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Risk factors associated with the different categories of piglet perinatal mortality in French farms

F. Pandolfi[a,*], S.A. Edwards[a], F. Robert[b], I. Kyriazakis[a]

[a] School of Agriculture Food and Rural Development, Newcastle University, Newcastle upon Tyne, NE1 7RU, UK
[b] CCPA group, ZA du Bois de Teillay, Quartier du Haut-Bois, 35150, Janzé, France

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ABSTRACT

We aimed to identify mortality patterns and to establish risk factors associated with different categories of piglet perinatal mortality in French farms. At farm level, the analyses were performed on data from 146 farms that experienced perinatal mortality problems. At piglet level, the analyses were performed on data from 155 farms (7761 piglets). All data were collected over a period of 10 years (2004–14) by a consulting company, using a non-probability sampling at farm level and a random sampling at sow level. Six main categories of mortality, determined by standardised necropsy procedure, represented 84.5% of all the perinatal deaths recorded. These six categories were, in order of significance: Death during farrowing, Non- viable, Early sepsis, Mummified, Crushing and Starvation. At farm level, the percentage of deaths due to starvation was positively correlated to the percentage of deaths due to crushing and the percentage of deaths during farrowing ($r > 0.30$, $P < 0.05$) .The percentage of deaths due to crushing was negatively correlated to the percentage of deaths due to early sepsis ($r < -0.30$, $P < 0.05$) and positively correlated to the deaths due to acute disease ($r > 0.30$, $P < 0.05$). Patterns of perinatal mortality at farm level were identified using a principal component analysis. Based on these, the farms could be classified, using ascending hierarchical classification, into three different clusters, highlighting issues that underlie farm differences. Risk factors were compared at piglet level for the different categories of death. Compared to other categories of death, deaths during farrowing were significantly fewer during the night than during the day. Compared to other categories of death, the likelihood of non-viable piglets tended to be higher in summer than other seasons. A smaller number of deaths in the litter was also identified for the piglets classified as non-viable or mummified. For the six main categories of perinatal mortality, the piglets which died from a specific category tended to have more littermates which died from the same category. Parity and litter size also had more significant effects on certain categories of death compared to others. The study provides novel information on the risk factors associated with specific categories of piglet perinatal mortality. The classification of farms into the 3 different clusters could lead to a more targeted management of perinatal mortality on individual farms.

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1. Introduction

Perinatal mortality is one of the main issues of concern for the pig industry worldwide, resulting in decreased sow performance and important economic losses (Houška et al., 2010). Piglet deaths are a result of the three way interactions between the piglets, the sow and the environment (Alonso-Spilsbury et al., 2007). The great majority of piglet deaths occur at an early stage: before birth or during the first days of life (Kilbride et al., 2012; Panzardi et al., 2013; Westin et al., 2015). The piglets die from a wide variety of causes, with crushing and stillbirth reported as being the most important ones. The breed of the sow, parity, litter size, placental weight and area, location in the uterus, prenatal nutrition and duration of farrowing all influence the health and growth of the fetus and the risk of piglet death (Milligan et al., 2002; Rehfeldt and Kuhn, 2006; Canario et al., 2007; Beaulieu et al., 2010; Rootwelt et al., 2013). Moreover, risk factors related to the piglet itself have also been identified, including weight, sex and vitality at birth (Rehfeldt and Kuhn, 2006; Canario et al., 2007; Panzardi et al., 2013).

The different causes of piglet perinatal mortality have been widely reported in the literature, but risk factors are not always reported for each individual cause. For example, in the study of Panzardi et al. (2013), although different causes of piglet

* Corresponding author.
E-mail addresses: fanny.pandolfi@gmail.com, f.pandolfi@newcastle.ac.uk (F. Pandolfi).

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mortality were recorded for the population of interest, the identification of risk factors was not related to specific causes of death. Studies have increased the understanding of particular causes of death, but they do not always provide insights into the understanding of piglet death in all farrowing systems (e.g. Pedersen et al., 2006). Moreover, the misclassification of dead piglets in a range of categories has been raised as a problem by several studies (Vaillancourt et al., 1990; Vanderhaeghe et al., 2009; Kilbride et al., 2012; Westin et al., 2015). Finally, most previous studies focus on one or more causes, but do not capture the different patterns of piglet mortality on different farms.

The above observations demonstrate the importance of undertaking further investigations on this important topic. We conducted a descriptive cross-sectional study of French pig farms who had requested support to reduce piglet perinatal mortality. The first objective of the study was to highlight the variation in the risk factors for the different categories of piglet death, instead of considering perinatal mortality as a single entity (Panzardi et al., 2013; Ferrari et al., 2014). The second objective was to determine whether characteristic clusters of farms could be identified on the basis of their mortality patterns. This classification will help to develop a more targeted response to reduce piglet mortality, through the development of different strategies adapted to the different mortality patterns.

2. Materials and methods

2.1. Population of interest

The data were collected by the CCPA-DELTAVIT Lab., a French consulting company for animal nutrition and health. The reference population for this study was French farms with piglet perinatal mortality problems; particularly those that had a proactive position to the problem. The farms included in the study had either a perinatal mortality problem reported by a consultant or veterinarian, or self-reported by the farmer. The farms were either breeder-fattener or specialized breeding farms (without fattening pigs). Perinatal mortality was defined as non-viable and mummified piglets, stillborn piglets, and piglets born alive which died within the first 48 h of life.

2.2. Sampling

For cost, convenience and to ensure representativeness of the piglet deaths in each farm selected, the sampling carried out by CCPA was a multistage cluster sampling. The first stage corresponded to a non-probability sampling of farms with perinatal mortality problems. This classification as a farm with a perinatal mortality problem was based on a self-assessment. The second stage corresponded to a targeted random selection of 20 sows per farm. The sows in a farrowing unit at a designated time were selected for this study, whether they had perinatal mortality or not. For the last stage of sampling, the litter size of these sows were recorded and all dead piglets were collected and examined by the laboratory and reported in the database. Overall, farms in 12 regions were involved in the study (Alsace, Aquitaine, Auvergne, Basse-Normandie, Bretagne, Centre, Franche-Comté, Lorraine, Midi-Pyrénées, Normandie, Pays-de-la-Loire, Poitou-Charente). A sample size calculation was carried out in order to confirm that, considering the 3 level sampling, the number of piglets available in the database was adequate for the objectives of the study (Teerenstra et al., 2008). The minimum sample size calculated was 4269 piglets. The details of the calculations are reported in the Material S1 of Supplementary file. In total, 162 farms reporting perinatal problems participated in the audit organized by CCPA between 2004 and 2014 and, therefore, were sampled for the study. The sample included 2849 sows and 8666 dead piglets.

2.3. Piglet necropsy

A necropsy was carried out by the laboratory, following a standardized methodology to classify piglets. A decision tree, based on multiple criteria, was developed by CCPA to classify the dead piglets into 16 different categories during the necropsy: anaemia, arthritis, starvation, dehydration/enteritis, crushing, acute disease, malformation, splayleg, killed by the sow, killed by the farmer, unknown category, early sepsis, mummified, death before farrowing, death during farrowing, non-viable piglet. Only the non-viable piglets, defined as piglets weighting less than 800 g, were not necropsied. The definitions and details for each of the categories are reported in Table S1 of the Supplementary file.

2.4. Data and data management

The field work resulted in two datasets: one at piglet and one a sow level. For the purpose of the analysis, these datasets were matched to each other to produce two datasets: one at farm and one at piglet level. Duplicate records were removed and further data management was then conducted either at farm level or piglet level.

2.4.1. Data management at farm level

For each farm, the percentage of total mortality attributable to each category of perinatal mortality, the total percentage of mortality, the average sow parity, the average litter size and the average weight of the dead piglets were calculated. The values of the variables for each farm were based on the sample of ~20 sows selected.

$$\begin{aligned}&\%\ \text{of mortality in the category X}\\&\quad = \text{Number of deaths in the category X / total piglet deaths}\end{aligned}$$

The region where the farm was located was identified from the farm address. Of the 162 farms assessed, one farm had no location recorded. This farm was kept in the dataset, but with region "unknown". In order to avoid misinterpretation of the percentages of the different categories of piglet death, thirteen farms were excluded due to several dead piglets without a reported category of mortality. The remaining 149 farms were inspected for outliers, for average weight at death and litter size. The first and the third quartiles were used for the calculation of the interquartile range (IQR). We identified the outliers as those outside the limits of 1.5 x IQR beyond the first and the third quartiles, and removed these from the dataset.

2.4.2. Data management at piglet level

After removal of duplicate data, data not biologically possible and piglets without death category, the dataset of dead piglets was analysed to identify and remove outliers using the IQR rule explained above. We then grouped, in a new "other categories" category, the less common causes of death which represented <5% of the total perinatal mortality. Therefore the piglets could be classified in one of 7 categories (Table 1). A season (spring, summer, autumn, or winter) was assigned to the piglet based on its date of birth.

2.5. Data analysis

For each continuous variable, at farm and piglet level, the median, the first and third quartile, minimum and

Table 1
Categories and definitons of piglet perinatal mortality.

Categories	Definitions
Non-viable	Piglets < 800 g excluding mummified piglets
Starvation	Mature lungs, abrasion of the feet, death after farrowing, empty stomach and intestine, no organ lesions visible during the necropsy, urate crystals in the kidneys
Crushing	Mature lungs, death after farrowing, lesions of trauma, signs of compression on the skin, internal bleeding, broken rib, tongue hanging out of the mouth
Early sepsis	Incomplete lung maturation, lack of abrasion of the feet, no signs of autolysis lesions but lesions of septicaemia, inflammatory lesions, peritonitis, fibrin in the abdomen, systemic lymphadenomegaly and lymphadenitis.
Mummified	Death during gestation after ossification, signs of mummification
Death during farrowing	Incomplete lung maturation, lack of abrasion of the feet, differential colour of the organs, congestion of the intestine, meconium on the skin, pale skin with purplish skin haemorrhage, no signs of septicaemia
Other categories	Piglets which have not been identified as one of the 6 categories reported above

maximum values were calculated The percentage distributions were described for the following categorical variables: Region, Regional categories (region E with >2000000 pigs, region D with 1000000–2000000 pigs, regionC with 500000–1000000 pigs, region B with 200,000–50,000 pigs, region A with <20,0000 pigs), Season and Time of death (night/day) (see Table S2 of the Supplementary file).

2.5.1. Farm level analysis

In order to understand the association between the different categories of piglet death and estimate the necessity of omitting variables in the Principal Component Analysis (PCA) (see below), correlation coefficients were calculated. Data on the percentages of mortality, the average litter size, the average weight of dead piglets and the average parity were evaluated for normality using the Shapiro-Wilk test. Pearson's correlation coefficients were calculated for continuous variables with a normal distribution and Spearman's rank correlation coefficients for the continuous variables not normally distributed.

To identify perinatal mortality patterns and classify the farms according to these, a PCA and an Ascending Hierarchical Clustering (AHC) were used (Messad, 2012). Eight variables were considered in the analysis to identify farm profils: the percentage of the 6 most common categories of perinatal mortality identified above, the average litter size and the average weight of the dead piglets. This analysis used a similar methodology to that applied to identify sub-scales in animal-based measures expressed in percentages (Munsterhjelm et al., 2015).

The average weight of dead piglets and the percentage of non-viable piglets were highly negatively correlated, which could increase their contribution to the components and slightly overemphasize the projected inertia of the components they belong to. However, considering that the weight of the dead piglets might also have an impact independently from the percentage of non-viable piglets, we decided to keep both of them in the analysis. We inspected the barplot of the Eigenvalues and we based the selection of the number of components on the Kaiser criterion (Kaiser, 1960). The cumulative percentage of the projected inertia was calculated. The contributions to the principal components (absolute contributions) and the quality of the representation of the variables on the component (relative contributions) were also calculated. In order to assess the possible impact of the small sampling error, we calculated the Jackknife values, the Jackknife estimate of standard error and the Jackknife estimate of bias for the eigenvalues of the 3 first components. The nonparametric bootstrap procedure was used to assess the stability of the Eigenvalues and visualize the histograms of these values (Besse, 1989).

We used an AHC based on the variables used in the PCA, to place individual farms into different classes. The "Euclidean" distance was calculated between the individual farms based on the 3 first components selected from the PCA and the clustering was achieved based on the "Ward" criteria. A diagram of the indices of clustering and a cluster dendogram were built to choose the number of clusters, which was based on the drop of the indices of clustering on the diagram and the length of the tree branches on the dendogram.

The association between the partition and the variables which had not been used to build the classes (the percentage of all other categories of mortality, total percentage of dead piglets, average parity, season, region category, year) was analysed with test values by comparing the mean of the continuous variables, or the proportion for categorical variables, in the cluster and the total sample (Messad, 2012).

2.5.2. Piglet level analysis

To identify risk factors for the 7 categories of perinatal mortality, we used models which captured the two levels of hierarchy (sows and farms) and the effect of time (year), in an analysis performed at piglet level. The nature of the available data did not allow a classical risk factor analysis through comparison with piglets still alive after 48 h, for which we had limited data. Therefore, the analysis focused on the comparison of each of the 7 categories of mortality with all the other categories, to highlight particular factors related to certain categories of mortality. To solve the problem of quasi-complete separation for certain variables in the dataset, we used a maximum *a posteriori* estimation for generalized linear mixed-effects models in a Bayesian setting (Dorie, 2014). A weak prior was added to the fixed effects of the generalized linear mixed-effects models. We built 7 models–one for each category of death. The dependent variable was the binary data related to the category of death (died from the category of interest vs died from another category) for the following 7 categories: early sepsis, death during farrowing, crushing, starvation, non-viable, mummified and 'other'. In each model, the independent variables were categorical variables (season, parity, time of death (night/day), weight of the dead piglets) and continuous variables (litter size, number of deaths in the same litter, number of other deaths from the same category). In order to solve the problem of convergence of the models, the weight of the dead piglets was transformed into a categorical variable (equal or under the mean(<=1031 g) vs above the mean (>1031 g)) and the parity was grouped in 3 categories (Parity1 to 2, Parity 3–5 and Parity >=6). The sow nested within farm and the year was considered as a random effect. For all models, univariate analyses were first conducted for the independent variables. Only the variables with $p \leq 0.25$ were selected for the multivariate models. Variables not significant in the multivariate model, which increased the value of

Table 2
Descriptive analysis of the categories of perinatal mortality at farm level: Median, 1 st quartile, 3rd quartile, minimum and maximum values for the percentage of dead piglets attributed to each category, the percentage of total piglet deaths (TPM), the average parity (AVGP), the average litter size (AVGL) and the average weight of the dead piglets (AVGW).

	min	1 st quartile	median	3rd quartile	max
Anemia (%)	0	0	**0**	0.58	34.4
Arthritis (%)	0	0	**0**	0	1.41
Starvation (%)	0	0.32	**0.81**	1.69	25
Dehydration/enteritis (%)	0	0	**0**	0.203	10.2
Crushing (%)	0	0.34	**1.33**	2.26	30.2
Unknown (%)	0	0	**0**	0.455	23.9
Early sepsis (%)	0	1.76	**2.86**	4.84	64.7
Acute disease (%)	0	0	**0.49**	1.26	28
Malformation (%)	0	0	**0**	0.31	5.63
Mummified (%)	0	0.933	**1.89**	3.08	40.5
Death before farrowing (%)	0	0	**0.57**	1.17	22.9
Death during farrowing (%)	0	2.83	**4.1**	5.58	65.8
Non-viable (%)	0	2.41	**3.95**	5.87	43.4
Splayleg (%)	0	0	**0**	0	7.98
Killed by the sow (%)	0	0	**0**	0.35	10.7
Killed by the farmer (%)	0	0	**0**	0	3.79
Total piglet mortality (TPM) (%)	5.15	16.8	**19.9**	23.5	40.1
Average sow parity (AVGP)	2.64	3.47	**3.93**	4.5	6
Average litter size (AVGL)	12.6	14.8	**15.6**	16.3	18.4
Average weight of the dead piglets(AVGW) (g)	765	963	**1036**	1125	1367

the AIC and the BIC, were removed from the model. The interactions between variables were not tested.

For two categories of mortality, the weight of the piglets was limited by definition: non-viable piglets could not exceed 800 g and mummification is associated with foetal death and therefore results in reduced average weight of the piglets. These impact on the general mean weight compared to the mean weight of the category of interest in the different models. For a better understanding of the weight differences between each of the categories of death, we conducted an ANOVA test to compare the mean weights of the different categories. A Fligner test was conducted to assess the homogeneity of the variance and a post hoc test carried out to compare the mean weights of individual categories of death, with the Bonferroni correction used for these comparisons to avoid an over-estimation of the differences. The difference was considered significant when a *p*-value lower than 0.05 was obtained (Crawley, 2013).

Finally, in order to comment on the timing of the death of the mummified piglets during pregnancy, we approximated the gestation day of the foetal death on the basis of the crown-rump length transformation developed by Ullrey et al. (1965), Straw et al. (2006) and described this distribution.

Data processing was carried out using Microsoft Access Office Professional Plus 2010 and Microsoft Excel Office Professional Plus 2010 to create the datasets. The data were analysed with RStudio for *R*-3.1.0 software for Windows (64 bit).

3. Results

3.1. Descriptive analysis at farm level

From the 149 selected, three farms were identified as outliers. One farm had an average parity of 6.42, which was considered abnormally high, while two farms had an average litter size of 11.7 and 11.1, which were considered abnormally low. After data processing and outlier removal, the final database included 146 farms in which an average of 18.1 ± 5.62 sows per farm was finally sampled. From these sows, 40,101 piglets were born including 7928 that died before farrowing or within the 48 h after birth. More than 80% of the farms were from the most pig productive regions in France, with a pig population of more than 1,000.000 pigs (Regions D and E). More than 90% of the farms had a percentage of perinatal mortality between 10 and 30%. The results of the descriptive analysis for the different categories of perinatal mortality are presented in Table 2.

3.2. Correlations at farm level

All variables, with the exception AVGL and AVGW, were not normally distributed ($P < 0.05$). The correlations were considered significant for $r > 0.3$ and $P < 0.05$. The average weight of dead piglets was negatively correlated to the percentage of mummified piglets ($r = -0.371$, $P < 0.01$) and non-viable piglets ($r = -0.728$, $P < 0.01$) and positively correlated with the percentage of early sepsis ($r = 0.324$, $P < 0.01$). The percentage of early sepsis was negatively correlated to the percentage of death by crushing ($r = -0.457$, $P < 0.01$). The percentage of piglet deaths due to acute disease was positively correlated to the percentage of deaths by crushing ($r = 0.408$, $P < 0.01$). The percentage of piglet deaths during farrowing was negatively correlated to the percentage of piglet deaths due to starvation ($r = -0.391$, $P < 0.01$). The percentage of piglet deaths by crushing was positively correlated with the percentage of piglet deaths due to starvation ($r = 0.333$, $P < 0.01$).

3.3. Principal components analysis

The results showed that 4 components had an Eigenvalue higher than 1. The 3 first components were retained in the model as the Eigenvalue of the fourth component was very close to 1. These 3 components explained 62.76% of the total variance for the 8 variables of the dataset [Table S3 of the Supplementary file]. The Jackknife estimations of the standard error of the Eigenvalues were 0.172 for the first component, 0.133 for the second component and 0.107 for the third component. After bootstrapping, the confidence intervals of the cumulative projected inertia of the 3 first components ranged from 56.86% to 72.41% [Table S4 of the Supplementary file]. The absolute and the relative contributions of the variables for each component are reported in Table S5 of the Supplementary file.

3.4. Ascending hierarchical classification

A partition into 3 clusters was determined after the examination of the diagrams. A drop in the indices of the clustering after the second barplot of the cumulative indices of clustering of the farms, and a longer length of the tree branches for a partition in 3

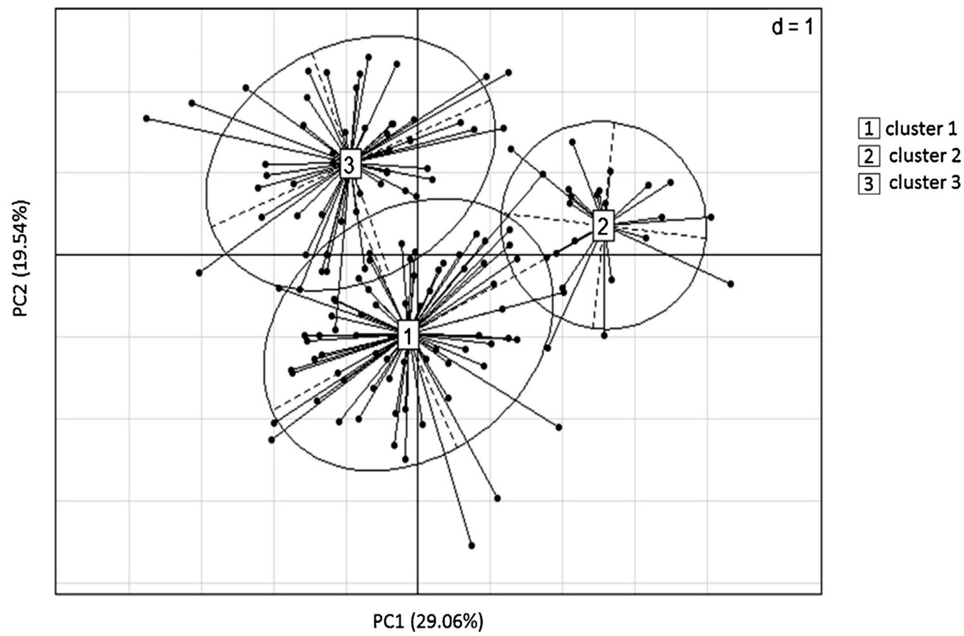

Fig. 1. Three different clusters identified by Ascendant Hierarchical Clustering (AHC) in a sample of French pig farms and represented on the factorial plane 1–2 of the Principal Component Analysis (x-axis: Principal Component 1 (PC1), y-axis: Principal Component 2 (PC2)). The percentage of the variance of the active variables explained by the two first Components are also given on the axes. Differences between clusters can be identified by the higher coordinates they show on particular factorial axes.

Table 3
Description of 3 clusters identified amongst 146 French pig farms through a Principal Component Analysis (PCA). This description was based on 8 active variables (the 6 most common categories of perinatal death, average litter size, average weight of the dead piglets) and supplementary variables. The supplementary variables tested for the analysis were: percentage of acute disease, dehydration/enteritis, splayleg, piglets killed by the sows, piglets killed by the farmer, death before farrowing, malformation, unknown categories, arthritis, anemia, average parity, year, season, region category.

	Cluster 1		Cluster 2		Cluster 3	
	Mean	SD	mean	SD	mean	SD
Active variables						
Starvation (%)	8.95	5.62	2.22	2.42	2.89	3.13
Crushing (%)	11.21	7.19	2.20	3.42	4.87	4.15
Early sepsis (%)	15.21	8.37	27.82	17.57	15.54	10.72
Mummified piglets (%)	10.33	5.85	4.13	3.64	13.86	7.66
Death during farrowing (%)	18.03	8.10	40.91	13.86	21.54	8.83
Non-viable piglets (%)	18.34	7.20	12.23	5.78	27.71	8.80
Average litter size	15.31	1.00	15.03	1.12	15.99	1.19
Average weight (g)	1082.46	84.27	1184.56	86.26	943.43	68.93
Supplementary variables						
Acute disease (%)	5.32*	5.61	1.27*	2.45	3.50	3.68
Dehydration/Enteritis (%)	1.33*	2.34	0.26	0.91	0.57	1.20
Splayleg(%)	0.77	1.66	0*	0.00	0.53	1.55
Killed by the sows (%)	1.14	1.83	0.25*	0.87	0.94	1.62
Total mortality (%)	21.04	5.76	16.65*	3.73	20.62	5.52

* variables significantly associated to the cluster.

clusters instead of a higher partition, suggested this to be the best classification [Fig. S1 of the Supplementary file].

A visual inspection of the partition of the farms, represented on the factor map of components 1 and 2, shows the differences between the different clusters [Fig. 1]. Cluster 2 tended to have higher coordinates on factorial axis 1; Cluster 3 tended to have higher coordinates on factorial axis 2 but lower on factorial axis 1, whereas Cluster 1 tended to have low coordinates on factorial axis 2.

The description of the variables used for the PCA and the additional continuous variables for each cluster can be seen in Table 3. The percentage of acute disease was significantly higher for cluster 1 and significantly lower for cluster 2. The percentage of dehydration/enteritis was significantly higher in cluster 1. The percentage of mortality, the percentage of splayleg and the percentage of piglets killed by the sow was significantly lower for cluster 2. The proportion of farms from the regions with more than 2, 000,000 pigs was significantly higher in cluster 1 and significantly lower for cluster 3. The proportion of farms from the regions with 200,000 to 500,000 pigs was significantly higher in cluster 3 and significantly lower for cluster 1.

3.5. *Descriptive analysis at piglet level*

After removing the outliers, 7761 piglets that died before farrowing or within the 48 h after birth were included in the analysis. These dead piglets were part of 37,356 piglets born and belonged to 155 different farms. The great majority of the farms were from two regions, Bretagne (50%) and Pays de la Loire (21%), due to the proximity of the Laboratory to these. The mean weight of the dead

Table 4
Categorical explanatory variables used for the multivariable analysis of the 7 categories of perinatal mortality considered at piglet level in French farms.

variable	level	n (piglets)	%	variable	level	n (piglets)	%
parity	1	1018	13.12	day	day	4456	57.42
	2	889	11.45		night	3305	42.58
	3	1169	15.06				
	4	1201	15.47	season	Autumn	1617	20.83
	5	1082	13.94		Winter	2213	28.51
	6	973	12.54		Spring	2185	28.15
	7	661	8.52		Summer	1746	22.50
	8	422	5.44				
	9	216	2.78				
	10	97	1.25				
	11	26	0.34				
	12	6	0.08				
	13	1	0.01				

Table 5
The 7 categories of perinatal mortality in the sample of French pig farms: number of piglets and percentages under each category.

Categories	Number of piglets	Percentages
Death during farrowing	1785	23.0%
Non- viable	1658	21.4%
Early sepsis	1366	17.6%
Mummified	856	11.0%
Crushing	608	7.83%
Starvation	433	5.58%
Other	1055	13.59%
Total	7761	100%

piglets was 1031 g with a standard deviation of 437.9 g. The average litter size at birth was 16.8 piglets per sow, with a minimum of 9 and a maximum of 25. The description of the categorical data is presented in Table 4.

The 6 mortality categories considered in the analysis represented 84.41% of the total perinatal mortality [Table 5].

3.6. Risk factor analysis

3.6.1. Early sepsis

Compared to all the other categories of death, the piglets which died with signs of early-sepsis tended to have more littermates which also died with signs of early sepsis. Piglets in parities 3–5 were more likely to die with signs of early sepsis than being classified in another category of death, compared to piglets from parities 1 and 2 [Table 6].

3.6.2. Non-viable piglets

Compared to all the other categories of death, the farms had less likelihood of non-viable piglets in summer than in autumn and spring ($P \sim 0.05$). The likelihood of being non-viable slightly decreased when the number of deaths in the litter increased. Compared to all the other categories of death, the non-viable piglets tended to have more littermates which were also non-viable piglets [Table 6].

3.6.3. Death during the farrowing

The deaths during farrowing were significantly fewer during the night than during the day compared to other categories of death. The piglets which died during farrowing tended to have more littermates which also died during farrowing. Piglets were more likely to die during farrowing than being classified in another category of death for parities 3–5 compared to parities 1 and 2 [Table 6].

3.6.4. Mummified

Compared to all other categories of death, the likelihood of being mummfied slightly decreased when the number of deaths in the litter increased. Mummified piglets tended to have more littermates which were also mummified piglets, than piglets which died from all other categories [Table 6].

3.6.5. Crushing

Piglets were less likely to die with signs of crushing than being classified in another category of death in parities 3 and above, compared to parities 1 and 2. The piglets which died with signs of crushing tended to have more littermates which also died with signs of crushing than piglets which died from all other categories [Table 7].

3.6.6. Starvation

Piglets were less likely to die with signs of starvation than being classified in another category in parities 3–5 compared to parities 1 and 2. The piglets that died from starvation tended to have more littermates which also died from starvation than piglets which died from all other categories [Table 7].

3.6.7. Other categories

Piglets were more likely to be classified in “other categories” than in the 6 main categories of piglet death in parities 3–5 than in parities 1 and 2. The piglets which died from “other categories” tended to be from smaller litters and to have more littermates which died from “other categories” than piglets which died from the 6 main categories of piglet death [Table 7].

3.7. Weight by category

The mean weights, the standard deviations (SD) and the number of piglets (N) for each category are reported in Table 8. The Fligner test showed heterogeneity of the variance of the weight for the different categories of mortality. However, the *ANOVA* had enough robustness to show the significant differences in weight between some categories of mortality ($P < 0.05$).

3.8. Length of mummified piglets

The length of the mummies ranged from 12 to 360 mm. Fetal age was estimated by the size of the mummies: 90.4% of the mummies had a size between 80 and 280 mm (equivalent to a foetal age between 45 and 108 days of gestation), 98.3% of the mummies occured after day 40 and 78% of the foetal mummification occurred after day 65 [Fig. S2 of the Supplementary file].

4. Discussion

The design of the analysis was chosen to identify the impact of various factors for a specific category of perinatal death, in comparison to the impact on all other categories of death, in a sample

Table 6
Multivariate analysis at piglet level for the categories: Early sepsis, Non-viable, Death during farrowing, and Mummified. Odd ratios, confidence interval and *p*-values of the explanary variables in the final models for the analysis of risk factors for the 7 categories and of perinatal mortality in a sample of French pig farms.

		Early sepsis				Non-viable				Death during farrowing				Mummified			
variables	level	Odd ratios	CI 95%		*P-values*	Odd ratios	CI 95%		*P-values*	Odd ratios	CI 95%		*P-values*	Odd ratios	CI 95%		*P-values*
	(Intercept)	0.061	0.044	0.084	<0.001	0.593	0.472	0.746	<0.001	0.093	0.075	0.116	<0.001	0.338	0.243	0.471	<0.001
Moment of the death during the day	Day	*NT*				*NT*				*Baseline*				*NT*			
	Night									0.853	0.753	0.966	0.012				
Weight	<Mean	*Baseline*				*Baseline*				*Baseline*				*Baseline*			
	>Mean	4.099	3.558	4.723	<0.001	0.000	0.000	0.002	<0.001	4.134	3.648	4.686	<0.001	0.069	0.054	0.089	<0.001
Number of death in the litter	DEATH	*NT*				0.950	0.923	0.977	<0.001	*NT*				0.880	0.850	0.911	<0.001
Other piglets death from the same cause	O...	1.210	1.124	1.303	<0.001	1.311	1.239	1.386	<0.001	1.206	1.146	1.269	<0.001	1.695	1.537	1.870	<0.001
Season	Summer	*NT*				*Baseline*				*NT*				*Baseline*			
	Autumn					1.258	0.994	1.592	0.056					0.940	0.665	1.328	0.726
	Spring					1.241	0.992	1.553	0.059					0.803	0.583	1.106	0.180
	Winter					1.152	0.927	1.432	0.201					0.893	0.650	1.227	0.485
Parity	P1-2	*Baseline*				*NT*				*Baseline*				*NT*			
	P2-5	1.241	1.033	1.490	0.021					1.346	1.142	1.585	<0.001	0.926	0.738	1.162	0.509
	P>=6	1.094	0.923	1.298	0.300					1.149	0.985	1.339	0.077	1.143	0.937	1.396	0.188
Litter size	LITTER	*NT*				*NT*				*NT*				*NT*			

NT: Not tested because not included in the final model. CI 95%: confidence intervals at 95%

Table 7
Multivariate analysis at piglet level for the categories: Crushing, Starvation and Other. Odd ratios, confidence interval and *p*-values of the explanary variables in the final models for the analysis of risk factors for the 7 main categories and of perinatal mortality in a sample of French pig farms.

		Crushing				Starvation				Other			
variables	level	Odd ratio	CI 95%		*P-values*	Odd ratios	CI 95%		*P-values*	Odd ratios	CI 95%		*P-values*
	(Intercept)	0.02698	0.019	0.037	<0.001	0.030	0.019	0.045	<0.001	0.169	0.108	0.264	<0.001
Moment of the death during the day	Day	*NT*				*Baseline*				*NT*			
	Night					1.198	0.976	1.470	0.084				
Weight	<Mean	*Baseline*				*Baseline*				*Baseline*			
	>Mean	3.901	3.198	4.758	<0.001	1.649	1.350	2.013	<0.001	2.274	1.966	2.630	<0.001
Number of death in the litter	DEATH	*NT*				*NT*				*NT*			
Other piglets death from the same cause	O...	1.546	1.386	1.724	<0.001	1.498	1.307	1.717	<0.001	1.332	1.258	1.412	<0.001
Season	Summer	*NT*				*NT*							
	Autumn												
	Spring												
	Winter												
Parity	P1-2	*Baseline*				*Baseline*				*Baseline*			
	P2-5	0.68292	0.539	0.865	0.002	0.734	0.558	0.965	0.027	0.694	0.571	0.844	<0.001
	P>=6	0.77129	0.622	0.957	0.018	0.901	0.708	1.146	0.394	0.927	0.779	1.104	0.395
Litter size	LITTER	*NT*				*NT*				0.959	0.937	0.982	<0.001

NT: Not tested because not included in the final model. CI 95%: confidence intervals at 95%.

of French pig farms which experienced perinatal mortality problems. Therefore, the study was designed to highlight the differences between categories, rather than identifying an independent list of risk factors for each of the categories considered.Moreover, the analysis undertaken allowed us to classify the farms according to their perinatal mortality patterns. Because of the nature of the dataset used, its limitations and potential for bias are considered first.

4.1. Sampling and design limitations

This study highlights the benefits from using available databases as a valuable source of information for a secondary data analysis. The sample used had a geographical stratification close to the one which exists in French pig farms. The average perinatal mortality rate for the whole experimental population was 20.2% which is very close to the French national average (20.0%) (IFIP-GTTT, 2014). It should be noted however, that our analysis only considered deaths in the first 48 h of life; a higher mortality rate might have been observed if we also had recorded mortality for a longer time after birth, as they did in different studies (Su et al., 2007; Strange et al., 2013; IFIP-GTTT, 2014). Moreover, the percentage of stillborn piglets, excluding mummified piglets, was 9.25% of the piglets born, which is higher than the French national average (6.90%) (IFIP-GTTT, 2014). The results should be of particular relevance to farms which experience perinatal mortality problems and proactively investigate this problem.

4.1.1. Selection bias and confounding

The missing information about the intra-cluster coefficient could have led to an underestimate of the minimal number of piglets necessary for the analysis, but the sample size was calculated to be more than adequate. Although there was a potential bias in the farm selection because of the voluntary decision to participate in the piglet mortality audit, the affiliation to CCPA had the positive impact of standardizing the reporting and the piglet mortality classification. This reduced the bias in selection of piglets, since a random group of sows was studied at each farm and all dead piglets were taken from the sampled litters. In order to control for unknown confounding factors connected to the farm or to the sow, we used a logistic regression with two levels of hierarchy (sow nested within farm). The multivariate analysis also permitted us to produce Odd ratios adjsted for the other covariates in the model. The PCA and AHC did not account for the potential sampling error, as the analysis was based on percentages. The quasi-normal bootstrap distribution of the Eigenvalues, based on the visualization of the histogram, was judged to provide an acceptable proof of the stability of the result of the PCA.

4.1.2. Information bias

The information was collected over a relatively long period of time and so the variable 'year' was included as a random effect in each model in order to control its impact. The necropsies were carried out according to a standard operating procedure by trained staff. Although the reporting form for farm data was standardized, each farmer was responsible for recording and may have noted variables in a different way (e.g. recall, intermediate record before completing the standardized reporting sheet); alternatively, bias might have been introduced by different interpretations of the real information. However, the fact that the data were collected on the same day as the piglet deaths reduced the bias which might be found in retrospective data.

4.2. Risk factors

4.2.1. Effect of litter size and number of littermates which died from the same category

Some risk factors had a similar impact on all main categories of death. Litter size did not influence the chance to die from one specific category compared to others, except for the category "other". This observation confirms that litter size acts as a general risk factor for the most important categories of piglet mortality (Canario et al., 2007; Beaulieu et al., 2010).

Table 8
Mean and Standard deviation of the weight (g) per category of mortality. Each mean weight significantly different from the mean weight of another category of perinatal death is reported. The crosses indicate which categories of death had a significantly different mean weight compared to the mean weights of the category of interest.

categories	Mean	SD	Significantly different weight (denoted by X)														N
			Anaemia	Starvation	Dehydration /enteritis	Crushing	Early sepsis	Acute disease	Malformation	Mummified	Death before farrowing	Death during farrowing	Non-viable	Splayleg	Killed by the sow	Killed by the farmer	
Anaemia	1289.3	339.50															
				X						X	X		X	X			160
Starvation	1156.9	275.12			X	X	X	X		X		X	X				433
Dehydration /enteritis	1317.5	370.86								X			X				72
Crushing	1285.9	301.75								X	X		X	X			608
Early sepsis	1275.3	316.57								X	X		X	X			1366
Acute disease	1299.1	320.40								X	X		X	X			323
Malformation	1149.5	341.49								X			X				55
Mummified	474.16	376.13									X	X		X	X	X	856
Death before farrowing	1123.7	363.36										X	X				304
Death during farrowing	1272.1	305.80											X	X			1785
Non-viable	612.65	126.79												X	X	X	1658
Splayleg	1071.7	223.52															53
Killed by the sow	1209.5	265.13															75
Killed by the farmer	1022.5	293.79															13

X: Significantly different mean weight (p value < 0.05, with Bonferroni correction).

For the six main categories of perinatal mortality, the piglets which died from a specific category tended to have more littermates which died from the same category of mortality. This fact raises the question of the influence of factors related to the sow, the animal keeper or the farm which impact several piglets in the litter at the same time (Pedersen et al., 2006; Kilbride et al., 2012; Kirkden et al., 2013). The total number of deaths in the litter tended to be lower for mummified and non-viable piglets than for other categories of mortality. These litters might have more deaths at the embryonic stage and therefore reduce the number of deaths considered at birth as these deaths couldn't be identified (Knight et al., 1977; Vanderhaeghe et al., 2009). Although, risk factors with a common influence on the different categories of piglet death were identified, some of the studied risk factors had a particular impact on specific categories of perinatal death.

4.2.2. *Stillbirths*

The mean weight of the piglets dead before farrowing with signs of autolysis was significantly lower than the mean weight for the two other categories of stillbirths (death during farrowing and early sepsis). A previous study has also reported weight differences amongst stillborn piglets, with 41% of the piglets with a weight smaller than 1 kg, but 45% with a weight higher than 1.4 kg (Fischer et al., 2005). In the literature, different mechanisms have been associated to stillborn piglets. A lower birth weight has been correlated to the probability of stillbirth and the level of asphyxia during farrowing (Le Cozler et al., 2002; Herpin et al., 2002). Limitation of the placental area by the litter size may lead to smaller piglets and less chance of survival (Rootwelt et al., 2013). The difference in litter size can impact litter weight, but this parameter alone may not be a good indicator of the placental capacity, as uterine capacity differs between sows (Van Der Lende and Van Rens, 2003). Low birth weight of the piglet has been associated with an increased risk of stillbirth and pre-weaning mortality in different studies (Škorjanc et al., 2007; Beaulieu et al., 2010). However, instead of the cause, low birth weight may also be a consequence of death early during the pregnancy due to causes such as infectious diseases (Maldonado et al., 2005; Basso et al., 2015). Studies have also reported other categories of stillbirths during labour due to hypoxia and the rupture of the umbilical cord (Mota-Rojas et al., 2002; Herpin et al., 2002; Fischer et al., 2005; Trujillo-Ortega et al., 2011).

We found fewer deaths at farrowing during the night than during the day compared to all the other categories of death, consistent with Vanderhaeghe et al. (2009) who highlighted the fact that other daylight activities might stress the sows during the farrowing and that stillbirths may be associated with the supervision of the farrowing itself. Thus, the absence of inappropriate supervision during the night might explain the reduced number of deaths during the farrowing. The details about farrowing assistance and drug injections carried out in the different farms might be of interest to understand the influence of such factors.

Finally, compared to all the other categories, piglets were more likely to die during farrowing or die with signs of early sepsis in parities 3–5 than in parities 1 or 2. This is in agreement with other studies in which the risk of stillbirth was higher for older parity sows (Lucia et al., 2002; Borges et al., 2005).

4.2.3. *Mummified piglets*

The distribution of the length of the mummies did not show the bimodal distribution found in a previous study (Vanderhaeghe et al., 2009) which might be the consequence of missing some of the smallest mummies, expelled with the placentae. The uterine crowding and placental development earlier in pregnancy impact the number of piglet deaths in later pregnancy (Le Cozler et al., 2002; Borges et al., 2005; Rootwelt et al., 2013). Previous studies suggested that the placenta reaches its maximum size at day 50–70 of pregnancy (Knight et al., 1977; Van Der Heyde et al., 1989; Mesa et al., 2012), but placental insufficiency can impact survival from day 40 of pregnancy (Knight et al., 1977; Marsteller et al., 1997). In this study 78% of the foetal mummification occurred after day 65, with a clear increase of the number of mummies following this day, but also more than 90% occurred after day 40 of the pregnancy. However, larger litter size and higher parity were not a greater risk for mummification than for other categories of death, confirming that the crowding effect of larger litter size would not only increase the incidence of mummies (Dewey et al., 1999; Mengeling et al., 2000; Maldonado et al., 2005; Rootwelt et al., 2013; Basso et al., 2015).

4.2.4. Non-viable, starvation, crushing

Low correlations were found between the percentages of the different mortality categories at farm level. Only crushing and starvation had significant correlations with more than one other category of death. This observation supports the idea that starvation and crushing are part of a process which impairs the viability and/or the thermoregulation of the piglet and can lead to other categories of death before or after birth (Herpin et al., 1996; Herpin et al., 2002; Edwards, 2002; Alonso-Spilsbury et al., 2007). Low birthweight, associated with other factors, may expose piglets to a higher risk of death or impact growth (Douglas et al., 2013). In our analysis, piglets which suffered from starvation had a significantly smaller weight than piglets which died from other categories except malformation and death before farrowing. The relationship between birth weight and time to first suckle, and the subsequent risk of starvation, have been documented (Ribeiro Caldara et al., 2014). However, direction of causality between lack of suckling and weight could not be assessed in the present study. In contrast, piglets which died due to crushing had a significantly higher weight compared to those which died from starvation or certain other categories of death. However, the bigger size of the piglet is not necessarily correlated to piglet metabolic development; new breeds may have bigger piglets, but less viable ones (Herpin et al., 1993).

Piglets were less likely to die with signs of crushing in older parities than in parities 1 and 2 and were less likely to die with signs of starvation in parities 3–5 than in parities 1 and 2. This is in agreement with another study that reported higher likelihood of crushing in younger parity sows (Kilbride et al., 2012).

The genetic selection for litter size generates heterogeneous litters with a greater number of small piglets which are more likely to suffer from successive uterine contractions and placental inefficiency (Knight et al., 1977; Alonso-Spilsbury et al., 2007; Rootwelt et al., 2013). If the piglet does not die during gestation or at farrowing, the simultaneous selection for lean tissue leads to piglets born in a less mature state; this makes them less able to maintain their body temperature, less viable at birth and unable to compete for food with their larger littermates (Herpin et al., 1993; Herpin et al., 2002; Panzardi et al., 2013). In the chain reaction illustrated above, some environmental factors may enhance the risk for certain categories of death more than other categories and at different moments of the piglet's life. Some of the less well developed piglets, defined as non-viable piglets with a smaller weight compared to the other categories, were less likely to die in summer than autumn and spring. From the six main categories of mortality, only the non-viable piglets showed this trend. Few studies have demonstrated the impact of high environmental temperature on other categories of piglet death (Odehnalova et al., 2008; Segura-Correa and Solorio-Rivera, 2007), but there is no evidence in the literature about the impact of the temperature on non-viable piglet. Nevertheless, we need to determine if this seasonal effect is real or acts as a proxy for other, non-recorded factors.

4.3. Farm clustering

In addition to risk factors related to particular categories of perinatal death, three mortality patterns were identified in the sample. The first cluster grouped farms with a higher perinatal mortality rate due to crushing and starvation, but also acute diseases and dehydration or enteritis. All these categories appear after the piglet birth, and some of these categories showed correlations, supporting the idea of a common process which impairs the viability, the thermoregulation and the susceptibility to infections of the piglets (Herpin et al., 1996; Edwards, 2002; Alonso-Spilsbury et al., 2007). Such farms tended to be located in Regions with an important pig production and this observation raised the question about the impact of the level of intensification on this cluster. However, other factors, not recorded, may influence post-natal death due to crushing or starvation (Cronin et al., 1996; Svendsen and Steen Svendsen, 1997; Weary et al., 1996; Wischner et al., 2009; Melišová et al., 2011). Further analyses are necessary to identify common risk factors for the different categories of death of this cluster and identify the potential connection between risk factors and the strategy adopted by a particular pig production system.

The second cluster grouped farms with a high rate of death during the farrowing and early sepsis. The mortality rate was low and the dead piglets had a higher average weight. One study highlighted that intra-partum stillbirths can be affected by the interaction between group gestation pens and the farrowing crate systems, especially in first parity sows (Cronin et al., 1993). Moreover, an inappropriate use of oxytocin has been suggested as a risk factor for intrapartum death (Mota-Rojas et al., 2007). As the prevalence of death during farrowing is particularly high in this group, the identification of other risk factors related to this category might help to identify if farrowing management practice and the farming system might have influenced the perinatal mortality pattern.

The third cluster grouped farms with a small average weight of the dead piglets, due to the higher rate of mummified and non-viable piglets. The deaths before farrowing seem to have the biggest influence in this cluster. The season and the number of deaths in the litter showed a significant impact on the mummified and non-viable piglets. The average litter size in this cluster was also higher, raising the question about an intra-uterine crowding effect (Herpin et al., 1996; Père and Etienne, 2000; Rootweltet al., 2013). Regarding the specificity of the hyperprolific sows, Martineau and Badouard (2009) highlighted the necessity to develop strategy but also tactics. More details are required to understand the strategy adopted for hyperprolific sows in this cluster and identify the risk factors for the prenatal death.

5. Conclusion

Through the comparison of the different categories of mortality and the classification of the farms according to their perinatal mortality problem, we provide new insights into the problem of piglet mortality. The deaths which occur before or during birth represent the main category of loss and should be given special attention in terms of remedial strategies. Our study highlighted the importance of identifying the different categories of death as the result of a chain reaction which impairs the viability of the piglets. However, our results also showed that the influence of risk factors differs between the categories of death and the problem of perinatal mortality should not be considered as homogenous. Considering different categories of stillbirth has proved to be valuable, as different categories of stillbirth are affected by different risk factors. The deaths during farrowing seemed to be more influenced by the time of the day when the piglets were born, implicating impact of management practices during the farrowing. The mummified and non-viable piglets represented an important part of piglet deaths, suggesting intra-uterine competition as a critical factor.

The separation of the farms into different clusters indicates the necessity for a better understanding of the similarities and differences between these clusters in order to target their specific weaknesses according to farm type. This knowledge will improve the diagnosis and solution of problems in terms of management or genetics.

Conflict of interest

The authors have no conflict of interest to declare.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.prevetmed.2016.12.005.

References

Škorjanc, D., Brus, M., Potokar, M.Č., 2007. Effect of birth weight and sex on pre-weaning growth rate of piglets. Arch. Tierz. 50 (5), 476–486.
Alonso-Spilsbury, M., Ramirez-Necoechea, R., Gonzlez-Lozano, M., Mota-Rojas, D., Trujillo-Ortega, M.E., 2007. Piglet survival in early lactation: a review. J. An. Vet. Adv. 6 (1), 76–86.
Basso, W., Handke, M., Sydler, T., Borel, N., Grimm, F., Sidler, X., Deplazes, P., 2015. Involvement of Toxoplasma gondii in reproductive disorders in Swiss pig farms. Parasitol. Int. 64, 157–160.
Beaulieu, A.D., Aalhus, J.L., Williams, N.H., Patience, J.F., 2010. Impact of piglet birth weight, birth order, and litter size on subsequent growth performance, carcass quality, muscle composition, and eating quality of pork. J. Anim. Sci. 88, 2767–2778, http://dx.doi.org/10.2527/jas. 2009-2222.
Besse P., 1989. Stabilité de l'Analyse en composantes principales par Ré-échantillonage, Approximation par la théorie des perturbation. Document N05-89 du laboratoire de Statistique et Probabilités de l'université Paul Sabatier de Toulouse.
Borges, V.F., Bernardi, M.L., Bortolozzo, F.P., Wentz, I., 2005. Risk factors for stillbirth and foetal mummification in four Brazilian swine herds. Prev. Vet. Med. 70, 165–176.
Canario, L., Foulley, J., Cantoni, E., Le Bihan, E., Caritez, J., Billon, Y., Bidanel, J., 2007. Analyse des facteurs de variation de la mortinatalité des porcelets. J. Rech. Porc. 39, 273–280.
Crawley, M.J., 2013. The r book. In: Analysis of Variance, second edition. John Wiley and Son Ldt (Chapter 11).
Cronin, G.M., Schirmer, B.N., McCallum, T.H., Smith, J.A., Butler, K.L., 1993. The effects of providing sawdust to pre-parturient sows in farrowing crates on sow behaviour, the duration of parturition and the occurrence of intra-partum stillborn piglets. Appl. Anim. Behav. Sci. 36, 301–315.
Cronin, G.M., Simpson, G.J., Hemsworth, P.H., 1996. The effects of the gestation and farrowing environments on sow and piglet behaviour and piglet survival and growth in early lactation. Appl. Anim. Behav. Sci. 46, 175–192.
Dewey, C.E., Wilson, S., Buck, P., Leyenaar, J.K., 1999. The reproductive performance of sows after PRRS vaccination depends on stage of gestation. Prev. Vet. Med. 40 (3–4), 233–241.
Dorie, V., 2014. blme: Bayesian Linear Mixed-Effects Models. R package version 1. 0–2. URL http://CRAN.R-project.org/package=blme.
Douglas, S.L., Edwards, S.A., Sutcliffe, E., Knap, P.W., Kyriazakis, I., 2013. Identification of risk factors associated with poor lifetime growth performance in pigs. Anim. Sci. 91, 4123–4132, http://dx.doi.org/10.2527/jas2012-5915.
Edwards, S.A., 2002. Perinatal mortality in the pig: environmental or physiological solutions? Livest. Prod. Sci. 78, 3–12.
Ferrari, C.V., Sbardella, P.E., Bernardi, M.L., Coutinho, M.L., Vaz Jr., I.S., Wentz, I., Bortolozzo, F.P., 2014. Effect of birth weight and colostrum intake on mortality and performance of piglets after cross-fostering in sows of different parities. Prev. Vet. Med. 114 (3–4), 259–266.
Fischer, K., Brüssow, K., Wähner, M., 2005. The influence of the condition of the umbilical cord at birth on the vitality of newborn piglet. Biotechnol. Anim. Husb. 21 (5–6), 191–194.
Herpin, P., Le Dividich, J., Amaral, N., 1993. Effect of selection for lean tissue growth on body composition and physiological state of the pig at birth. J. Anim. Sci. 71, 2645–2653.
Herpin, P., Le Dividich, J., Hulin, J., Fillaut, M., De Marco, F., Bertin, R., 1996. Effects of the level of asphyxia during delivery on viability at birth and early postnatal vitality of newborn pigs. J. Anim. Sci. 74 (9), 2067–2075.
Herpin, P., Damon, M., Le Dividich, J., 2002. Development of thermoregulation and neonatal survival in pigs. Livest. Prod. Sci. 78, 25–45.
Houška, L., Wolfová, M., Nagy, I., Csörnyei, Z., Komlósi, I., 2010. Economic values for traits of pigs in Hungary. Czech J. Anim. Sci. 55 (4), 139–148.
IFIP-GTTT, Evolution des résultats moyens nationaux de 1970 à 2014. Retrieved on 10 January 2016, from http://www.ifip.asso.fr/PagesStatics/resultat/pdf/retro/00gttt.pdf.
Kaiser, H.F., 1960. The application of electronic computers to factor analysis. Educ. Psychol. Meas. 20, 141–151, http://dx.doi.org/10.1177/001316446002000116.
Kilbride, A.L., Mendl, M., Statham, P., Held, S., Harris, M., Cooper, S., Green, L.E., 2012. A cohort study of preweaning piglet mortality and farrowing accommodation on 112 commercial pig farms in England. Prev. Vet. Med. 104, 281–291.
Kirkden, R.D., Broom, D.M., Andersen, I.L., 2013. Piglet mortality: the impact of induction of farrowing using prostaglandins and oxytocin. Anim. Reprod. Sci. 138, 14–24.
Knight, J.W., Bazer, F.W., Thatcher, W.W., Franke, D.E., Wallace, H.D., 1977. Conceptus development in intact and unilaterally hysterectomized-ovariectomized gilts: interrelations among hormonal status, placental development, fetal fluids and fetal growth. J. Anim. Sci. 44 (4), 620–637.
Le Cozler, Y., Guyomarc'h, C., Pichodo, X., Quinio, P., Pellois, H., 2002. Factors associated with stillborn and mummifed piglets in high-prolific sows. Anim. Res. 51, 261–268.
Lucia Jr., T., Corrêa, M.N., Deschamps, J.C., Bianchi, I., Donin, M.A., Machado, A.C., Meincke, W., Matheus, J.E.M., 2002. Risk factors for stillbirths in two swine farms in the south of Brazil. Prev. Vet. Med. 53, 285–292.
Maldonado, J., Segalés, J., Martıínez-Puig, D., Calsamiglia, M., Riera, P., Domingo, M., Artigas, C., 2005. Identification of viral pathogens in aborted fetuses and stillborn piglets from cases of swine reproductive failure in Spain. Vet. J. 169, 454–456.
Marsteller, T.A., Armbruster, G.A., Anderson, D.B., Wuethrich, A.J., Taylor, J.L., Symanowski, J.T., 1997. Effect of lactation length on ovulation rate and embryo survival in swine, American Association of Swine Veterinarians. J. Swine Health Prod. 5 (2), 49–56.
Martineau, G.P., Badouard, B., 2009. Managing highly prolific sows. London Swine Conference –Tools of the Trade 1–2 April.
Melišová, M., Illmann, G., Andersen, I.L., Vasdal, G., Haman, J., 2011. Can sow pre-lying communication or good piglet condition prevent piglets from getting crushed? Appl. Anim. Behav. Sci. 134, 121–129.
Mengeling, W.L., Lager, K.M., Vorwald, A.C., 2000. The effect of porcine parvovirus and porcine reproductive and respiratory syndrome virus on porcine reproductive performance. Anim. Reprod. Sci. 60–61, 199–210.
Mesa, H., Cammack, K.M., Safranski, T.J., Green, J.A., Lamberson, W.R., 2012. Selection for placental efficiency in swine: conceptus development. J. Anim. Sci. 90, 4217–4222, http://dx.doi.org/10.2527/jas2011-5001.
Messad, S., 2012. Traitement statistique des données d'élevage Les méthodes d'analyses factorielles et de classification, Université de Montpellier. URL http://mon.univmontp2.fr/claroline/backends/download.php?url=L0FuYWx5c2VzTXVsdGl2YXJpZWVzLnBkZg%3D%3D&cidReset=true&cidReq=FMOM322.
Milligan, B.N., Fraser, D., Kramer, D.L., 2002. Within-litter birth weight variation in the domestic pig and its relation to pre-weaning survival weight gain, and variation in weaning weights. Livest. Prod. Sci. 76, 181–191.
Mota-Rojas, D., Martínez-Burnes, J., Trujillo-Ortega, M.E., Alonso-Spilsbury, M., Ramírez-Necoechea, R., López, A., 2002. Effect of oxytocin treatment in sows on umbilical cord morphology, meconium staining, and neonatal mortality of piglets. Am. J. Vet. Res. 63 (11), 1571–1574.
Mota-Rojas, D., Villanueva-García, D., Velazquez-Armenta, E.Y., Nava-Ocampo, A.A., Velázquez-Armenta, Y., Ramírez-Necoechea, R., Alonso-Spilsbury, M., Trujillo, M.E., 2007. Influence of time at which oxytocin is administered during labor on uterine activity and perinatal death in pigs. Biol. Res. 40, 55–63.
Munsterhjelm, C., Heinonen, M., Valros, A., 2015. Application of the Welfare Quality® animal welfare assessment system in Finnish pig production, part I: identification of principal components. Anim. Welf. 24, 151–160, http://dx.doi.org/10.7120/09627286.24.2.151.
Odehnalova, S., Vinkler, A., Novak, P., Drabek, J., 2008. The dynamics of changes in selected parameters in relation to different air temperature in the farrowing house for sows. Czech J. Anim. Sci. 53 (5), 195–203.
Père, M.C., Etienne, M., 2000. Uterine blood flow in sows: effects of pregnancy stage and litter size. Reprod. Nutr. Dev. 40, 369–382.
Panzardi, A., Bernardi, M.L., Mellagi, A.P., Bierhals, T., Bortolozzo, F.P., Wentz, I., 2013. Newborn piglet traits associated with survival and growth performance until weaning. Prev. Vet. Med. 110, 206–213.
Pedersen, L.J., Jørgensen, E., Heiskanen, T., Damm, B.I., 2006. Early piglet mortality in loose-housed sows related to sow and piglet behaviour and to the progress of parturition. Appl. Anim. Behav. Sci. 96, 215–232.

Rehfeldt, C., Kuhn, G., 2006. Consequences of birth weight for postnatal growth performance and carcass quality in pigs as related to myogenesis. J. Anim. Sci. 84 (E. Suppl), E113–E123.
Ribeiro Caldara, F., Sousa dos Santos, L., Teixeira Machado, S., Moi, M., De Alencar Nääs, I., Foppa, L., Garófallo Garcia, R., De Kássia Silva Dos Santos, R., 2014. Pigletsä surface temperature change at different weights at birth, asian-Australas. J. Anim. Sci. 27 (3), 431–438, http://dx.doi.org/10.5713/ajas.2013.13505.
Rootwelt, V., Reksen, O., Farstad, W., Framstad, T., 2013. Postpartum deaths: piglet, placental, and umbilical characteristics. J. Anim. Sci. 91 (6), 2647–2656, http://dx.doi.org/10.2527/jas.2012-5531.
Segura-Correa, J.C., Solorio-Rivera, J.L., 2007. Evaluation of three models and risk factors associated with stillborn piglets in Yucatan. Mexico Téc. Pecu. Méx. 45 (2), 227–236.
Strange, T., Ask, B., Nielsen, B., 2013. Genetic parameters of the piglet mortality traits stillborn, weak at birth, starvation, crushing, and miscellaneous in crossbred pigs. J. Anim. Sci. 91, 1562–1569, http://dx.doi.org/10.2527/jas2012-5584.
Straw, B.E., Zimmerman, J.J., D'Allaire, S., Taylor, D.J., 2006. Disease of swine. In: Chapter 6: Disease of the Reproductive System, 9th edition. Blackwell Publishing Ames, USA (pp.127).
Su, G., Lund, M.S., Sorensen, D., 2007. Selection for litter size at day five to improve litter size at weaning and piglet survival rate. J. Anim. Sci. 85, 1385–1392, http://dx.doi.org/10.2527/jas.2006-631.
Svendsen, J., Steen Svendsen, L., 1997. Intensive (commercial) systems for breeding sows and piglets to weaning. Livest. Prod. Sci. 49, 165–179.
Teerenstra, S., Moerbeek, M., Van Achterberg, T., Pelzer, B.J., Borm, G.F., 2008. Sample size calculations for 3-level cluster randomized. Clin. Trials 5, 486–495.
Trujillo-Ortega, M.E., Mota-Rojas, D., Juárez, O., VillanuevaGarcía, D.P., Roldan-Santiago, P., Becerril-Herrera, M., HernándezGonzález, R., Mora-Medina, P., Alonso-Spilsbury, M., Rosales, A.M., Martínez-Rodríguez, R., Ramírez-Necoechea, R., 2011. Porcine neonates failing vitality score: physio-metabolic profile and latency to the first teat contact. Czech. J. Anim. Sci. 56 (11), 499–508.
Ullrey, D.E., Sprague, J.L., Becker, D.E., Miller, E.R., 1965. Growth of the swine fetus. J. Anim. Sci. 24, 711–717.
Vaillancourt, J., Stein, T.E., Marsh, W.E., Leman, A.D., Dial, G.D., 1990. Validation of producer-recorded categories of preweaning mortality in swine. Prev. Vet. Med. 10 (1–2), 119–130.
Van Der Heyde, H., De Mets, J.P., Porreye, L., Henderickx, H., Calus, A., Bekaert, H., Buysse, F., 1989. Influence of season, litter size, parity, gestation length, birth weight, sex and farrowing pen on frequency of congenital splayleg in piglets. Livest. Prod. Sci. 21, 143–155.
Van Der Lende, T., Van Rens, B.T., 2003. Critical periods for foetal mortality in gilts identified by analysing the length distribution of mummified foetuses and frequency of non-fresh stillborn piglets. Anim. Reprod. Sci. 75, 141–150.
Vanderhaeghe, C., Dewulf, J., De Vliegher, S., Papadopoulos, G.A., de Kruif, A., Maes, D., 2009. Longitudinal field study to assess sow level risk factors associated with stillborn piglets. Anim. Reprod. Sci. 120, 78–83.
Weary, D.M., Pajor, E., Thompson, B.K., Fraser, D., 1996. Risky behaviour by piglets: a trade-off between feeding and risk of mortality by maternal crushing? Anim. Behav. 51, 619–624.
Westin, R., Holmgren, N., Hultgren, J., Ortman, K., Linder, A., Algers, B., 2015. Post-mortem findings and piglet mortality in relation to strategic use of straw at farrowing. Prev. Vet. Med. 119 (3–4), 141–152.
Wischner, D., Kemper, N., Stamer, E., Hellbruegge, B., Presuhn, U., Krieter, J., 2009. Characterisation of sows postures and posture changes with regard to crushing piglets. Appl. Anim. Behav. Sci. 119, 49–55.