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Factors associated with specific health, welfare and reproductive performance indicators in pig herds from five EU countries

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ABSTRACT

Production diseases are often of multi-factorial origin in which environment (housing, nutrition and management) health and reproductive challenges show complex interactions. The aim of this study was to identify specific environment-related factors and to discuss their associations with health, welfare and reproductive performance in sows and piglets, in diverse systems using data from 130 farms from five EU countries.

Two sets of data were used: a) a questionnaire was developed for sows and piglets covering farm management, interventions and housing and b) farm production data covering various performance parameters. Eight parameters were further selected, four of which were related to sow reproductive performance (litter index, replacement rate, repeat breeding (*i.e.* failure to breed after one mating), weaning to first mating interval) and the remaining four to litter / piglet health performance (piglets born alive per litter, piglets born dead per litter, preweaning mortality rate and weaned piglets per litter).

Univariable and multivariable linear models were employed to identify risk factors. Associations were considered significant if $P \leq 0.007$ (a criterion of $p \leq 0.05$ corrected for the number of parameters tested). Various risk and protective factors were identified for each tested outcome variable. Country effects were included in all models as a fixed factor. Adjusted R-squared values for the multivariable models varied between 9.6% (preweaning mortality) and 66% (litter index).

Litter index (litters/sow/year) was negatively associated with a higher weaning age of the piglets. Housing recently weaned sows to be inseminated in a separate unit from the gestation unit had a positive association with litter index. Repeat breeding was negatively associated with PRRS-free farms, farms that bred (raised) all gilts on the farm and farms that perform farrowing induction of sows. PRRS-free farms were also associated with a higher replacement rate.

Farms that bred gilts on the farm and PRRS-free farms were negatively associated with preweaning mortality. Natural ventilation in the gestation unit was associated with fewer piglets born alive and with fewer weaned piglets. Closed type of farms was associated with less piglets born dead. The use of open box housing system for pregnant sows (provision of individual resting areas) was associated with more weaned piglets.

In conclusion, several factors related to applying good farm and health management, and optimal housing conditions showed positive association with various sow and piglet performance parameters. Further studies will help to assess causal links for these factors.

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1. Introduction

Pig meat represents 9% of the total EU agricultural output and is the major type of meat produced in the EU-28 (Eurostat, 2015). Intensification of porcine farming in Europe has improved production performance (Rocadembosch et al., 2016; Eurostat, 2017). Yet, challenges linked to this intensification have been described and have led to the introduction of the term “production diseases” to describe this phenomenon (Nir, 2003; Clark et al., 2016). Such challenges include management, nutritional and reproductive-related diseases among others. These challenges have led all relevant stakeholders to systematically collect and monitor various production data. Farm data analysis could be used to maximize sow reproductive potential, herd productivity and stable output in breeding herds (Koketsu et al., 2017). Moreover, these data are very useful to identify which management factors are associated with reduced sow and piglet performance.

Different risk factors for suboptimal sow performance have been identified. Sow farm housing has been associated with reproductive performance in breeding herds (Spoolder et al., 2009; Koketsu and Iida, 2017). Koketsu and Iida (2017) concluded that although no difference in the number of pigs born alive were reported between group housing and individual stall housing, more risk factors for poor reproductive performance were associated with group housing than stall housing (e.g. bedding). Apart from that, risk factors for suboptimal piglet performance have also been studied. Selection for increased litter size has been associated with more low-birth-weight piglets per litter (Milligan et al., 2002). Farrowing house management has been shown to significantly affect piglet mortality (Kirkden et al., 2013; Thomsson et al., 2016). For instance, proper management of farrowing induction (timing and dosage, close supervision) is shown to reduce piglet mortality (Decaluwe et al., 2012; Kirkden et al., 2013). Apart from that, an effect of the housing condition concerning lactating sows has been linked to piglet mortality. More specifically, the use of free-farrowing pens has been linked to increased piglet mortality when compared to the use of farrowing crates (Marchant et al., 2000, Hales et al., 2014). Yet, other studies did not find this association (Weber et al., 2007; KilBride et al., 2012).

Farm management data have been used by several studies that have focused either on the perceptions and beliefs of farmers regarding animal health and animal welfare (Bock and van Huik, 2007; Alarcon et al., 2014; Laanen et al., 2014; Clark et al., 2016), or on performance parameters and their change due to certain interventions (e.g. biosecurity levels, antimicrobial use) (Ribbens et al., 2008; Van der Fels-Klerx et al., 2011; Laanen et al., 2013; Postma et al., 2016a, b). Furthermore, studies have focused on management factors affecting performance of fattening pigs at a regional level (Dewey et al., 1995; Maes et al., 2004; Agostini et al., 2014). Yet, there is scarce information on risk and protective factors for different sow and piglet performance parameters that have been investigated simultaneously and at a European level in pigs. The aim of this study was to identify these factors and quantify their effect on different sow and piglet performance parameters. To this end, datasets with performance data of sow farms from different EU countries with intensive production systems were used.

2. Methods

2.1. Data selection and collection

Farms were selected by the locally assigned members of the Prohealth (hereafter called “the interviewers”) in order to provide a representative population of herds for each participating country. It must be noted that since no official data were available for all countries regarding the distribution of the farms with respect to their characteristics, these selections cannot be seen as truly representative of each country’s population. To partially remedy for that, the interviewers made use of the ProHealth’s extensive network to decide on the inclusion of a farm in this study so that the final sample would portray largely the traits of each participating country.

For a farm to be included, a minimum population of 100 breeding sows was required (farm size ranged from 130 to 3200 breeding sows). Further inclusion criteria were the correctness and traceability of the provided performance data (i.e. the selected farms were to provide systematically collected performance data) and the active participation by the farmer (i.e. the selected farms were willing to collaborate). To goal was to collect data from at least 50 farms per country.

Upon the farmers’ agreement to participate, information regarding the questionnaire was sent (on paper or electronically) and the personal information of each farmer was recorded. In order to fill in accurately the responses of the questionnaire and to collect performance parameters data, herds were visited once during the period from February to November 2016. Upon collection of the data, all personal information was removed from the subsequent databases and all data were treated anonymously to maintain confidentiality.

2.1.1. Questionnaire data

An anonymous web-based questionnaire was designed for the needs of this study and was disseminated to the interviewers involved in each country. A standardized protocol for the farm visit was developed by Ghent University based on discussion and consensus with the different project partners, including pig veterinarians and integrators. All interviewers employed for this study received a training to standardize the method for data collection through this protocol. Thus, a similar approach was employed throughout the participating countries allowing to grasp all necessary information and avoid any contextual misunderstandings.

The questionnaire was structured into three main sections (Management, Disease Prevention, Housing) comprising of 69 main questions. The questions were assessed quantitatively (number of responses) and qualitatively (logical reasoning) concerning the dependent variables tested. The 24 most relevant and most answered questions were further considered and selected for the statistical analyses. After assessing the information provided, seven question items with multiple answers were dichotomized in order to test the most relevant association.

2.1.2. Performance parameters

Performance parameter data covering the two most recent years preceding the questionnaire survey (2014–2015) were obtained from high quality datasets held on farm or by integrators. These data were recorded on a monthly basis, except farms from one country that provided measurements mostly on a 3-monthly basis. For each farm, average values were calculated and used further in the statistical analyses. Per parameter, the average corresponded to the two year average value. Whenever needed, parameters were translated, and revised accordingly so that they were accurately describing the same condition for all countries. For some parameters (*e.g.* sow mortality, abortion rate) there was a considerable amount of missing data and hence they were excluded from the analysis. Eight parameters were further selected, four of which were more related to sow performance (litter index, replacement rate, repeat breeding rate, weaning to first mating interval). Litter index is the number of farrowings per sow per year, while replacement rate refers to the percentage of newly-introduced sows in a farm to maintain the census. Repeat breeding rate refers to the percentage of sows failing to breed after one mating and weaning to first mating interval is the period (expressed in days) from the first day of post-weaning of a sow until the sow returns to heat. The remaining four parameters refer to litter / piglet performance (piglets born alive per litter, piglets born dead per litter, preweaning mortality rate and weaned piglets per litter). Preweaning mortality informs of the percentage of piglets born alive that die during the lactation period.

2.2. Statistical analyses

Initially, possible causal routes linking the questionnaire material and the included performance parameters were identified based on logical reasoning and focusing either on piglet health or sow performance. Linear models were employed to identify risk or protective factors taking into account the country-level effects. For each performance parameter (hereafter called the 'dependent' variable) all possible associations between this variable and the result from each question (hereafter called the 'independent' variable) were tested. When needed, dependent variables were transformed accordingly to meet the assumptions of linear regression (*e.g.* in the case of repeat breeding, a natural log transformation was used to transform the positively-skewed dependent variable). Per model, the target p value was divided by the sum of the dependent variables tested in this study. Those variables with univariable p-values of < 0.025 (0.2/8 dependent variables tested) were retained for further analysis in a multivariable model. Subsequently, with univariable associations that were retained, a multivariable general linear model was constructed using the stepwise backward selection procedure, including testing of two-way interactions of significant main effects. We checked for confounding effects during modelling by evaluating changes in parameter estimates. The association was considered significant if p-value ≤ 0.007 (approximating the criterion of 0.05/8 dependent variables tested). In other words, a Bonferroni correction was applied but the correction was limited to the pairwise comparisons within one level (*e.g.* an independent variable). Bonferroni correction for multiple testing did not consider all pairwise comparisons performed, as this was deemed a too strict criterion in relation to the needs of this study.

The assumptions of normality and homogeneity of variance of the final model were tested by examining histograms, normal probability plots of residuals, and plots of studentized residuals versus predicted values. For independent variables, multicollinearity was checked initially via correlation matrix and when needed (correlation value > $|0.65|$ for a set of independent variables) the most significant variable was retained. In the final model, multicollinearity was also checked with the use of the Variance Inflation Factor. All cases were inspected for unusual points (outliers, leverage). Upon finding an outlier, the analysis was run both with and without the outlier. If the outlier was not influential for the results of the models, it was kept in the model and no further actions were performed. If the outlier was influential, both models were to be presented and discussed accordingly. Statistical analyses were performed using IBM SPSS version 24®, Armonk, New York.

3. Results

3.1. Descriptive results

In total, 130 farms provided data either partially or fully for both datasets (questionnaire and performance parameters data). More specifically, data from 28 (Country A), 18 (Country B), 26 (Country C), 25 (Country D) and 33 (Country E) farms were used in this study.

Descriptive results from the questionnaire overall and per country are shown in appendix (Table S1). An overview of the averaged performance parameters data was summarized by category (Table 1) and by country (Table S2).

3.2. Associations between performance parameters and the results from the questionnaire

3.2.1. Litter index

Six variables were found to be risk or protective factors for litter index during the univariate analysis, with most of them being related to housing concerning gestation (Tables 2, S3). Two variables were retained as potential risk or protective factors in the multivariable model (Table 3). More specifically, increasing the average weaning age was negatively associated with litter index while the presence of a separate room for sows during the first weeks after insemination showed a positive association with litter index.

3.2.2. Replacement rate

Six variables were found to be risk or protective factors in the univariate analysis (Tables 2, S3). There was a statistically significant negative correlation (-0.78) between two independent variables namely "PRRS-free farms" and "Farms vaccinated for PRRS". The "Farms vaccinated for PRRS" variable was dropped and the model was rerun with five variables. Finally, two factors were retained in the multivariable model (Table 3). Farms that bred (raised) all gilts on the farm showed a positive association with replacement rate. Moreover, PRRS-free farms are expected to have a higher replacement rate.

3.2.3. Repeat breeding rate (Re-inseminations)

Ten variables were found to be risk or protective factors (Tables 2, S3) by the univariate model. Again, a statistically significant negative correlation (-0.79) for "PRRS-free farms" and "Farms vaccinated for PRRS" was seen. "Farms vaccinated for PRRS" variable was dropped and the model was rerun with nine variables. Finally, three factors were retained in the multivariable model (Table 3). Repeat breeding rate was negatively associated with farms where farrowing induction is performed, with PRRS-free farms and with farms that provide a separate room for inseminations (weaned sows are housed separately from pregnant sows).

3.2.4. Weaning to first mating interval (expressed in days)

No significant associations were seen at a univariable level (Tables 2, S3).

3.2.5. Preweaning mortality

Three variables were found to be risk or protective factors (Tables 4, S4). Two factors remained in the final multivariable model (Table 5). PRRS-free farms and farms that bred all gilts on the farm were both associated with lower rates of preweaning mortality.

3.2.6. Piglets born alive per litter

Univariably, six variables were found to be risk or protective factors (Tables 4, S4) out of which two factors were retained in the multivariable model (Table 5). Both factors are linked to housing. An older interior design of the farrowing unit and the use of natural ventilation system in the gestation unit are both associated with fewer pigs born alive.

3.2.7. Piglets born dead per litter

Univariably, two variables were found to be risk or protective factors (Tables 4, S4). For the multivariable model, an outlier case was identified (standardized residual value of 3.1) and it was kept in the analysis. Finally, one factor remained in the multivariable model (Table 5). A farm where piglets are fattened on the farm (single site farrow-to-finish farm) was associated with less piglets born dead.

3.2.8. Weaned piglets per litter

Univariably, four variables were found to be risk or protective factors (Tables 4, S4). For the multivariable model, an outlier case was identified (standardized residual value of 3.8). The model was tested either with or without the outlier case and it was finally retained in the analysis. Two variables that focused on housing in the gestation unit remained in the final multivariable model (Table 5). A positive association was seen between the number of weaned sows per litter and the use of an open group housing system with individual resting areas for pregnant sows in the gestation unit (compared to no individual resting areas). The use of natural ventilation in the gestation unit was associated with fewer weaned piglets per litter.

Table 1
Overview of averaged performance parameters data for sows using data from five countries and 130 farms.

	Mean	Standard Deviation	Minimum	Percentile 25th	Median	Percentile 75th	Maximum	Number of farms
Litter index	2.38	0.08	2.11	2.35	2.39	2.43	2.52	129
Replacement rate (%)	42.57	11.90	10.58	36.20	44.43	48.65	73.30	124
Reinseminations rate (%)	7.69	3.94	2.19	4.98	6.83	9.36	21.79	127
Weaning to first mating interval (expressed in days)	5.71	0.84	3.86	5.06	5.54	6.30	8.20	118
Piglets born alive per litter	14.04	1.48	10.23	12.87	14.03	15.12	16.94	121
Piglets born dead per litter	1.28	0.40	0.27	1.07	1.21	1.58	2.33	112
Preweaning mortality (%)	13.88	3.01	6.80	11.90	14.10	15.80	21.45	125
Weaned piglets per litter	12.00	1.23	9.10	11.11	11.97	12.82	14.97	129

4. Discussion

This study identified risk and protective factors associated with specific health, welfare and reproductive performance indicators in pig herds. We used both a questionnaire and a farm data based approach to address our objective. The data were collected from 130 farms across Europe. All these farms were associated with conventional pig breeding and rearing, although there were some differences between countries, which were accounted for in the analysis.

4.1. Sow-related performance parameters

One of the major components of litter index is lactation length (Abell et al., 2013). In a simplistic approach, farms that opt out for a

Table 2
Results of univariable linear regression models regarding sow performance. The independent variables are denoted with superscripts either as binary (b) or continuous (c). For (b), existence of a condition was considered as a comparison level, whereas absence was considered as a baseline level. The independent variables are shown alongside with the number of farms that provided data (N), the unstandardized coefficients (B) and the p values (Sig.). Country effects are included in all models as a fixed factor. Each column corresponds to a different dependent variable. All associations with p values < 0.025 (shown in bold) were included in multivariable models. The independent variables that are denoted with an asterisk are the variables that remained in the final multivariable models.

	Litter Index			Replacement rate			Reinseminations % (log[1])			Weaning to insemination interval		
	N	B	Sig.	N	B	Sig.	N	B	Sig	N	B	Sig
Are all the gilts bred on the farm? [b]	129	0.016	0.169	124	**6.066**	**< 0.001****	127	**−0.255**	**0.005**	118	−0.001	0.994
When are the gilts inseminated for the first time (days)? [b]	124	< 0.005	0.816	119	0.115	0.047	122	−0.004	0.252	118	0.002	0.735
Farm SPF for M. hyopneumoniae? [b]	129	−0.008	0.629	124	1.649	0.493	127	−0.154	0.228	113	0.157	0.480
Farm SPF for PRRS? [b]	129	0.001	0.945	124	**5.561**	**0.010****	127	**−0.345**	**0.003****	118	−0.001	0.997
Farm SPF for APP? [b]	129	−0.002	0.908	124	3.222	0.196	127	0.147	0.275	118	0.151	0.514
Sows vaccinated for Influenza? [b]	129	0.003	0.800	124	−1.800	0.319	127	0.066	0.511	118	0.008	0.963
Sows vaccinated for PRRS? [b]	129	−0.004	0.749	124	**−5.181**	**0.015**	127	**0.428**	**< 0.001**	118	0.193	0.324
How old is the interior design of the units?	121	< 0.005	0.691	120	**−0.228**	**0.012**	119	**0.012**	**0.019**	113	−0.007	0.454
Farrowing Unit [c]	119	< 0.005	0.713	118	−0.143	0.136	117	**0.012**	**0.016**	111	0.003	0.769
Insemination Unit [c]	118	−0.001	0.517	117	**−0.340**	**0.005**	116	**0.016**	**0.008**	111	0.003	0.786
Gestation Unit [c]												
Natural ventilation in gestation unit? [b]	123	**−0.048**	**0.002**	120	−0.671	0.782	121	**0.281**	**0.024**	112	0.062	0.783
Are the sows in the farrowing unit fed using manual system? [b]	127	−0.034	0.041	122	−1.655	0.508	125	0.220	0.096	116	−0.001	0.998
How many times per day are sows fed in the farrowing unit? [c]	126	0.018	0.033	122	0.951	0.464	124	**−0.154**	**0.022**	115	−0.057	0.656
What is the average weaning age of the piglets (in days)? [c]	125	**−0.018**	**< 0.001****	122	−0.056	0.899	123	0.035	0.143	116	0.009	0.823
Are weaned sows housed separately before insemination? [b]	127	**0.031**	**0.021****	123	3.888	0.047	125	**−0.293**	**0.005****	116	0.041	0.831
Are teaser boars present in the insemination room? [b]	126	−0.007	0.568	122	0.312	0.868	124	0.008	0.940	115	−0.117	0.513
Is an open box group housing system used for pregnant sows? [b]	126	**0.029**	**0.012**	123	0.614	0.614	124	−0.131	0.148	115	0.161	0.331
Gestation unit: Are these groups static (all in – all out)? [b]	125	0.029	0.057	122	2.149	0.328	123	−0.133	0.277	114	0.106	0.656
Type of farm (piglets fattened on the farm)? [b ǂ]	129	−0.022	0.163	124	0.362	0.883	127	0.225	0.082	118	0.235	0.298
Is the drinking water disinfected during the production cycle? [b]	124	0.003	0.822	120	1.285	0.583	122	0.110	0.356	113	0.003	0.988
Is a dead animal found in the pen removed immediately and placed in storage? [b]	124	−0.006	0.665	121	0.455	0.816	122	0.214	0.043	113	0.155	0.423
Is a 1-week sow batch farrowing system used on the farm? [b]	128	0.027	0.038	123	−0.448	0.828	126	0.008	0.942	117	−0.110	0.565
Is genetic selection for robustness considered important in the replacement gilt program? [b]	117	**−0.058**	**< 0.001**	113	**5.588**	**0.017**	115	0.248	0.065	108	0.142	0.570
Is farrowing induction of sows performed? [b]	126	**0.036**	**0.003**	123	3.019	0.109	124	**−0.295**	**0.003****	115	0.024	0.899
Is the manure/slurry from farrowing unit stored in a pit? [b]	124	−0.039	0.065	121	−0.749	0.816	122	0.366	0.032	113	−0.217	0.492

[1] The natural logarithm was used to ease the interpretation of the results. Interpretation of the results: The dependent variable changes by 100*(coefficient B) percent for a one unit increase in the independent variable while all other variables in the model are held constant.
ǂ The baseline level for this question is: sow breeding farm (piglets stay until weaning or until 10 weeks).

Table 3
Final multivariable linear regression models (one model for each dependent variable studied) regarding sow performance. The independent variables are denoted with superscripts either as binary (b) or continuous (c). For (b), existence of a condition was considered as a comparison level, whereas absence was considered as a baseline level. The independent variables are shown alongside with the unstandardized coefficients (B), standard errors, p values (Sig.) and the Pearson's rho and partial correlation coefficient. For each model, the number of farms that provided data for both the dependent and all independent variables, is presented in the far-right column. In all models, country was included as a fixed effect.

		Unstandardized Coefficients	Std. Error	Sig.	Model fit R^2	Number of farms
Dependent variable	Independent variable	B			(adjusted R^2)	
Model 1: litter index	What is the average weaning age of the piglets (in days)? [c]	−0.019	0.064	< 0.001	67.9%	106
	Are the recently weaned sows housed separately before insemination? [b]	−0.031	0.011	0.007	(66%)	
	Country effect			< 0.001		
Model 2: replacement rate	Are all the gilts bred on the farm? [b]	6.207	1.724	< 0.001	56.9%	107
	Does the farm have an SPF status for PRRS? [b]	6.159	2.028	0.003	(54.3%)	
	Country effect			< 0.001		
Model 3: repeat breeding rate (log[1])	Does the farm have an SPF status for PRRS? [b]	−0.353	0.113	0.002	25%	109
	Are the recently weaned sows housed separately before insemination? [b]	−0.301	0.100	0.003	(19.8%)	
	Is farrowing induction of sows performed? [b]	−0.281	0.095	0.004		
	Country effect			0.470		
Model 4: weaning to first mating interval	Country effect			0.905	1.5%	117

[1] The natural logarithm was used to ease the interpretation of the results. The dependent variable changes by 100*(coefficient B) percent for a one unit increase in the independent variable while all other variables in the model are held constant.

higher weaning age of the piglets are expected to have a lower litter index. However, early weaning systems (weaning when piglets are 10–20 days old) have been negatively linked with the reproductive performance of lactating sows (Koketsu et al., 1998). It must be noted that in our study this could not be evaluated as all farms had an lactation length of at least 20 days and overall the mean lactation length was approximately 26 days. Furthermore, there is a concern that sows with increased lactation length can lose too much of their body reserves due to high milk yields, and so they may have prolonged weaning to first mating interval and lower farrowing rates (Koketsu et al., 2017). Thus, such farms that opt out for a higher weaning age of the piglets increase the non-productive sow days and –in agreement with the findings of this study- are associated with a lower litter index. Apart from that, litter index was positively associated when recently weaned sows were housed separately from pregnant sows in order to be inseminated. The latter was also associated with a reduced repeat breeding rate. The aggression which occurs during mixing does result in physiological stress responses, and such responses can have detrimental effects on reproductive parameters, especially at a critical time in the reproductive cycle, such as the period of implantation (Arey and Edwards, 1998). Thus, it is recommended to move weaned sows to the same room or barn with the pregnant sows only after embryo implantation has been complete (Stevens et al., 2015; Peltoniemi et al., 2016). Providing a separate housing unit for insemination ensures a less stressful environment for the weaned piglets and the pregnant sows as well (Koketsu and Iida, 2017). Moreover, it enables the animal caretakers to easier monitor for oestrus during the first weeks after insemination as the majority of returns to oestrus occurs during that time (Iida and Koketsu, 2013). As shown, the effect of repeat breeding in subsequent reproductive performance is more pronounced in the gilts than the sows (Vargas et al., 2009). As a result, the findings from our study stress the need for including housing -besides other contributing factors- when assessing causal links to factors such as litter index or repeat breeding rate.

In our study, farrowing induction was negatively associated with the repeat breeding rate. Farrowing induction is mainly used to reduce the variability of gestation length and to allow for close supervision of the farrowing process (Decaluwe et al., 2012). Moreover, this close supervision is expected to reduce the duration of parturition (Decaluwé et al., 2014). When studying the effect of duration of farrowing on subsequent repeat breeding rate, sows with longer duration of farrowing were associated with higher repeat breeding rate at the first insemination after weaning (Oliviero et al., 2013).

Both strategies used to combat PRRS (PRRS-free farms, PRRS sow vaccinations) resulted in significant differences to replacement rate and repeat breeding rate. Here the latter strategy was removed from the analysis due to the high negative correlation between the two parameters. PRRS-free farms were negatively associated with the repeat breeding rate and with preweaning mortality. Besides the obvious beneficial effect of the absence of PRRS, the strict rules on biosecurity and health control in SPF farms is expected to play a role in both associations (Backhans et al., 2016; Antunes et al., 2017). The replacement rate was higher in PRRS-free farms. Such farms are expected to follow strict measures, including the rigorous elimination of any sows that underperform (McCaw, 2000). As a result, more sows are expected to be replaced (Corzo et al., 2010).

Replacement rate is viewed as the combined result of unplanned removals on the one hand and more economically-based decisions on the other to increase productivity (Dijkhuizen et al., 1989). This makes replacement rate a not so straightforward parameter to indicate production problems. Apart from PRRS-free farms, a higher replacement rate and a lower preweaning mortality rate was seen on farms where all breeding gilts were bred on the farm. An explanation for the lower mortality could be that these gilts are longer and better exposed to farm specific microorganisms (e.g. *Mycoplasma hyopneumoniae*, PRRS) when compared to introduced gilts, especially when there is a short acclimatization period. Due to the considerable differences between gilts and the older sows, farms where breeding gilts were raised on the farm are expected to have separate units to raise breeding gilts usually allowing these farms to have a large pool of replacement gilts (Safranski, 2016). First, a breeding gilt may be considered less expensive by the farmer. Also, opting out for a higher replacement rate is not considered as such a high biosecurity risk compared to the purchase of breeding gilts. These aspects may explain the higher replacement rate in these farms (Williams et al., 2005).

Farms that breed all gilts at the farm were associated also with a lower preweaning mortality. A large pool of replacement gilts is expected to help meet breeding targets (Safranski, 2016). The farmer can carefully select gilts within the farm (avoid transportation stress) to replace the older sows by closely monitoring various physical attributes

Table 4
Results of univariable linear regression models regarding piglet performance. The independent variables are denoted with superscripts either as binary (b) or continuous (c). For (b), existence of a condition was considered as a comparison level, whereas absence was considered as a baseline level. The independent variables are shown alongside with the number of farms that provided data (N), the unstandardized coefficients (B) and the p values (Sig.). Country effects are included in all models as a fixed factor. Each column corresponds to a different dependent variable. All associations with p values < 0.025 (shown in bold) were included in multivariable models. The independent variables that are denoted with an asterisk are the variables that remained in the final multivariable models.

	Preweaning mortality			Piglet born alive per litter			Piglets born dead per litter			Weaned piglets per litter		
	N	*B*	*Sig*	*N*	*B*	*Sig.*	*N*	*B*	*Sig.*	*N*	*B*	*Sig*
Are all the gilts bred (raised) on the farm? [b]	125	**−1.352**	**0.015***	121	−0.195	0.355	112	−0.124	0.080	130	0.000	0.998
When are the gilts inseminated for the first time (days)? [c]	120	0.010	0.604	116	0.002	0.780	107	−0.002	0.349	125	< 0.001	0.988
Does the farm has an SPF status for M. hyopneumoniae? [b]	125	−0.241	0.758	121	−0.172	0.549	112	0.036	0.709	130	−0.072	0.753
Does the farm has an SPF status for PRRS? [b]	125	**−1.719**	**0.014***	121	0.319	0.234	112	0.133	0.141	130	0.319	0.130
Does the farm has an SPF status for APP? [b]	125	0.473	0.564	121	0.045	0.887	112	0.016	0.877	130	0.041	0.863
Are the sows vaccinated against Influenza? [b]	125	−0.652	0.277	121	−0.044	0.845	112	−0.053	0.486	130	0.158	0.356
Are the sows vaccinated against PRRS? [b]	125	0.331	0.624	121	−0.527	0.036	112	**−0.205**	**0.016**	130	−0.217	−0.608
How old is the interior design of the units? Farrowing Unit [c]	117	−0.003	0.916	114	**−0.036**	**0.002***	107	−0.003	0.486	122	**−0.022**	**0.016**
Insemination Unit [c]	115	−0.018	0.570	113	**−0.030**	**0.018**	107	0.003	0.476	120	−0.011	0.233
Gestation Unit [c]	114	−0.071	0.078	112	**−0.044**	**0.003**	107	−6.000	0.200	119	−0.026	0.026
Natural ventilation in gestation unit? [b]	119	0.818	0.282	115	**−0.977**	**0.001***	107	−0.179	0.056	124	**−0.796**	**< 0.001***
Are the sows in the farrowing unit fed using manual system? [b]	123	−0.098	0.903	119	−0.597	0.041	110	−0.055	0.590	128	−0.445	0.056
How many times per day are sows fed in the farrowing unit? [c]	122	0.357	0.357	118	0.276	0.073	109	−0.002	0.976	127	0.266	0.027
What is the average weaning age of the piglets (in days)? [c]	122	0.139	0.338	117	−0.071	0.193	109	0.004	0.806	126	−0.072	0.093
Are weaned sows housed separately before insemination? [b]	123	−0.410	0.533	119	0.512	0.037	110	0.030	0.703	128	0.317	0.093
Are teaser boars present in the insemination room? [b]	122	−1.126	0.073	118	−0.273	0.249	109	0.016	0.834	127	−0.022	0.901
Is an open box group housing system used for pregnant sows? [b]	122	−0.759	0.181	118	0.405	0.060	109	0.040	0.575	127	**0.433**	**0.008***
Gestation unit: Are these groups static (all in – all out)? [b]	121	−1.036	0.171	117	0.215	0.472	108	0.062	0.531	126	0.261	0.225
Type of farm? (piglets fattened on the farm)? [b] [ǂ]	125	0.469	0.545	121	−0.613	0.030	112	**−0.237**	**0.011***	130	−0.296	0.200
Is the drinking water disinfected during the production cycle? [b]	120	**1.721**	**0.023**	116	0.279	0.315	107	0.014	0.884	125	0.091	0.669
Is a dead animal -found in the pen- removed immediately and placed in storage? [b]	120	−0.863	0.200	117	−0.079	0.751	107	−0.184	0.028	125	0.018	0.925
Is a 1-week sow batch farrowing system used on the farm? [b]	120	0.240	0.719	120	−0.341	0.162	111	−0.024	0.762	129	−0.164	0.381
Is genetic selection for robustness (resistance against diseases) considered important in the replacement gilt program? [b]	114	−1.460	0.071	112	**−0.808**	**0.008**	102	−0.158	0.137	118	−0.481	0.037
Is farrowing induction of sows performed? [b]	122	−0.373	0.555	118	**0.634**	**0.006**	110	0.100	0.190	127	**0.480**	**0.005**
Is the manure/slurry from farrowing unit stored in a pit? [b]	120	1.096	0.331	116	−0.295	0.474	108	0.095	0.449	125	−0.256	0.396

ǂ The baseline level for this question is: sow breeding farm (piglets stay until weaning or until 10 weeks).

Table 5
Final multivariable linear regression models (one model for each dependent variable studied) regarding piglet/litter performance. The independent variables are denoted with superscripts either as binary (b) or continuous (c). For (b), existence of a condition was considered as a comparison level, whereas absence was considered as a baseline level. The independent variables are shown alongside with the unstandardized coefficients (B), standard errors, p values (Sig.) and the Pearson's rho and partial correlation coefficient. For each model, the number of farms that provided data for both the dependent and all independent variables, is presented in the far-right column. In all models, country was included as a fixed effect.

Dependent variable	Independent variable	Unstandardized Coefficients B	Std. Error	Sig.	Model fit R^2 (adjusted R^2)	Number of farms
Model 5: preweaning mortality	Are all the gilts bred on the farm? [b]	−1.498	0.547	0.007	14.2%	120
	Does the farm has an SPF status for PRRS? [b]	−1.946	0.682	0.005	(9.6%)	
	Country effect			0.488		
Model 6: piglets born alive per litter	How old is the interior design of the farrowing unit? [c]	−0.033	0.011	0.005	59.7%	99
	Natural ventilation in gestation unit [b]	−0.960	0.279	0.001	(57.1)	
	Country effect			< 0.001		
Model 7: piglets born dead per litter	Type of farm (piglets fattened on the farm)? [b ǂ]	−0.217	0.080	0.002	30%	111
	Country effect			< 0.001	(26.7%)	
Model 8: weaned piglets per litter	Natural ventilation in gestation unit [b]	−0.799	0.203	< 0.001	62.6%	117
	Open box group housing system (individual resting areas) used for the pregnant sows [b]	0.486	0.150	0.002	(60.6%)	
	Country effect			< 0.001		

ǂ The baseline level for this question is: sow breeding farm (piglets stay until weaning or until 10 weeks).

(*e.g.* number of productive nipples, leg soundness). Such gilts are expected to better feed (sufficient colostrum or milk) and nurture piglets and hence result in a lower preweaning mortality (Sultana et al., 2017).

4.2. Piglet-related performance parameters

The parameters that had significant associations with preweaning mortality rates were discussed in the previous paragraph. Regarding the infrastructure of the farm, the newer the design of the farrowing unit, the higher the number of piglets born alive per litter is expected to be. New buildings are likely to be better equipped to accomplish the needs for high standards of management, housing and biosecurity (Andres and Davies, 2015). Moreover, older farms were identified by pig farmers as an obstacle for taking measures in disease prevention (Laanen et al., 2014).

Mechanical ventilation in gestation unit was associated with more piglets born alive and accordingly with more weaned piglets per litter compared to gestation units that operate with natural ventilation systems. This could be attributed to the better air quality (lower humidity levels and less gaseous contaminants) found in mechanically-ventilated units (Saha et al., 2010; Agostini et al., 2014). Many studies, mainly in tropical environments, have suggested the negative effects of increased humidity in gestation stables on the number of piglets born alive (Tantasuparuk et al., 2000; Tummaruk et al., 2004; Suriyasomboon et al., 2006).

The number of stillborn piglets has been associated with several non-infectious factors with parity and litter size being of primary importance (Vanderhaeghe et al., 2013; Pandolfi et al., 2017). In our study, breeding farms were shown to be associated with more stillborn piglets. This could be attributed to the bigger litter sizes that were found on average in breeding farms. In accordance, it has been shown that the number and the probability of stillbirth increased in piglets from large (> 15 piglets) litters (Canario et al., 2006).

In accordance with the EU animal welfare requirements that were introduced via various EU Directives (91/630/EEC, 2001/88/EC, 2001/93/EC), group housing in sow farms became mandatory since 2013 (Maes et al., 2016). To reduce aggressiveness, lameness incidents and stress of the pregnant sows, the presence of individual resting areas in these units has been proposed with beneficial results (Verdon et al., 2015; Peltoniemi et al., 2016). In our study, when individual resting areas were used in the gestation unit, this was found to be positively associated with the number of weaned piglets per litter. The provision of individual resting areas are expected to result in less aggression incidents and fights among the animals. These animals are expected to show lower levels of stress. It has been shown that increased maternal stress during late gestation can affect the immune system of the piglets hampering its ability to react against infections during the suckling period and around weaning (Couret et al., 2009).

4.3. Study limitations and remarks

Our target was to analyze a sample that was representative of the population (Pandolfi et al., 2018). However, no official data or relative publications were available for all countries regarding the distribution of the farms with respect to their characteristics. To counter this limitation, a selection of farms based on their characteristics was performed after extensive consulting with several stakeholders. Thus, although these selections cannot be seen as truly representative, the farms were still considered as representative for each country's pig sector. Despite the effort by all interviewers to gather the questionnaire and the performance parameters data, no country met the target to provide sufficient data from 50 farms. Thus, compared to what was expected, the "response rate" (farms providing sufficient data for both datasets) ranged from as low as 36% (Country B) to 66% (Country E). Although not compared with official national data regarding the population of farms per type, the selected farms were still able to portray the general farm traits of each participating country. The latter was assessed by the interviewers of each participating country after reviewing the respective data. Yet, as the farms that finally participated in the study were lower than needed to ensure representativeness, the results should be extrapolated with additional caution to a population level for these five countries and –by all means- with a greater caution to a more general level.

The size of the questionnaire and the nature of some questions (semi-open or open) resulted in many farmers failing to answer all items found in the questionnaire. The presence of missing values might impair the data quality and the ability to conduct analysis with the data available. However, for the most relevant questions that contained a sufficient number of responses, the data were further processed. The questionnaire was designed in order to minimize recall bias and focused on present situation while all technical information that required data from the two previous years was systematically collected. Interviewer bias cannot be excluded as different interviewers were assigned per country, although common guidelines were laid before the start of the interviews. Respondent bias cannot be excluded as the people willing to answer questionnaires and provide technical information over their farms are expected to positively affect the responses regarding management and disease prevention strategies.

Overall, the questionnaire allowed to portray several general and more specific (e.g. farrowing unit) management traits of farmers. Data from five EU countries with a geographical range from south to the north of Europe were included. The effects attributed per country were included in this study as a fixed factor as has been the case with other studies (Postma et al., 2016a; Van Limbergen et al., 2017). Thus, the variation or the clustering due to country was taken into account. This allowed us to evaluate differences between countries in management practices. To avoid additional complexity, the current analyses did not delve into how these country-level differences in some management practices are influencing each production parameter. Due to the multiple number of variables assessed, a lower p value was assigned to indicate a significant difference.

The present study is a cross-sectional study and as such any associations cannot be readily extrapolated in causal relationships. Yet, these associations could form a basis to further explore with more studies that will allow to better assess the causal links of management, housing and production diseases. Moreover, such findings could be employed to produce improvement strategies at a European level by estimating the benefit or cost of various interventions in porcine farm management.

5. Conclusions

At a supranational level, factors relating to management and housing were found to have a significant effect on various sow and piglet performance parameters. Multivariable statistical analyses ensure a better understanding of the multifactorial nature of production diseases in pigs.

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Appendix A. Supplementary data

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