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Animal Health and Well Being

Improving sow welfare and outcomes in the farrowing house by identifying early indicators from pre-farrowing assessment

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Abstract

Poor outcomes reflect low performance during the farrowing and lactation periods and unanticipated sow removals. Since the period around farrowing has the highest risk for sow health issues, monitoring of sows in that time-period will improve both welfare and productivity. The aim of this study was to identify the most relevant risk factors for predicting poor outcomes and the implication for sow welfare. Identifying these factors could potentially enable management interventions to decrease incidences of compromised welfare or poor performance. Data from 1,103 sows sourced from two nucleus herds were recorded for a range of variables investigated as potential predictors of poor outcomes in the farrowing house. Poor outcomes (scored as binary traits) reflected three categories in a sow's lifecycle: farrowing, lactation, and removals. Univariate logistic regression was used to identify predictors in the first instance. Predictors from univariate analyses were subsequently considered together in multi-variate models. The least square means representing predicted probabilities of poor outcomes were then reported on the observed scale. Several predictors were significant across two different environments (farms) and for all three categories. These predictors included feed refusal (lack of appetite), crate fit, locomotion score, and respiration rate. Normal appetite compared to feed refusals reduced the risk of farrowing failure (13.5 vs. 22.2%, $P = 0.025$) and removals (10.4 vs. 20.4%, $P < 0.001$). Fit in the crate was significant ($P < 0.001$) for farrowing and lactation outcomes, and was more informative than parity. Sows with sufficient space had two to three times reduced risk of poor outcomes compared to restrictive crates relative to sow dimensions. Sows with good locomotion score pre-farrowing had two to three times less risk of farrowing failure ($P = 0.025$) and reduced piglet mortality ($P < 0.001$), weaned two piglets more relative to affected sows ($P < 0.001$), and were less likely to be removed before weaning (3.24 vs. 12.3%, $P = 0.014$). Sows with higher respiration rates had a significantly ($P < 0.001$) reduced risk of poor farrowing outcomes. This study demonstrated it is possible to predict poor outcomes for sows prior to farrowing, suggesting there are opportunities to decrease the risk of poor outcomes and increase overall sow welfare.

Lay Summary

Farrowing and lactation are the most vulnerable events in sows' lifecycle with high risk of compromised health. For at-risk sows, poor health could result in an increased level of stillborn piglets, a decreased number of weaned piglets, or premature removals of sows from the herd. This can potentially be avoided by identifying at-risk sows prior to farrowing, to enable effective management interventions, thereby improving sow welfare. Several risk factors are shown to be consistent in identifying sows with compromised health or welfare across two different management systems. These risk factors are low appetite before farrowing, low respiration rate, leg problems, and the sows' fit within the farrowing crate relative to their dimensions. This study suggested that at-risk sows may be identified; altering their subsequent management and treatment could result in higher performance and reduced risk of premature removals.

Key words: farrowing, gestation, maternal performance, sows, stillbirths, well-being

Abbreviations: BGRP, breed group; CAL, count of increments on caliper (measuring body condition); CFIT, crate dimension score relative to sow size; DIRTU, presence or absence of dirtiness on udder; DIRTV, presence or absence of dirtiness on vulva; DIRTY, presence or absence of dirtiness on either udder or vulva or both; E2F, days from entry to farrowing house until farrowing; EYE, presence or absence of bloodshot or irritated eyes; FFAIL, farrowing failure; FIGHT, fight lesion score; FRBF, feed refusal before farrowing; FTYPE, feed type; GEST, gestation length GLM, generalized linear models GS, parity group (gilts and sows); HB, haemoglobin levels; INJUR, injuries, binary; INJURL, leg injurie score; LFAIL, lactation failure; LOCO, locomotion score; LSM, least square means; M2E, days from mating even until entry to farrowing house; MAST, presence or absence of mastitis; MJME, megajoules of metabolizable energy; MUM, number mummified piglets; NBA, number born alive piglets; NWEAN, number weaned piglets; P2F, predicted days to farrow after entry to farrowing house; PGRP, farrowing parities (4 levels); PMORT, piglet mortality; RECT, rectal temperature; REM142, sow removal 142 d post-farrowing; REM60, sow removals 60 d post-farrowing; REMW, sow removals pre-weaning; RESP, respiration rate; SB, number stillborn piglets; SBFAIL, an excessive number of stillborn piglets; SBLIT, stillborn piglets in litter; SLESION, shoulder lesion score; TACC, teat access score for piglets to reach teats; TB, number of total born piglets; TEATDG, count of distinct mammary glands; TEATI, count of injured teats; TREAT, treatment of sows; USCORE, udder development score; VLESION, vulva lesion score

Introduction

The time around farrowing and lactation are the periods with the highest risk of poor outcomes in a sow's productive life, including low performance, premature sow removals, and sow or piglet death. During that time, sows are more vulnerable to health issues, including infections (Hoy, 2006), have a

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higher risk of lowered immunity (Friendship and O'Sullivan, 2015), exhaustion (Anil et al., 2008), heart failure (Chagnon et al., 1991; Friendship and O'Sullivan, 2015), and physical injuries (Chagnon et al., 1991; Anil et al., 2008). Further, 40% of overall sow mortality occurs around farrowing (Chagnon et al., 1991; Anil et al., 2008). These findings highlight the importance of monitoring sows more closely around farrowing to improve sow welfare.

Decreased risks of poor outcomes can be achieved by assessing sows pre-farrowing for health status (Vargovic, 2020). Given that the term "health status" is generic and complex, and cannot be covered in one paper in detail, some of the measurements indicating poor health pertinent for this study can be categorized into four areas: (1) feed intake (Madec and Leon, 1992; Abiven et al., 1998) or related interactive behavior, e.g. fight lesions (Bunter and Boardman, 2015); (2) health, e.g. signs of mastitis (Perestrelo et al., 1994; Anil et al., 2008; Kongsted et al., 2021), urinary tract infection (Madec and Leon, 1992), or body condition (Lundeheim et al., 2014); (3) physiology, e.g. respiration rate or hemoglobin levels (Anil et al., 2008; Noblett et al., 2021); and (4) infrastructure, e.g. crate size (McGlone et al., 2004; Primary Industries Standing Committee, 2008; Moustsen et al., 2011). Typically, there is a lack of routine monitoring for the above-mentioned variables, and this can hinder the timely and effective management of sows.

Many potentially useful predictors for health and welfare, leading to reduced risk of poor performance could be recorded on-farm, but recording such variables is often not a feasible or effective use of labor. A stockperson typically spends approximately 4 h in total per sow per reproductive cycle, implying the time allowed to assist sows is very limited (Roguet et al., 2011). Therefore, the objective of this study was to identify the most informative variables observed in the farrowing house for predicting poor farrowing or lactation outcomes. The hypothesis was that informative predictors can be identified, implying at-risk sows can be identified and potentially managed to reduce incidences of poor outcomes.

Materials and Methods

This research was funded by the Australian Pork Research Institute Ltd. under project 2A-116, approved by the University of New England Animal Ethics Committee through CHM Alliance Pty Ltd (CHM PP 103/17) and Rivalea Australia (17R031C) ethics committees. This was an observational study with sows managed according to the standard farm practice regime at each farm.

General farm details

The data were collected from two nucleus farms, operated by independent companies within the periods of October to December 2017 (Farm A) and March to June 2018 (Farm B). On Farm A data were collected on 558 purebred sows representing two maternal and one terminal sire line. Data from Farm B included 545 purebred sows from three maternal and three terminal sire lines. All sows were bred using artificial insemination and after weaning were either re-bred or culled according to the farm protocol. During the gestation period, sows from Farm A were kept in static groups of about 10 sows per pen and manually fed, and sows from Farm B were kept in large dynamic groups of about 250 sows per pen and fed using electronic sow feeders. On both farms, gilts were kept separately from sows. Feeding curves differed for gilts versus sows on Farm A, whereas a common feeding curve was applied to all sows regardless of parity on Farm B. Stockpersons were visually (subjectively) scoring sows and assigning them to categories: thin, normal, and fat. A very small proportion of fat sows were fed less, and thin sows were fed more, on both farms.

Sows were moved to the farrowing house (hereafter termed "entry") at an average gestation length (GEST) of 110 d. However, GEST at transfer for individual sows ranged from 102 to 115 d (Farm A: entry once per week) and 107 to 114 d (Farm B: entry twice per week). In the farrowing house, the feed delivered from entry until farrowing was the same for both gilts and sows. Farm A fed a lactation diet (14.3 MJME/kg) once per day, as either dry or liquid feed. Sows from Farm B received a low energy (12.5 MJME/kg) pre-farrowing diet (dry), fed close to *ad libitum* from entry until 3 d post-farrowing, followed by a high energy lactation feed (14.3 MJME/kg) thereafter. After farrowing, sows were offered feed *ad libitum* on both farms. The water supply on both farms was unlimited at all times. The targeted lactation lengths were four (Farm A) and three (Farm B) weeks.

Sow attributes recorded

Data were collected on project sows, from entry to the farrowing house through to weaning as described in Table 1. Both farms were compliant with the Model Code of Practice and APIQ Standards (Primary Industries Standing Committee, 2008; Australian Pork Limited, 2021). The first author, with support from farm staff, collected all records. Measurements were recorded in the farrowing house at entry unless noted otherwise. All scores were subjective.

Production and medication records available from companies

Both farms provided routine performance and medication data. Reproductive data for all sows included: mating date(s), parity at mating, farrowing date, number born alive (NBA), number of stillborn (SB) and mummified (MUM) piglets, weaning date(s), number of weaned piglets (NWEAN), removal dates and reasons for culling sows. Treatment was defined as absent (0) or present (1) during the gestation period (TREAT). Blanket medication events (i.e., medication applied to all sows) were not included, as that was a part of standard farm routine, and was not a treatment provided due to impaired health of individual sows. Unless a clear welfare issue needed to be addressed, sows were not treated in response to this additional recording. This was done to avoid bias in assessing the association between predictors and outcomes.

Data preparation and the outcome definitions

Data preparation was carried out using R (R Core Team, 2020) and the outcome definitions are listed in Table 2. Raw data were examined for obvious errors and outliers, which were excluded from analyses. Outliers for hemoglobin within the farm (Farm A: $N = 3$ and Farm B: $N = 1$) were considered to be values outside the range of 4 SDs from the farm means. For sows used as foster sows (Farm A: $N = 1$ and Farm B: $N = 2$), NWEAN was based on the number of piglets weaned from the first litter only. If sows did not wean piglets due to piglet deaths, or if all piglets were removed prematurely, these were assigned with NWEAN = 0 ($N = 41$ sows). If the sow did

Table 1. Description of pre-farrowing predictors and recording methods used

Predictor	Description	Score analyzed
Locomotion (LOCO)	Ease of locomotion while sows were walking (at least 20 m) from the gestation housing to the farrowing house, adapted from Harris et al. (2006) and Bunter (2015)	Scores: 0—good mobility (easy movement); 1—restricted mobility (stiffness, slow movement); 2—poor mobility (limping, reluctance, uneven slow movement); 3—very limited mobility (inability to bear weight on one or more limbs)
Injuries (INJUR)	Excluding fight lesions. The presence of any injuries or wounds	Scored as 0—no injuries, and 1—injuries observed
Shoulder lesions (SLESION)	Adapted from Tabuaciri et al. (2010)	Scores: 0—no lesions observed; 1—mild; 2—moderate; 3—severe shoulder lesions
Vulva lesions (VLESION)	Adapted from Zurbrigg and Blackwell (2006)	As above
Leg injuries (INJURL)	Adapted from Harris et al. (2006)	As above
Fight lesions (FIGHT)	Number of lesions from fighting assessed over the whole body, adapted from Bunter (2015)	Scores: 0—no lesion observed; 1—1–5 lesions observed; 2—6–10 lesions; 3—10+ lesions
Dirtiness (DIRTY)	Scored upon the transfer, before washing (Farm A) and in the farrowing house (Farm B). Farm B did not wash sows at entry	Scored as 0/1. DIRTU = 1 for dirty udder, DIRTV = 1 for dirty around vulva, DIRTY = 1 if an animal is dirty either around vulva or udder or both
Udder development (USCORE)	Adapted from Balzani et al. (2016)	Scores: 0–individual mammary glands not well defined; 1–udder well developed, but mammary glands not clearly distinct; 2–udder well developed, with clear distinction of individual mammary glands
Distinct mammary gland (TEATDG)	The count of distinct mammary glands, adapted from Balzani et al. (2016)	Count
Pre-farrowing mastitis (MAST)	Swelling (localized or generalized) or congestion suggestive of mastitis adapted from Martineau et al. (2012)	MAST = 1 for sows with a hard, swollen udder at entry, irrespective of rectal temperature
Injured teats (TEATI)	The total number of teats with injuries	Count
Eyes (EYE)	The extent to which the eyes were bloodshot or irritated, adapted from Neary and Hepworth (2005) and Tabuaciri (2012)	Scores: 0–not bloodshot; 1–mildly bloodshot; 2–heavily bloodshot
Caliper (CAL) increments	The caliper was placed on the back of the sow at the last rib(Knauer and Baitinger, 2015), quantifying the angularity from the spinous to the transverse process of the sow's back	The number of increments represented an increase in body condition from "thin" to "fat" based on fat and muscle accumulation around the vertebrae
Crate dimension relative to sow size (CFIT)	Assessed when sows were recumbent, adapted from Tabuaciri (2012)	Scores: 1–represented plenty of room and crate not filled; 2–moderate room and overall crate filled; and 3–represented limited room, crate filled and movements likely to be restricted
Teat access (TACC)	Assessed when sows were recumbent, adapted from Tabuaciri (2012)	Scores: 1–represented teat access unrestricted; 2–interference to teat access, back and teats were close to crate bars; and 3–represented teat access clearly restricted, and teats were in contact with lower bar of farrowing crates
Resting respiration rate (RESP)	Recorded as the number of expirations per 30 s when sows were recumbent, converted to per minute	Count
Rectal temperature (RECT)	Measured using thermometer "Liberty", model DT-KO1A (Farm A) and thermometer "Vicks" (Farm B). Rectal temperatures were taken with the thermometer in contact with the rectal wall, after RESP was recorded	Measured in °C
Haemoglobin level (HB)	Measured once before farrowing using the Hemocue H201+ (HemoVue AB, Angelholm, Sweden) using a single drop of a blood obtained from a skin prick on the sow's ear, adapted from Kutter et al. (2012)	Measured in g/l. Sows that farrowed prior to the measurement date, or appeared distressed at the time of procedure were not tested for hemoglobin
Feed refusal before farrowing (FRBF) and feed type (FTYPE)	Feed refusals were scored 3–4 h after the first morning feed was delivered. Feed refusal was represented as a percent of days with score 1	Scores: 0–majority eaten and 1–more than half of the meal remained. Feed type identified sows on dry or liquid feed at Farm A

Table 2. Description of the outcome traits (all traits except NWEAN were binary)

Outcome trait	Description
Farrowing failure (FFAIL)	Present (1) if: an excessive number of stillborn piglets relative to litter size, where excessive was defined as ≥1 SB for TB (TB = NBA + SB + MUM) < 9, ≥2 SB for TB = 9–12, ≥3 for TB 13–16, ≥4 for 17–20 and ≥5 for TB >20; less than 5 NBA, presence of late stillborn piglets, or sows that experienced a caesarean or prolapse. This trait identifies sows with health issues prior to, or during the farrowing process
An excessive number of stillborn piglets (SBFAIL)	Present (1) if: an excessive number of SB relative to TB, defined as ≥1 SB for TB (TB = NBA + SB) < 9, ≥2 SB for TB 9–12, ≥3 SB for TB = 13–16, ≥-4SB for TB17 to 20 and ≥5SB for TB > 20. This trait identifies sows with health issues during the farrowing process that could potentially be prevented
Stillborn piglets in litter (SBLIT)	Present (1) if: a sow had any stillborn piglet, regardless of litter size
Lactation failure (LFAIL)	Present (1) if: weaned piglets <7, lactation length <15 d or removal reasons that included lactation issues (e.g., poor mothering ability, bad udder, no milk, mastitis)
Piglet mortality (PMORT)	Present (1) if: the percentage of NBA which died before weaning was > 15% of the birth litter. PMORT was recorded regardless of the sow on which piglets nursed, and was expressed as a trait of the dam
Weaned piglets (NWEAN)	The total number of piglets weaned by a sow (including cross-fostered piglets)
Sow removals (REMW, REM60, REM142)	Present (1) if: sows were removed pre-weaning (REMW); un-successfully re-mated (REM60); and sows that were re-mated, but subsequently culled before the next farrowing event (REM60, REM142)

Abbreviations: SB: stillborn piglets, TB: total born piglets, NBA: number born alive piglets, MUM: mummified piglets.

not lactate at all (culled or died), LFAIL was considered missing (N = 3, Farm A). The information about individual piglet mortality was available for a proportion of project sows at each farm (Farm A = 449 sows and 5,225 piglets, Farm B = 256 sows and 2,694 piglets). For trait PMORT only litters with all piglets (or no more than one piglet missing) individually identified were included in the analysis. For a forced (unanticipated) removal of sows, a score of 1 did not include sows removed due to old age, high parity, or low index value. These removal reasons were reassigned as a score of 0 since these represented management decisions (planned) and not health issues.

A number of variables were calculated from the recorded information. Gestation length (GEST) for sows that did not farrow successfully (e.g. cesarean or death during farrowing) was the interval between mating and the outcome date (N = 3). Lactation length (LACT) was the interval between farrowing date and the weaning date of the sow (including extended lactation if multiple litters were suckled). Intervals (in days) between mating and the entry to the farrowing house (M2E) and from entry until farrowing (E2F) were calculated as the difference in the dates of these events. The predicted time to farrowing (P2F) after entry was calculated as 116—M2E, where 116 reflects the average gestation length.

Traits that indicate the absence (0) or presence (1) of poor outcomes for sows are in brief described in Table 2; to avoid repetition more detailed description can be found in Vargovic et al. (2021a, 2021b).

Grouping of predictors

Sow attributes, recorded and described (with their abbreviations) in Table 1 were investigated as possible predictors. Predictors recorded as continuous variables were grouped into levels to facilitate the identification of non-linear effects (Table 3). Thresholds used for the grouping of predictors were the same across both farms, with the exception of P2F, due to the differences in entry times between farms. Farrowing parities were grouped (PGRP) as: parity 1 = group 1; parity 2 = group 2; parities 3–5 = group 3 and parity >5 was assigned to group 4. An alternative grouping of sows according to parity (GS) was considered as 0 (gilts) and 1 (sows). Values for most characteristics were divided into groups based on group size and the data distribution. Respiration rate was divided into three groups: 1 = normal range (≤20) for gestating sows (Ramirez and Karriker, 2012); 2 = double and 3 = triple the normal respiration rate. Rectal temperature was divided into absence (0) or presence (1) of an elevated rectal temperature: >38.6 °C (Ramirez and Karriker, 2012). Values for HB were arbitrarily divided into groups, with an exception of group 1 representing anemia ≤ 87 g/l (National Research Council 1998). Grouping for feed refusals before farrowing (FRBF) was based on the proportion of days where sows ate less than half of their morning meal. Group 0 represented no feed refusals observed. If a sow did not eat more than 50% of the total feed allocated for that meal, it represented group 4. When a predictor had a low number of observations within a group, it was consolidated into larger groups. Missing values (unrecorded sows) were assigned to a separate group for most predictors (not presented in Table 3), or the most common group if the number of missing observations was <10.

Statistical analysis

Logistic regression (Venables and Ripley, 2002) was applied to the binary outcome traits using generalized linear models (GLM) in R (R Core Team, 2020), (family = binomial), whereas a Poisson distribution was assumed for NWEAN. The data from both farms were merged into a combined data set. This combined data were used to identify predictors that were consistent across farms. An F-test was used to assess the significance of all predictors.

Due to relatively few records and independent data sets, the development of the final prediction model was conducted in two steps. Firstly, each factor (Table 3) was tested for its contribution to each outcome, fitting one predictor at a time

Table 3. Grouping of predictors recorded with factor levels

Variable, unit	Factor levels					
	0	1	2	3	4	5
BGRP		M	T			
Farm		A	B			
BGRP:Farm		MA	MB	TA	TB	
GS		Gilt	Sow			
LOCO, score	0	1	2–3			
INJUR, 0/1	No	Yes				
SLESION, score	0	1–3				
VLESION, score	0	1	2–3			
INJURL, score	0	1	2–3			
FIGHT, score	0	1	2 – 3			
DIRTY, 0/1	No	Yes				
DIRTU, 0/1	No	Yes				
DIRTV, 0/1	No	Yes				
EYE, score	No	Yes				
VSCORE, score	0	1	2			
CAL, increments		≤10	11–12	13–14*	15–16	≥ 17
CFIT, score		1*	2	3		
TACC, score		1*	2	3		
USCORE, score	0	1*	2			
TEATDG, count		≤11	≥12*			
MAST, 0/1	No*	Yes				
TEATI, count	0*	1	2	≥3		
RESP, expiration/min		≤20	21–39	≥40		
RECT, °C	≤38.6	≥ 38.7				
HB, g/l		≤ 87	88–94	95–101	102–109	≥110
FRBF, score	0	1–25%	26–50%	> 50%		
FT, type of feed		Dry	Liquid			
TREAT, 0/1	No	Yes				
M2E, days		≤105	106–108	109–111	≥112	
GEST, days		≤114	115–116*	117–118	≥119	
E2F, days		≤4	5–7	8–10	≥11	
P2F, days (FarmA)		≤4	5–6	7–8	>8	
(FarmB)		≤3	4 –5	6–7	>7	

Abbreviations: BGRP: maternal (M) and terminal (T) lines for farms A and B, GS: parity group, LOCO: locomotion score; INJUR: injuries; SLESION and VLESION: shoulder and vulva lesions; INJURL: leg injuries; FIGHT: fight lesions; DIRTY: dirtiness on udder and vulva; DIRTU: dirty udder; DIRTV: dirty vulva; EYE: bloodshot eyes; CAL: caliper score; CFIT: crate fit; TACC: teat access; USCORE: udder development score; TEATI: number of teats with injuries; TEATDG: number of distinct glands; MAST: mastitis; RESP: respiration rate; RECT: rectal temperature; HB; hemoglobin; FRBF: feed refusals; FT: feed type (Farm A dry and liquid, Farm B dry feed); TREAT: treatment of sow; M2E: mating to entry; GEST: gestation length; E2F: entry to farrow; P2F: predicted farrowing; *missing values were assigned to this group

to the base model (univariate analyses). The base model included a parity group (2 levels: gilts vs sows) fitted across farms (2 farms) and a line group nested within the farm (4 levels: Farm A maternal, Farm B maternal, Farm A terminal, Farm B terminal). For Figure 1, P-values were transformed to log10 for better presentation, and to allow for easier comparisons between predictors. This transformation is similar to that performed in Manhattan plots. In the second step, all significant predictors, including those approaching significance ($P < 0.10$) in univariate models, and those close to $P = 0.10$, due to a low frequency but with large effect, were fitted together in a multivariate model, followed by stepwise elimination of nonsignificant ($P < 0.05$) effects. The R package "emmeans" (Lenth, 2018) was used to back-transform solutions from the final multivariate logistic regression model to the least square means for each factor level. These least square means represented the predicted probability of the outcomes occurring. Means between pairs of levels for multivariate models were compared with no adjustment for multiple comparisons. This strategy was chosen because the data sets were relatively small and unbalanced, with a low number of observations for some factor levels. Therefore, there was a lack of statistical power in *post-hoc* (e.g., pairwise) tests, while global effects were still significant ($P < 0.05$). Significance solely arising from the contrast between levels of unrecorded versus recorded sows for specific factors were excluded from multivariate models.

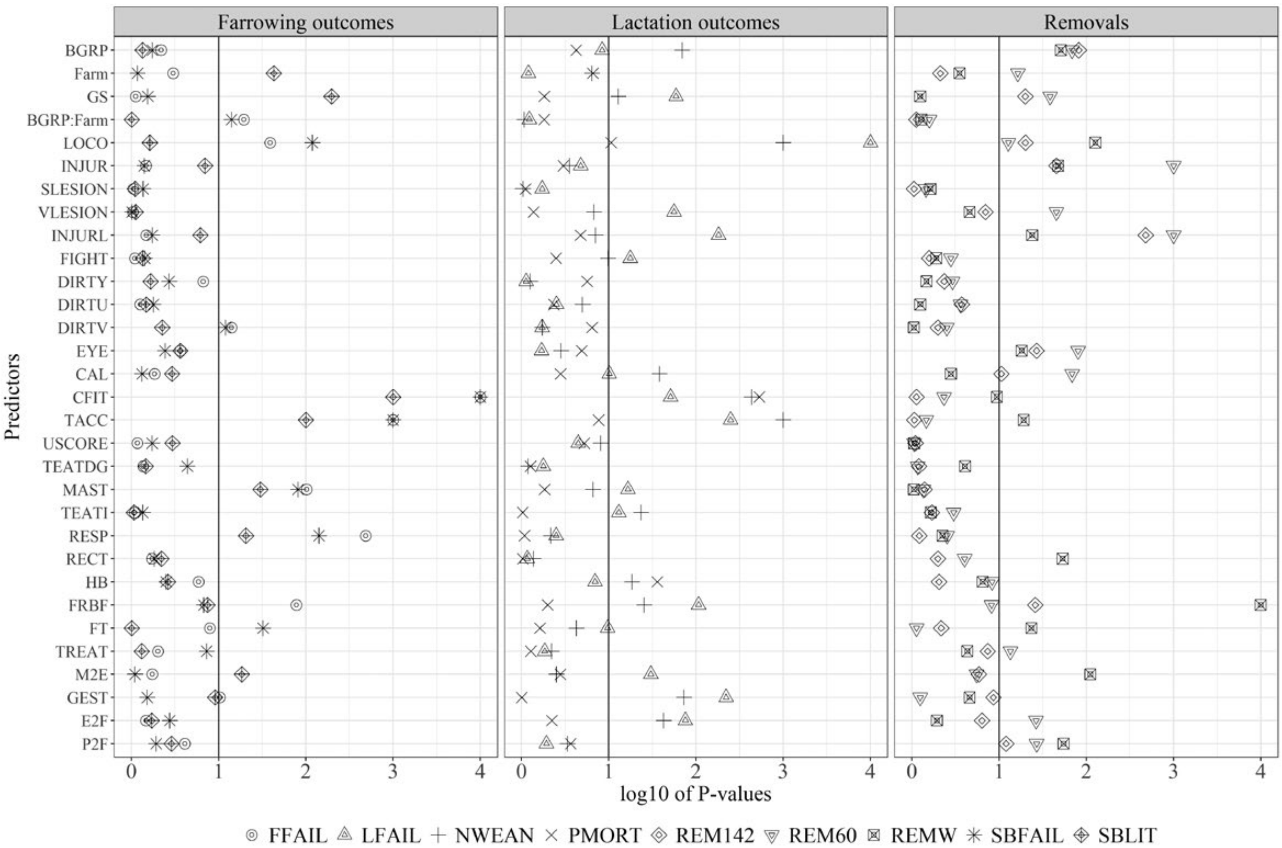

Figure 1. The *P*-values for predictors from univariate models for outcomes. Vertical line represents the threshold of approaching significance with *P*-value = 0.10 (left side not significant, right side < 0.10). x-axis represents log10 of *P*-values. For abbreviations on y-axis and for outcomes see Tables 1–3.

This was done because failure to record some variables was frequently associated with sow death or culling events and, therefore, an undesirable outcome.

Results and Discussion

Predictors identified as significant for both univariate and multivariate models were common to two management systems that differed in housing and feeding management.

The significance of predictors from univariate models

All characteristics recorded were significant for at least one of the outcomes, recorded across farms (Figure 1). The exceptions were dirtiness, dirty udder, and the number of functional glands, which were subsequently excluded from multivariate models. Predictive capacity for all characteristics was generally expected, as many variables recorded were chosen on the basis of previous literature on this topic. The results, in combination with previous literature from different studies and populations, support the concept that the variables considered here have robust predictive capacity across several populations in conventional production systems. However, the relative value of predictive variables was specific to outcomes. For example, dirty vulva or respiration rate was only predictive factors for farrowing outcomes; the number of injured teats or fight lesions was significant for lactation outcomes; eye score or treatment were predictive of removals; whereas feed refusal was significant for all outcomes. On occasions, predictive variables were also specific to individual farms, e.g., feed type only differed on Farm A, and are therefore not presented (Vargovic, 2020). The results may also not be translatable to outdoor or extensive systems.

The significance of predictors retained in multivariate models

Line and parity group effects

The parity group did not have a significant effect on the outcomes in most multivariate models (Table 4). This was in part because other significant predictors (e.g., teat access score, crate fit, or caliper increments) are confounded with parity and were more explanatory of outcomes than the parity group *per se*. Gilts tended to have a higher probability of experiencing poor outcome(s) than sows (Table 4). Gilts have a higher risk of LFAIL (11.4 ± 2.10% vs. 6.74 ± 0.98%), PMORT (44.1 ± 3.87% vs. 40.0 ± 2.65%) and weaned less piglets (9.12 ± 0.19 vs. 9.42 ± 0.12 piglets) than sows. Although not statistically significant in the multivariate model, this demonstrated that different management strategies need to be put in place for gilts vs sows to reduce poor lactation outcomes and removals. Gilts still have significant nutrient needs required for growth (Kemp and Soede, 2004), accompanied by lower appetite or feed intake capacity than sows (Eissen et al., 2000; Tummaruk and Sang-Gassanee, 2013). Progeny of gilts have lower birth weight (Santiago et al., 2019) and higher mortality (Craig et al., 2017), which was reflected in this study by elevated lactation failure (LFAIL) and piglet

Table 4. Line group (BGRP) by Farm interaction (1: maternal Farm A, 2: maternal Farm B; 3: terminal Farm A and 4: terminal Farm B) and parity group (GS) effect (1: gilts and 2: sows) for the outcome traits in models with other significant predictors

Outcome	Variable	*P*-value	Probability of poor outcomes			
			1	2	3	4
FFAIL, 0/1	BGRP:Farm	<0.001	13.9 (1.74)[a]	12.5 (1.71)[a]	32.9 (5.38)[b]	16.7 (3.24)[a]
	GS	0.226	17.4 (2.58)[a]	13.8 (1.40)[a]		
SBLIT, 0/1	BGRP:Farm	0.016	50.7 (2.47)[a]	39.8 (2.54)[a]	50.1 (5.35)[a]	40.0 (4.34)[a]
	GS	0.844	44.7 (3.34)[a]	45.5 (1.99)[a]		
SBFAIL, 0/1	BGRP:Farm	<0.001	13.0 (1.67)[a]	9.96 (1.52)[a]	27.7 (5.09)[b]	13.3 (2.93)[a]
	GS	0.085	16.5 (2.59)[a]	11.3 (1.29)[a]		
PMORT, 0/1	BGRP:Farm	0.521	41.4 (2.86)[a]	37.8 (4.29)[a]	41.8 (5.64)[a]	47.8 (5.50)[a]
	GS	0.433	44.1 (3.87)[a]	40.0 (2.65)[a]		
LFAIL, 0/1	BGRP:Farm	0.041	6.53 (1.22)[a]	7.45 (1.39)[a]	12.7 (3.47)[b]	13.3 (3.15)[b]
	GS	0.030	11.4 (2.10)[a]	6.74 (0.98)[b]		
NWEAN, count	BGRP:Farm	<0.001	9.87 (0.16)[a]	9.04 (0.16)[b]	9.21 (0.35)[b]	8.52 (0.27)[c]
	GS	0.074	9.12 (0.19)[a]	9.42 (0.12)[a]		
REMW, 0/1	BGRP:Farm	<0.01	3.39 (0.87)[a]	2.51 (0.73)[a]	8.79 (2.90)[b]	6.87 (2.16)[b]
	GS	0.958	3.54 (0.99)[a]	3.60 (0.71)[a]		
REM60, 0/1	BGRP:Farm	<0.01	8.41 (1.38)[a]	6.20 (1.23)[a]	16.0 (4.04)[b]	13.7 (3.19)[b]
	GS	0.066	10.9 (1.78)[a]	7.52 (0.99)[a]		
REM142, 0/1	BGRP:Farm	0.012	11.3 (1.55)[a]	10.9 (1.59)[a]	20.8 (4.43)[b]	19.5 (3.58)[b]
	GS	0.036	16.0 (2.08)[a]	11.3 (1.18)[b]		

Abbreviations: FFAIL: farrowing failure; SBLIT: stillborn piglet in litter; SBFAIL: excessive stillborn piglets relative to the litter size; PMORT: piglet mortality >15%; LFAIL: lactation failure; NWEAN: number of weaned piglets; REMW, REM60, REM142: removal from entry until 28/35 d; 60 d post-farrowing; or up to 142 d post-farrowing.

mortality (PMORT), and reduced number of weaned piglets (NWEAN).

The contrast of maternal vs. terminal line sows differed between farms. Overall, maternal line sows were less likely to have a farrowing failure (13.9 ± 1.74% vs. 32.9 ± 5.38% and 12.5 ± 1.71% vs. 16.7 ± 3.24%), or an excessive number of stillborn piglets (13.0 ± 1.67% vs. 27.7 ± 5.09% and 9.96 ± 1.52% vs. 13.3 ± 2.93%) compared to terminal line sows, which implies better maternal performances. Maternal line sows had a lower probability of lactation failure (and weaned more piglets) compared with terminal line sows (9.87 ± 0.16% vs 9.21 ± 0.35% and 9.04 ± 0.16% vs 8.52 ± 0.27%). This result reflects long-term selection for piglet survival, mothering ability, or teat number, which are commonly incorporated into maternal line breeding programs (Gäde et al., 2008). In addition, maternal sows had a lower risk of removal throughout different stages in a production cycle than terminal-line sows ($P < 0.001$).

Nonsignificant factors (line and parity) included in base models for outcomes were fitted in the multivariate models, before testing the significance of other predictors for outcomes. This was because gilts and sows differ both physiologically and have different management applied to them. Similarly, lines can differ in performance levels.

Poor farrowing outcomes and the predictors associated with the increased risk

Several variables were significantly associated with farrowing outcomes demonstrating predictive capacity. These predictors were crate fit, locomotion score, feed refusals, respiration rate, and the timing of when sows entered the farrowing house relative to the mating or farrowing events.

After accounting for the base model terms (Table 4), the most consistent predictor with the largest effect was crate fit (Table 5), despite the subjective scoring. Plenty of space relative to the sow dimensions (level 1) in the farrowing crate resulted in a reduced probability of sows having any stillbirths (SBLIT), decreasing from 59.7 ± 3.64% to 41.1 ± 2.40%, and probabilities for both farrowing and stillborn failure halved for crate fit = 3 levels vs. 1 level. Restrictive crates affect sow movement and can obstruct piglet delivery, e.g., rear bars. To the knowledge of the authors, similar results have not previously been quantified. Specific benefits and drawbacks of different types of crates have recently been described by Peltoniemi et al. (2021), and are supported by results demonstrated in this study.

Both farms had farrowing crates meeting requirements outlined in the Model Code of Practice (Primary Industries Standing Committee, 2008). However, it is recognized that variation amongst sows alters the relative space available. This is particularly evident pre-farrowing when sows are at their largest. Several authors have shown that sow mature weight and therefore sow size is increasing, as a correlated response with breeding objective traits (Rauw et al., 1998; Hermesch, 2010). Given that crate sizes have remained constant (Goumon et al., 2022), this places modern sows at higher risk of poor farrowing or lactation outcomes. The main justification for using farrowing crates is to prevent the crushing of piglets by slowing sows when lying down (Alonso-Spilsbury et al., 2007; Peltoniemi et al., 2021). At the same time, overly restrained sows can have prolonged farrowing (>4–5 h) leading to both an increased number of stillborn piglets (Peltoniemi and Oliviero, 2015) and an impact on the health of sows (Tummaruk andSang-Gassanee, 2013; Peltoniemi

Table 5. The predicted probability (%) with standard errors in parentheses for predictors indicating farrowing outcomes from multivariate models

Outcome (%)	Variable, unit	*P*-value	Levels of predictors					
			0	1	2	3	4	Unrecorded
FFAIL, 0/1	CFIT, score	<0.001		13.6 (1.69)[a]	11.6 (1.81)[a]	26.6 (3.49)[b]		
	LOCO, score	0.047	14.4 (1.18)[a]	15.2 (3.84)[ab]	31.9 (8.41)[b]			
	FRBF, score	0.025	13.2 (1.52)[a]	13.5 (2.06)[a]	15.3 (2.77)[ab]	22.2 (3.94)[bc]		38.5 (12.7)[c]
	RESP, count	<0.001		20.1 (1.88)[a]	10.5 (1.65)[b]	12.3 (2.69)[b]		
SBLIT, 0/1	CFIT, score	<0.001		41.1 (2.40)[a]	43.0 (2.81)[a]	59.7 (3.64)[b]		
	M2E, days	0.031		51.5 (8.50)[ab]	38.3 (4.36)[ab]	47.6 (1.83)[b]	33.7 (5.02)[a]	
SBFAIL, 0/1	LOCO, score	<0.01	12.3 (1.10)[a]	11.0 (3.29)[a]	35.5 (8.64)[b]			
	CFIT, score	<0.001		11.0 (1.54)[a]	9.97 (1.70)[a]	26.0 (3.51)[b]		
	RESP, count	0.012		16.4 (1.71)[b]	8.63 (1.49)[a]	12.0 (2.65)[ab]		9.77 (5.47)[ab]

See Tables 1 and 2 for abbreviations and Table 3 for grouping levels of predictors. The difference in means between factor levels is represented with superscripts.

and Oliviero, 2015). Therefore, restrictive crates should be avoided to reduce the incidence of farrowing problems by placing larger sows into larger crates. In an additional analysis with more levels for the parity group (PGRP), crate fit (CFIT) remained a better predictor of difficulties at farrowing than the parity group. A strong correlation between crate fit and teat access score (Spearman correlation of 0.71, not shown) resulted in only one of these predictors remaining significant in multi-variate models (depending on the outcomes), whereas in univariate models both were significant.

Sows with good locomotion scores had a lower probability (P < 0.01) for both farrowing and stillborn failure. The probability increased from 15.2 ± 3.84% and 11.0 ± 3.29% for sows without locomotion issues, to more than 30% for sows with severe locomotion issues. Locomotion disorders have been associated with the incidence of mummified piglets (Anil et al., 2009; Pluym et al., 2013), an increased number of stillborn piglets, and a decreased number of born alive piglets (Anil et al., 2009). Sows with restricted movement (e.g., due to lameness or a long time-period restrained within the farrowing crate) often adopt a sitting position (also indirectly shown by dirty vulva in this study), which can contribute to cystitis and pyelonephritis (Carr and Walton, 1993; Sanz et al., 2007), and thus later reproductive issues.

Sows with good appetite observed by mid-morning had a reduced risk of farrowing failure (P = 0.025) in comparison to sows with more than 50% of morning meals uneaten (from 13.2 ± 1.52% to 22.2 ± 3.94%). Since feed delivered to sows is typically restricted pre-farrowing, the probability of completing these meals was expected to be high. Therefore, it was hypothesized that feed refusal at this time was indicative of compromised health. Feed refusals in growing animals (Kyriazakis and Houdijk, 2007) or lactating sows (Kim et al., 2013) are indicators of poor health (Bunter et al., 2009). Sows with poor feed intake have complications during the farrowing process and an increased number of stillborn piglets (Theil, 2015). Therefore, this simplified method of observing sows for feed refusals before farrowing was a useful way to identify sows at higher risk of poor outcomes. Sows fed ad libitum during the peri-parturient period had increased lactation feed intake, reduced loss in body condition, and higher litter weaning weight (Cools et al., 2014).

Sows with a high respiration rate (P < 0.001) had a reduced probability of poor farrowing outcomes (20.1 ± 1.88% vs. 12.3 ± 2.69%). This result may reflect coping mechanisms for heat stress (Brown-Brandl et al., 2001), where sows that breathe faster are also better in heat dissipation. In the current study, all project sows were recorded during months where ambient temperatures typically exceeded comfort zones (Baxter et al., 2011; Machado et al., 2016). Therefore, any generalization regarding the use of respiration rate as a predictor needs to be based on data recorded across all seasons. Recording in winter could have implications for both respiration rates and feed refusals, which may alter the usefulness of these variables as predictors. This possibility should be investigated further. Sows that experience heat stress has shorter gestation lengths and more stillborn piglets (Lucy and Safranski, 2017). Therefore, the ability to dissipate heat (Carabaño et al., 2019) and/or provide better climate control (Baxter et al., 2011) might be avenues to increase performance.

Sows contained in crates for the optimum number of days pre-farrowing (indicated by low M2E, 106–111 d of gestation) were less likely (P = 0.031) to experience a stillbirth (SBLIT). Sows with a good locomotion score (LOCO), which does not restrict mobility, had lower occurrences of excessive stillbirths (SBFAIL, Table 5). For farrowing outcomes, mating to entry (M2E) was fitted in preference to entry to farrowing (E2F), because E2F reflects farrowing date when it is too late to impact farrowing outcomes and therefore not considered useful as a predictor. The probability of having any stillborn piglet increased from 33.7 ± 5.02% to 51.5 ± 8.50% for sows with more than 111 d of M2E compared to sows that had M2E less than 106 d (i.e., entry too distant to farrowing).

Sow body condition, measured with a caliper (CAL), was not significant for farrowing outcomes across farms when common thresholds were applied, in contrast to expectation (Rangstrup-Christensen et al., 2017). The reason might be that sow condition is only important for farrowing outcomes on farms where sow condition is suboptimal for a large proportion of sows. Studies such as Vanderhaeghe et al. (2010) reported higher risk of stillborn piglets in thin sows. In this study only 6.61% of sows were considered thin based on the number of increments on the caliper (not shown), thus the overall impact was reduced in comparison to other risk factors. Further, the caliper score was also correlated with other significant predictors (e.g. CFIT), which were retained in the models.

Table 6. The predicted probability with standard errors in parentheses for predictors indicating lactation outcomes from multivariate models

Outcome (%)	Variable, unit	*P*-value	Levels of predictors						
			0	1	2	3	4	5	Unrecorded
PMORT, 0/1	CFIT, score	<0.01		39.3 (2.94)^{a}	37.7 (3.56)^{a}	57.6 (5.17)^{b}			
	USCORE, score	0.092	45.7 (4.86)^{ab}	44.3 (2.74)^{a}	34.8 (3.51)^{b}				
	LOCO, score	0.067	40.0 (2.00)^{a}	56.3 (7.43)^{b}	51.6 (10.3)^{ab}				
	HB, g/mL	0.020		45.8 (6.89)^{abc}	50.8 (6.57)^{bc}	33.5 (4.48)^{a}	35.5 (4.13)^{a}	40.3 (3.45)^{ab}	54.5 (5.37)^{c}
LFAIL, 0/1	LOCO, score	<0.001	7.09 (0.86)^{a}	17.3 (4.13)^{b}	24.6 (7.71)^{b}				
	TACC, score	0.016		7.70 (1.21)^{a}	5.60 (1.38)^{a}	13.1 (2.58)^{b}			
	E2F, days	0.016		13.6 (2.90)^{a}	6.57 (1.00)^{b}	7.87 (1.72)^{ab}	15.1 (4.97)^{a}		
	VLESION, score	0.052	6.74 (0.97)^{a}	10.2 (2.03)^{ab}	13.0 (3.30)^{b}				
	USCORE, score	0.094	7.92 (2.39)^{ab}	9.84 (1.35)^{b}	5.98 (1.23)^{a}				
NWEAN, count	LOCO, score	<0.001	9.45 (0.10)^{a}	8.78 (0.32)^{a}	7.50 (0.48)^{b}				
	TACC, score	0.01		9.50 (0.14)^{a}	9.59 (0.19)^{a}	8.59 (0.22)^{b}			
	CAL, increments	0.071		8.49 (0.35)^{a}	9.47 (0.24)^{b}	9.38 (0.17)^{b}	9.55 (0.19)^{b}	9.17 (0.22)^{ab}	
	TEATI, count	0.045	9.50 (0.12)^{a}	9.32 (0.19)^{a}	9.01 (0.27)^{ab}	8.50 (0.35)^{b}			
	FIGHT, score	0.028	8.91 (0.19)^{a}	9.43 (0.16)^{b}	9.55 (0.17)^{b}				
	DIRTU, 0/1	0.063	9.29 (0.10)^{a}	10.4 (0.51)^{b}					
	E2F, days	0.037		8.83 (0.25)^{a}	9.54 (0.13)^{b}	9.26 (0.20)^{ab}	8.75 (0.38)^{ab}		

See Tables 1 and 2 for abbreviations and Table 3 for levels of predictors. The difference in means between factor levels is represented with superscripts.

Poor lactation outcomes and the predictors associated with the increased risk

Several pre-farrowing predictors important to farrowing success were also significant for lactation outcomes. Across lactation outcomes (LFAIL, PMORT, NWEAN), predictors from multi-variate models varied (Table 6). These predictors differed between piglet mortality (PMORT) and lactation failure (LFAIL), highlighting that PMORT represented the contribution of piglet quality to survival, regardless of the nurse sow, whereas LFAIL represented a sow's lactation success (or failure) regardless of whether she nursed her own or another sow's piglets. For sows only nursing their own piglets, these traits will be identical. The lower number of sows with records for piglet mortality potentially contributed to differences in predictors identified. It is more common to express the nursing ability of a sow as the number of piglets weaned (NWEAN), and the majority of significant predictors were consistent between LFAIL and NWEAN.

Sows less restricted at farrowing (CFIT, $P < 0.01$) had substantially decreased PMORT (39.3 ± 2.94% vs. 57.6 ± 5.17%). A good teat access score (TACC, level 1) almost halved LFAIL (7.70 ± 1.21% vs. 13.1 ± 2.58%) and increased the number of weaned piglets (9.50 ± 0.14 vs. 8.59 ± 0.22 piglets). Physical restriction for piglets to reach teats and obtain colostrum increases the risk of higher pre-weaning mortality (Vasdal and Andersen, 2012; Baxter et al., 2018). Similarly, suboptimal body condition, represented by caliper score and referred to as thin or fat sows (CAL = 1 and 5), resulted in fewer piglets weaned (8.49 ± 0.35 and 9.17 ± 0.22 piglets) compared to sows in CAL = 2–4 (9.47–9.55 piglets weaned). Teat access score and crate fit were highly correlated; CFIT was more informative for farrowing outcomes, while TACC was more informative for lactation outcomes (Table 6).

The probability of poor lactation outcomes increased ($P = 0.016$) for sows transferred to farrowing crates too close to farrowing (≤ 4 d) or conversely, too long before farrowing (≥11 d). This increase was from 6.57 ± 1.00% for optimal timing to more than 13% for transfers outside the optimum. The optimum timing of transfer relative to the actual farrowing event might relate both to the length of time sows are physically immobilized in farrowing crates prior to farrowing, as well as the length of time they are subjected to restricted access to feed prior to farrowing (Farmer, 2019). Difficulties in mobility observed pre-farrowing, illustrated by locomotion score, also increased the probability of poor lactation outcome (7.09 ± 0.86% vs. 24.6 ± 7.71%). Sows with no signs of a locomotion disorder were weaned 9.45 ± 0.10 piglets, whereas sows with very limited mobility were weaned 7.50 ± 0.48 piglets, aligning with previous studies reporting a higher risk of production failure for injured or lame sows (Anil et al., 2008; Bunter and Tabuaciri, 2011; Pluym et al., 2011).

Sows with well-developed udders at entry had the lowest probability of lactation failure (PMORT and LFAIL), approaching significance ($P = 0.092$ and 0.094), whereas no association was found with the number of weaned piglets. Kim et al. (1999) suggested that nutrient requirements should account for the need to develop adiposity, influencing udder development, and Farmer et al. (2017) reported a positive association between back fat and udder development (higher back fat, more mammary parenchymal tissue). Poor mammary development can lead to poor lactation outcomes (Edwards and Baxter, 2015), also confirmed in this study.

Lower levels of sow hemoglobin (HB) significantly increased the probability of increased mortality of piglets (PMORT, $P = 0.020$). Sows with the lowest HB had elevated PMORT (45.8 ± 6.89% vs. 40.3 ± 3.45%), but data were generally limited due to the lower number of sows recorded for HB (Farm A) and the low number of sows recorded for PMORT (Farm B). This means that 455 of sows had piglet

Table 7. The predicted probability with standard errors in parentheses for predictors indicating removals through different stages of production cycle from multivariate models

Outcome (%)	Variable, units	*P*-value	Levels of predictors						
			0	1	2	3	4	5	unrecorded
REMW,	LOCO, score	0.014	3.24 (0.60)^{a}	6.99 (2.61)^{ab}	12.3 (5.47)^{b}				
0/1	RECT, °C	0.031	3.43 (0.62)^{a}	13.4 (5.83)^{b}					2.85 (2.33)^{ab}
	FRBF, score	<0.001	2.67 (0.69)^{a}	2.31 (0.81)^{a}	6.58 (1.90)^{b}	11.2 (3.07)^{b}			11.4 (6.86)^{b}
	INJUR, 0/1	0.041	2.68 (0.67)^{a}	4.81 (0.97)^{b}					
	GEST, days	0.061		5.27 (2.25)^{ab}	2.88 (0.73)^{a}	3.56 (0.91)^{a}	12.0 (5.28)^{b}		
	E2F, days	0.073		1.64 (0.85)^{a}	4.41 (0.88)^{a}	4.20 (1.34)^{a}	1.34 (1.04)^{a}		
REM60,	CAL, increments	0.035		17.9 (4.68)^{a}	9.61 (2.18)^{ab}	8.88 (1.58)^{b}	5.55 (1.34)^{b}	9.09 (1.94)^{ab}	
0/1	FRBF, score	0.052	6.98 (1.13)^{a}	7.57 91.54)^{a}	10.8 (2.43)^{ab}	15.4 (3.52)^{b}			13.7 (6.95)^{ab}
	EYE, score	0.037	8.09 (0.91)^{a}	15.4 (4.20)^{b}					
	INJURL, score	<0.01	7.26 (0.95)^{a}	10.9 (2.21)^{a}	20.4 (4.88)^{b}				
	E2F, days	<0.01		3.82 (1.43)^{a}	9.72 (1.23)^{b}	10.8 (2.03)^{b}	4.33 (2.08)^{ab}		
REM142,	FRBF, %	0.036	10.4 (1.35)^{a}	12.1 (1.98)^{ab}	16.5 (2.92)^{bc}	20.4 (3.93)^{c}			18.1 (7.88)^{abc}
0/1	INJURL, score	<0.001	11.4 (1.15)^{a}	13.5 (2.45)^{a}	29.1 (5.62)^{b}				
	EYE, score	0.086	12.2 (1.07)^{a}	19.5 (4.71)^{a}					
	GEST, days	0.022		24.3 (5.15)^{b}	11.2 (1.46)^{a}	11.4 (1.65)^{a}	16.2 (5.41)^{ab}		
	E2F, days	<0.01		7.14 (2.11)^{a}	14.5 (1.51)^{b}	14.8 (2.56)^{b}	5.45 (2.61)^{a}		

See Tables 1 and 2 for abbreviations and Table 3 for levels of predictors. The difference in means between factor levels is represented with superscripts.

mortality above 15%. Anemic sows had more born alive and more stillborn piglets, suggesting that the litter size gestated might influence HB (Noblett et al., 2021). Hemoglobin levels in sows and their piglets are positively correlated (Jensen and Nielsen, 2013). In addition, strong associations between HB levels of piglets and their survival until weaning has been previously reported (Hultén et al., 2003; Rootwelt et al., 2012). Hemoglobin of piglets was not recorded in the current study, but results for sow hemoglobin levels are consistent with the literature.

Sows with no injured teats pre-farrowing had a significantly higher number of weaned piglets compared to sows with multiple teats injured (9.50 ± 0.12 vs. 8.50 ± 0.35 piglets). Injuries to teats reduce the number of functional teats available for piglets to suckle and increase the risk of infection that lead to mastitis (Hultén et al., 2003). The presence of injured teats may have also altered cross-fostering decisions, thereby having an impact on the maximum possible number of weaned piglets. Piglet survival can improve by 6% with each additional functional teat (Bunter and Tabuaciri, 2011).

Sow removals and the predictors associated with the increased risk

Sow removals can be forced by death or ill health, failure to rebreed, and due to general management. Removal traits defined in this study excluded culling for parity and or/management reasons (i.e. low breeding values). Reasons for removals at weaning (REMW), without successful rebreeding (REM60) or due to later performance or health issues (REM142) prior to a subsequent parity illustrated undesirable forced removals, which could have been avoidable (Table 7).

Predictors consistent across removal traits were related to locomotion (LOCO, INJURL), the timing when sows were transferred to the farrowing house (E2F), and appetite (FRBF). Removal by weaning (REMW) was predicted by LOCO, whereas post-weaning removals (REM60 and REM142) were also predicted by the pre-farrowing presence of leg injuries. This suggested that LOCO is a known welfare indicator and definite culling criteria, whereas leg injury or LOCO = 1 might be treatable but, if not successful, lead to later removals. Predictors such as gestation length, injuries, rectal temperature, and eye score were not significantly associated with farrowing or lactation outcomes but were significant for removal outcomes. Eye score, i.e. bloodshot eyes could indicate elevated body temperature (Peltoniemi and Oliviero, 2015), infection of the eyes such as pig conjunctivitis (Done et al., 2012), and irritation resulting from the environment, such as ammonia (Zulovich, 2012).

Feed refusals observed before farrowing more than doubled removals at all-time points, and leg problems more than tripled the probability for removal. Associations between peri-parturient feed intake, lameness, health issues, and the risk of removals have been previously demonstrated in several studies (Abiven et al., 1998; Anil et al., 2008). Sows with the lowest caliper increments had the highest probability (17.9 ± 4.68% vs. 5.55 ± 1.34%) for REM60 ($P < 0.05$). Sow fatness is an important contributor to sow survival and productivity (Bunter and Lewis, 2011; Calderón Díaz et al., 2015). Fatter sows generally stay longer in the herd (Lewis and Bunter, 2013). Sows with higher breeding values for back fat had a lower probability of urinary tract infection (Vargovic et al., 2021a), one well-known reason for reproductive failure and sow removal. In contrast, very high back fat has been associated with prolonged farrowing and farrowing difficulties (Peltoniemi and Oliviero, 2015), along with decreased appetite, poor lactation performance (Eissen et al., 2000), and rebreeding success, which could explain the increased probability for REM60 in fat sows (CAL= 5).

Sows with a long gestation had higher risk of premature removals ($P = 0.061$ and $P = 0.022$). To a lesser extent, the same pattern was observed for sows with shorter gestation. The risk of REMW for sows with regular (115–118 d) gestation length was 2.88 ± 0.73%. That risk increased to 12% for sows with prolonged gestation and to 5.27 ± 2.25% for sows with shorter gestation length. Sows transferred to the farrowing house outside the optimum (5–10 d pre-farrowing), had a lower probability for removals, which is in contrast to results for farrowing and lactation outcomes. Since gestation length is repeatable (Sasaki and Koketsu, 2007), the information on previous gestations may assist with better timing of transfer for individual sows.

Sows with increased rectal temperature pre-farrowing had a significantly ($P = 0.031$) higher probability of removal before weaning (13.4 ± 5.83% vs. 3.43 ± 0.62%). Pre-farrowing rectal temperature was not significant for later REM60 and REM142, where it is likely that sows have either been already removed (i.e. REMW) or treated, and other factors assume more importance.

The extent of physical restriction of sows in crates did not have a direct impact on sow removals. More consistency across farms was observed for predictors of removal at weaning, than for the removal outcomes that evolved over a longer time period (60 or 142 d post-farrowing).

Conclusions

This study identified multiple variables that could be considered as predictors of sows at-risk of reproduction failure or premature removals. However, only a few of those predictors were robust across farrowing or lactation issues, and removals in different stages in the production cycle of a sow. The most consistent predictors were feed refusals observed from entry to the farrowing house until farrowing, the relative suitability of farrowing crate for individual sows, respiration rate at the entry to the farrowing house, locomotion issues, and the timing when sows are transferred to farrowing house relative to the mating date. However, although respiration rate was significant for both farms, this particular predictor requires additional investigation across seasons, to exclude potential bias due to seasonal effects. Most of these predictors are observed but are not routinely recorded, thus it is recommended to incorporate an additional recording of these variables as a part of standard farm procedures.

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Conflict of Interest Statement

The authors disclose no actual or potential conflicts of interest that may affect the ability to objectively present or review research or data.

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