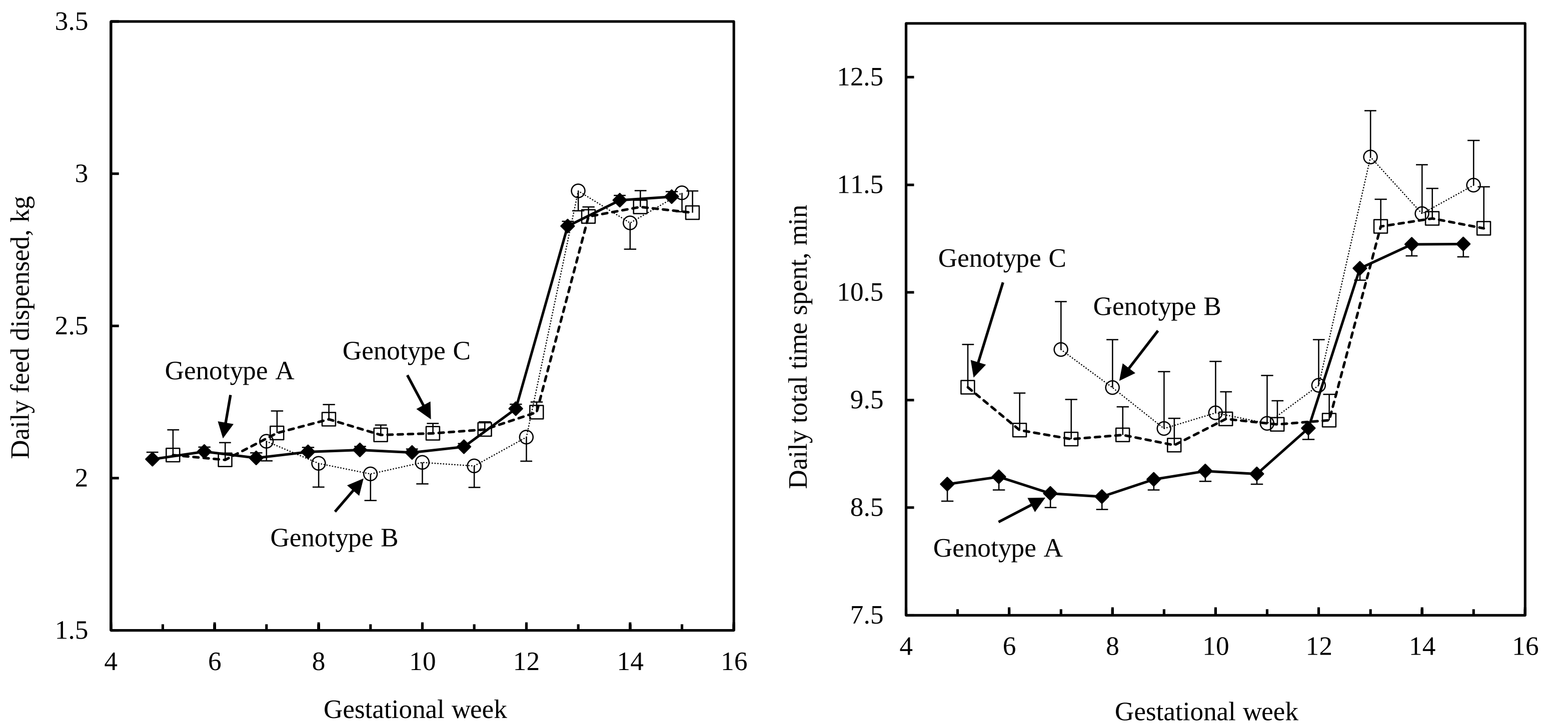

Fig. 3. Daily feed dispensed in the electronic sow feeder system and daily total time spent in the feeding stations for different genotype groups. Means and 95% confidence intervals were estimated by using the model.

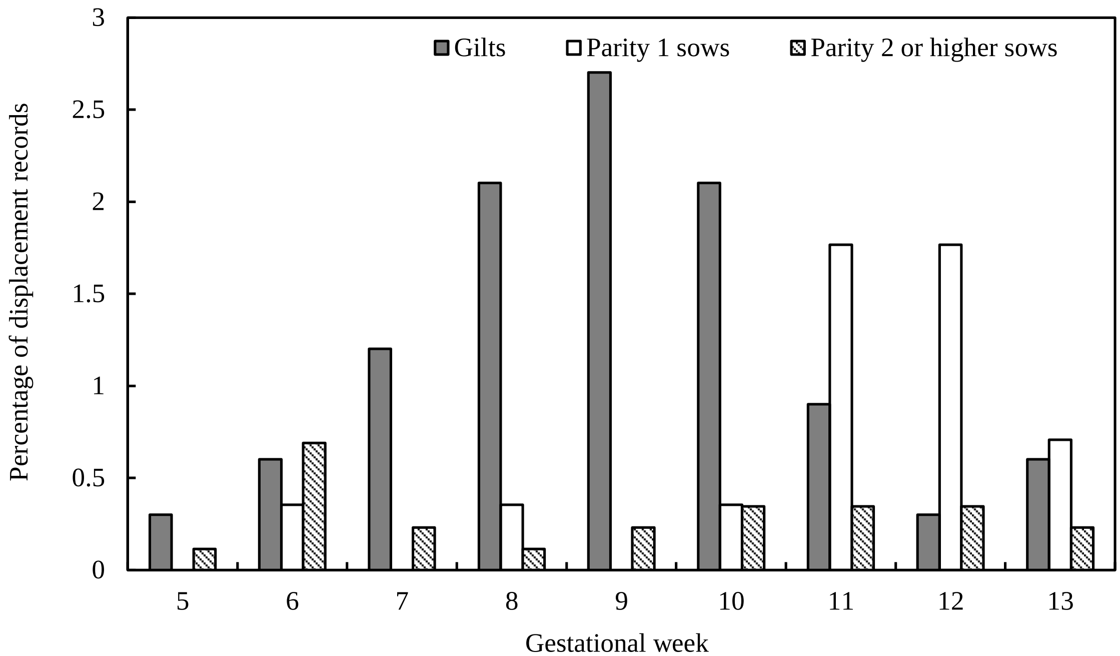

Fig. 4. Frequency distributions of 333 pregnancy records of displaced gilts, 283 pregnancy records of displaced parity 1 sows and 870 pregnancy records of displaced parity 2 or higher sows at different weeks of gestation in the ESF system. Records for pigs displaced at or after week 14 of gestation are not shown. Records of pregnancy loss females were not used in this figure.

CHAPTER 2

INCIDENCES AND RISK FACTORS FOR PROLAPSE REMOVAL IN SPANISH SOW HERDS

ABSTRACT

Prolapses in sows are an emerging concern in pig production. The objectives of this study were to estimate the incidence rate of prolapses and to determine risk factors associated with prolapse occurrences. Data included 905,089 service records in 819,754 parity records of 155,238 sows from 144 swine herds in Spain. Producers were required to record a removal reason, including type of prolapse. A 1:4 matched case-control study was carried out to investigate prolapse risk factors, and piecewise exponential models were applied to the data. The following factors were assessed: parity, number of services, service season, weeks after service, prior gestational length, total number of piglets born, and number of stillborn and mummified piglets. Almost 1% of sows (0.8%) were removed due to prolapses (95% confidence interval: 0.76, 0.85), and the annualized incidence rate for all prolapse cases was 3.8 cases per 1000 sow-years (95% confidence interval: 3.59, 4.01). Significant factors were the 16^{th} week after service, being in parity 3 or higher, re-service, servicing in summer, autumn or winter, shorter gestational length, fewer piglets born and more stillborn piglets ($P \leq 0.04$). For example, the prolapse incidence was 30.6 times higher at 16 weeks after service than during the first 14 weeks ($P < 0.01$). Also, 60.9% of 1198 prolapses occurred during the first 0 to 4 weeks after farrowing. The prolapse incidence was 1.5-1.8 times higher in parity 3 or higher sows than in parity 0 sows ($P < 0.01$), and 1.3 times higher in re-serviced sows than in first serviced sows ($P = 0.02$). It was also 1.3-1.5 times higher in sows serviced in summer, autumn or winter than in those serviced in spring ($P \leq 0.02$), and 1.3-1.5 times higher in sows with a prior gestational length of 113 days or less than in sows with 114 days or more gestational length ($P < 0.01$).

Lastly, the prolapse incidence rate was 1.2 times higher in sows with 11 or fewer piglets born than in sows with 12-16 piglets born ($P = 0.04$), and was also 1.4 times higher in sows with two or more stillborn piglets than in sows with no stillborn piglets ($P < 0.01$). However, there was no association between prolapse incidence and mummified piglets ($P = 0.54$). Consequently, producers should pay more attention to sows exposed to high risks, while trying to identify prolapse cases at an early stage.

Keywords: cohort study; nested case-control study; porcine disease; prolapse; shared frailty model

1. Introduction

An increase in the incidence of sow prolapses is a serious concern in U.S.A. swine herds (Mahan-Riggs et al., 2016; Pittman, 2017; Supakorn et al., 2017). For example, the percentage of sows in 36 herds of a large pork cooperative that were removed due to prolapses increased from 2.0% in 2012-2013 to 3.5% in 2016 (Pittman, 2017). The economic impact for these prolapses was estimated to be from approximately $5,000-9,000 per 1000 sow-years for 2.0-3.5% prolapsed sows, assuming an average culled sow weight of 212 kg and an average cull value of $1.21 per kg live weight (Supakorn et al., 2017). In addition, Engblom et al. (2007) reported that in Sweden 1.0% of sows in 21 commercial herds were removed due to prolapses. Herd-level analysis showed that the percentage of prolapsed sows in each individual herd varied from 0.0 to 3.0%. However, despite the serious incidence of prolapses in herds, there is no accurate system to measure prolapse incidence rates. Currently, the common way of calculating the percentage of prolapsed sows uses the number of removed sows as the denominator. However, this method does not take account of the number of sow-days at risk, which can vary in commercial herds. Therefore, it would be more accurate to measure the prolapse incidence rate using animal years at risk as the denominator.

Prolapses in sows can occur in the uterus, vagina or rectum, raising animal welfare issues and can lead to the death of individuals. Although risk factors vary between types of prolapses, few studies of these types of prolapses have investigated sow-level factors such as weeks from service, parity, number of services and service season. There are various other potential causes of prolapses. One issue is a larger number of total born piglets in a litter, or large piglets, which can lead to complicated parturition and excessive abdominal pressure, resulting in prolapses (Alonso et al., 2017; Pittman, 2017). Also, the number of stillborn piglets and gestational length relate to total number of piglets born (Sasaki and Koketsu, 2007; Vanderhaeghe et al., 2013), and so these also could be risk factors of prolapse symptoms. In addition, farrowing assistance or farrowing induction can be associated with an incidence of prolapses (Alonso et al., 2017). Therefore, based on these potential causes of prolapses, herd-level factors such as herd size and number of piglets weaned per sow per year (PWSY), which indicates herds' reproductive efficiency, could explain variability of prolapse incidences among herds.

There has been no research about the incidence rate, or herd- or sow-level risk factors for prolapse occurrences in Spanish herds. Spain is one of the major pig producing countries in Europe; the country had approximately 20% of sows in the EU countries in 2016 (European commission, 2017). Therefore, the objectives of our study were 1) to estimate the incidence rate for each type of prolapse in Spanish herds while taking between-herd variability into account, and 2) to quantify herd- or sow-level risk factors associated with these prolapse occurrences.

2. Materials and methods

2.1. Herds

A veterinary consultancy firm (PigCHAMP Pro Europa S.L., Segovia, Spain) has accumulated a pig database by requesting all client producers to mail their data files on a regular basis. In July 2017, reproductive performance records of 155 Spanish client herds were extracted from the database. Female pigs in the studied herds were mainly crossbred pigs between Landrace and Large White, which were either purchased replacement gilts from breeding companies, or were replacement gilts home-produced through internal multiplication programs. Lactational and gestational diets were formulated using cereals (barley, wheat, and corn) and soybean meal.

The veterinary consultancy firm software requires producers to record a removal date and a removal reason for each sow. Prolapse is one of the possible options for removal reason, with producers able to record rectal, uterine, vaginal or unspecified prolapses. However, 11 of the 155 herds (7.1%) failed to record a reason for removal of more than

30% of removed sows (range: 31.7-97.1%), so these herds were excluded from the present study. In the remaining 144 herds, an average of 98.0% of sow removal records included a recorded reason for removal, ranging from 77.3 to 100%. Average herd size and PWSY were 756 sows and 24.3 piglets, respectively, in the studied herds (Table 1).

2.2. Data

Records of 155,238 sows in the 144 herds were extracted from the veterinary firm database. The data included reproductive performance records of the sows serviced from January 2011 to December 2016. The serviced sows were entered into the herds between 2011 and 2013. The dataset included all the service records of the sows from their herd entry to removal (entry cohort data). The dataset contained 905,089 service records in 819,754 parity records.

The following records were treated as missing values: age at first service either 159 days or less, or 401 days or more (Hoving et al., 2011); gestational length of either 104 days or less, or 126 days or more (Sasaki and Koketsu, 2007). In addition, records of total number of piglets born, and number of stillborn and mummified piglets were regarded as missing when the total number of piglets born was either 0 or 31 piglets or more (Bloemhof et al., 2013). Furthermore, records of 126 days or more after service to prolapse removal were regarded as extreme for pregnant sows. Finally, records of days from last service or last farrowing to prolapse removal were regarded as missing as extreme when the time form last service to prolapse was 182 days or more after service for farrowed sows.

2.3. Definitions

A sow is a female pig that has been serviced at least once. Parity is defined as the number of farrowing, and the number of parities are retained for sows with pregnancy loss. In this study, days from service and weeks from service were the respective numbers of days and weeks from the date of service (days 0 and weeks 0). Types of removal included culling, death and euthanasia.

The percentage of sows removed due to prolapses was calculated as the number of sows removed due to prolapse divided by the number of removed sows, multiplied by 100. An annualized incidence rate for prolapses (cases per 1000 sow-years) was calculated as the number of sows removed due to prolapse divided by the sum of the number of sow-years at risk, multiplied by 1000 sows (Dohoo et al., 2009). The number of years at risk was defined as the time between the date of first service and the date of removal. In active and surviving sows when the data were extracted, the sow-years at risk was defined as the number of years from the first service date to the last event date (e.g. service, farrowing, or weaning date).

The herd-level factors that we examined were herd size, PWSY, annualized culling rate and annualized mortality rate. Annualized culling rate (%) and mortality rate (%) were calculated respectively as the number of culled sows and the number of dead sows divided by the sum of reproductive life years in all sows, multiplied by 100. Assessed sow-level factors included age at first service, weeks from service, parity, number of services, service season, prior gestational length, total number of piglets born, and number of stillborn and mummified piglets prior to service.

2.4. Categories

Weeks from service was split into seven groups: 0-14, 15, 16, 17, 18, 19 and 20 or later, because preliminary analysis showed that few prolapse incidences occurred during the first 14 weeks, and because most sows were serviced around the fourth week after parturition. Sows were categorized into seven parity groups: 0, 1, 2, 3, 4, 5 and 6 or higher. Number of services was categorized into two groups: first service and re-service. Service month was categorized into quarterly groups (Jan. to Mar., Apr. to Jun., Jul. to Sept. and Oct. to Dec.). Records for age at first service, prior gestational length, and total number of piglets born were categorized into three groups based on the lower and upper 25th percentiles of the respective performance measurements (Table 1). Also, records for number of stillborn and mummified piglets were categorized into three groups (0, 1 and 2 or more piglets) and two groups (0 and 1 or more piglets), respectively.

2.5. Statistical analysis

Data management, descriptive statistics and all analyses were performed using SAS University Edition (SAS Institute Inc., Cary, NC, U.S.A.).

2.5.1. Study of variability between herds

Using the NLMIXED procedure, a two-level Poisson regression model or a zero-inflated Poisson (ZIP) regression model were fitted to the herd-level data to estimate herd variability of a prolapse incidence (Gbur et al., 2012; Kurada, 2016). The Poisson model was fitted to data from the 75 herds with at least one prolapse record, because it was not possible to validate if the other herds without any prolapse records really did not have any prolapse removals, or just did not properly record a prolapse removal. The ZIP model was constructed for each specific type of prolapse using the data from the 29 herds that had recorded prolapse type. Three defined types of prolapses, i.e. uterine, vaginal and rectal prolapses, were used for the analysis. Three sows were categorized as having both uterine and rectal prolapses. The response variable was the number of sows removed due to prolapses in a herd. Random herd effects were included in the Poisson model and in the Poisson part of the ZIP model, allowing the intercept to vary randomly across herds. The logarithm of the sum of the sow-years at risk divided by 1000 was treated as an offset in the model to predict the number of cases per 1000 sow-years. Residual plots of the herd-level random effects were used to evaluate the model assumptions about normal distribution of random effects.

An intra-class correlation coefficient (ICC) was calculated to determine the proportion of the variance explained by herd-level information. The ICC was estimated by the simulation-based approach (Vigre et al., 2004; Stryhn et al., 2006):

1) the random effect vector u_i was simulated from Normal (0, σ^2_{herd}) for i = 1, …, 100,000,

2) the expected values for the Poisson model [$\exp(X\beta + u_i)$] and for the ZIP model [$\exp(X\beta + u_i) \times (1 - \text{logit}^{-1}(X\beta))$] were computed for the subject-specific predictors, as were the respective variances (i.e. $\exp(X\beta + u_i)$ and $(1 - \text{logit}^{-1}(X\beta)) \times (\exp(X\beta + u_i) + \text{logit}^{-1}(X\beta) \times \exp(X\beta + u_i)^2)$),

3) the variance of the expected values and the mean of the variances were computed across the i simulations, and

4) the ICC was computed as the variance of the expected values/(the variance of the expected values + the mean of the variances) x 100.

Population average and interquartile range (IQR) for the herd-level incidence rates were estimated by using the expected values that were derived from the above simulation (Yang, 2005; Torres and Macchiavelli, 2007).

Herd size, PWSY, annualized culling rate and annualized mortality rate were univariately assessed in the above model as continuous fixed variables to assess the herd-level risk factors. These fixed variables were normalized to have approximately standard Normal distributions prior to the analyses. For the ZIP model, these factors were included in the Poisson part of the model.

2.5.2. Matched case-control study

A nested case-control study was designed to examine the associations between prolapse occurrences and sow-level factors because the outcome is not a common disease. One case was matched to four controls by using the SURVEYSELECT procedure (Diseker and Permanente, 2004). The case was a sow removed due to prolapses, and the control was either a sow removed due to another reason or a surviving sow. A prolapse record was considered as extreme and so not treated as a case if the pregnant sow was removed 126 days or more after service, or if the farrowed sow was removed 182 days or more after service. Each individual case was matched to four control sows based on the herd, entry year and entry month.

A piecewise exponential model was applied to the service-level data of the case and control sows by using the GLIMMIX procedure (Yang and Goldstein, 2003; Allison, 2010). Service-level data were divided into a week-level risk set before modeling. For each week after each service the following were recorded, a prolapse binary outcome variable, weeks from service, and a time-period indicating the fraction of the week that passed until either the start of the following week or a prolapse or censoring event. If no prolapse or censoring event occurred during a week, the primary outcome variable was set to 0 and the time-period was set to 1 (full) week. This was repeated for each week after a service until a prolapse removal or a censoring event occurred. If a prolapse removal occurred, the binary outcome variable was set to 1, and the time-period was recorded as the fraction of the week from the start of the week until the prolapse removal. Subsequent services, removals due to other reasons and last events of the active and surviving sows (e.g. farrowing or weaning) were treated as censoring events. When a censoring event occurred the binary outcome variable was set to 0 for that week and the time-period was the fraction of the week from the start of the week until the censoring event. This expansion lead to the following features:

1) the hazard was assumed constant within each week but could vary across weeks,

2) fitting a Poisson model with log link to the outcome was straightforward,

3) the logarithm of the time-period would be treated as an offset in the model,

4) weeks from service could be treated as blocking factor or step function, and

5) the time since service was the number of weeks from service plus the time-period for the final week of the service.

Three statistical models were constructed because the number of missing records varied in each reproductive performance. Model 1 contained the following groups as fixed effects, namely number of weeks from service, parity, and two service-level factors of number of service and service season. Model 2 included an additional sow-level factor of groups for age at first service. Model 3 also included the same fixed effects used in Model 1, as well as the following parity-level factors, groups for prior gestational length (for parity 1 sows this indicates days from service at parity 0 to farrowing), total number of piglets born, number of stillborn and mummified piglets. Values at the time of service were set in these reproductive performance measurements until the next service even though sows farrowed. The logarithm of the derived time variable, i.e. the at risk time period during each week, was divided by 1000 to rescale the regression coefficients, and was treated as an offset in the models. These models were built for all prolapse data, and for each individual type of prolapse data.

A two-step testing procedure was implemented to test mean differences within the nine factor groups. In the first step, a global test was performed for the null hypothesis that all the differences between the groups were zero. If this null hypothesis was rejected, then in the second step, all pairwise multiple comparisons were made using the Tukey-Kramer method. All significance levels were set at 0.05.

2.5.3. Test for farrowing assistance and farrowing induction

The associations between prolapse incidences and either farrowing assistance or farrowing induction were assessed using Fisher's exact test. Only herds where sows were removed due to prolapse and that recorded either farrowing assistance or farrowing induction were used in these analyses.

3. Results

Descriptive statistics on herd data and reproductive data for sows are detailed in Table 1. Appendix shows the number of service records, parity records, sows and herds that were used in each specific type of analysis (Table S1). Prolapse removals were recorded in 75 of the 144 herds (52.1%), with the means size (range) of herds having prolapse records being 930 sows (80-3180) compared with a mean herd size of 568 sows (102-2276) in herds having no prolapse records.

Sows removed due to prolapses comprised 0.8% of all sow removals (95% confidence interval [CI]: 0.76, 0.85), and the incidence rate of all prolapse cases was 3.8 cases per 1000 sow-years (95% CI: 3.59, 4.01). This compared with an estimated percentage and incidence rate of 1.2% (95% CI: 1.17, 1.31) and 5.9 cases per 1000 sow-years (95% CI: 5.60, 6.26), respectively when only herds having at least one prolapse record were used for sensitivity analysis. There were 1227 prolapse cases, of which 8.2, 2.8 and 9.3% were recorded as uterine, vaginal and rectal prolapses, respectively (Table 2), but 79.5% did not have any record of a specific prolapse type. Fig. **1** shows the relative frequency distribution (%) of sows removed due to prolapses at different weeks from last service. The majority (80.8%) of prolapsed sows were removed between 105 and 153 days after last service (15 to 21 weeks), with 69.1% removed due to prolapses after farrowing, particularly between 0 to 4 weeks after farrowing when 60.9% were removed.

In the multilevel models, the median incidence rate across herds was estimated to be 4.1 cases per 1000 sow-years for all prolapse cases (95% CI: 2.96, 5.15; Table 3). Also, the simulation study for all prolapse cases showed that 50% of 100,000 simulated herds had incidence rates of 2.0-8.4 cases per 1000 sow-years. The median incidence rates for uterine, vaginal and rectal prolapses (95% CI) were 1.2 (0.33, 2.11), 0.5 (- 0.01, 0.96) and 1.3 (0.51, 2.16) cases per 1000 sow-years, respectively. The ICCs for incidence rates of uterine, vaginal, rectal and all prolapse cases were 99.4, 16.9, 99.6 and 94.1%, respectively. In the 29 herds that were used in the analysis of each type of prolapse, only one herd had recorded all the three types of prolapses. Three herds had recorded only uterine and rectal prolapses, while another three herds had recorded vaginal and rectal prolapses.

In the multilevel models, there were no associations between incidences of all prolapse cases and any univariate herd-level factors (herd size (regression coefficient [95% CI]: - 0.2 [- 0.49, 0.03]; $P = 0.08$), PWSY (0.0 [- 0.30, 0.24]; $P = 0.82$), culling rate (- 0.1 [- 0.38, 0.16]; $P = 0.41$) and mortality rate (0.1 [- 0.20, 0.33]; $P = 0.64$)). In the Poisson part of the ZIP model there were also no associations between uterine prolapse incidence and either herd size (0.3 [- 0.20, 0.85]; $P = 0.22$), PWSY (- 0.3 [- 0.72, 0.04]; $P = 0.07$), culling rate (0.0 [- 0.94, 0.85]; $P = 0.92$) or mortality rate (0.5 [- 0.04, 1.00]; $P = 0.07$). Furthermore, there were no associations between vaginal prolapse incidence and either herd size (- 0.5 [- 1.57, 0.48]; $P = 0.28$), PWSY (0.1 [- 0.88, 1.08]; $P = 0.84$), culling rate (0.2 [- 0.06, 0.45]; $P = 0.12$) or mortality rate (0.1 [- 0.33, 0.57]; $P = 0.59$). However, rectal prolapse incidence was associated with PWSY (- 0.7 [- 1.28, - 0.16]; $P = 0.01$), but not with herd size (- 0.5 [- 1.11, 0.10]; $P = 0.10$), culling rate (0.0 [- 0.62, 0.53]; $P = 0.87$) or mortality rate (- 0.1 [- 0.53, 0.29]; $P = 0.56$).

The incidence of all prolapse cases was associated with weeks from service, parity, number of services and service season in Model 1 ($P \leq 0.02$; Table 4). The incidence was 30.6 times higher at 16 weeks after service, and 41.9 times higher at 20 or more weeks after service than during the first 14 weeks ($P < 0.01$). Also, the incidence was 1.5-1.8 times higher in parity 3 or higher sows than in parity 0 sows ($P < 0.01$), and 1.3 times higher in re-serviced sows than in first serviced sows ($P = 0.02$). It was also 1.3-1.5 times higher in sows serviced in summer, autumn or winter than in sows that were serviced in spring ($P \leq 0.02$). Also, two additional models (Models 2 and 3) found significant effects of age at first service, shorter gestational length, fewer piglets born and more stillborn piglets ($P \leq 0.04$;

Table 5). The prolapse incidence was 1.3 times higher in sows first serviced at 235-274 days old than in sows first serviced at 234 days old or younger (*P* = 0.03), and it was 1.3-1.5 times higher in sows with gestational length of 113 days or less than in sows with gestational length of 114 days or more (*P* < 0.01). It was also 1.2 times higher in sows with 11 or fewer piglets born than in sows with 12-16 piglets born (*P* = 0.04), and was 1.4 times higher in sows with two or more stillborn piglets than in sows with no stillborn piglets (*P* < 0.01). However, there was no association between a prolapse incidence and the number of mummified piglets (*P* = 0.54).

The incidence rate ratios for the nine factors assessed on each type of prolapse are shown in Tables 6 and 7. The removal incidences of uterine, vaginal and uterine prolapses were 11.5-63.9 times higher at 16 weeks after service than during the first 14 weeks (*P* < 0.01), and the incidences were 19.8-116.1 times higher at 20 or more weeks after service than during the first 14 weeks (*P* < 0.01). With regard to parity, the incidence of uterine prolapses was 3.3-4.2 times higher in parity 4 or higher sows than in parity 0 sows (*P* ≤ 0.04). However, there was no such variability for the vaginal prolapses (*P* = 0.60). Meanwhile, the rectal prolapse incidences were numerically but non-significantly 2.9-3.1 times higher in parity 0 sows than in parity 5 or higher sows (global test for the association between the incidence and parity: *P* = 0.08). Service season was associated with the incidence of uterine and vaginal prolapses (*P* ≤ 0.03). The incidence of uterine prolapses was 2.8 times higher in sows serviced during autumn than in those serviced during spring (*P* = 0.02), whereas the incidence of vaginal prolapses was 5.6 times higher in winter than in spring (*P* = 0.02). However, there was no seasonal variability in the incidence of rectal prolapses (*P* = 0.23). There was no association between number of services and any type of prolapse (*P* ≥ 0.26). The removal incidence of rectal prolapses was 2.4 times higher in sows with two or more stillborn piglets than in sows with no stillborn piglets (*P* = 0.01; Table 7). However, no similar association was found for the incidence of either uterine and vaginal prolapses (*P* ≥ 0.40). Also, there were no associations between the removal incidence of any type of prolapse and any of the other reproductive performance measurements (*P* ≥ 0.10).

Finally, only one herd had any sows removed due to prolapses and had recorded farrowing induction (herd size: 661 sows; PWSY: 23.0 piglets), and only three herds had sows removed due to prolapses and had recorded farrowing assistance (herd size: 440-661 sows; PWSY: 21.8-26.7 piglets). No sows that had at least one induced farrowing in their lifetime were removed due to prolapses (0/315 sows), whereas 0.2% of sows with no induced farrowing were removed due to prolapses (1/450 sows). Meanwhile, 1.3% of sows that received farrowing assistance at least once in their lifetime were removed due to prolapses (3/239 sows), whereas 1.1% of sows with no farrowing assistance were removed due to prolapses (19/1,769 sows). In the exact test, we could not find any associations between prolapse incidence and either farrowing induction (*P* = 1.00) or farrowing assistance (*P* = 0.74).

4. Discussion

In our study, the 0.8% of sows removed due to prolapses is consistent with a previous Swedish study (1.0%; Engblom et al., 2007), but is lower than a study in the U.S.A. reporting 2.0 to 3.5% prolapse removal incidences in 36 herds under a pork production integrator (Pittman, 2017).

Based on our simulation, 50% of herds would have 2.0 to 8.4 prolapsed sows per 1000 sow-years. Therefore, some small herds may not have a prolapse occurrence every year. To the authors' knowledge, this is the first study that has quantified the incidence rate of prolapses for sows by taking account of herd variability.

For herd-level risk factors of prolapses, our study suggested that herds having high reproductive productivity had low risk of an incidence of rectal prolapses. These high-performing herds typically have advanced herd health practices with improved hygiene, and would have low risk of mycotoxins, acute diarrhea and severe coughing induced by respiratory infections which are considered to be risk factors for prolapses (Supakorn et al., 2017). However, except for PWSY, we could not identify any herd-level risk factors that could explain the variability in prolapse incidences among herds, even though the ICCs indicated that almost all of the prolapse incidence variability was explained by herd variability. Therefore, it is possible that the variability between herds might be explained by a low occurrence of prolapses or by other herd-level information that we did not collect, such as information related to herd health, and housing, and also to feed ingredients that can be attributed to imbalance in calcium to phosphorus and to vitamin deficiency (Papatsiros et al., 2012; Pittman, 2017). Also, the magnitude of ICCs could depend on the sampling frame i.e., herds used in the model. A relatively low ICC for vaginal prolapses was shown because only four out of 29 herds that were used in the model had recorded vaginal prolapses.

The first and second highest peaks of prolapse removal incidence were found in the peripartum period and around time of weaning (IQR of lactation length in our herds: 21.0-27.0), respectively. Uterine prolapses often occur when the cervix is open during parturition and immediately after farrowing (Supakorn et al., 2017). Supakorn et al. (2017) suggested that vaginal prolapses were observed during the late pregnancy, and rectal prolapses were mostly found around the time parturition (Smith and Straw, 2006). Furthermore, it is likely that sows that had had prolapses during lactation would have been removed after weaning.

In our study, high parity sows had high incidences of uterine prolapses, which is consistent with a previous study (Chagnon et al., 1991). Older sows are likely to experience loss of uterine tone or decreased muscle tone, and therefore would be at higher risk of having prolapses. In contrast, our study also suggested a higher incidence of rectal prolapses in parity 0 sows than in older sows, which also supports another recent study (Supakorn et al., 2017). Some low parity sows still tend to have immature muscle and supporting tissues around the anus, and so this could explain the higher incidence of rectal prolapses because rectal prolapses can occur when the supporting tissue around the anus becomes unable to retain the rectum (Pittman, 2017).

Our study indicates a seasonal effect on occurrences of uterine and vaginal prolapses. Another report also showed a seasonal influence, with the highest incidence of prolapses occurring in winter in the U.S.A. (Pittman, 2017). Even though there is no obvious biological explanation for the higher uterine prolapse incidences in autumn and the higher vaginal prolapses in winter in our study, the seasonal effect may be related to fluctuations in temperature.

Our study also suggested that sows that had farrowed few piglets in the previous litter were more likely to have a prolapse incidence. This could be explained by the fact that too large piglets or too heavy piglets which were related to a small litter size (Holl and Long, 2006) may damage the vaginal canal. The obstruction of the birth canal by the heavy piglets could cause trauma with swelling or inflammation in the canal. Our study also showed that farrowing more stillborn piglets was clearly associated with incidences of rectal prolapses. One possible reason for this association is that farrowing stillborn piglets can cause increased abdominal pressure due to the difficulty of piglet delivery or infection in the pre-farrowing period.

Another prolapse risk factor identified by our study is shorter gestational length in a previous litter. Gestational length has been shown to have relatively high (50%) repeatability (Sasaki and Koketsu, 2007), so sows with repeated short gestational length may have weakened uterine and muscle tone.

Re-serviced sows also were associated with a higher incidence of prolapses. Re-serviced sows might have had an abortion or pregnancy loss in the previous litter, and problems like abortion could increase the risk of a prolapse occurrence.

However, our study did not show any association between prolapse occurrences and induction of farrowing or farrowing assistance. Pittman (2017) also reported that prolapses were not associated with any treatment prior to prolapse occurrence, such as receiving oxytocin for farrowing assistance. However, Alonso (2017) did find an association between assistance during farrowing and deaths of sows with prolapse. In our study, there was only a small number of herds used in the test, so the lack of any association in our study may not be conclusive. Finally, our study suggested that sows first serviced at 235-274 days of age had a relatively high risk of prolapses. Some sows that were first serviced during this age period would have had a high body condition score, and it is possible that fat pregnant sows have more adipose tissue surrounding the birth canal, which can result in a dystocia occurrence (Vanderhaeghe et al., 2013).

In conclusion, to identify prolapse occurrences at an early stage, producers should pay close attention to at-risk sows in peripartum periods. Prolapsed sows can recover through surgical and therapeutic treatments (Supakorn et al., 2017), but because future prolapse risks in the treated sow are unclear, owners tend to cull sows with severe prolapses due to concerns about reduced economic returns and welfare problems (Supakorn et al., 2017).

There are some limitations that should be noted when interpreting the results of our observational study. First, the type of prolapse was not specified in approximately 80% of the prolapse records. Also, the average size of the herds in our study that use the PigCHAMP software, was larger than the average herds in Spain. Therefore, they may not be the best representatives of average Spanish herds, but they do have better reproductive productivity than average herds, and so would survive in the competitive industry. In addition, because prolapses are not a highly prevalent disease in the swine industry, it was estimated, using the POWER procedure, that approximately 45-135 prolapsed sows would be needed for each subgroup in a factor to detect 2.0-3.0 times a difference in risk, assuming a power of 80% with a reference rate of two cases per 1000 sow-weeks and the animal weeks at risk set to be 100 weeks. Therefore, a bigger database with more total recorded prolapses would help to improve the precision of the assessment of risk factors for each type of prolapse. However, even with such limitations, this research provides valuable information for producers, veterinarians and researchers about prolapse occurrences.

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Table 1
Descriptive statistics for herd and reproductive data of sows in 144 herds in a study on incidences and risk factors for prolapse removal in Spanish sow herds.

Measurements	N	Mean	SD	Median (IQR)	Range
Herd-level data					
Herd size, sows	144	756.3	679.6	538.8 (293.3, 968.9)	80-3180
PWSY, piglets	144	24.3	2.4	24.2 (22.6, 26.2)	19-30
Annualized culling rate, %	144	35.8	8.5	35.8 (30.1, 40.8)	17-61
Annualized mortality rate, %	144	7.1	2.7	6.5 (5.4, 8.3)	2-18
Sow-level data					
Age at first service, days old[1]	134,917	254.8	39.4	250.0 (234.0, 275.0)	160-400
Parity at removal[2]	152,641	4.9	2.8	5.0 (2.0, 7.0)	0-15
Percentage of culled sows[2]	152,641	86.1	-	-	-
Percentage of dead sows[2]	152,641	13.9	-	-	-
Days from last service to prolapse					
Overall[3]	1198	119.6	30.8	122.0 (114.0, 138.0)	0-181
Sows removed before farrowing[4]	370	88.9	34.9	109.0 (67.0, 114.0)	0-125
Days from last farrowing to prolapse[5]	828	18.6	14.6	19.0 (5.0, 27.5)	0-67
Parity-level data					
Number of parity at service	819,754	2.8	2.2	2.0 (1.0, 4.0)	0-14
Gestational length, days[6]	662,683	114.9	1.6	115.0 (114.0, 116.0)	105-125
Total number of piglets born[6]	664,171	13.7	3.3	14.0 (12.0, 16.0)	1-30
Number of stillborn piglets[6]	664,171	0.9	1.4	0.0 (0.0, 1.0)	0-24
Number of mummified piglets[6]	664,171	0.2	0.7	0.0 (0.0, 0.0)	0-19
Service-level data					
Number of services	905,089	1.1	0.4	1.0 (1.0, 1.0)	1-8

IQR: interquartile range; PWSY: number of piglets weaned per sow per year; SD: standard deviation.
[1]The remaining records (155,238 - N) were regarded as missing records.
[2]The remaining sows (155,238 - N) were sows that had not yet been removed.
[3]The remaining records (1227 - N) were regarded as missing records.
[4]The remaining records (378 - N) were regarded as missing records.
[5]The remaining records (849 - N) were regarded as missing records.
[6]The remaining sows' records (665,196 - N) were regarded as missing records.

Table 2

Relative frequencies (%) of removal types and types of prolapses for 1227 sows that were removed due to prolapses in a study on incidences and risk factors for prolapse removal in Spanish sow herds.

Category	N	Percentage
Removal types[1]		
Culling	732	59.7
Death	495	40.3
Types of prolapses		
Rectal prolapses	114	9.3
Uterine prolapses	101	8.2
Uterine and rectal prolapses	3	0.2
Vaginal prolapses	34	2.8
Unspecified prolapses	975	79.5

[1]There were no euthanasia records in the prolapsed sows.

Table 3
Model estimates for herd-level incidence rates of prolapses in a study on incidences and risk factors for prolapse removal in Spanish sow herds.

Variable	Types of prolapses			
	All cases[1]	Uterus[2]	Vagina[2]	Rectum[2]
Number of events	1227	104	34	117
Number of sows	100,598	32,991	32,991	32,991
Model estimate (± SE)				
Poisson part				
Intercept	1.4 (0.14)	1.1 (0.30)	1.2 (0.18)	0.4 (0.35)
Herd variance	1.2 (0.23)	0.5 (0.39)	0.0 (0.10)	1.3 (0.61)
Zero-inflation part				
Intercept	-	0.4 (0.40)	1.8 (0.54)	- 2.3 (1.27)
ICC, %[3]	94.1	99.4	16.9	99.6
Estimated median incidence rate (95% CI)	4.1 (2.96, 5.15)	1.2 (0.33, 2.11)	0.5 (- 0.01, 0.96)	1.3 (0.51, 2.16)
Estimated population average of incidence rate (IQR)	7.3 (2.0, 8.4)	1.6 (0.8, 2.0)	0.5 (0.4, 0.5)	2.5 (0.6, 2.8)

CI: confidence interval; ICC: intra-class correlation coefficient; IQR: interquartile range; SE: standard error.
[1]The Poisson model was fitted using 75 herds that had at least one prolapse recorded.
[2]The zero-inflated Poisson model was fitted using 29 herds that had prolapse type recorded. Uterine, vaginal and rectal prolapses were respectively recorded in 11, 4 and 22 herds.
[3]The sow-years at risk was set to 1000 sow-years.

Table 4

Results from fitting the piecewise exponential model to the incidence rate for all prolapse cases in a study on incidences and risk factors for prolapse removal in Spanish sow herds[1, 2].

Variable	Estimate (± SE)	Ratio (95% CI)	Estimated rate[3]	*P*-value
Weeks (days) from service				< 0.01
0-14 (0-104)	0	1	0.4[e]	
15 (105-111)	1.68 (0.155)	5.38 (3.97, 7.29)	2.1[d]	
16 (112-118)	3.42 (0.096)	30.64 (25.38, 37.00)	12.0[b]	
17 (119-125)	2.63 (0.115)	13.82 (11.03, 17.31)	5.4[c]	
18 (126-132)	2.16 (0.133)	8.70 (6.70, 11.29)	3.4[d]	
19 (133-139)	2.85 (0.111)	17.36 (13.97, 21.57)	6.8[c]	
20 or more (140 or more)	3.73 (0.099)	41.86 (34.50, 50.80)	16.4[a]	
Parity				< 0.01
0	0	1	3.0[c]	
1	0.17 (0.102)	1.18 (0.97, 1.44)	3.5[bc]	
2	0.22 (0.105)	1.24 (1.01, 1.53)	3.7[bc]	
3	0.46 (0.102)	1.58 (1.29, 1.93)	4.7[ab]	
4	0.59 (0.104)	1.80 (1.47, 2.21)	5.4[a]	
5	0.44 (0.114)	1.55 (1.24, 1.94)	4.6[ab]	
6 or higher	0.42 (0.107)	1.53 (1.24, 1.88)	4.5[ab]	
Number of services				0.02
First service	0	1	3.7[b]	
Re-service	0.23 (0.100)	1.26 (1.03, 1.53)	4.6[a]	
Service season				< 0.01
January to March	0	1	4.1[a]	
April to June	- 0.26 (0.089)	0.77 (0.65, 0.92)	3.2[b]	
July to September	0.07 (0.082)	1.07 (0.91, 1.26)	4.4[a]	
October to December	0.17 (0.079)	1.18 (1.01, 1.38)	4.9[a]	

CI: confidence interval; SE: standard error.

[1]1196 cases and 4778 controls were used in this model. Two cases were excluded because these cases had no matched controls.

[2]Intercept and coefficients of herd entry year and entry month are not shown in this Table.

[3]Estimated incidence rate indicates the number of cases per 1000 sow-weeks.

[a-d]Estimates within a group with different letters are different ($P < 0.05$).

Table 5

Results of additional model parameters that were added to the piecewise exponential model for the incidence rate of all prolapse cases in a study on incidences and risk factors for prolapse removal in Spanish sow herds.

Variable	Estimate (± SE)	Ratio (95% CI)	Estimated rate[4]	*P*-value
Model including age at first service groups[1, 3]				
Age at first service				0.03
234 days old or younger	0	1	3.4[b]	
235-274 days old	0.23 (0.090)	1.25 (1.05, 1.49)	4.3[a]	
275 days old or older	0.14 (0.099)	1.15 (0.94, 1.39)	3.9[ab]	
Model including the following reproductive performance measurements before service[2, 3]				
Prior gestational length				< 0.01
113 days or less	0	1	5.9[a]	
114-116 days	- 0.27 (0.077)	0.76 (0.65, 0.89)	4.5[b]	
117 days or more	- 0.42 (0.127)	0.65 (0.51, 0.84)	3.8[b]	
Total number of piglets born				0.04
11 piglets or fewer	0	1	5.4[a]	
12-16 piglets	- 0.20 (0.083)	0.82 (0.69, 0.96)	4.4[b]	
17 piglets or more	- 0.22 (0.107)	0.80 (0.65, 0.99)	4.3[ab]	
Number of stillborn piglets				< 0.01
0 piglets	0	1	4.1[b]	
1 piglet	0.06 (0.081)	1.06 (0.91, 1.25)	4.4[b]	
2 piglets or more	0.32 (0.081)	1.38 (1.18, 1.62)	5.7[a]	
Number of mummified piglets				0.54
0 piglets	0	1	4.8	
1 piglet or more	- 0.06 (0.096)	0.94 (0.78, 1.14)	4.5	

CI: confidence interval; SE: standard error.

[1]1146 cases and 4576 controls were used in this model. Missing records of age at first service were not used in this model.

[2]991 cases and 3955 controls were used in this model. Missing records of the reproductive performance measurements were not used in this model.

[3]Intercept and coefficients of weeks from service, parity, number of services, service season, herd entry year and herd entry month are not shown in this Table.

[4]Estimated incidence rate indicates the number of cases per 1000 sow-weeks.

[a, b]Estimates within a group with different letters are different ($P < 0.05$).

Table 6
Incidence rate ratios for each type of prolapse by the four factors included in the model in a study on incidences and risk factors for prolapse removal in Spanish sow herds[1].

Variable	Uterine prolapse		Vaginal prolapse		Rectal prolapse	
	Ratio (95% CI)	*P*-value	Ratio (95% CI)	*P*-value	Ratio (95% CI)	*P*-value
Weeks (days) from service		< 0.01		< 0.01		< 0.01
0-14 (0-104)	1		1		1	
15 (105-111)	4.79 (1.92, 11.93)		23.43 (3.91, 140.26)		3.78 (1.27, 11.24)	
16 (112-118)	32.67 (19.10, 55.89)		63.87 (13.56, 300.82)		11.48 (5.48, 24.03)	
17 (119-125)	9.23 (4.42, 19.26)		16.43 (2.31, 116.71)		7.76 (3.35, 17.97)	
18 (126-132)	1.71 (0.40, 7.34)		8.35 (0.76, 92.18)		1.97 (0.45, 8.52)	
19 (133-139)	4.46 (1.67, 11.89)		-[2]		13.44 (6.53, 27.67)	
20 or more (140 or more)	19.76 (10.61, 36.82)		116.05 (26.78, 502.85)		52.10 (30.16, 90.01)	
Parity		< 0.01		0.60		0.08
0	1		1		1	
1	1.53 (0.65, 3.57)		2.39 (0.86, 6.66)		0.93 (0.56, 1.56)	
2	1.79 (0.80, 4.02)		1.28 (0.40, 4.12)		0.74 (0.40, 1.35)	
3	2.27 (1.02, 5.04)		1.35 (0.33, 5.55)		0.96 (0.54, 1.70)	
4	4.18 (1.98, 8.81)		1.28 (0.32, 5.18)		0.51 (0.22, 1.14)	
5	4.06 (1.89, 8.72)		1.49 (0.40, 5.63)		0.34 (0.12, 0.96)	
6 or higher	3.26 (1.50, 7.09)		0.42 (0.05, 3.45)		0.32 (0.13, 0.82)	
Number of services		0.59		0.26		0.49
First service	1		1		1	
Re-service	1.20 (0.62, 2.33)		0.32 (0.04, 2.36)		1.21 (0.70, 2.11)	
Service season		0.03		< 0.01		0.23
January to March	1		1		1	
April to June	0.42 (0.21, 0.84)		0.18 (0.06, 0.56)		0.92 (0.52, 1.62)	
July to September	1.01 (0.59, 1.72)		0.36 (0.14, 0.91)		0.87 (0.48, 1.55)	
October to December	1.16 (0.70, 1.94)		0.16 (0.05, 0.57)		1.41 (0.84, 2.36)	

CI: confidence interval.
[1]Models used 104 cases and 416 controls for uterine prolapses, 34 cases and 136 controls for vaginal prolapses, and 110 cases and 440 controls for rectal prolapses.
[2]Data are not shown because there was no case in this category.

Table 7
Incidence rate ratios for each type of prolapse by the additional five factors included in the models in a study on incidences and risk factors for prolapse removal in Spanish sow herds.

Variable	Uterine prolapse		Vaginal prolapse		Rectal prolapse	
	Ratio (95% CI)	*P*-value	Ratio (95% CI)	*P*-value	Ratio (95% CI)	*P*-value
Model including age at first service groups[1]						
Age at first service		0.94		0.95		0.36
234 days old or younger	1		1		1	
235-274 days old	1.09 (0.66, 1.79)		0.88 (0.34, 2.29)		0.79 (0.46, 1.35)	
275 days old or older	1.02 (0.39, 2.63)		0.99 (0.36, 2.72)		1.09 (0.62, 1.93)	
Model including the following reproductive performance measurements before services[2]						
Prior gestational length		0.36		0.10		0.90
113 days or less	1		1		1	
114-116 days	0.65 (0.35, 1.20)		0.43 (0.16, 1.17)		1.05 (0.54, 2.04)	
117 days or more	0.63 (0.30, 1.31)		1.36 (0.30, 6.11)		1.22 (0.49, 3.01)	
Total number of piglets born		0.45		0.92		0.80
11 piglets or fewer	1		1		1	
12-16 piglets	0.81 (0.51, 1.29)		0.88 (0.34, 2.29)		1.13 (0.58, 2.21)	
17 piglets or more	0.63 (0.30, 1.34)		0.75 (0.19, 3.01)		0.93 (0.40, 2.17)	
Number of stillborn piglets		0.83		0.40		0.01
0 piglets	1				1	
1 piglet	0.85 (0.50, 1.47)		0.81 (0.32, 2.04)		1.26 (0.68, 2.34)	
2 piglets or more	0.90 (0.52, 1.53)		0.35 (0.07, 1.63)		2.35 (1.31, 4.21)	
Number of mummified piglets		-[3]		0.76		0.99
0 piglets	-		1		1	
1 piglet or more	-		1.17 (0.43, 3.18)		1.01 (0.50, 2.02)	

CI: confidence interval.
[1]Models used 102 cases and 408 controls for uterine prolapses, 34 cases and 136 controls for vaginal prolapses, and 104 cases and 416 controls for rectal prolapses.
[2]Models used 93 cases and 372 controls for uterine prolapses, 25 cases and 100 controls for vaginal prolapses, and 71 cases and 284 controls for rectal prolapses.
[3]This variable was not examined because no event occurred in sows with mummified piglets.

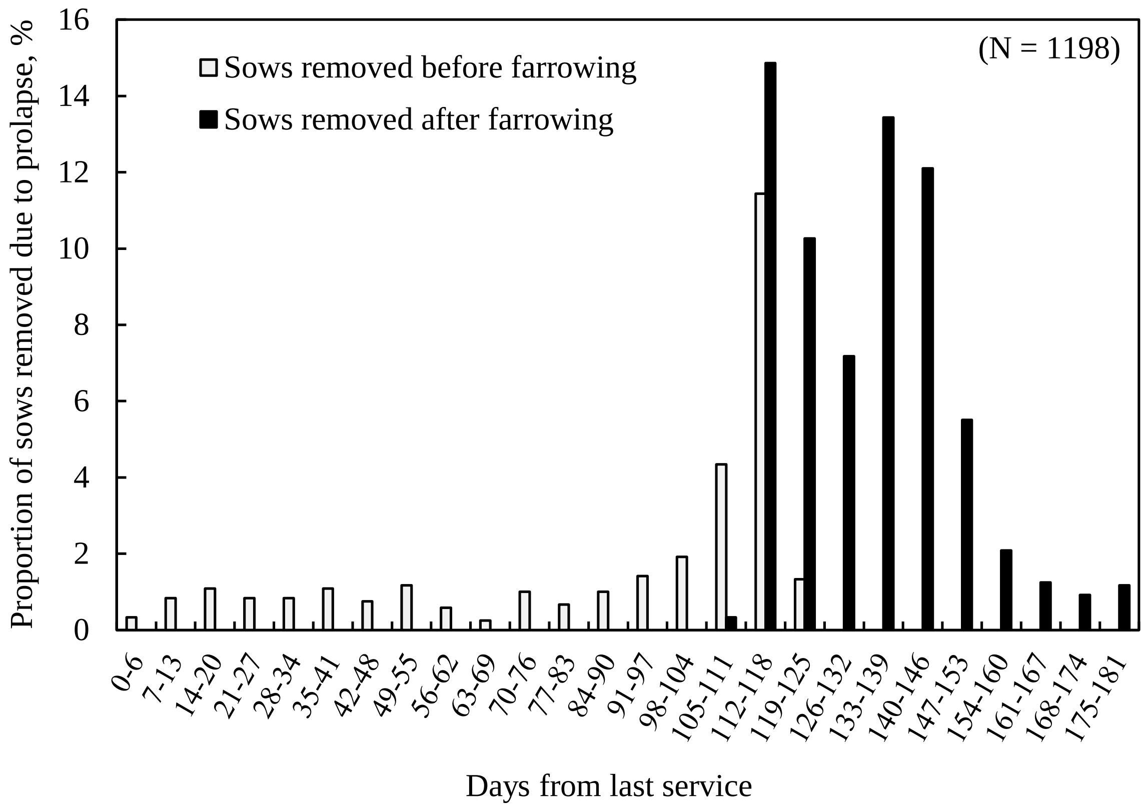

Fig. 1. Relative frequencies (%) of the number of sows that were removed due to prolapses after last service in a study on incidences and risk factors for prolapse removal in Spanish sow herds. Data omitted were records of pregnant sows that were removed at 126 days or more after service (8 of 378 sows) and sows that had farrowed and were subsequently removed at 182 days or more after service (21 of 849 sows). Sows were classified into sows that were either removed before due date or after farrowing.

Table S1

The number of service records, parity records, sows, and herds that were used in a study on incidences and risk factors for prolapse removal in Spanish sow herds.

Purpose of analysis Outcome	Model Set of fixed effects[1]	Number of records Herds	 Sows	 Parity	 Service
Descriptive statistics	-	144	155,238	819,754	905,089
Study of variability between herds					
All prolapse cases	Poisson model	75	100,598	-	-
Uterine prolapses	ZIP model	29	32,991	-	-
Vaginal prolapses	ZIP model	29	32,991	-	-
Rectal prolapses	ZIP model	29	32,991	-	-
Matched case-control study					
All prolapse cases	PE model				
	1	75	5974	30,098	33,175
	2	72	5722	29,200	32,285
	3	70	4946	22,864	25,019
Uterine prolapses	PE model				
	1	11	520	2687	3031
	2	10	510	2679	2999
	3	10	465	2218	2471
Vaginal prolapses	PE model				
	1	4	170	743	812
	2	4	170	768	824
	3	4	125	539	570
Rectal prolapses	PE model				
	1	22	550	2558	2900
	2	21	520	2331	2666
	3	19	355	1494	1670

ZIP: zero-inflated Poisson; PE model: piecewise exponential model.

[1]PE model 1 contained number of weeks from service, parity, number of service and service season as fixed effects; PE model 2 contained age at first service in addition to the variables in PE model 1; PE model 3 included prior gestational length, total number of piglets born, number of stillborn, mummified piglets and the variables in PE model 1.

CHAPTER 3

LAMENESS REMOVAL OF SOWS IN BREEDING HERDS: INCIDENCE, RELATED FACTORS AND REPRODUCTIVE PERFORMANCE OF REMOVED SOWS

ABSTRACT

Lameness is a major reason for sow removal in breeding herds. Increased occurrences of lameness decrease reproductive efficiency and increase welfare concern. Therefore, the objectives of this study were to estimate the incidence rate of lameness removal in breeding herds and to investigate the longevity and reproductive performance of sows removed due to lameness. Poisson regression models were applied to a cohort dataset of 165,918 sows in 148 Spanish breeding herds. The Wilcoxon rank sum test was used to compare the performance of sows removed due to lameness and their controls in one-to-two matched case-control datasets. Removal due to lameness accounted for 4.3% of all sows, and the incidence rate for lameness removal was 19.9 cases per 1000 sow-years (95% confidence interval: 15.61, 25.36). The majority (72.6%) of these removal cases were farrowed sows, whereas only 27.4% were serviced sows. In farrowed sows, a higher incidence of lameness removal was associated with weeks 4-8 after farrowing, higher parity and winter farrowing ($P < 0.01$). The removal incidence was 32.6-39.9 times higher in weeks 4-8 after farrowing than during the first week after farrowing. It was also 1.3-1.7 times higher in parity 4-5 than in parity 1, and 1.3 times higher in winter farrowing than summer farrowing ($P < 0.01$). In contrast, with serviced sows, the main factors associated with lameness removal were weeks 4-5 after service and being re-serviced ($P < 0.01$). For example, the removal incidence was 5.0 times higher in weeks 4-5 after servicing than during the first 2 weeks after servicing ($P < 0.01$). Also, it was 2.1 times higher in re-serviced sows than in first serviced sows ($P < 0.01$). However, lameness removal was not associated with parity ($P = 0.07$) or service season ($P = 0.27$). In case-control datasets, in comparison with control sows, sows that were removed due to lameness had higher weaning-to-first-mating interval (means: 6.5 vs. 5.8 days), fewer piglets born alive (11.7 vs. 12.5 piglets) and piglets weaned (10.5 vs. 11.1 piglets), and lower parity at removal (3.4 vs. 4.9; $P < 0.01$). However, there was no difference in gilt age at first service between the case and control groups ($P = 0.53$). In conclusion, considering weeks form service or farrowing, re-service, parity and season, we recommend checking sows' subclinical lameness and making a quick decision to cull a sow at risk in order to decrease the welfare concern.

Keywords: downer animals; gait; locomotory disorders; pig production; shared frailty model

1. Introduction

Lameness in sows is an important health problem and welfare concern in the swine industry (Heinonen et al., 2013; Pluym et al., 2013a; Maes et al., 2016), and is the one of the most commonly reported reasons for sow removal (Engblom et al., 2007; Sasaki and Koketsu, 2011; Wang et al., 2019). Also, lameness occurrences negatively affect sow longevity and lifetime performance, and reduces herd reproductive efficiency, which consequently decrease farm profitability (Anil et al., 2009; Sasaki and Koketsu, 2011; Wang et al., 2019). Recent studies show that lameness accounts for 5.0% to 10.5% of all removal cases (Engblom et al., 2007; Sasaki and Koketsu, 2011; Wang et al., 2019). Also, a herd-level analysis showed that the proportions of removal due to lameness varied from

0.7% to 19.9% in individual herds (Engblom et al., 2007). However, the most common method to calculate the proportions of sows removed due to lameness just counts the number of animals but does not take account of the number of sow-days at risk which can also vary between herds. Therefore, instead of using the number of sows removed as the denominator in the calculation, it would be more accurate to use the incidence rate to measure lameness removal, where the denominator is the number of animal-time units at risk.

The number of sow removal occurrences varies between sow reproductive cycle stages and parities (Anil et al., 2008; Engblom et al., 2008; Pluym et al., 2013b). So, both the numbers of days from service and the number of days after farrowing could be important. Engblom et al. (2008) reported that the hazard of lameness removal was greater at weaning (30 to 40 days after farrowing) than at other stages, but no study has reported on possible changes in the incidence rate of lameness removal from the time of service. Other studies have also shown that the risk of lameness removal is highest in low parity sows, and decreases as the parity increases (Lucia et al., 2000; Engblom et al., 2008; Wang et al., 2019). However, there has been little reporting on the effects of other sow-level and herd-level factors (e.g. herd size and culling rate) on the incidence rate of lameness removal.

Lameness is a painful condition that negatively affects the eating behaviour of sows (Cornou et al., 2008; Heinonen et al., 2013; Maes et al., 2016), which could compromise their reproductive performance. However, few studies have investigated the effect of lameness on reproductive performance, with little comparison of farrowing performance between lame and non-lame sows. It has been reported that lameness occurrence was not associated with pregnancy failure, farrowing failure or delayed post-weaning estrus (Heinonen et al., 2006; Pluym et al., 2013b). Also, Pluym et al. (2013b) found that the only adverse effect of lameness during gestation on farrowing performance was an increase in mummified fetuses. Furthermore, lameness during lactation would cause an increase in piglet mortality due to overlaying.

Therefore, in order to obtain more precise information on sow lameness, the objectives of this study were 1) to examine the incidence rates of lameness removal at different stages of the reproductive cycle in sows across different parities while taking between-herd variability and the number of sow-days at risk into account, 2) to clarify herd- and sow-level factors associated with these incidence rates of lameness removal, and 3) to investigate longevity, lifetime performance and reproductive performance of sows removed due to lameness.

2. Materials and methods

2.1. Herds and data extraction

A veterinary consultancy firm (PigCHAMP Pro Europa S.L., Segovia, Spain) has accumulated a pig database by requesting all their client producers, in 155 Spanish herds, to mail their data on a regular basis. Sows in the herds were mainly crossbred pigs between Landrace and Large White, which were either purchased replacement gilts from breeding companies, or were replacement gilts home-produced through internal multiplication programs.

Individual sow data in the 155 herds were extracted from the database in July 2017 to construct an entry cohort dataset. The extracted dataset included lifetime reproductive performance records of all sows that were entered into the herds between 2011 and 2013, with service records from January 2011 to December 2016. The dataset did not include records of gilts removed before first service.

Although producers are required to record a removal reason for each sow in the PigCHAMP software, seven of the 155 herds (4.5%) did not have removal reasons for more than 50% of the sows (range: 62.6-97.1%), and so were excluded from this present study. The remaining 148 herds had an average of 97.0% (range: 55.4-100%) recorded reasons for sow removal.

The data from the 148 herds included 958,975 service records in 165,918 sows. The following records were treated as missing values: gilt age at first service either 159 days or less, or 401 days or more (Hoving et al., 2011); gestational length of either 104 days or less, or 126 days or more (Sasaki and Koketsu, 2007); lactational length and number of piglets weaned of sows used as nurse sows; lactational length of either 6 days or less, or 42 days or more; number of piglets weaned of either 0 or 31 piglets or more; weaning-to-first-mating interval of 42 days or more; the total number of piglets born of either 0 or 31 piglets or more (Bloemhof et al., 2013); nonproductive sow days of 366 days or more. In addition, removal intervals were regarded as extreme and treated as missing if sows were removed after 126 days or more post service without subsequent events, or if sows were removed after 70 days or more post farrowing.

2.2. Definitions

A sow is a female pig that has been serviced at least once. Parity is defined as the number of farrowing, and the number of parities are retained for sows with pregnancy failure or farrowing failure. A mating is defined as any single insemination of a sow during estrus, and a service includes one or more mating events in the estrus period. A re-service is defined as when more than one service event occurred within a parity. Days and weeks from service or farrowing are the respective numbers of days and weeks from the date of service or farrowing (days 0 and weeks 0).

An annualized incidence rate of lameness removal (cases per 1000 sow-years) was calculated as the number of sows removed due to lameness divided by the sum of the number of sow-years at risk, multiplied by 1000 sows (Dohoo et al., 2009). The at-risk interval was defined as starting at the date of first service and ending at the date of removal. In active and surviving sows, when the data were extracted the sow-years at risk was defined as the number of years from the first service date to the last event date (e.g. service, farrowing, or weaning date). In addition, nonproductive sow days was defined as the number of days when sows were neither gestating nor lactating from the date of first service to the removal date.

The herd management measurements that were examined as herd-level factors were herd size, number of piglets weaned per sow per year (PWSY), culling rate and mortality rate. The measurements were annually calculated from 2011 to 2016, and then were averaged for each herd in six 1-year periods. The culling rate (%) and mortality rate (%) were respectively calculated as the number of culled sows per year and the number of dead sows per year divided by annual sow inventory, multiplied by 100.

Assessed sow-level factors included the number of weeks from service, the number of weeks from farrowing, number of parity (0, 1, 2, 3, 4, 5 and 6 or higher), number of services (first service and re-service), service or farrowing season (Jan. to Mar., Apr. to Jun., Jul. to Sept. and Oct. to Dec.) and entry year. Also, the following nine reproductive performance measurements were assessed, gilt age at first service, whether or not a sow had been used as a nurse sow, lactational length, number of piglets weaned, weaning-to-first-mating interval, gestational length, number of piglets born alive, stillbirths and mummies. Additionally, the following lifetime performance measurements were examined, parity at removal, lifetime number of piglets born alive, lifetime piglets weaned and nonproductive sow days.

2.3. Statistical analysis

Data management, descriptive statistics and the other all analyses were performed using SAS University Edition (SAS Institute Inc., Cary, NC, U.S.A.).

2.3.1. Cohort data analyses

Using the GLIMMIX procedure, two-level Poisson regression models were applied to the cohort data 1) to estimate the incidence rate of lameness removal taking account of the herd variability, and 2) to examine the associations between the incidence and the sow-level factors. The logarithm of the sow-years at risk divided by 1000 was treated as an offset in the model to predict the number of lameness removal cases per 1000 sow-years. The models were separately constructed for two stages of the reproductive cycle (i.e. the period from service until farrowing and the period from farrowing until subsequent service) and the overall duration. Intercept-only models with no fixed and random effects were also applied to the data to estimate the simple incidence rates of lameness removal and their 95% confidence intervals.

Intra-class correlation coefficients (ICCs) were calculated as the proportion of the variance explained by herd-level information. The herd variability was estimated by models with no fixed effect. The ICCs were estimated by the simulation-based approach (Stryhn et al., 2006):

1) the random effect vector u_i was simulated from Normal (0, σ^2_{herd}) for i = 1, …, 100,000,
2) the expected values and their variances $[\exp(X\beta + u_i)]$ were computed,
3) the variance of the expected values and the mean of the variances were computed across the i simulations, and

4) the ICC was computed as the variance of the expected values/(the variance of the expected values + the mean of the variances) x 100.

The Pearson's correlation coefficient was estimated between the incidence of lameness removal and the herd-level factors.

Sow-level factors were univariately added into the two-level model as a fixed effect. Individual service or farrowing records were divided into week-level risk sets before modeling when the number of weeks from service or weeks from farrowing was analyzed (Yang and Goldstein, 2003; Iida et al., 2019).

2.3.2. Creation and analyses of matched case-control data

A nested case-control study was carried out taking account of the factors examined in the cohort data analyses (i.e. herd effect and sow-level factors). Three case-control datasets were prepared to compare retrospectively 1) gilt age at first service and weaning-to-first-mating interval, 2) the other seven reproductive performance measurements after farrowing and 3) the lifetime performance measurements between sows that were removed due to lameness and their matched control sows. One service record for a sow removed due to lameness (case) was matched to two service records for sows removed for another reason or surviving sows (controls) by using herd, number of parity, number of service, service year and season as the matching variables in the 1st dataset. One farrowing case record was similarly matched to two farrowing control records by using the variables of herd, parity, farrowing year and season in the 2nd dataset. In the 3rd dataset, one lifetime case record was matched to two lifetime control records by using herd, first service year and season. These case-control analyses were performed using the SURVEYSELECT procedure. Continuous and dichotomous measurements were analyzed by the Wilcoxon rank sum test and the Fisher's exact test, respectively. Finally, in order to check the validity of the results, stratification analyses were applied to the original cohort data by using either the van Elteren test or the exact Cochran-Mantel-Haenszel test. The matching variables which were used to construct the case-control datasets were used as the stratification variables in the analyses.

3. Results

Descriptive statistics of herd and sow reproductive data are detailed in Table 1. Means of herd size and number of piglets weaned per sow per year (PWSY) over six years were 783.5 sows and 24.4 piglets, respectively. Table 2 shows the risk and proportion of lameness removal in each parity, with an overall removal rate due to lameness of 4.3% (7053/163,316 records). The risks of lameness removal increased from 0.2% in parity 0 to 0.8% at parity 1 and to 1.6 % at parity 6 or higher. Also, 93.0% of lameness removal records were culling records (6558 records), with the other 7.0% recorded as death or euthanasia (495 records).

Fig. 1 shows the frequency distribution of lameness removal at each week from last service. The majority (72.6%: 4924/6784 records) of lameness removals occurred in farrowed sows, with 40.1% (2719 records) of removals during weeks 19-20 after service

(133-146 days). There was also a slight increase in lameness removals in weeks 3-5 after service (21-41 days), but this only accounted for 9.1% (614 records) of lameness removals.

The overall incidence rate (cases per 1000 sow-years) for lameness removal was 19.9 (95% confidence interval [CI]: 15.61, 25.36; Table 3). The respective rates in serviced sows and farrowed sows were 6.8 (5.29, 8.64) and 74.7 (56.65, 98.60) cases per 1000 sow-years. The herd-level incidence rates of lameness removal in serviced sows and farrowed sows were estimated to be 2.4 (1.60, 3.66) and 15.8 (9.96, 25.03) cases per 1000 sow-years, respectively (Table 3). Also, in 31 of the 148 herds (20.9%) there were no records of any lameness removal cases. The ICCs for the incidence rates of lameness removal were estimated to be between 99.6 and 99.9%.

Table 3 shows Pearson's correlations between the incidence rates of lameness removal and the herd management measurements. The incidence rate in farrowed sows was correlated with herd size (r = 0.21), PWSY (r = 0.28) and culling rate (r = 0.43; $P < 0.01$). Fig. 2 shows the scatter plots of the incident rates for farrowed sows in each herd and either PWSY or culling rate.

Lameness removal in serviced sows was associated with the number of weeks from service and the number of services (Table 4). The removal incidence rate was 5.0 times higher at 4-5 weeks after service (4.5 cases per 1000 sow-years) than during the first 2 weeks after service (0.9 cases; $P < 0.01$), and 8.4 times higher at 16-17 weeks after service (7.6 cases; $P < 0.01$). Furthermore, the removal incidence rate was also 2.1 times higher in re-serviced sows (4.6 cases) than in first serviced sows (2.2 cases; $P < 0.01$). However, the removal incidence in serviced sows was not associated with either parity ($P = 0.068$), service season ($P = 0.27$) or entry year ($P = 0.10$).

A higher incidence of lameness removal in farrowed sows was associated with the 4-8 weeks after farrowing, higher parity, winter farrowing and herd entry in 2012 and 2013 ($P \leq 0.01$; Table 5). The removal incidence rate was 32.6-39.9 times higher at 4-8 weeks after farrowing (58.7-71.8 cases per 1000 sow-years) than during the first week after farrowing (1.8 cases; $P < 0.01$). It was also 1.3-1.7 times higher in parity 4-5 sows (17.6-22.3 cases) than in parity 1 sows (13.4 cases; $P < 0.01$), and 1.3 times higher in sows farrowed in winter (18.2 cases) than in those farrowed in summer (14.0; $P < 0.01$). The incidence rate in the entry cohorts increased from 13.8 cases per 1000 sow-years in 2011 to 17.3 cases in 2013 ($P < 0.01$).

Table 6 shows comparisons of lameness removed sows (cases) and the control sows for the nine reproductive performance measurements. Mean weaning-to-first-mating interval in the case group was greater than that in the control group (6.5 vs. 5.8 days; $P < 0.01$), as were the numbers of stillborn piglets and mummified fetuses ($P < 0.01$). In contrast, gestational length and lactational length were shorter in the case group than in the controls ($P < 0.01$). Also, the numbers of piglets born alive and piglets weaned were lower in the case group than in the controls ($P < 0.01$). However, there were no significant differences between the case and control groups for gilt age at first service ($P = 0.53$), nor for the percentage of nursing between the cases and the controls ($P = 0.84$). The stratified analyses showed consistent results.

Finally, with the exception of gilt age at first service ($P = 0.67$), all the other assessed lifetime performance measurements were lower in sows removed due to lameness (cases) than in the controls (Table 7; $P < 0.01$). The stratified analyses showed the same associations as the case-control studies for lifetime performance of sows.

4. Discussion

This study has characterized lameness removal in sows including reproductive performance and the time pattern of removal due to lameness. One of the main characteristics of lameness removed sows is that they had delayed weaning-to-first-mating interval, and had subsequently lower farrowing and weaning reproductive performance than their matched control sows. The lameness removed sows could have had minor feet or leg problems during lactation which may have caused a reduction in lactational feed intake (Cornou et al., 2008; Heinonen et al., 2013). A reduced feed intake in sows during lactation has been associated with delayed post-weaning estrus and reduced subsequent litter size (Koketsu et al., 1996). Other similar conditions have also been associated with negative reproductive performance. For example, claw lesions have been negatively associated with these reproductive performance (Lisgara et al., 2015a). Also, sows with prolonged periods lying down could be predisposed to urinary and genital infections which may increase the risk of stillborn piglets (Heinonen et al., 2013). In addition, lameness can hinder sow movement during lactation, and this could cause piglet mortality due to crushing (Anil et al., 2009). In fact, Pluym et al. (2013b) reported that the presence of wall cracks, white line lesions and skin lesions above the claw increased the odds of stillbirths and mummified fetuses, whereas heel lesions increased the odds of a sow crushing her piglets.

Also, the shorter lactational length sows removed due to lameness implies that lame sows were culled just after the minimum lactation period. However, the small difference of only 0.1 days shorter gestational length in lameness removed sows may not be biologically important.

Our study corroborated previous studies showing that lameness impedes sows reaching optimal breeding efficiency. The sows removed due to lameness had lower longevity, fewer lifetime piglets born alive and fewer lifetime piglets weaned than sows removed for other reasons, which is consistent with previous studies (Lucia et al., 2000; Sasaki and Koketsu, 2011; Pluym et al., 2013b). Also, our study suggests that first serviced sows, regardless of gilt age, were equally at risk of lameness removal.

Most of the lame sows were removed after weaning without any subsequent service, which is consistent with previous studies (Anil et al., 2008; Engblom et al., 2008). This indicates that producers would usually retain a sow with mild-to-moderate lameness until the litter was weaned. However, it is still likely that acutely lame sows will be removed immediately from the herd (Anil et al., 2009). Furthermore, it could take more effort to detect and cull less severe or subclinically lame sows fed in a large group during gestation.

Although most sows were removed for lameness in the weeks after farrowing, about 9% were removed between the 3-5 weeks after service. There are two main possible reasons for lameness removal at this time. One is that lameness was detected when the serviced sows were moved to group housing from an individual stall. A previous study showed that more lame sows were found when sows were moved from the insemination stalls to the gestation unit (Pluym et al., 2013b). The other main possible reason is that mild-to-moderately lame sows would be culled just after having a negative pregnancy check. Some cases of pregnancy failure can be a consequence of lameness because it could inhibit the display of behavioral estrus when the sow should be inseminated. In fact, re-serviced sows were more likely to be removed than first serviced sows in our study. This result is consistent with a previous study showing high culling hazard due to lameness in sows with a long weaning-to-farrowing interval (Engblom et al., 2008).

Since January 2013, group housing for gestating sows has been mandatory in the European Union for a certain period (European Commission, 2008). This change could explain the increased incidence rate of lameness removal of sows in our study that were entered into herds in 2013, because pregnant sows in group housing could exhibit more lameness than those in individual stalls (Harris et al., 2006; Anil et al., 2007; Cador et al., 2014).

Additionally, we found an increased incidence of lameness removal in winter farrowed sows. There is still some debate about the relationship between farrowing season and increased lameness removal (Anil et al., 2005; Knage-Rasmussen et al., 2014; Masaka et al., 2014). However, in Spain the humidity is higher in winter than in summer, and this may have caused an increase in infections of lesions of sows. Also, gestational housing floors in winter could be more slippery than in summer which may cause progressive lameness during gestation. Furthermore, culling of sows from a herd depends on other production factors, such as availability of gilts to replace the culled sow and pricing of sow carcass (Heinonen et al., 2013), so these may also affect when sows are removed due to lameness.

The proportion of lameness removal in our study (4.3% in all 144 herds) was relatively lower than recent studies that have reported 5.0-10.5% (Engblom et al., 2007; Sasaki and Koketsu, 2011; Wang et al., 2019). This discrepancy suggests that there may be some variability among countries in factors affecting lameness removal decisions, such as replacement gilt selection, the program of identifying lame sows or sow culling strategy. Also, sow- and herd-level incidence rates of lameness removal were respectively estimated to be 19.9 and 4.9 cases per 1000 sow-years. This suggests that some small herds may have some years when they do not have any lameness removal case. In fact, 20.9% of our studied herds did not record any lameness removal cases over the six-year period of the cohort dataset. Another report in the also showed a similar value with no lameness removal records in 26% of 76 herds in England (Willgert et al., 2014).

High PWSY herds would be more likely to voluntarily cull sows with minor leg injuries to keep their sow population healthy. In our study, lameness incidence increased as the culling rate increased, which could indicate that the herds with a high culling rate more actively culled sows with health problems, such as lameness, than herds with a low culling rate. In addition, we found that almost all of the variability of lameness removal was explained by herd variability (ICC: 99.6-99.9%). A possible reason for this is that the number of cases of lameness removal after farrowing per 1000 sow-years varied between zero and 300 or more. This suggests that there are herd risk factors for lameness, such as housing system and herd management, and that they can differ between herds (Heinonen et al., 2013; Pluym et al., 2017; Bergman et al., 2019).

Finally, our analysis showed a higher risk of lameness removal after farrowing in high parity sows than in low parity sows. High parity sows are more likely to suffer from claw lesions or foot problems than low parity sows because high parity sows have heavier body weight and greater pressure on their feet and joints (D'Eath, 2012; Fitzgerald et al., 2012; Lisgara et al., 2015b). However, Engblom et al. (2008) reported that the hazard for removal is greater for first parity sows than for other age groups in Sweden, and suggested that producers were likely to remove young sows with affected legs and therefore sows with good legs remained in the subsequent parity groups (Engblom et al., 2008). Therefore, it appears that the culling policy for lame sows differs between countries.

There are some limitations that should be noted when interpreting the results of our observational study. First, the analyses in our study could not take into account of housing system factors such as herd health, floor type and space, number of sows per stockman, nutrition and genetics information, which have been reported to be associated with the occurrence of lameness in sows (Cador et al., 2014; Willgert et al., 2014; Maes et al., 2016). In addition, euthanasia and death records could not be separated in our study. However, even with such limitations, this research provides valuable information for producers, veterinarians and researchers about sow lameness.

In conclusion, we recommend detecting sows with minor leg injuries or subclinical lameness at each stage of the reproductive cycle, especially before service. We also suggest that producers should make a quick decision to cull a sow at risk in order to minimize the lameness prevalence in a herd and decrease the welfare concern, because it seems there is no economically appropriate way to treat lameness in sows (Heinonen et al., 2013; Pluym et al., 2013a).

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Table 1

Descriptive statistics of herd and sow reproductive data in 148 herds.

Measurements	N	Mean	SD	Median (IQR)	Range
Herd-level data					
Herd size, sows	148	783.5	730.5	538.8 (298.3-983.3)	80-3678
PWSY, piglets	148	24.4	2.4	24.4 (22.7-26.2)	19-30
Culling rate, %	148	36.1	8.7	36.1 (30.1-40.8)	17-61
Mortality rate, %	148	7.1	2.6	6.6 (5.4-8.1)	2-18
Sow-level data					
Gilt age at first service, days old[1]	145,594	254.4	38.2	249.0 (235.0-273.0)	160-400
Parity at removal[2]	163,316	4.9	2.7	5.0 (2.0-7.0)	0-15
Lifetime number of piglets born alive per sow[3]	163,215	60.1	36.7	64.0 (27.0-89.0)	0-214
Lifetime number of piglets weaned per sow [3]	160,952	53.7	30.5	58.0 (28.0-78.0)	0-174
Nonproductive sow days[3]	162,678	73.9	57.6	56.0 (33.0-102.0)	0-365
Days from last service to lameness removal before farrowing[4]	1860	56.2	33.1	47.0 (30.0-84.0)	0-124
Days from last farrowing to lameness removal[5]	4924	27.7	11.9	27.0 (21.0-34.0)	0-69
Parity-level data					
Number of parity at service	868,851	2.8	2.2	2.0 (1.0-4.0)	0-14
Gestational length, days[6]	812,645	114.9	1.6	115.0 (114.0-116.0)	105-125
Number of piglets born alive[6]	814,208	12.4	3.2	13.0 (11.0-14.0)	0-28
Number of stillborn piglets[6]	814,208	1.0	1.5	0.0 (0.0-2.0)	0-24
Number of mummified fetuses[6]	814,208	0.2	0.7	0.0 (0.0-0.0)	0-22
Percentage of nursing[6]	814,304	0.94	-	-	-
Lactational length, days[6]	792,516	23.3	4.2	22.0 (21.0-26.0)	7-41
Number of piglets weaned[6]	790,125	10.9	2.1	11.0 (10.0-12.0)	1-30
WMI, days[7]	697,691	5.7	4.7	5.0 (4.0-5.0)	0-41
Service-level data					
Number of services	958,975	1.1	0.4	1.0 (1.0-1.0)	1-8

IQR: interquartile range; PWSY: number of piglets weaned per sow per year; SD: standard deviation; WMI: weaning-to-first-mating interval.

[1]The remaining records (165,918 - N) were regarded as missing records.

[2]The remaining sows (165,918 - N) were sows that had not yet been removed.

[3]The remaining records in removed sows (163,316 - N) were regarded as missing records.

[4]The remaining records (1959 - N) were regarded as missing records.

[5]The remaining records (5094 - N) were regarded as missing records.

[6]The remaining records (814,838 - N) were regarded as missing records.

[7]The remaining records (703,315 - N) were regarded as missing records.

Table 2

Risk and proportion of lameness removal by parity at removal.

Parity at removal	Number of lameness removal	Number of sows at risk[1]	Number of removed sows	Risk of lameness removal[2]	Proportion of lameness removal[3]
0	365	165,238	10,491	0.2	3.5
1	1307	155,216	17,466	0.8	7.5
2	1005	137,793	13,450	0.7	7.5
3	1014	124,478	13,465	0.8	7.5
4	1016	111,036	14,118	0.9	7.2
5	1059	96,913	15,314	1.1	6.9
6 or higher	1287	81,575	79,012	1.6	1.6
Total	7053	165,918	163,316	4.3	4.3

[1]Sows that had missing parity records were not counted in the number of sows at risk.
[2]Denominator was the number of sows at risk.
[3]Denominator was the number of removed sows.

Table 3

Incidence rate for lameness removal in serviced and farrowed sows in 148 herds.

Measurements	Duration of at-risk		
	From service until farrowing	From farrowing until subsequent service	Total duration
Number of cases	1860	4924	6784
Number of sows at risk	165,918	155,334	165,918
Total sow-years at risk	275,107.6	65,883.5	340,991.1
Incidence rate, cases per 1000 sow-years (95% CI)			
Simple estimate (95% CI)	6.8 (5.29, 8.64)	74.7 (56.65, 98.60)	19.9 (15.61, 25.36)
Estimate taking account of herd effect (95% CI)	2.4 (1.60, 3.66)	15.8 (9.96, 25.03)	4.9 (3.15, 7.53)
Model intercept (SE)	0.88 (0.210)	2.76 (0.233)	1.58 (0.221)
Random herd effect (SE)	3.1 (0.55)	4.3 (0.68)	4.3 (0.65)
ICC, %[1]	99.6	99.9	99.9
Pearson's correlation coefficient with herd management measurements (*P*-value)			
Herd size	- 0.05 (0.56)	0.21 (< 0.01)	0.13 (0.12)
PWSY	0.14 (0.09)	0.28 (< 0.01)	0.25 (< 0.01)
Culling rate	0.22 (< 0.01)	0.43 (< 0.01)	0.39 (< 0.01)
Mortality rate	- 0.00 (0.997)	0.01 (0.88)	0.01 (0.90)

CI: confidence interval; ICC: intra-class correlation coefficient; PWSY: number of piglets weaned per sow per year.

[1]The sow-years at risk was set to 1000 sow-years in the ICC calculation.

Table 4
Estimated incidence rate (cases per 1000 sow-years) for removal of serviced sows due to lameness prior to farrowing, using the cohort data.

Variable[1]	Number of cases	Number of records	Total sow-years at risk	Incidence rate (95% CI)
Overall	1860	958,975	275,107.6	2.4 (1.60, 3.66)
Weeks from service; $P < 0.01$				
0-1 (0-13 days)	96	958,975	36,684.5	0.9 (0.52, 1.64)[e]
2-3 (14-27 days)	289	954,780	35,683.7	2.9 (1.79, 4.60)[c]
4-5 (28-41 days)	428	900,448	33,825.1	4.5 (2.89, 7.03)[b]
6-7 (42-55 days)	256	870,424	32,982.7	2.8 (1.78, 4.33)[c]
8-9 (56-69 days)	185	855,020	32,587.2	2.0 (1.26, 3.27)[ce]
10-11 (70-83 days)	138	846,781	32,350.6	1.5 (0.97, 2.42)[de]
12-13 (84-97 days)	138	841,706	32,156.9	1.5 (0.97, 2.45)[de]
14-15 (98-111 days)	184	836,858	31,864.6	2.1 (1.31, 3.29)[cd]
16-17 (112-125 days)[2]	146	816,073	6972.2	7.6 (4.62, 12.51)[a]
Number of parity at service; $P = 0.068$				
0	331	190,629	53,308.1	2.1 (1.32, 3.44)
1	313	163,886	46,546.0	2.3 (1.49, 3.67)
2	253	143,779	41,564.7	2.1 (1.37, 3.35)
3	238	127,708	37,086.9	2.3 (1.46, 3.59)
4	236	112,038	32,541.1	2.6 (1.66, 4.09)
5	225	94,375	27,384.1	3.0 (1.88, 4.74)
6 or higher	264	126,560	36,676.7	2.8 (1.77, 4.32)
Number of services; $P < 0.01$				
First service	1550	868,851	252,640.2	2.2 (1.45, 3.32)[b]
Re-service	310	90,124	22,467.4	4.6 (2.99, 7.23)[a]
Service season; $P = 0.27$				
January to March	424	234,994	67,625.9	2.3 (1.48, 3.48)
April to June	436	236,594	68,240.6	2.3 (1.50, 3.51)
July to September	480	241,966	68,735.0	2.5 (1.63, 3.80)
October to December	520	245,421	70,506.1	2.6 (1.71, 4.00)
Entry year; $P = 0.10$				
2011	520	311,255	89,156.7	2.2 (1.39, 3.34)
2012	582	302,275	86,649.0	2.3 (1.54, 3.58)
2013	758	345,445	99,301.9	2.7 (1.77, 4.16)

CI: confidence interval.
[a-e]Estimates within a group with different letters are different ($P < 0.05$).
[1]Variables were univariately assessed by using the model including the herd random effect.
[2]Reasons for censoring during the period: 799,468 farrowings; 5629 removals due to reasons other than lameness; 2590 reservices; 8240 records had no any event during this period.

Table 5
Estimated incidence rate (cases per 1000 sow-years) for removal of farrowed sows due to lameness without subsequent service, using the cohort data.

Variable[1]	Number of cases	Number of records	Total sow-years at risk	Incidence rate (95% CI)
Overall	4924	813,765	65,883.5	15.8 (9.96, 25.03)
Weeks from farrowing; $P < 0.01$				
0 (0-6 days)	172	813,765	15,535.5	1.8 (0.93, 3.66)[d]
1 (7-13 days)	288	808,787	15,445.0	3.1 (1.67, 5.79)[d]
2 (14-20 days)	679	803,143	15,224.7	7.5 (4.23, 13.32)[c]
3 (21-27 days)	1495	779,751	11,873.9	23.5 (13.59, 40.55)[b]
4 (28-34 days)	1185	411,709	4460.4	61.8 (35.57, 107.48)[a]
5 (35-41 days)	544	120,193	1540.2	71.8 (41.22, 125.13)[a]
6 (42-48 days)	247	59,812	856.0	58.7 (31.38, 109.76)[a]
7 (49-55 days)	164	34,653	480.2	69.9 (37.64, 129.92)[a]
8 (56-62 days)	98	18,653	286.6	63.8 (33.49, 121.45)[a]
9 (63-69 days)[2]	52	12,866	180.9	56.4 (27.48, 115.68)[ab]
Number of parity at farrowing; $P < 0.01$				
1	916	154,413	13,417.5	13.4 (8.20, 21.74)[c]
2	707	137,553	11,144.8	12.9 (7.93, 21.03)[c]
3	746	124,226	9955.6	15.5 (9.56, 25.05)[bc]
4	743	110,865	8805.7	17.6 (10.90, 28.58)[b]
5	809	96,822	7633.3	22.3 (13.75, 36.27)[a]
6 or higher	1003	189,886	14,926.6	15.7 (9.66, 25.65)[bc]
Farrowing season; $P < 0.01$				
January to March	1427	206,323	16,504.4	18.2 (11.45, 28.95)[a]
April to June	1251	201,881	16,236.4	16.2 (10.21, 25.85)[ab]
July to September	1134	207,259	17,096.4	14.0 (8.80, 22.13)[c]
October to December	1112	198,302	16,046.4	14.8 (9.28, 23.47)[bc]
Entry year; $P = 0.011$				
2011	1373	264,840	21,487.3	13.8 (8.63, 22.18)[b]
2012	1567	255,935	20,689.9	16.0 (10.03, 25.56)[a]
2013	1984	292,990	23,706.2	17.3 (10.83, 27.60)[a]

CI: confidence interval.
[a-d]Estimates within a group with different letters are different ($P < 0.05$).
[1]Variables were univariately assessed by using the model including the herd random effect.
[2]Reasons for censoring during the period: 1581 removals due to reasons other than lameness; 2120 reservices; 9113 records had no any event during this period.

Table 6
Comparisons of reproductive performance between sows removed due to lameness (case sows) and control sows in the matched case-control study.

Reproductive performance	Cases		Controls		*P*-value
	N	Mean (SD)	N	Mean (SD)	
Gilt age at first service, days old (only parity 0 sows)	227[1]	265.2 (34.29)	454	264.9 (36.33)	0.53[3]
Weaning-to-first-mating interval, days	1278[1]	6.5 (6.03)	2568	5.8 (4.77)	< 0.01[3]
Gestational length, days	4920[2]	114.6 (1.69)	9840	114.7 (1.50)	< 0.01[3]
Number of piglets born alive	4913[2]	11.7 (3.56)	9833	12.5 (3.24)	< 0.01[3]
Number of stillborn piglets	4913[2]	1.4 (1.99)	9833	0.9 (1.42)	< 0.01[3]
Number of mummified fetuses	4913[2]	0.33 (0.889)	9833	0.27 (0.739)	0.03[3]
Percentage of nursing	4923[2]	0.75	9842	0.72	0.84[4]
Lactational length, days	4408[2]	21.6 (5.46)	9599	22.4 (4.14)	< 0.01[3]
Number of piglets weaned	4136[2]	10.5 (2.47)	9582	11.1 (2.42)	< 0.01[3]

SD: standard deviation.
[1]Each individual case was matched to two control service records based on the herd, number of parity at service, number of services, service year and season.
[2]Each individual case was matched to two control farrowing records based on the herd, number of parity at farrowing, farrowing year and season.
[3]Wilcoxon rank sum test was performed.
[4]Fisher's exact test was performed.

Table 7

Comparisons of lifetime performance between sows removed due to lameness (case sows) and control sows in the matched case-control study[1, 2].

Lifetime performance	Cases		Controls		*P*-value
	N	Mean (SD)	N	Mean (SD)	
Gilt age at first service, days old	6197	258.0 (32.64)	12,388	257.9 (32.75)	0.67
Parity at removal	7053	3.4 (2.09)	14,095	4.9 (2.75)	< 0.01
Lifetime number of piglets born alive	7046	42.0 (27.91)	14,085	60.8 (37.18)	< 0.01
Lifetime number of piglets weaned	6889	38.1 (23.28)	13,878	54.5 (30.92)	< 0.01
Nonproductive sow days	7040	59.0 (56.29)	14,065	73.2 (56.32)	< 0.01

SD: standard deviation.

[1]Each individual case was matched to two control service records based on the herd, first service year and season.

[2]Wilcoxon rank sum test was performed.

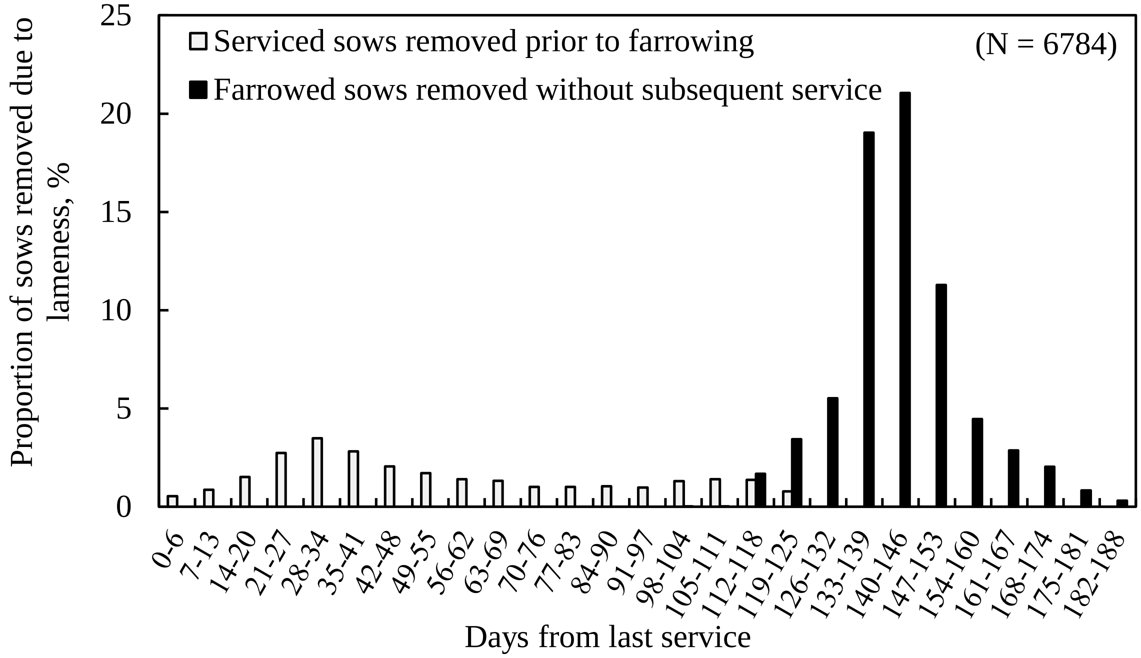

Fig. 1. Relative frequencies (%) of the number of sows removed due to lameness after last service. Sows were classified into those removed before the due date or after farrowing.

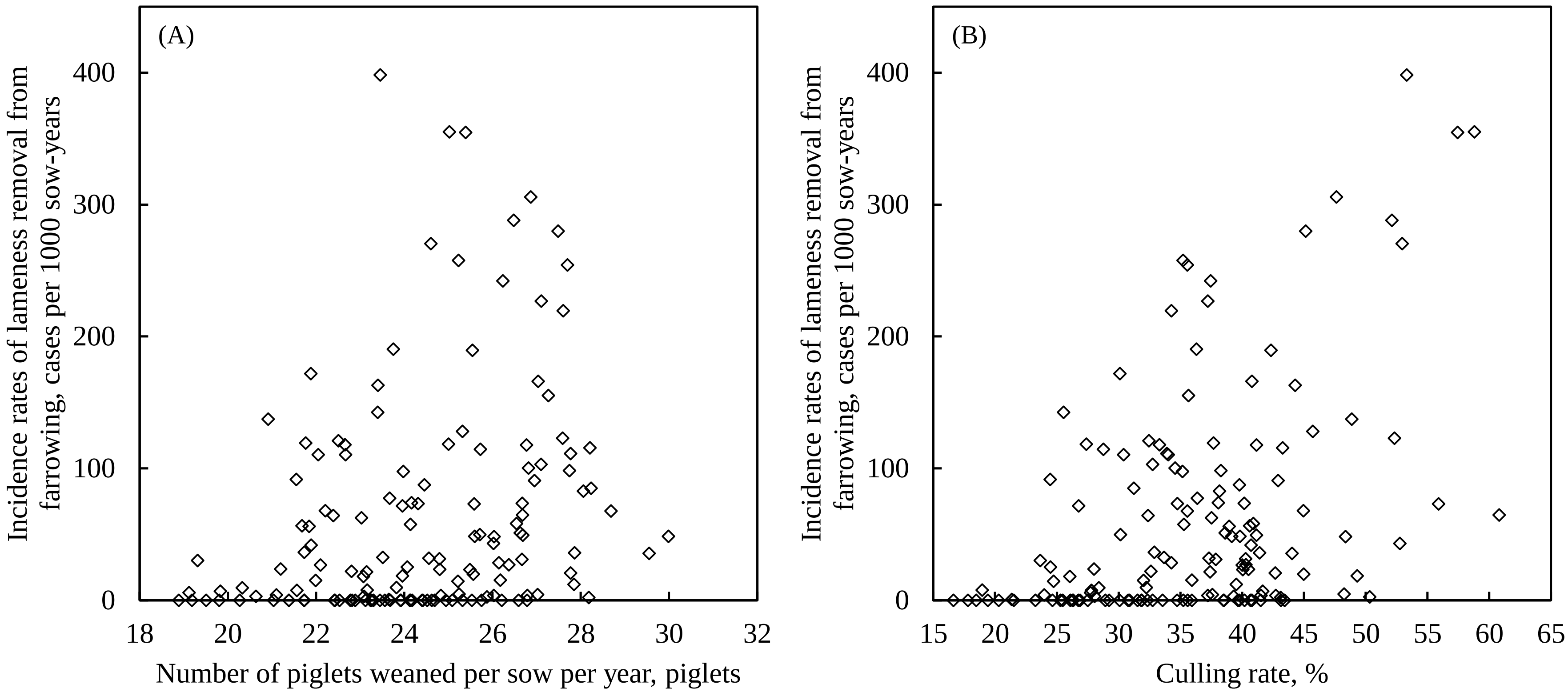

Fig. 2. Scatter plots for incidence rates of lameness removal for farrowed sows in 148 herds and either number of piglets weaned per sow per year or culling rate.

GENERAL DISCUSSION

Results in Chapter 1 showed that both weekly averages of daily feed dispensed (ADFD) and daily total time spent in the feeding stations (TTSF) were associated with parity, entry month and genotype. Also, less ADFD was associated with a higher hazard of a sow being displaced from her group for health reasons. Meanwhile, sows that had pregnancy loss had shorter TTSF than healthy pregnant sows. Therefore, measuring ADFD and TTSF could help producers predict sows that have a health problem in the electronic sow feeder (ESF) system, or sows that are likely to have a problem of pregnancy loss. Producers could improve the care of sows in ESF systems if they consider the eating behavior of each pig based on parity, entry month and genotype.

Chapter 1 also showed the weekly hazard of gestating sows in different parity being displaced from an ESF system. Parity 0 sows had a higher risk of displacement than parity 2 or higher sows in weeks 8-10 of gestation. Also, over 10% of parity 0 sows had been displaced from a group before the expected farrowing date. These results suggest that some parity 0 sows cannot adjust to the ESF or cannot get along with other parity sows in the ESF system, and have to be removed from the pen. Therefore, it has been recommended that parity 0 sows are housed separately from parity 1 or higher sows.

The incidence rate of prolapses for sows has been quantified by taking account of herd variability in Chapter 2. Based on the simulation, 50% of herds would have 2.0 to 8.4 prolapsed sows per 1000 sow-years. Therefore, some small herds may not have a prolapse occurrence every year. In addition, risk factors were explored for each type of prolapses, i.e. uterine, vaginal and rectal prolapses. Weeks from service was associated with the removal incidences in all types of prolapses: the first and second highest peaks of the incidences were found in the peripartum period and around time of weaning, respectively. Also, high parity sows had high incidences of uterine prolapses. In contrast, it was suggested that parity 0 sows have a higher incidence of rectal prolapses than older sows. In addition, the study indicates a seasonal effect on occurrences of uterine and vaginal prolapses. Furthermore, the study showed that farrowing more stillborn piglets was clearly associated with incidences of rectal prolapses. Therefore, in order to identify prolapse occurrences at an early stage, producers should pay close attention to such at-risk sows in peripartum periods.

Finally, sow lameness removal was characterized in Chapter 3. One of the main characteristics of lameness removed sows is that they had delayed weaning-to-first-mating interval, and had subsequently lower farrowing and weaning reproductive performance than their matched control sows. In addition, the study revealed that lameness impedes sows reaching optimal breeding efficiency.

The analysis showed a higher risk of lameness removal after farrowing in high parity sows than in low parity sows. Also, about 9% were removed between the 3-5 weeks after service although most sows were removed for lameness in the weeks after farrowing. Some cases of pregnancy failure can be a consequence of lameness because it could inhibit the display of behavioral estrus when the sow should be inseminated. In fact, re-serviced sows were more likely to be removed than first serviced sows in the study. Therefore, I recommend detecting sows with minor leg injuries or subclinical lameness at each stage of the reproductive cycle, especially before service.

In conclusion, I recommend that both ADFD and TTSF should be measured in ESF systems as part of daily practice, to help identify sows having an eating problem. Also, producers should pay more attention to sows exposed to high risks, while trying to identify prolapse cases at an early stage and to check sows' subclinical lameness. I recommend making a quick decision to cull a sow at risk in order to decrease the welfare concern.