# Identification of risk factors for production diseases in commercial pig farms through secondary data analyses

by

Fanny Pandolfi

DVM

MSc

A thesis submitted for the degree of

Doctor of Philosophy

School of Agriculture, Food and Rural Development

Newcastle University

June 2018

# Abstract

The aim was to identify risk and protective factors for production diseases in commercial pig farms. Data from on-farm questionnaires and three industry databases holding relevant information were collected and analysed to identify inter-relationships between indicators for production diseases, welfare and performance, and to explore different risk factors for these indicators.

The connection of different data sources, combined with the sampling of pig farms to represent the commercial population, proved challenging. However, inter-connections between health, welfare, performance and biosecurity in commercial pig farms in the UK were identified by multivariate analyses. Internal biosecurity scores were generally lower than those for external biosecurity, and little impact of biosecurity was observed on indicators like mortality, prevalence of lameness and pigs requiring hospitalization.  Assessment of the UK "Real Welfare" scheme data showed in general low prevalence of welfare issues and demonstrated a reduction in prevalence in 2014, 2015 and 2016 compared to 2013. A risk factor analysis pointed towards the need for attention to pen environment and feeding management across all farming systems. While the provision of substrate was associated with a reduction of prevalence of some welfare outcomes, tail docking on its own did not seem to be effective in reducing tail biting. In commercial pig farms in France, additional analyses were conducted on risk factors associated with piglet mortality, considered as a production disease, utilising a necropsy database. The identification of different mortality patterns and specific risk factors for different categories of perinatal mortality highlighted the necessity for a better understanding of the differences between farm types in order to develop targeted remedial strategies. Additional analyses from a retrospective survey highlighted the positive impact of supporting both suckling and thermoregulation to reduce piglet mortality after birth.

Our results illustrated the potential value of secondary analyses to identify factors influencing the production diseases and derive recommendations for their alleviation.

# Acknowledgements

I would like to thank my supervisors, Sandra Edwards and Ilias Kyriazakis, whose expertise and guidance has contributed largely to the preparation of this thesis.

I acknowledge the contribution of Newcastle University for their academic support.

I am extremely thankful to the Prohealth project for sponsoring me for this PhD. The opportunity I had with Prohealth was a great chance for professional development.

I acknowledge the contribution of the CCPA group for sharing their data to conduct studies about piglet mortality.

Thanks are also due to AHDB, and the staff involved in the Real Welfare project, in particular Katja Stoddard, for sharing their interesting dataset and for sponsoring the analysis of the data. Moreover, I would like to thank AHDB staff involved in the BPHS scheme for providing access to their dataset and helping me to recruit pig producers for my study.

I would like to thank all pig producers that have participated in my study for receiving me in their farm and sharing with me lot of useful information and experiences.

I would like to thank Ghent University for making available the Biocheck-UGhent$^{TM}$ scoring tool. I would also like to thank Dominiek Maes for his support for the studies that have been conducted under Workpackage 1 of Prohealth, but also Tommy Van Limbergen and Marlijn Klinkenberg, PhD students in the same project, for the interesting conversations we had about Prohealth.

Finally, I thank profusely my friends and my family for recognizing the great effort a PhD represents and for supporting me in this task.

## Publications arising from this thesis

### *Journal articles*

Chapter 2: F. Pandolfi, S. A. Edwards, D. Maes and I. Kyriazakis. 2018. Connecting Different Data Sources to Assess the Interconnections between Biosecurity, Health, Welfare, and Performance in Commercial Pig Farms in Great Britain. Front. Vet. Sci., 5: 41.

Chapter 3: F. Pandolfi, K. Stoddart, N. Wainwright, I. Kyriazakis and S. A. Edwards. 2017. The 'Real Welfare'scheme: benchmarking welfare outcomes for commercially farmed pigs, Anim., 11: 1816–1824.

Chapter 4: F. Pandolfi, K. Stoddart, N. Wainwright, I. Kyriazakis and S. A. Edwards. 2017. The "Real Welfare" scheme: Identification of risk and protective factors for welfare outcomes in commercial pig farms in the UK, Prev. Vet. Med., 146: 34-43.

Chapter 5: F.Pandolfi, S.A. Edwards, F. Robert and I. Kyriazakis. 2017. Risk factors associated with the different categories of piglet perinatal mortality in French farms, Prev. Vet. Med., 137: 1-12.

Chapter 6: F. Pandolfi, S.A. Edwards, F. Robert, D. Gardan and I. Kyriazakis. 2018. Impact of neonate management on different categories of piglet mortality in French farms. Under revision for publication in The Veterinary Journal.

### *Conference*

Pandolfi F, Edwards S, Robert F, Kyriazakis I. 2016. Identification of neonatal mortality patterns and risk factors related to the different causes of piglet neonatal mortality in French farms. Proc 24th International Pig Veterinary Society Congress, 7-10 June 2016, Dublin, Ireland.

Pandolfi F, Edwards S, Robert F, Kyriazakis I. 2016. Identification of neonatal mortality patterns and risk factors related to the different causes of piglet neonatal mortality in French farms. IPV Diergeneeskunde, 12 January 2017, Ghent, Belgium.

Pandolfi F, Edwards S, Robert F, Kyriazakis I. 2016. Identification of neonatal mortality patterns and risk factors related to the different causes of piglet neonatal mortality in French farms. Pejsakówka Conference, 6-7 June 2017, Pulawy, Poland.

Pandolfi F, Stoddart K, Wainwright N, Kyriazakis I, Edwards SA. 2017. Welfare benchmarking for commercially farmed pigs in the UK. In Proceedings WAFL 2017, 7th International Conference on the Welfare assessment of animal welfare and group level. 5-8 September 2017, Ede, The Netherlands.

Pandolfi P, Edwards SA, Robert F, Kyriazakis I. 2018. Identification of farm profiles based on different causes of perinatal mortality. 6-7 February 2018. Journées de la Recherche Porcine, Paris, France.

# Table of Contents

# List of Figures

# List of Tables

## Abbreviations and definitions

ADG: Average Daily Gain

AHC: Ascendant Hierarchical Clustering

AHDB: Agriculture and Horticulture Development Board

AIAO: All-in/all-out

ANOVA: Analyse of variance

APP-like: Actinobacillus pleuropneumonia-like

Biocheck UGent: risk-based scoring tool (Ghent University)

BPHS: British Pig Health Scheme

CCPA: French company specialized in animal nutrition and health

Data velocity: big data volume and accessibility

EC: European Commission

EFSA: European Food Safety Authority

EU: European Union

FAO: Food and Agriculture Organization

FSA: Food Standards Agency

GTT: Gestion Technique des Troupeaux de Truies

H1N1: Influenza virus subtype H1N1

In&outdoor: pens with both indoor and outdoor space

Information biais: Bias arising from measurement error

MCA: Multiple Correspondance Analysis

N: Number

NPA: National Pig Association

PCA: Principal Component Analysis

PCV2: Porcine Circovirus subtype 2

Productivism: belief that measurable economic productivity and growth are the purpose of human organization

Prohealth: EU funded project which aims at improving the understanding of the multi-factorial dimension of animal pathologies linked to the intensification of production

PRRS: Porcine reproductive and respiratory syndrome

SD: Standard Deviation

Selection bias: selection of individuals, groups or data for analysis in such a way that proper randomization is not achieved

Split suckling: separating suckling of small and big piglets

Real Welfare: Real Welfare involves on-farm assessment of pig welfare using a set of five objective and repeatable measures

UK: United Kingdom

# Chapter 1 Introduction

## 1.1 Farming intensification and production diseases in pigs

### *1.1.1 Consequences of pig farming intensification*

Over recent decades, specialization, concentration and regionalization of pig production has taken place across Europe (Rieu and Roguet 2012). Pig farms have become larger and more specialized and, from the intensification of the farming systems, critical points have emerged: high density of animals, high dependency on inputs, such as feed and diverse changes in the husbandry with consequences for animal health and welfare (Chambert et al., 2008; Rieu and Roguet, 2012). Industrialization of agriculture has led to specific genetics, livestock movement and specialized nutrition and management practices, which have increased the risk of diseases connected to intensification (Kimman et al., 2013).

In Europe, diseases connected to intensive farming have resulted in a series of food scares and have raised the interest in farm animal welfare (Fraser, 2008; Veissier et al., 2008; Clark et al., 2017). The internet and social media have considerably increased access to different sources of information and influence consumer behaviour (Grandin, 2014). Publication of the UK Brambell Report (Brambell, 1965) initially raised concern about farm animal welfare amongst society and caused policy makers to become more concerned about the ethical treatment of animals (Veissier et al., 2008). Harmonised EU rules were put in place, through Council Directive 98/58/EC, to ensure welfare of different animal species and set standards for transportation and slaughter (European Council, 1998). However, more recent opinion suggests that welfare improvement should be achieved through the combination of governmental and market initiatives in order to meet consumer demands (Clark et al., 2017). Farmers and retailers have started to consider welfare as a selling point for animal products (Bock and Huik, 2007; Hubbard et al., 2007; Miranda-de la Lama et al., 2013; Saitone and Sexton, 2017). Numerous research projects have been conducted to assess animal welfare (Temple et al., 2012; Munsterhjelm et al., 2015a, 2015b) and their results used to formulate standards for Quality Assurance schemes in response to consumer demands regarding welfare and health issues connected to farm intensification (Peet, 2002). These include standards intended to address the issue of production diseases, such as the prevalence of lameness or tail lesions.

### *1.1.2 What are production diseases?*

The intensification of pig production facilitates disease transmission by increasing population density, leading to higher risk of diseases including zoonoses (Graham et al., 2008; Drew, 2011, Jones et al., 2012). Production diseases are defined as "diseases which tend to persist in intensive animal production systems and become more prevalent or severe, in proportion to the potential productivity of the system" (http://www.fp7-prohealth.eu/about/about-prohealth/) (Nir, 2003). These diseases have negative impacts on production performance, leading to economic losses. Several health conditions of growing and finishing pigs, including gastro-intestinal disorders in piglets and fattening pigs (Jacobson et al., 2003; Herskin et al., 2016; Jensen et al., 2017), post weaning multisystemic wasting syndrome (Alarcon et al., 2011), respiratory problems (Meyns et al., 2011; Nathues et al., 2013) and locomotor problems (Van Grevenhof et al., 2011), have been associated with the intensification of pig production in conventional farming systems. Therefore, all these health problems should be considered as production diseases. Breeding herds also experience problems connected to production intensification, as highlighted by the increase in piglet mortality for the systems with higher litter size (Baxter and Edwards, 2016), or endemic diseases such as porcine respiratory and reproductive syndrome (PRRS) in regions with high herd density (Fahrion et al., 2014), both having also a major economic impact (Crooks et al., 1992; Nathues et al., 2017). Production diseases can have multiple manifestations with a specific etiology, such as post-weaning multisystemic syndrome (Martineau and Morvan, 2010). They not only involve infectious agents, but also tend to increase due to influences of management and environmental factors connected to agricultural intensification (Nir, 2003; Baxter and Edwards, 2016; Muns et al., 2016).

It is therefore apparent that a multitude of diseases and health conditions can be labelled as production diseases. This includes for pigs: Neonatal mortality and chronic diseases affecting subsequent productivity, Locomotory problems, Mastitis/Metritis/Agalactia following parturition and for growing and finishing pigs specifically Post-weaning diarrhoea, Post-weaning multisystemic wasting syndrome (PMWS), Porcine respiratory disease complex (PRDC), Enteritis/colitis. These diseases compromise animal health and welfare and are one of the major reasons for antibiotic use in pig farms (Postma et al., 2016a) as they are generally the diseases that are the most prevalent in conventional systems. Targeting solutions to increase the sustainability of intensive pig production, a better understanding of the inter-connections between production diseases, welfare and performance needs to be achieved.

### *1.1.3 Inter-connections between production diseases, welfare and performance*

Studies often focus on specific diseases and their causation and treatment, but many interacting factors are connected to overall animal health. In general, risk factors for production diseases also have negative impacts on welfare and productivity, showing the close connection between production diseases, welfare and performance. For example, space allowance and stocking density can increase the risk for specific health issues such as enzootic pneumonia and pleuropneumonia (Amory et al., 2007; Munsterhjelm et al., 2015b) and have a negative impact on the welfare and the performance of the pigs (Vermeer et al., 2014). Feeding system and nutrition, combined or not with other factors such as environment or genetics, also have a significant impact on health issues (Doeschl-Wilson et al., 2009) but also production performance (Doeschl-Wilson et al., 2009; Magowan et al., 2010) and welfare (Munsterhjelm et al., 2015b).

No specific method to measure the impact of production diseases is widely accepted. As production diseases are generally connected to a decline in welfare and productivity, indicators measuring these two parameters could be used to assess the impact of production diseases. This approach is supported by Martineau and Morvan (2010), who suggest that a decline in performance under the standards of the systems should be considered as a production disease. Better understanding of production diseases should be achieved by identifying indicators of production diseases, welfare and performance and the interconnections between these indicators. Moreover, improvement of the knowledge of predisposing factors and the way production diseases relate to the farm environment, should provide a wider view on the global performance and sustainability of a farming system. Therefore, biosecurity, as part of the risk factor matrix for entry and spread of infection, could be one of the important determinants of production diseases.

### *1.1.4 Importance of biosecurity for the control of production diseases*

Production diseases are often infectious diseases which are compounded by management practices (Nir et al., 2003), including biosecurity measures applied by the farmers. Biosecurity measures aim to protect pig herds from the introduction and spread of infectious diseases in order to increase animal health and performance (Amass and Clark, 1999; Boklund 2004; FAO, 2010; Rojo-Gimeno et al., 2016; Postma et al., 2016a). Several studies have shown that the level of biosecurity differs between pig herds of different size and production type (Boklund et al., 2004; Bottoms et al., 2013) and that this results in different health status (Boklund et al., 2004). Whilst the frequency of some biosecurity measures might be different between countries or between farms, several biosecurity measures are generally interconnected (Boklund et al., 2004; Casal et al., 2007). The level of biosecurity in a farm is usually assessed through a set of questions relating to internal biosecurity (measures which prevent the spread of diseases inside the farm) and external biosecurity (measures limiting the entrance of pathogens into the farm) (Laanen et al., 2013). The different steps in the elaboration of biosecurity questionnaires are rarely mentioned, or the questionnaires are sometimes developed for other purposes (Boklund et al., 2004; Casal et al., 2007; Bottoms et al., 2013), making it difficult to assess the results and compare the level of biosecurity between farms and studies.

Numerous studies exist about the perception of disease risks and biosecurity measures by farmers. Generally, farmers are convinced that they are applying all the relevant biosecurity measures for their farm and tend to apply biosecurity measures they interpret as important (Casal et al., 2007; Garforth et al., 2013). However a lack of awareness regarding unseen risks, including diseases with no clinical signs, was identified amongst farmers (Garforth et al., 2013). A multitude of factors can influence the implementation of biosecurity measures including the credibility of the information provided (Garforth et al., 2013). Moreover, the possible complexity of the output from academia suggests that a tool which translates the results of research into a simple message to assess biosecurity and provide feedback to the farmer, would be beneficial to improve the level of biosecurity in pig farms. A biosecurity tool called Biocheck.UGent™ was created in order to quantify the level of internal, external and general biosecurity, and provide subsequent advice to farmers (Dewulf, 2014). The reliability of Biocheck.UGent™ was demonstrated by Laanen et al. (2010) and the online-based questionnaire has been used in different studies in several countries (http://www.biocheck.ugent.be) (Laanen et al., 2013; Backhans et al., 2015; Postma et al., 2016a). Internal biosecurity scores of farms in these studies were generally weaker than external biosecurity scores, with room for improvement in hygienic measures in and between compartments, in staff working procedures between groups and in smaller herds (Backhans et al., 2015; Laanen et al., 2013). Previous studies showed that improvement of biosecurity could be achieved over a short period of time and that the associated better herd management led breeding farms to increase the number of piglets weaned (Postma et al., 2016c). Such a tool has not yet been applied in the UK and would help in identifying the current level of biosecurity and the critical points of biosecurity in commercial pig farms. A lower prevalence of some production diseases might be expected with improved biosecurity, but indicators to directly assess the impact of such diseases need to be defined.

## 1.2 How to assess production diseases?

### *1.2.1 Indicators of production diseases*

Both clinical observations and biological analyses can be used to identify the occurrence of specific production diseases. On-farm observation of clinical symptoms is usually the first stage in disease identification and diagnosis. Serological testing is also widely used for disease surveillance or disease diagnosis in order to apply the appropriate treatment (Picardeau et al., 2014; Giles et al., 2017). Meat inspection at the time of slaughter has been developed to protect human health against meat-borne biological hazards (Felin et al., 2016), but has progressively been recognized as a good source of information to monitor animal health and welfare by assuring a high population coverage (Correira-Gomes et al., 2017). This approach is especially relevant for endemic diseases, not subject to systematic control (Stark et al., 2014). Moreover, the feedback provided to the farmer and veterinarian can be particularly useful for on-farm decision making (Stark et al., 2014).

Better identification of animal diseases based on reliable indicators was one of the objectives highlighted by the European Commission (European Commission, 2007b). Benchmarking systems based on post mortem inspection have been developed to assess pig health and improve health surveillance (Stark et al., 2014). Post-mortem inspection at the abattoir is an easy tool to systematically assess pig health in a large number of herds over a country. However, despite the cost reduction compared to on-farm inspection, the assessment needs to be easily repeatable with sufficient financial incentive to enable its implementation. The first programs were implemented in Scandinavia and Netherlands (Willeberg et al., 1984; Elbers et al., 1992). The failure in detecting important disease issues led to subsequent improvement in the protocols (Willberg et al., 1997). For example, several tools have been developed to assess lung lesions indicative of the respiratory diseases having important economic impact. The Slaughterhouse Pleurisy Evaluation System is a fast and simple scoring system which is used to score the presence of APP-like lesions in lungs and pleura, the Madec system enables the scoring of lesions of catarrhal bronchopneumonia, and an Enzootic Pneumonia-like lesion score is used to approximate the percentage of lung area showing consolidation (Sanchez-Vasquez et al., 2010; Meyns et al., 2011; Sibila et al., 2014). Image analysis software can be used to quantify the affected lung area (%), but can currently be difficult to use at a slaughterhouse, and the ratio of lung weight/body weight can be used to quantify the increased lung weight due to lesions (Sibila et al., 2014).

Feedback from basic slaughter checks is legally required by the European Commission regulations (EC) 854/2004 and (EC) No 1244/2007 (European Commission 2004; 2007a). Meat inspections follow the same legal basis across Europe, but each country has developed its own individual scoring system. Amongst others, Germany, Italy, Austria and Denmark have developed scoring systems to assess lung lesions based on pathological anatomical and lung lesion scoring (Merialdi et al., 2012; Wanda et al., 2013; Steinmann et al., 2014; Alban et al., 2015). Some abattoirs have further developed the system to cover different lesions in the liver, heart, respiratory tract and on the skin (Wanda et al., 2013; Alban et al., 2015; Nielsen et al., 2015; Gottardo et al., 2017; Scollo et al., 2017). The British Pig Health Scheme (BPHS), created in 2005 by the Agriculture and Horticulture Development Board (AHDB) which is a statutory levy board, funded by farmers. BPHS is one of the most developed national programmes for post-mortem assessment of pig health. The BPHS is an industry-sponsored health monitoring scheme which aims at improving herd health by developing a scoring system of health conditions and feeding information back to the farmer and veterinarian. The assessment of pig carcasses is conducted by specialist veterinarians, a consortium of independent veterinarians that undertook specialist training in condition scoring. Although voluntary, the BPHS program might provide more sensitive results about pig health compared to the statutory Food Standards Agency (FSA) inspection results. This can be justified by the fact that BPHS assessors are focused on specific animal health-related lesions while FSA inspection is more focussed on public health and meat quality (Correira-Gomes et al., 2017). All the assessed health conditions and the respective scoring systems of BPHS are reported in Table 1.1. Enzootic pneumonia-like lesions are assessed using the lung lesion scoring system developed by Goodwin (1969). The cranial and cardiac lobes are designated a score of 0 to 10 each, and the cranial areas of the diaphragmatic lobes and the intermediate lobe a score of 0 to 5 each, giving a maximum score of 55. The score of Pleurisy can be 0 for absence, 1 for mild and 2 for severe. Papular dermatitis is scored from 0 to 3 according to severity. The score for all the other lesions only considers the absence (0) or the presence (1) of the lesions (Table 1.1). The BPHS scores provide useful indicators for health conditions and have enabled further analyse s (Holt et al., 2011). These include studies about pleurisy, enzootic-pneumonia, milk spots and their impact on health, welfare and performance (Tucker et al., 2009; Sanchez-Vazquez et al., 2010, 2011, 2012).

**Table 1.1** Scoring system of the British Pig Health Scheme (BPHS) used to assess the incidence and the severity of animal disease on member farms (http://pork.ahdb.org.uk/health-welfare/health/safe-traceable-pork/bphs/).

| Anatomical location | Abbr. | Lesions | Scores* |
|---|---|---|---|
| Lungs and Chest | | | 0, 5, 10, 15, 20, 25, 30, 35, 40, |
| | EP | Enzootic Pneumonia | 45, 50, 55 |
| | PL | Pleurisy | Blank, 1 or 2 |
| | Viral | Viral-type distribution | Blank or 1 |
| | PPAcute | Pleuropneumonia - Acute | Blank or 1 |
| | PPChronic | Pleuropneumonia - Chronic | Blank or 1 |
| | Abscess | Abscess | Blank or 1 |
| | Pyaemia | Pyaemia | Blank or 1 |
| Liver | MS | Milk Spot | Blank or 1 |
| | HS | Hepatic Scarring | Blank or 1 |
| Other | PC | Pericarditis | Blank or 1 |
| | PT | Peritonitis | Blank or 1 |
| Skin | PD | Papular Dermatitis | Blank, 1, 2 or 3 |
| | Tail | Tail-bitten | Blank or 1 |

**Details about the meaning of the scores can be found on the AHDB website (http://pork.ahdb.org.uk/health-welfare/health/safe-traceable-pork/bphs/). Blank means no lesions, 1 means presence of lesions. For Enzootic pneumomia, Pleurisy and Papular dermatitis, the higher the score, the more severe and extended are the lesions.*

The quality of the data recorded during meat inspection has been questioned in several studies. These studies have suggested a lack of inter-assessor reliability or a lack of sensitivity to detect certain health problems, but also the positive impact of training to improve lesion detection without specifically changing the scoring system itself (Wanda et al., 2013; Steinmann et al., 2014). Moreover, one recently conducted study found meat inspection effective to detect affected animals and welfare issues; the probability of detection of diseases or health conditions, including ante and post mortem inspection, ranged between 0.33 to 0.95, but welfare issues were more likely to be detected during the ante-mortem inspection (Stark et al., 2014).

The associations between different indicators of health and performance have also been assessed. Associations between different pathologies were identified by Sanchez-Vazquez et al. (2012) and associations between lesions of EP, pleurisy and pleuropneumonia and positive serological tests for PPRS or H1N2 were also identified (Holt et al., 2011). Another study identified association between salmonella infection and EP-like lesions, pericarditis, peritonitis and milk spot, suggesting a possible synergistic relationship (Smith et al., 2011a). BHPS lesions were also associated to low carcass weight at slaughter (Holt et al., 2011). However, very little information exists regarding the association between BPHS data, welfare indicators and biosecurity. Understanding the inter-connection between these indicators would improve our knowledge regarding production diseases. The current scientific evidence suggests that the results of post mortem inspection provide an efficient tool to assess herd health but, considering that the prevalence of production diseases are generally connected to a decline in welfare and productivity, indicators measuring the prevalence of these two parameters could be additionally used to assess the impact of such diseases.

### *1.2.2 Indicators of production performance*

#### *1.2.2.1 Indicators of performance for fattening pigs*

Several parameters measure fattening pig performance and affect profitability: mortality, average daily gain (ADG), feed conversion ratio (FCR), duration of the fattening period, and are therefore accepted as good indicators of performance (Maes, 2001; Kyriazakis and Whittemore, 2006; De Lange et al., 2009). Data recording can be overwhelming for farmers. Some basic data tend to be systematically collected by the farmers in commercial farms, aiming to increase profit, which make these performance indicators easily accessible for research purposes. These include starting and slaughter weight to measure the ADG, and total feed intake of a batch to calculate the FCR (Leen et al., 2017). Moreover, recording of mortality is a requirement for farmers, as farmers not respecting EU law on animal health or farmers not respecting requirements of the quality assurance scheme to which they belong will see the support they receive reduced or might be excluded from their quality assurance scheme. This should facilitate access to this parameter in order to conduct further analysis. However, compliance with legal requirements for data recording is not always appropriately applied by farmers (Escobar and Demeritt, 2015).

A decline in health and performance is associated with economic losses (Newmann et al., 2005; Magowan et al., 2007), which explains their particular interest for the pig industry. As suggested previously, a decline in performance should be considered as a production disease since it reveals the impact of production diseases with sub-clinical expression. For example, only 20-35% of a pig herd infected by H1N1 show typical symptoms of the disease (Brown, 2000). As with many other infectious diseases, PCV2 subclinical infection includes a decrease in average daily weight gain with no clear clinical signs or histopathological lesions (Alarcon et al., 2013). Moreover, treatment against intestinal pathogens administered earlier in the weaning period resulted in better ADG (Weber et al., 2017), showing the importance of monitoring performance in order to monitor subclinical expression of production diseases or dietary inadequacy that could lead to production disease. Subclinical disease can be also indicated by alterations in immune system parameters, including cell-mediated response and cytokine production, which are important in defence against infection in pigs (Pomorska-Mol et al., 2014, Correas et al., 2017). Following experimental infection by H1N1 influenza virus, the level of acute phase proteins, mediated by pro-inflammatory cytokines, increased after the infection but piglets did not show a decline in their general health status or food intake (Pomorska-Mol et al., 2012). However, another study suggested that both the concentration of cytokines and the viral load play a role in the severity of the lung lesions (Pomorska-Mol et al., 2014), and the severity of lung lesions tended to decrease production performance in the study of Brewster et al. (2017); this supports the suggestion that internal changes related to disease infection, including inflammatory response, can be revealed by production performance.

Several health issues have also been connected to a decrease in production performance. Higher prevalence of enzootic pneumonia and pleurisy (Regula et al., 2000; Brewster et al., 2017), and gastro-intestinal infection (Adewole et al., 2016) have been associated with lower performance in previous studies. This further illustrates that the impact of different production diseases can be captured through production performance. However, biosecurity measures, which influence disease challenges and disease prevalence, were not connected to all production parameters in the study of Postma et al. (2016b), suggesting that production performance depends on severeal parameters The level of biosecurity needs to be further assessed in order to better understand the impact of production diseases.

#### *1.2.2.2 Indicators of performance for breeding pigs*

Production performance data are collected on a more regular basis for the breeding herd than for the finishing herd, and the quality of the data have been improved thanks to new software and technologies. Number of litters per sow per year, number of piglets born, the number of piglets born alive and the number of pigs weaned per sow, as well as pre- and post- weaning mortality, are usually collected by commercial pig farms to benchmark their productivity (AHDB, 2014;

Koketsu et al., 2017). Sow performance data and piglet mortality in particular have been widely explored in the literature, including the impact of different risk factors (Knecht et al., 2015) and the influence of the level of biosecurity (Postma et al., 2016a). However, as shown by Baxter and Edwards (2016), piglet mortality tends to increase with the number of piglets born alive suggesting several limitations connected to the increase of litter size, such as the reduction of placental area and lower maturity of the newborns at birth (Rootwelt et al., 2013). Moreover, the increase in the number of piglets weaned over recent decades is largely due to the increase in the number of piglets born instead of a reduction in mortality (Edwards, 2002). Therefore, piglet mortality highlights the loss hidden behind the improvement of productivity and raises an ethical issue arising from higher sow performance. This suggests that productivity assessed through the prism of piglet mortality, instead of the number of piglets produced, could give a clearer view of some weaknesses of farming intensification.

Born weaker, with lower weight and vitality, the piglets from larger litters may be exposed to higher risk of death (Herpin et al., 2002, Douglas et al., 2013). The breed of the sow, parity, litter size, placental weight and area, location in the uterus, prenatal nutrition, duration of farrowing, farrowing management, piglet management strategies, infectious diseases, environment and genetics have all been identified as risk factors for piglet mortality (Milligan et al., 2002; Rehfeldt and Kuhn, 2006; Alonso-Spilsbury et al., 2007; Canario et al., 2007; Beaulieu et al., 2010; Rootwelt et al., 2013). While crushing and stillbirth have been identified as the main causes of mortality, misclassification of piglets regarding the different causes of death has often been reported in the literature (Vanderhaeghe et al., 2010; Westin et al., 2015). A standardized methodology should therefore be used to accurately assess the prevalence of the different causes of mortality in order to capture the complexity of piglet mortality issues. Moreover, although the different causes of death have been studied individually, the piglet mortality pattern across different farms need to be clarified in order to better develop targeted strategies for intervention. Although piglet mortality represents a good indicator of production diseases and performance in breeding herds, this particular issue needs to be assessed in a more integrated manner in order to identify the best strategies to improve piglet survival.

### *1.2.3 Indicators of welfare*

Welfare friendly agricultural systems can be poorly understood by consumers and consumer perception can be influenced by many factors (Popa et al., 2011; Clark et al, 2017; Erian and

Phillips, 2017). The food attributes sought by the consumer are not easily recognizable at the time of purchase or consumption (Saitone and Sexton, 2017). Concerns about intensive animal production systems, and increased interest in animal welfare, have encouraged the development of food standards and welfare standards (Lundmark et al., 2014). Quality Assurance schemes which demonstrate the farmer's commitment to quality assurance principles to ensure food safety, quality and respect for animal welfare grew up in response to consumer demands for recognizable welfare-friendly, safe and high quality food (Peet, 2002). The strict compliance with these quality assurance principles is regularly controlled through assessment by independent assessment teams. Moreover, feedback results from farm audits have been recognized as a helpful tool for the farmer to identify welfare and health issues and implement remedial strategies (Main et al., 2007; Blokuis et al., 2010). Quality Assurance schemes were rapidly developed, especially in countries oriented to meat exports (Wood et al., 1998), and have become an important part of the food supply chain. Farm Assurance was defined as "the application of the quality assurance principles to schemes at farm level and/or schemes which apply along the food chain, at market, in transit and up to the point of slaughter" (Farm Animal Welfare Council, 2001) with welfare considered as a key part of the standards. This highlights the need for scientifically grounded methodology to define and assess animal welfare.

Different opinions and perceptions exist regarding animal welfare (Fraser et al., 2008; Vanhonacker et al., 2008; Tuyttens et al., 2010). Originally, welfare was assessed through resource-based measures, but the complexity to assess the multifactorial impact of environmental variables on animal welfare and set animal welfare standards based on these variables has led to further developments in animal welfare assessment (Webster et al., 2004). The difficulty to provide detailed housing requirements and management procedures in legislation of husbandry practices led the European Commission to focus on animal-based outcome measures (Blokhuis et al., 2010), which are considered to be a better alternative to measure animal welfare compared to resource-based measures (Whay et al., 2003; EFSA, 2012). Farmer preference for a European or worldwide system to assess animal welfare, and public concern about industrial farming (Veissier et al., 2008; Blokuis et al., 2010), highlighted the necessity to develop a standardized methodology to assess animal welfare on-farm. Manning et al. (2006) suggested benchmarking quantitatively different steps in the food supply chain in order to improve the quality of meat production. At farm level, the new approach based on animal-based measures was first applied in the EU Welfare Quality® project, which aimed to define animal-based criteria of good welfare based on scientific evidence and stakeholder views, and to integrate these criteria into an overall assessment. From this project a definition of animal welfare has emerged, based on 4 principles: good feeding, good housing, good health and appropriate behaviour, subdivided in 12 criteria. Standardized measures, which were applicable under commercial conditions, were developed for all criteria (Blokhuis et al., 2010). However, completing a full assessment could take up to 8 hours, making it difficult to implement on a large number of farms and suggesting that it is necessary to reduce the number of parameters in order to implement it on a large scale.

On-farm assessment is subject to many constraints; in order to be well accepted and facilitate its implementation, a welfare assessment must be cheap, quick and flexible (Edwards, 2007). For this reason, the possibility of using a restricted list of welfare indicators has been investigated (Heath et al., 2014; Munsterhjelm et al., 2015a). Munsterhjelm et al. (2015a) conducted a study to attempt to demonstrate the possibility of establishing a shortlist of animal-based measures used in the Welfare Quality project to reduce the time of the welfare assessment and adapt the system to on-farm use. This was undertaken, based on a statistical methodology, by identifying welfare problem types in the form of shortlists of attributes measuring a common phenomenon. In a UK project, a protocol was developed for on-farm welfare assessment, based on animal-based measures validated by experts (Main et al., 2007). Mullan et al. (2009a, 2009b) assessed the possibility of estimating the prevalence of a few key welfare outcome measures on finishing pig farms in the UK and identified low redundancy between measurements. Tail lesions and wounds found on other parts of the pig's body, have been identified as "iceberg indicators" for pig welfare (Spoolder et al., 2011), and have been repeatedly used in the short list of animal-based measures to assess animal welfare (Whay et al., 2007; Mullan et al., 2009a, 2009b; Munsterhjelm et al.,2015a). These "iceberg indicators" are usually chosen because they reflect a series of other welfare and health issues and enable the prediction, with some degree of subjectivity, of the overall welfare state of the animals. Moreover, the assessment of the prevalence of other welfare outcomes, such as pigs requiring hospitalization or lameness, which are not significantly correlated to tail or body lesions, appeared to be complementary measures that could be used to identify different welfare issues in pigs.

The low prevalence, and the variability of the prevalence of the different welfare outcomes between pens, suggests a large number of pens and a large number of pigs in the pens should be targeted to obtain an accurate estimate which characterises a farm (Mullan et al., 2009a). Several studies have been conducted to assess the intra- and inter-observer reliability in recording of key welfare outcome measures (Mullan et al., 2011a; Temple et al., 2012), showing that good reliability between observers could be achieved if they received adequate training. The prevalence of several welfare outcomes on commercial farms has been studied in different countries such as UK, France and Spain (Whay et al., 2007; Courboulay et al., 2009; Kilbride et al., 2009b; Temple et al., 2012) and has rarely exceeded 1% when only severe lesions were considered. This confirmed the need for well-designed and large samples to accurately estimate their prevalence. The farm prevalence of minor lesions could reach up to 90% (Whay et al., 2007) and might require smaller samples but the connection between such lesions and animal welfare is less straightforward and more difficult to interpret.

The British pig industry was the first to conduct an assessment of pig welfare at national level (Farm Animal Welfare Council, 2001). Based on the underpinning research, the "Real Welfare" project developed a welfare assessment protocol to assess pig welfare on-farm as part of the Red Tractor Assurance Scheme. Red Tractor Pigs Scheme Standards are "part of the Red Tractor Food Assurance Scheme assuring food safety, animal welfare, hygiene and environmental protection through every part of the food chain" in the UK (Red Tractor Assurance, 2014). The "Real Welfare" assessment scheme has been carried out since 1st April 2013 by vets from the Pig Veterinary Society, as part of their quarterly farm visits which are a requirement of the Red Tractor Scheme. This project was created in order to communicate scientifically grounded welfare standards to the different stakeholders. The assessment is based on 5 main measures (prevalence of lameness, number of pigs requiring hospitalization, with severe tail lesions with severe body marks and enrichment use ratio) and is applied in most of the commercial pig farms in the UK (farms with at least 300 fattening pigs) (http://pork.ahdb.org.uk/health-welfare/welfare/real-welfare/). However the data collected by the scheme have yet to be analysed and no information related to the changes of the prevalence of the different welfare outcomes over time are currently available. The average prevalence in the UK for all welfare outcomes, the characteristics of the population of pig farms involved in the Scheme and the risk factors for higher prevalence of the welfare outcomes also need to be investigated. Information collected by the Real Welfare Scheme on the farm characteristics represents a good opportunity to identify risk factors for higher prevalence of the different welfare outcomes for a population of farms representative of the commercial pig farms in the UK. A welfare assessment, combined with a scientifically grounded approach to analyse the output, will strengthen the validity of the scheme.

For this reason, the output of the “Real Welfare” protocol needed to be further assessed through statistical analysis. Moreover, the connection between Real Welfare data and other indicators of health, performance and environmental impact collected on farm or at the abattoir have not been explored and would be essential to further understand the importance of pig welfare in the pig industry.

## 1.3 The challenge of collecting and connecting data from different sources.

### *1.3.1 Associations between production diseases, welfare and performance*

Associations between indicators of health, welfare, performance and the production environment have been identified in previous studies; different health and welfare parameters were significantly correlated in some studies (Holt et al., 20011; Munsterhjelm et al., 2015a). Different measures of animal health, such as high antibody titre, the frequency of lung lesions (Regula et al., 2000), pleuropneumonia-like lesions (Sibila et al., 2014) or antibiotic usage (Postma et al., 2016b) have been connected to production parameters, such as average daily gain (ADG), and also to the level of external biosecurity (Postma et al., 2016b). Welfare parameters have also been associated with production performance such as the prevalence of tail lesions with back-fat levels (Moinard et al., 2003; Sinisalo et al., 2012) and lung lesions (van Staaveren et al., 2016)). However, there is room for improvement regarding the understanding of inter-connections between environment, health, welfare and performance, which have seldom been assessed in an integrated manner, because of the difficulty of combining all the measurements required in a single study. Large quantities of data on different aspects of livestock production are routinely recorded by different stakeholders: farmers, veterinarians, governmental institutions and private sector bodies, and could be used for this purpose. The value of these sources of information should be emphasized and the possibility of connecting and analysing these data in an integrated way needs to be further explored.

### *1.3.2 The challenge of connecting different data sources*

In order to have a global view of production diseases, different indicators relevant for production diseases should be collected and the connection between these indicators should be better understood. Governmental institutions, farmers and different representatives of the pig industry record a large quantity of data regarding pig farm characteristics and pig production, with some of these data described in the previous paragraphs. These data are usually collected for purposes other than scientific research, and the form in which they are collected and stored differs widely.

However, this remains a large source of information and highlights the potential for secondary data analyses in order to use these data in the most sustainable way.

Secondary data analysis arises from the disconnection between the persons who collect the data, not to answer a specific research question, and those that analyse it for the purpose of research (Boslaugh, 2007). Secondary data analyses are largely used in public health research to answer research questions (Tripathy, 2013). The data enable researchers to conduct analyses which would have been extremely expensive and time consuming; sometimes impossible to conduct in the time allotted (Smith et al, 2011b; Grady et al., 2013). Moreover, data collected on the whole population, or from a sample representative of the population, are rarely achieved by researchers (Grady et al., 2013) and such data collected by governmental institutions give a good opportunity for a better overview of the population of interest. The difficulty to locate and access appropriate data (Boslaugh, 2007), and the challenge of connecting different databases (Grady et al., 2013), constitute a major concern in secondary data analysis and can represent important limitations to achieve a work of quality. Moreover, several other issues are connected to secondary data analysis, such as preserving confidentiality of individuals involved in the sample, manipulating the information without breaking confidentiality agreements, accuracy of the purpose of the analysis, missing relevant data, and period of data collection (Tripathy, 2013). The researchers who use such data have not usually participated either in the research design or the data collection process, meaning that the data are sometimes suboptimal for the subsequent research purpose. However, the ease of sharing data stored electronically allows researchers to easily receive these data and conduct analysis in order to address new research questions (Boslaugh, 2007). This requires a good system of identification of individual entries and records of sufficient descriptive characteristics, especially when answering a research question requiring the connection of several data sources. Sprague et al. (2017) highlighted that specific organisations usually have a good understanding of their own database but several issues emerge when attempting to connect these data with data from other organisations, due to missing or ambiguous information or lack of standardization.

Considering the amount of information collected about pig farms in the UK by the Agricultural and Horticultural Development Board (AHDB), through the Real Welfare and the British Pig Health Schemes, by the Department for Environment, Food & Rural Affairs, by the farmers themselves and by different representatives of the pig industry, the accessibility and the possibility of connecting and analysing these data for research purposes need to be explored. Collecting data incurs a significant cost which can limit the research conducted on certain topics. Using existing data can represent an alternative way to conduct research on different topics for which information has already been recorded by different organisations. Identifying specific barriers for accessing, connecting and analysing these data would represent a first step in possible suggestions to increase the utility of the data collection conducted by the pig industry. The connection of different data sources will also improve our understanding of the resources available for researchers working on pig farming and pig health.

## 1.4 Thesis aims

The main aim of this thesis is to identify risk factors forproduction diseases in pigs. The first objective was to collect information on indicators of health, welfare and performance from different UK data sources and assess the possibility to connect these data sources in order to better understand the impact of production diseases. Considering the novelty and the lack of analyses that have been conducted on the data collected about welfare from the UK Real Welfare Scheme, further analyses were conducted on these data. The second objective was related to one specific production disease, namely piglet mortality, as this represents one of the biggest challenges facing the pig industry and a standardized database which included details about the different possible categories of piglet mortality had been identified during the Prohealth project. Specific gaps identified in the literature regarding piglet mortality were addressed by collecting necropsy data from a French nutrition company. This dataset offered the possibility to explore piglet mortality in an integrated manner by classifying dead piglets in different categories. The different parts of this thesis therefore illustrate the possibilities for conducting valuable secondary data analyses to address issues in pig production. The specific aims of the thesis are:

1. To connect different data sources to assess the associations between biosecurity, health and welfare and performance in commercial pig farms in Great Britain and better describe a possible methodology and challenges of connecting these data (Chapter 2)
2. To analyse the data collected by the Real Welfare scheme since its implementation in April 2013. More precisely, to describe the changes of prevalence over calendar years of the different measures of welfare, as well as the characterisation of the farm population involved through different variables related to farm environment and management (Chapter 3).

3. To identify risk and protective factors for welfare outcomes in commercial pig farms in the UK based on the farm characteristics collected by the Real Welfare Scheme for a population of farms representative of the pig farms in the UK (Chapter 4).
4. To identify different categories of piglet perinatal mortality in a sample of French pig farms with perinatal mortality problems, and to highlight the variation in the risk factors for the different categories of piglet death, instead of considering perinatal mortality as a single entity. Finally, to determine whether characteristic clusters of farms could be identified on the basis of their mortality patterns (Chapter 5).
5. To identify different piglet management strategies between farms and to understand the impact of neonate management on different categories of piglet mortality in French farms (Chapter 6)

# Chapter 2 Connecting different data sources to assess the associations between biosecurity, health, welfare and performance in commercial pig farms in Great Britain

## 2.1 Abstract

By identifying possible links between on-farm data and large scale industry databases, this study aimed to provide a general overview of the inter-connections between biosecurity, health, welfare and performance in commercial pig farms in Great Britain. We collected on-farm data about the level of biosecurity and animal performance in 46 commercial pig farms between 2015 and 2016. We identified inter-connections between these data, slaughterhouse health indicators and welfare indicator records in fattening pig farms. After achieving the connections between databases, a secondary data analyses were performed to assess the associations between biosecurity, health, welfare and performance using correlation analysis, principal component analysis and hierarchical clustering.

Although we could connect the different data sources the final sample size was limited, suggesting room for improvement in database connection to conduct secondary data analyses. The farm biosecurity scores ranged from 40-90 out of 100, with internal biosecurity scores being lower than external biosecurity scores. The initial correlation analysis showed that the prevalence of lameness and severe tail lesions was associated with the prevalence of enzootic pneumonia-like lesions and pyaemia, and the prevalence of severe body marks was associated with several disease indicators, including peritonitis and milk spots ($r>0.3$; $P<0.05$). Higher average daily gain (ADG) was associated with lower prevalence of pleurisy ($r>0.3$; $P<0.05$), but no connection was identified between mortality and health indicators. In the subsequent cluster analysis, farms from cluster 1 had lower biosecurity scores, lower ADG and higher prevalence of several disease and welfare indicators. Farms from cluster 2 had higher biosecurity scores than cluster 1, but higher prevalence of pigs requiring hospitalization and lameness which confirmed the correlation between biosecurity and the prevalence of pigs requiring hospitalization ($r>0.3$; $P<0.05$). Farms from cluster 3 had higher biosecurity, higher ADG and lower prevalence for some disease and welfare indicators. The study suggests a limited impact of biosecurity on issues like mortality, prevalence of lameness and the number of pig requiring hospitalization. The associations identified between health indicators, welfare outcomes and production performance highlighted the importance of animal welfare for the pig industry.

## 2.2 Introduction

In the livestock sector, many data are collected by both public and private sector bodies for purposes other than research (FAO, 1997; Tripathy, 2013). These data may represent an opportunity to conduct secondary data analyses, and offer a cost-effective approach to address research questions (Smith et al., 2011b; Goodwin et al., 2012; Koo, 2016), including ones relating to animal health and welfare. Access to large sample numbers, recorded over long periods of time, time saving and lower cost are generally reported as some of the advantages of secondary data analysis (Smith et al., 2011b; Tripathy, 2013; Koo, 2016). These data can also be used to complete findings from a primary study (Koo, 2016). At the same time, several disadvantages have also been reported, including poor control of the studied populations and measures (Smith et al., 2011b). When using several data sources, the ability to connect the different databases will drive the quality of the study and can greatly affect the sample available to conduct the analysis. With the objective of using the available resources in a cost-effective and sustainable way, the potential for connection between different data sources related to pig health, welfare and performance needs to be assessed.

Large datasets exist within the industry which document the prevalence of indicators of health and welfare collected on-farm or at the abattoir (ADHB, 2008, 2017). A few studies have investigated the connection between different abattoir data and carcass weight (Jaeger et al., 2009; Holt et al., 2011; Brewster et al., 2017), but the connections between these data and extensive on-farm data have seldom been made. Associations between pig health, welfare and performance have been identified in many studies (Regula et al., 2000; Sinisalo et al., 2007; Brewster et al., 2017). For example, tail lesion prevalence, which is considered as one of the most important welfare indicators, has been connected to sneezing frequency (Munsterhjelm et al., 2015a), acute phase protein titres and abscesses (Heinonen et al., 2010), and lung lesions (Van Staaveren et al., 2016). This suggests that tail biting might be connected to an inflammatory reaction resulting from the environment or from interactions with pen-mates. While biosecurity, health, welfare and performance have been well studied individually, they have seldom been assessed in an integrated manner and their connections need to be further explored. Moreover, connections between biosecurity and welfare in pig farms are still lacking in the literature.

This study aimed at identifying possible connections between on-farm data and large scale industry databases holding complementary information, and aimed at understanding if better welfare and biosecurity are connected to better health and performance. This was achieved by connecting data collected for different purposes over the same time period. Initially, a survey was conducted to collect on-farm data about animal performance and assess the level of biosecurity in commercial breeding and fattening pig farms in Great Britain. Subsequently, we identified the connections between these data collected on-farm and two different large scale industry databases holding information about commercial pig farms in Great Britain: indicators of health and welfare collected by Agricultural and Horticultural Development Board (AHDB) Pork for the British Pig Health Scheme (BPHS) and the data held for the Real Welfare Scheme. After achieving the connections between different databases, we conducted a secondary data analysis to assess the associations between biosecurity, health, welfare and performance in commercial pig farms in Great Britain.

## 2.3 Materials and methods

### *2.3.1 Sampling*

#### *2.3.1.1 Farm classification.*

The list of the county parish holding number (CPH) and the number of breeding pigs and fattening pigs of all pig farms in Great Britain was obtained from the Animal and Plant Health Agency (APHA), and the Scottish Government Rural and Environment Science and Analytical Services (RESAS) in 2014. The most recent data communicated for fattening pigs allowing us to perform farm classification based on the same year for the 3 countries (England, Wales and Scotland) were from 2010. The population figures (number of breeding pigs and number of other pigs) of all pig farms in these three countries were used to stratify the population similarly to the EUROSTAT classification (Marquer et al., 2014).

The whole population of fattening pig farms was classified into 4 different groups according to herd size: Group 1: small fatteners (no breeding pigs and less than 10 other pigs), Group 2: large fatteners (no breeding pigs; at least 400 other pigs), Group 3: large breeder-fatteners (at least 400 other pigs and 100 breeding pigs), Group 4: all the other farms that could not be classified in Groups 1 to 3. In this analysis, breeding pigs were defined according to available data as sows, gilts, suckled or dry sows or dry sows kept for further breeding and gilts of 50kg and over expected to be used or sold for breeding. The other pigs were defined as all fattening pigs over 20kg including barren sows. The whole population of breeding pig farms in England, Wales and Scotland was used to classify the farms into 2 groups as follows: Group A: specialized breeders with no fattening pigs over 20 kg, Group B: breeding-fattening herds with at least one fattening pig over 20 kg in the herd.

##### *2.3.1.2 Sampling.*

We obtained 2 convenience samples: one with fattening pig farms (specialized fatteners and breeder-fatteners) and the other with breeding farms (specialized breeders or breeder-fatteners), with some overlap (breeding-fattening farms were included in both categories of farms). First we used a stratified random sampling to select fattening pig farms from the whole population of fattening pig farms. One thousand farms with fattening pigs were selected from the four different groups of fattening pig farms cited in the previous paragraph (targeting ~100 farms, based on no more than 10% positive response to participate in the study). In order to avoid the over-representation of the smallest farms, we used a stratified random sampling in which the percentage of farms selected in each stratum was equivalent to the corresponding percentage of pigs in each group (1, 2, 3 and 4) for the whole population. This strategy was used to select the larger herds and reduce the number of farms from Group 1 and Group 4, which were of peripheral interest to the study. The CPH number of the selected farms was communicated to the AHDB, the custodian of farmer identity, which sent a letter to the selected pig producers to invite them to participate in the study. The farmer name and farm location remained confidential to the mailing body. Due to the low percentage of replies to the initial mailing, we had to recruit additional fattening farms by advertising online on the National Pig Association (NPA) website (a letter , similar to the one sent to the producers through AHDB, was shared online by NPA on their website) and contacting farms that had previously participated in similar studies. The breeding farms were not originally part of the objective of this study. However, considering the number of breeder-fatteners visited in the fattening pig farm sample, a breeding farm sample was constituted afterwards, which also included the breeding-fattening farms from the fattening pig farm sample and was completed by additional specialized breeding farms not randomly selected.

### *2.3.2 Data collection*

If the farmer agreed to participate in the study, the first step was to complete a biosecurity questionnaire (online or paper version) and communicate their name, address and phone number. We then arranged a convenient time for a farm visit to confirm the accuracy of the responses to the biosecurity questionnaire and to collect performance data (Table 2.1) for the year prior to the visit. Herd visits took place between July 2015 and December 2016. After the visits, the prevalence of welfare indicators for the sample of fattening pig farms, collected during quarterly veterinary visits in 2015 and 2016, were acquired from the database of the AHDB Pork "Real Welfare" scheme (Pandolfi et al., 2017a) and the prevalence of different lesions recorded at the abattoir were acquired, for all batches assessed in 2015 and 2016, from the database of the AHDB Pork "British Pig Health Scheme" (BPHS) (http://pork.ahdb.org.uk/health-welfare/health/safe-traceable-pork/bphs/) (Table 2.1). The connection between the farm ID and the BPHS and Real Welfare databases was processed by AHDB in order to maintain confidentiality. A diagram which summarizes the sampling and the data collection for fattening pig farms is presented in Figure 2.1.

**Table 2.1** Production data for the study farms, collected during a farm visit, and health and welfare indicator data collected from the BPHS and Real Welfare databases of AHDB Pork.

| | |
|---|---|
| | Performance data for breeding pigs |
| **PB (Number)** | piglets born[1] |
| **PBA (Number)** | piglets born alive[1] |
| **PW (Number)** | piglets weaned [1] |
| | Performance data for fattening pigs |
| **ADG (g/day)** | Average daily weight gain[2] |
| **FCR (ratio)** | Feed conversion ratio[2] |
| **MOR (%)** | Mortality[2] |
| | Real Welfare data[6] |
| Hosp (%) | Percentage of pigs seen by the veterinarian that require hospitalization[3] |
| Lam (%) | Percentage of lame pigs[3] |
| Stl (%) | Percentage of pigs with severe tail lesions[3] |
| Sbm (%) | Percentage of pigs with severe body marks[3] |
| | BPHS data[7] |
| *ep* (%) | Enzootic Pneumonia[4] |
| *pl* (%) | Pleurisy[4] |
| *pc* (%) | Pericarditis[4] |
| *pt* (%) | Peritonitis[4] |
| *ms* (%) | Milk Spot[4] |
| *hs* (%) | Hepatic Scarring[4] |
| *pd* (%) | Papular Dermatitis[4] |
| *tail* (%) | Tail-bitten[4] |
| *viral* (%) | Viral-type distribution[4] |
| *ppa* (%) | Pleuropneumonia - Acute[4] |
| *ppc* (%) | Pleuropneumonia - Chronic[4] |
| *abscess* (%) | Abscess[4] |
| *pyaemia* (%) | Pyaemia[4] |
| *ep score* (%) | Score Enzootic Pneumonia[5] |
| *pl score* (%) | Score Pleurisy[5] |
| *pd score* (%) | Score Papular Dermatitis[5] |

[1] Average number per litter for the farm

[2]Average for the farm from weaning to slaughter

[3] Estimated mean farm prevalence for 2015 and 2016 based on repeat samples of pigs selected to be representative of the farm

[4] Estimated mean farm prevalence for 2015 and 2016 based on repeat samples of pigs selected at the abattoir

[5] Estimated mean scores for 2015 and 2016 based on repeat samples of pigs selected at the abattoir. For *ep score,* each lobe is designated a score, giving a total score between 0 and 55 according to severity, *pl score* is scored (0-2) and *pd score* is scored (0-3) also according to severity.

[6] Percentage of pigs assessed in the farm for the years 2015-16

[7] Percentage of pigs in a sample of a batch at slaughter

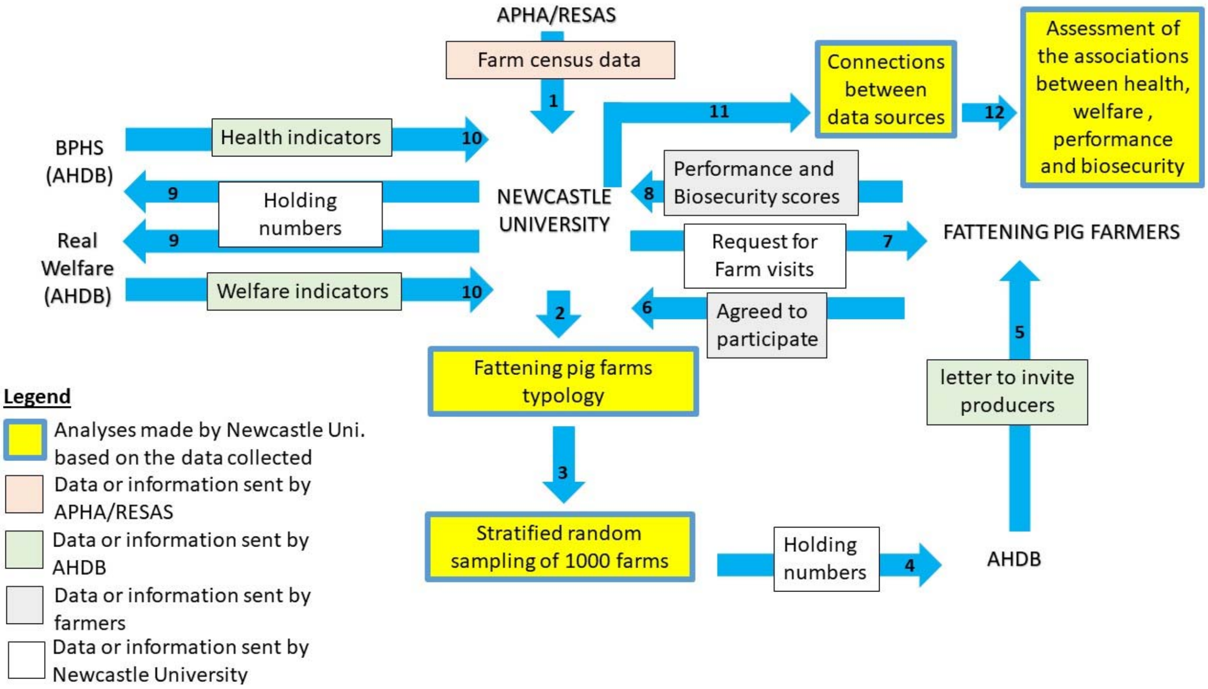



**Figure 2.1** Diagram representing the sampling and data collection. Data about biosecurity, health, welfare and performance were collected on-farm and from the Agricultural and Horticultural Development Board (AHDB) databases (British Pig Health (BPHS)and Real Welfare schemes). The sampling was based on farm census data from the Animal and Plant Health Agency (APHA) and the Rural and Environmental Science and Analytical Services (RESAS).

### *2.3.3 Biosecurity scoring tool*

The level of farm biosecurity was assessed using a risk-based scoring tool which was a slightly modified version of « Biocheck-UGhent™ » (http://www.biocheck.ugent.be/v4/about/pig/) (Laanen et al., 2013). The risk-based scoring tool is a questionnaire with 130 questions. Fifteen questions are used to collect contact information and data about herd characteristics (Herd ID, presence of other animals, number of breeding pigs, number of weaners, number of fattening pigs, number of boars, number of years of working experience working with pigs, number of people working on the farm in full time equivalents (FTE)). The answers of all the other 115 questions were translated into a score between 0 and 10 according to the relative importance of the question regarding farm biosecurity and disease prevention (Laanen et al., 2013). The 115 questions were grouped into 12 different sub-categories: A. Purchase of animals and semen; B. Transport of animals, removal of manure/dead animals; C. Feed, water and equipment supply; D. Personnel and visitors; E. Vermin/bird control; F. Environment and region; G. Disease management; H. Farrowing period; I. Nursery, J. Fattening pigs; K. Measures between compartments and the use of equipment; L. Cleaning and disinfection. The sub-categories have specific weight factors according to the relative importance for disease prevention, giving a score for external biosecurity (EXT) based on the score of the categories A to F and a score for internal biosecurity (INT) based on the score of the categories G to L. The total biosecurity (TOT) score was the average of the internal and external biosecurity score.

### *2.3.4 Statistical analysis*

#### *2.3.4.1 Farm description*

Using the methodology of classification described in Section 2.3.1.2, the sample of farms that participated in the study was compared to the proportion of farms in the different groups (Groups 1, 2, 3&4 for fattening pigs and Group A & B for breeding pigs) in the national pig population using Fisher or Chi Square tests. The null hypothesis $H_0$ was: "No difference in the proportion of farms in the different groups between the whole population and the sample". If $P < 0.05$ the null hypothesis was rejected.

For the sample of farms (fattening farms and breeding farms), the correlations between herd characteristics were identified. First, a Shapiro test was used to assess the normality of the different variables. When $P > 0.05$ in the Shapiro test, Pearson correlation coefficients were calculated. When $P < 0.05$ in the Shapiro test for at least one of the variables, Spearman rank correlation coefficients were calculated. The correlation was considered significant if the correlation coefficient $r > |0.3|$ and $P < 0.05$, and considered strongly correlated if $r > |0.6|$ and $P < 0.05$.

#### *2.3.4.2 Biosecurity score and farm types*

We assessed the association between internal, external and total biosecurity scores (dependent variables) with the different independent variables related to farm characteristics (farm system, presence of other animals, number of breeding pigs, number of weaners, number of fattening pigs, number of boars, years of experience, people working (as FTE) using univariate regression analysis. All the variables with $P < 0.25$ were retained for a multivariate analysis. We used a stepwise variable selection to build the final model and we also tested the interactions between the dependent variables by calculating the variance inflation factors. The association between the dependent variables and the independent variables was considered significant if $P <0.05$. Finally, we calculated the biosecurity score for each production type (breeders, weaners & fatteners; breeders only or breeders & weaners; weaners & fatteners; fatteners only).

#### *2.3.4.3 Associations between biosecurity scores, health indicators, welfare outcomes and production performance.*

The correlations between total and individual scores of internal and external biosecurity were assessed separately for the fattening pig farms and the breeding pig farms. The correlations between total, internal and external biosecurity score, the health indicator prevalence from BPHS data, the welfare outcomes and the production performance (Table 2.1) were assessed using Pearson or Spearman correlations.

In order to provide an overview of the inter-connection between biosecurity score, the BPHS data, welfare outcomes and production performance in the sample of fattening pig farms, a Principal Component Analysis (PCA) was used. For the PCA, 13 variables were considered in order to broadly cover the overall biosecurity level, the main indicators of performance that could be collected in most of the farms, all welfare issues recorded by the Real Welfare project and the most prevalent abattoir lesions. These indicators were the main biosecurity scores (INT, EXT, TOT), production performance (**ADG**, **FCR**, **MOR)**, welfare outcomes from Real Welfare dataset (hosp, lam, stl, sbm), the prevalence of enzootic pneumonia and pleurisy from BPHS dataset (*ep, pl)* and the prevalence of tail-biting lesions (*tail*) (Table 2.1). Tail-biting lesions (recorded at the abattoir) were included to allow assessment of the connection with the on-farm prevalence of the welfare outcome of severe tail lesions (stl) in the Real Welfare dataset.

We imputed missing entries using the iterative PCA algorithm. The two first components from the PCA, considered as the most discriminating, were selected and the cumulative percentage of inertia was calculated for these components. Then we plotted the farms and the variables on the factor map. We used an Ascendant Hierarchical Clustering (AHC), based on the selected principal components of the PCA, in order to place individual farms into different clusters. The clustering was achieved based on the "Ward" criteria. Then, the sum of the within-cluster inertia was calculated for each partition. The number of clusters corresponds to the partition with the higher relative loss of inertia (i(clusters n+1)/i(cluster n)) which was identified according to the length of the tree branches on a hierarchical tree. Anova or Kruskal-Wallis tests and post-hoc pairwise comparisons using Tukey and Kramer (Nemenyi) tests with a Tukey-Dist approximation were used to assess the differences between clusters in production performance, biosecurity scores, the prevalence of the BPHS lesions (included the ones not used in the PCA) and of the different welfare outcomes. Differences were considered significant if $P \leq 0.05$.

## 2.4 Results

### *2.4.1 Sample of fattening and breeding pig farms*

The number of fattening and breeding farms in each classification group (Groups 1, 2, 3&4 for fattening pigs and Group A & B for breeding pigs) for the whole population and in the study sample is reported in Tables 2.2 and 2.3 respectively. As expected, the proportion of fattening pig farms in the 4 different groups was different between the whole population figure and the sample ($P<0.05$), since we sampled according to the proportion of pigs rather than farms. Thus the sampled fattening pig farms belonged mainly to group 2 (0 breeding pigs and ≥ 400 fattening pigs) and group 3 (≥ 100 breeding pigs and ≥ 400 fattening pigs); the sample represents mainly the fattening pig farms with the bigger herds. The proportion of breeding pig farms in the two different groups was also different between the whole population figure and the sample ($P<0.05$). The sample had a higher percentage of farms from group B (breeder-fatteners), which represented the larger breeding herds in the pig farm population.

**Table 2.2** Number of farms and number of pigs per classification group[1] in the whole population (Pop.) and in the study sample (Samp.) of fattening pig farms. The whole population figure is based on the data collected in 2010 for England, Scotland and Wales. The sample is based on the farms visited in Great Britain between 2015 and 2016.

| | Group 1 Pop. | Group 1 Samp. | Group 2 Pop. | Group 2 Samp. | Group 3 Pop. | Group 3 Samp. | Group 4 Pop. | Group 4 Samp. | Total Pop. | Total Samp. |
|---|---|---|---|---|---|---|---|---|---|---|
| Number of fattening pig farms | 1 848 | 1 | 806 | 19 | 603 | 17 | 10 556 | 3 | 13 813 | 40 |
| Percentage of fattening pig farms | 13.4 | 2.5 | 5.8 | 47.5 | 4.4 | 42.5 | 76.4 | 7.5 | 100 | 100 |
| Total number of pigs | 5 691 | 4 | 1 158 028 | 62976 | 1 066 601 | 92447 | 295 661 | 2460 | 2 525 961 | 157 887 |
| Percentage of pigs | 0.2 | <0.01 | 45.8 | 39.9 | 42.2 | 58.6 | 11.4 | 1.5 | 100 | 100 |

[1] Group 1: small fatteners (no breeding pigs and less than 10 other pigs), Group 2: large fatteners (no breeding pigs, at least 400 other pigs), Group 3: large breeder-fatteners (at least 400 other pigs and 100 breeding pigs), Group 4: other farms

**Table 2.3** Number of farms and number of pigs per classification group[1] in the whole population (Pop.) and in the study sample (Samp.) of breeding pig farms. The whole population figure is based on the data collected in 2010 for England, Scotland and Wales. The sample is based on the farms visited in Great Britain between 2015 and 2016.

| | Group a Pop. | Group a Samp. | Group b Pop. | Group b Samp. | Total Pop. | Total Samp. |
|---|---|---|---|---|---|---|
| Number of breeding pig farms | 2 698 | 6 | 3 512 | 22 | 6 210 | 28 |
| Percentage of breeding pig farms | 43.4 | 21.4 | 56.6 | 78.6 | 100 | 100 |
| Number of breeding pigs | 106 668 | 5 658 | 367 782 | 8 755 | 474 450 | 14 413 |
| Percentage of breeding pigs | 22.5 | 39.3 | 77.5 | 60.7 | 100 | 100 |

[1] Group a: breeding only, Group b: breeding-fattening farms

### *2.4.2 Description of the sample of farms and connection of the data sources*

We recruited 46 farms for the study (18 specialized fatteners (weaners & fatteners or fatteners only), 22 breeder-fatteners & 6 specialized breeders), providing one sample of 40 fattening pig farms and one sample of 28 breeding farms, with 22 farms (breeders-fatteners) that were included in both categories. From the 1000 farms initially sampled, only 902 were present in the AHDB dataset. Only, 35 farms recruited by the stratified random sampling consented to participate in our study; this was lower than the expected participation. Five additional fattening farms were recruited by advertising online on the National Pig Association (NPA) website or contacted because they were involved in a previous study. Twenty-two breeding farms were recruited from the fattening pigs sample and 6 breeding farms were additionally recruited through advertising or directly contacted. Of the 40 fattening farms in the final study sample, only 28 could be identified by AHDB in the Real Welfare and BPHS databases.

Among the 46 farms (fattening pig farms and breeding pig farms), 16 farms had other animals: 14 had sheep or lambs, 10 had beef or cattle and one had poultry. The description of herd characteristics (first part of the questionnaire) is reported in Table 2.4. None of the variables related to herd characteristics were normally distributed. As would be expected, there were strong inter-correlations between the number of boars, the number of breeding pigs, weaner pigs and number of employees ($r > 0.6$, $P < 0.05$), but the number of employees was not correlated to the number of fattening pigs or to the number of years of experience of the farmer ($r < 0.3$, $P > 0.05$).

**Table 2.4** Description of the herd characteristics for the study sample of fattening and breeding pig farms in Great Britain.

| | | | | | |
|---|---|---|---|---|---|
| | Fattening pig farms [1] | | | | |
| | mean | SD | median | min | max |
| Number of breeding pigs | 219 | 269 | 105 | 0 | 1000 |
| Number of weaners | 1166 | 1194 | 904 | 0 | 4600 |
| number of fattening pigs | 2003 | 1397 | 1700 | 2 | 6200 |
| Number of boars | 3 | 4 | 3 | 0 | 15 |
| Years of experience | 30 | 13 | 30 | 2 | 60 |
| Number of employees (FTE) | 2.8 | 1.7 | 2 | 0.6 | 7 |
| | Breeding pig farms [2] | | | | |
| | mean | SD | median | min | max |
| Number of breeding pigs | 515 | 370 | 435 | 85 | 1700 |
| Number of weaners | 1776 | 1443 | 1500 | 0 | 5400 |
| Number of fattening pigs | 1553 | 1567 | 1425 | 0 | 6200 |
| Number of boars | 8 | 7 | 6 | 3 | 33 |
| Years of experience | 31 | 12 | 30 | 3 | 60 |
| Number of employees (FTE) | 4.0 | 1.6 | 4.0 | 1.5 | 7 |

[1] 40 fattening pig farms (specialized fatteners and breeder-fatteners)

[2] 28 breeding pig farms (specialized breeders and breeder-fatteners)

### 2.4.3 Inter-relationships between biosecurity scores, health indicators, welfare outcomes and production performance.

#### 2.4.3.1 Description of biosecurity scores, health indicators, welfare outcomes and production performance.

The different biosecurity scores for all pig farms (breeding farms and fattening pig farms) are presented in Table 2.5. The total biosecurity score ranged from 40.1 to 89.5 (on the scale of 0 to 100). The highest mean sub-category score was for score A (purchase of animals and semen) and the lowest mean score was for score H (farrowing period).

**Table 2.5** Description of Internal, External biosecurity score, their respective sub-category scores and the total biosecurity scores for a sample of fattening and breeding pig farms in Great Britain visited in 2015-16.

| | Fattening pig farms (n=40) | | | | | Breeding pig farms (n=28) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | mean | SD | median | min | max | mean | SD | median | min | max |
| A. Purchase of animals and semen [1] | 92.1 | 9.31 | 95.7 | 72.8 | 99.8 | 90.8 | 10.6 | 96.7 | 73 | 99.8 |
| B. Transport of animals, removal of manure/dead animals [1] | 76.4 | 11.3 | 78.3 | 41.6 | 95.7 | 77.3 | 10.6 | 78.7 | 54 | 95.7 |
| C. Feed, water and equipment supply [1] | 55.9 | 21.8 | 53.6 | 14.3 | 100 | 55.0 | 23.4 | 51.8 | 14 | 100 |
| D. Personnel and visitors [1] | 63.5 | 19.9 | 64.7 | 14.7 | 100 | 66.3 | 20.8 | 67.6 | 18 | 100 |
| E. Vermin/bird control [1] | 67.3 | 21.5 | 72.8 | 27.3 | 100 | 61.4 | 21.8 | 63.7 | 27 | 100 |
| F. Environment and region [1] | 85.9 | 19.3 | 85 | 10 | 100 | 88.2 | 15.2 | 90.0 | 30 | 100 |
| **External biosecurity score** | 74.5 | 7.89 | 74.8 | 54.5 | 90.5 | 74.4 | 6.95 | 74.8 | 55 | 84.5 |
| G. Disease management [2] | 80.3 | 20.7 | 80 | 0 | 100 | 80.0 | 21.8 | 80.0 | 0 | 100 |
| H. Farrowing period [2] | 27.9 | 26.4 | 33.9 | 0 | 78.5 | 43.1 | 18.4 | 39.3 | 0 | 67.8 |
| I. Nursery [2] | 43.2 | 32 | 53.6 | 0 | 89.3 | 57.2 | 23.8 | 60.7 | 0 | 89.3 |
| J. Fattening pigs [2] | 56.7 | 36.3 | 78.5 | 0 | 100 | 47.4 | 36.6 | 42.8 | 0 | 100 |
| K. Measures between compartments and the use of equipment [2] | 49.3 | 18.3 | 46.4 | 14.3 | 100 | 45.6 | 15.4 | 46.4 | 17.9 | 85.7 |
| L. Cleaning and disinfection [2] | 66.8 | 24.5 | 72.5 | 0 | 100 | 59.2 | 24.1 | 61.3 | 0 | 95.0 |
| **Internal biosecurity score** | 60.5 | 14.4 | 59.6 | 25.7 | 89.9 | 55.9 | 12.0 | 57.1 | 29.0 | 87.0 |
| **Total biosecurity score** | 67.5 | 10 | 68.3 | 40.1 | 89.5 | 65.1 | 8.15 | 65.4 | 43.8 | 83.8 |

[1] External biosecurity sub-categories

[2] Internal biosecurity sub-categories

For the fattening pig farms, the mean **ADG, FCR** and **MOR** were 772(±104) g/day, 2.45(±0.39)kg of feed/kg of weight gain and 3.6(±1.5)% respectively. For the breeding pig farms, the mean piglets born (**PB**), piglets born alive (**PBA**) and piglets weaned (**PW**) per litter were 13.67(±0.88), 12.89(±0.73) and 11.47(±0.74) respectively. The description of the mean prevalence of the welfare outcomes for 2015-2016 is reported in Table 2.6.

**Table 2.6** Number of pigs assessed and prevalence (%) of pigs requiring hospitalisation, lame pigs, pigs with severe tail lesions and severe body marks for 2015-16 in the study sample of fattening pig farms (n=28).

| | mean | SD | median | min | max |
|---|---|---|---|---|---|
| Number of pig assessed* | 3028 | 2208 | 2840 | 300 | 8858 |
| Pigs requiring hospitalization (%) | 0.03 | 0.04 | 0 | 0 | 0.14 |
| Lameness (%) | 0.1 | 0.23 | 0 | 0 | 0.91 |
| Severe tail lesions (%) | 0.23 | 0.43 | 0 | 0 | 1.51 |
| Severe body marks (%) | 0.23 | 0.31 | 0.11 | 0 | 1.04 |

*For units of 300 finisher places or less, a minimum of 300 pigs should be sampled each year; for units of 900 finisher places or more, a total of 900 pigs should be sampled per year; for units of 300-900 finisher places, a representative proportion should be sampled per year: 30% on an average.

The mean prevalence of the different lesions recorded in BPHS data during the two years of the farm visits (2015 and 2016) and the mean lesion scores for enzootic pneumonia, Pleurisy and Papular dermatitis are reported in Table 2.7. The two most common lesions were enzootic pneumonia (*ep*) and Pleurisy (*pl*), recorded in 15.30 and 4.72 % respectively of pigs assessed.

**Table 2.7** Prevalence (%) of the 13 pathologies recorded in BPHS data and mean scores of Enzootic pneumonia, Pleurisy and Papular dermatitis for a sample of fattening pig farms in Great Britain visited in 2015-16 (n=28).

| | mean | SD | median | min | max |
|---|---|---|---|---|---|
| EP-like lesions (%) | 15.30 | 11.65 | 12.61 | 0 | 52.17 |
| Pleurisy(%) | 4.72 | 5.75 | 3.00 | 0 | 28.78 |
| Pericarditis(%) | 1.79 | 1.12 | 1.55 | 0 | 4.65 |
| Peritonitis(%) | 0.15 | 0.28 | 0.01 | 0 | 1.10 |
| Milk spots(%) | 0.05 | 0.12 | 0.00 | 0 | 0.45 |
| Hepatic Scarring(%) | 1.40 | 2.46 | 0.38 | 0 | 9.18 |
| Papular Dermatitis(%) | 1.30 | 4.07 | 0.00 | 0 | 17.35 |
| Tail-bitten(%) | 0.67 | 1.99 | 0.00 | 0 | 8.19 |
| Viral-type distribution(%) | 0.17 | 0.35 | 0.00 | 0 | 1.30 |
| Pleuropneumonia - Acute(%) | 0.12 | 0.19 | 0.00 | 0 | 0.65 |
| Pleuropneumonia - Chronic(%) | 0.08 | 0.21 | 0.00 | 0 | 1.08 |
| Abscess(%) | 0.16 | 0.25 | 0.02 | 0 | 1.17 |
| Pyaemia(%) | 0.08 | 0.15 | 0.00 | 0 | 0.50 |
| Score Enzootic Pneumonia[1] | 3.11 | 2.86 | 2.69 | 0 | 14.17 |
| Score Pleurisy[1] | 0.11 | 0.10 | 0.09 | 0 | 0.45 |
| Score Papular Dermatitis[1] | 0.04 | 0.12 | 0.00 | 0 | 0.58 |

[1]ep score is scored (0-55), pl score is scored (0-2) and pd score is scored (0-3) according to the severity of the lesions.

#### *2.4.3.2 Associations between biosecurity scores and farm types*

The only scores which were normally distributed (Shapiro-test P>0.05) were internal biosecurity score, external biosecurity score, total biosecurity score, score C (feed, water and equipment supply) and score D (Personnel and visitor). The correlations between different biosecurity scores for the fattening farms are reported in Appendix A.1, and those for the breeding farms in Appendix A.2. External biosecurity score was strongly correlated to scores for the sub-categories: B. Transport of animals, removal of manure/dead animals; C. Feed, water and equipment supply; D. Personnel and visitor (P<0.05, r>0.6). Total biosecurity and internal biosecurity scores were strongly correlated and were also strongly correlated to external biosecurity score and scores for the sub-categories: J. Fattening pigs; K. Measures between compartments and the use of equipment; L. Cleaning and disinfection (P<0.05, r>0.6).

The total biosecurity score was 6.2/100 units lower when other animals were present in the herd (P<0.05). After the stepwise backward selection procedure, no other farm characteristic variables were included in the final model. Only borderline results were found for internal biosecurity. The internal biosecurity score tended to be 8.1 units lower when other animals were present in the herd (P=0.056) and increased by 0.3 when the fattening pig herd size increased by 100 (P=0.054). No significant association was identified between the external biosecurity scores and farm characteristics (P>0.05). Regarding the influence of farm type on biosecurity scores, the univariate analysis showed a borderline result with higher internal biosecurity score for the farms with fatteners only (P=0.06); more likely to be all-in/all-out (AIAO). However, the farm types were not significantly different when other variables were considered (Table 2.8).

**Table 2.8** Internal (INT), external (EXT) and total (TOT) biosecurity scores for the different types of farm. The scores are out of a maximum of 100 for a sample of pig farms in Great Britain visited in 2015-16.

| | Breeders weaners & fatteners | Breeders only or breeders & weaners | Weaners & fatteners | Fatteners only |
|---|---|---|---|---|
| EXT | 73.0(±7.17) | 79.3(±2.86) | 74.1(±12.22) | 75.4(±6.01) |
| INT | 55.3(±13.3) | 58.1(±5.42) | 66.0(±20.63) | 69.3(±7.96) |
| TOT | 64.2(±8.87) | 68.7(±2.97) | 70.0(±16.11) | 72.3(±5.13) |

#### *2.4.3.3 Associations between biosecurity scores, health indicators, welfare outcomes and production performance for fattening and breeding pig farms*

The correlations between production performance, biosecurity scores recorded during the farm visits and the mean prevalence for health indicators and welfare outcomes for 2015-2016 are reported in Appendix A.3 for the fattening herds and in Appendix A.4 for the breeding herds in the supplementary file. In fattening herds, the percentage of mortality was strongly correlated to the percentage of lameness (r=0.67, P<0.05), the percentage of enzootic pneumonia (*ep*) was strongly correlated to the percentage of pleurisy(*pl*) (r=0.66, P<0.05), the *ep score* was strongly correlated to the percentage of *ep* (r=0.79, P<0.05), the *pl score* was strongly correlated to the percentage of *pl* (r=0.9, P<0.05), the percentage of peritonitis was strongly correlated to the percentage of papular dermatitis (r=0.64, P<0.05), the percentage of hepatic scaring was strongly correlated to the percentage of tail-bitten pigs (r=0.62,P<0.05), the percentage of abscess was strongly correlated to the percentage of pyaemia (r=0.62,P<0.05). In breeding herds, the number of piglets born, the number of piglet born alive and the number of piglet weaned were strongly inter-correlated (r>0.6, P<0.05). All non significant correlation coefficients are reported in Appendix A.3, A.4, A.5 & A.6.

A PCA was used to assess the association between biosecurity scores, health indicators, welfare outcomes and production performance for fattening pig farms. The plot of the PCA on the 2 first components for the farms and the variables is presented in Figure 2.2. The first component explained 31.33% of the total variance and the second component 23.66% of the total variance, giving a cumulative percentage of inertia for the 2 first components of 54.99%. The biosecurity scores, the number of fattening pigs and production performance were grouped together on the right side of the PCA plot while the percentages of lameness, pigs requiring hospitalization and mortality were grouped on the upper side, the percentage of severe body marks and tail lesions were grouped on the left side and the percentage of enzootic pneumonia and pleurisy on the lower side. A partition in 3 clusters was inferred from the length of the branches of the dendogram and can be visualized on Figure 2.2.

Cluster 1 had lower external, internal and total biosecurity scores compared to clusters 2 and 3 (P≤0.05). Cluster 1 had higher prevalence of peritonitis than cluster 2. Cluster 1 had lower (better) FCR, a smaller number of fattening pigs in the unit and higher prevalence of severe tail lesions and severe body marks compared to cluster 3 (P≤0.05). Cluster 2 had higher mortality and prevalence of lameness than cluster 3 (P≤0.05). Cluster 3 had higher ADG than cluster 1 and cluster 2 (P≤0.05). The variables hosp, ep, pl, tail, pc, ms, hs, pd, viral, ppa, ppc, abscess, pyaemia were not significantly different between the three clusters (P>0.05) (Table 2.9).

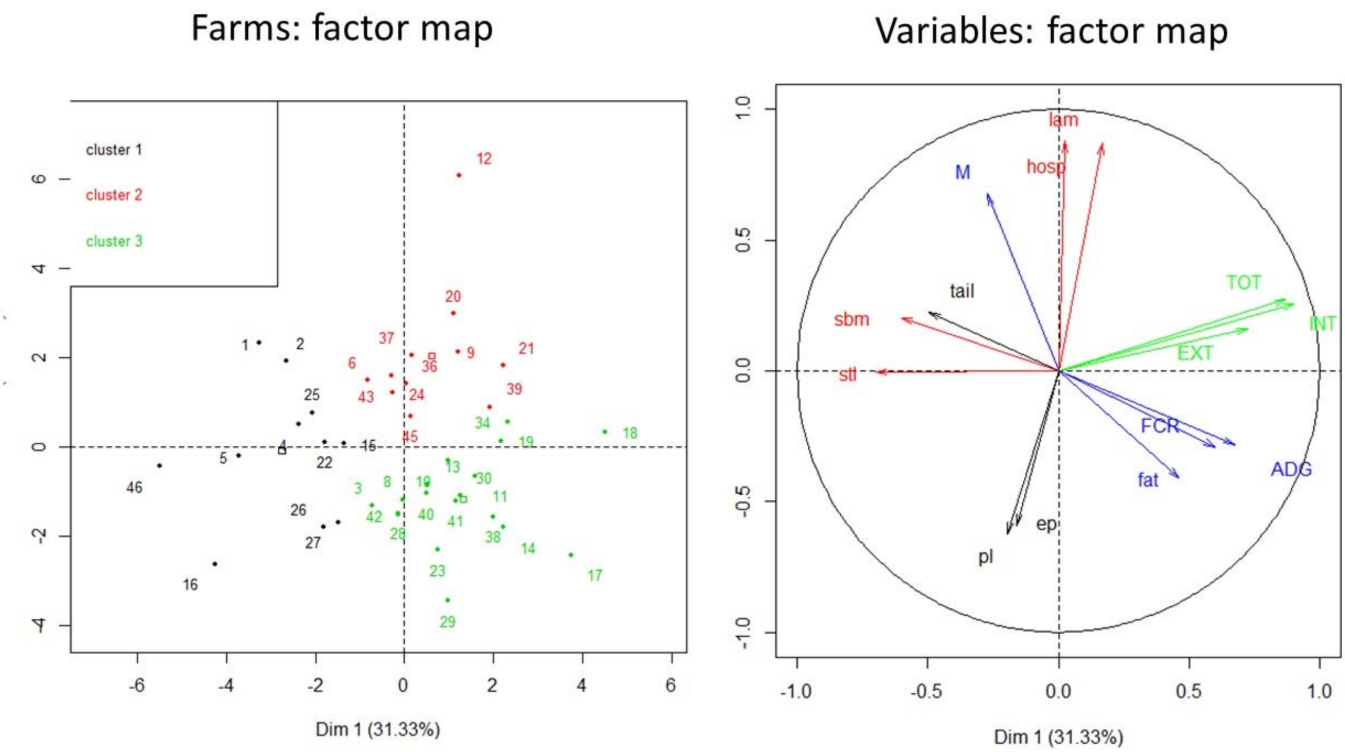



**Figure 2.2** On the right, the PCA plot of the fattening farms (individual farms) and the variables on the two first components (CP1: 31.33%, CP2: 23.66%) shows the inter-connections between the variables that tend to be close to each other on the plot. Biosecurity (external (EXT), internal (INT), total (TOT) biosecurity) is represented in green. The number of fattening pigs (fat) and the performance (average daily gain (ADG), feed conversion ratio (FCR), mortality (MOR)) are represented in blue. Welfare outcomes (% pigs requiring hospitalization (hosp), lame pigs (lam), pigs with severe tail lesions (stl), severe body marks (sbm)) are represented in red. Health indicators (% of enzootic pneumonia -like lesions (ep), pleurisy (pl), tail-bitten lesions (tail)) are represented in black. On the left, the hierarchical clustering based on the result of the PCA confirmed the partition of the farms into 3 clusters as the partition with the higher relative loss of inertia.

**Table 2.9** Mean and standard deviation of biosecurity scores, health indicators, welfare outcomes and production performance and of the study sample of fattening pig farms in Great Britain according to three clusters derived from the PCA analysis (based on the active variables).

| | cluster 3 (n=18) | | cluster 2 (n=11) | | cluster 1 (n=11) | |
|---|---|---|---|---|---|---|
| | mean | SD | mean | SD | mean | SD |
| **Active variables** | | | | | | |
| No. fattening pigs | 2733[b] | 1513 | 1578 [a,b] | 1220 | 1232[a] | 646 |
| Average daily weight gain | 834[b] | 60 | 734[a] | 54 | 718[a] | 46 |
| Feed conversion ration | 2.55[b] | 0.46 | 2.44[a,b] | 0.19 | 2.15[a] | 0.17 |
| Mortality | 2.82[b] | 0.71 | 5.22[a] | 1.18 | 3.96 [a,b] | 1.64 |
| No. pig requiring hospitalization | 0.01 | 0.03 | 0.12 | 0.02 | 0.03 | 0.04 |
| No. lameness | 0.02[b] | 0.05 | 0.62[a] | 0.42 | 0.05 [a,b] | 0.06 |
| No. severe tail lesions | 0.03[b] | 0.06 | 0.29 [a,b] | 0.18 | 0.63[a] | 0.64 |
| No. severe body marks | 0.08[b] | 0.13 | 0.09 [a,b] | 0.02 | 0.58[a] | 0.35 |
| External biosecurity score | 77[b] | 8 | 76[b] | 5 | 68[a] | 8 |
| Internal biosecurity score | 65[b] | 13 | 70[b] | 10 | 46[a] | 12 |
| Total biosecurity score | 71[b] | 9 | 73[b] | 6 | 57[a] | 9 |
| Enzootic pneumonia | 16.49 | 13.11 | 9.43 | 4.41 | 21.08 | 12.62 |
| Pleurisy | 5.33 | 7.17 | 1.95 | 1.30 | 6.45 | 5.64 |
| No. tail-bitten pigs | 0.26 | 0.86 | 0.07 | 0.14 | 2.28 | 3.69 |
| **Supplementary variables** | | | | | | |
| Pericarditis | 1.85 | 1.22 | 1.60 | 1.04 | 2.14 | 0.89 |
| Peritonitis | 0.12[a,b] | 0.15 | 0.01[b] | 0.04 | 0.42[a] | 0.46 |
| Milk spots | 0.06 | 0.12 | 0.01 | 0.04 | 0.07 | 0.17 |
| Hepatic scarring | 0.86 | 1.15 | 0.33 | 0.60 | 3.01 | 4.11 |
| Papular dermatitis | 0.97 | 3.50 | 0.00 | 0.00 | 3.65 | 6.67 |
| Viral-type distribution | 0.25 | 0.43 | 0.12 | 0.33 | 0.09 | 0.17 |
| Pleuropneumonia - Acute | 0.14 | 0.19 | 0.00 | 0.00 | 0.22 | 0.26 |
| Pleuropneumonia - Chronic | 0.15 | 0.30 | 0.01 | 0.02 | 0.03 | 0.05 |
| Abscess | 0.25 | 0.33 | 0.04 | 0.10 | 0.14 | 0.13 |
| Pyaemia | 0.12 | 0.19 | 0.02 | 0.04 | 0.09 | 0.12 |

[a,b] means in the same row with different letters are significantly different ($P<0.05$)

## 2.5 Discussion

Our study aimed at identifying possible connections between on-farm data and large scale industry databases holding information about health and welfare for commercial pig farms in Great Britain. During farm visits, we collected data about pig performance and assessed the level of biosecurity in fattening and breeding farms. Subsequently, we sought to provide a global overview of the connections between biosecurity, health, welfare and performance by identifying the associations between these data and the mean prevalence of welfare outcomes from the Real Welfare Scheme and health indicators from the BPHS scheme.

### *2.5.1 Sampling and the challenge of connecting different databases*

Secondary data analyses were used in this study, as direct implementation for such a study would have been logistically and financially impossible within the time contraints of this study (Smith et al., 2011b Goodwin et al., 2012). Data about pig health and welfare are regularly recorded by the Real Welfare and BPHS scheme for the purpose of informing farm management decisions and aiding farm improvement, and cover a large majority of the fattening pig farms in Great Britain (BPHS, 2008; Pandolfi et al., 2017). Our study illustrates the challenge of connecting these data sources with data collected on-farm and the complexity of designing a random sampling from the whole population of pig farms.

The target of most studies is to analyse a sample representative of the population (Fox et al., 2009). Targeting to select the intensive pig farms with the larger herds, we decided to use a stratified random sampling proportionate to the number of fattening pigs produced in each stratum. However, in our final study, selection biases can be identified. Despite the possibility to select a stratified random sampling from the full database of pig farms in Great Britain, we were not able to access the farm identification and address for confidentiality reasons. As a consequence, a first selection bias occurred due to the exclusion of all farms not registered in the AHDB database (the registration is not mandatory, AHDB is independent of both commercial industry and of Government), which was a requirement to be able to invite farmers to participate in our study. Another selection bias was due to a very high percentage of pig farmers who did not reply to the invitation or declined to participate. Indeed, farmers are regularly approached to participate in different studies which may be time-consuming and in which they might not be interested. This level of non-response reduced the level of precision and increased the risk of non-representativeness (Toma et al., 2010). Higher response rates have been achieved in other agricultural studies involving pig farms (Nöremark et al., 2013; Laanen et al., 2014), but, in these studies, the farmers were not pre-selected from the whole national population. Moreover, the length of the biosecurity questionnaire, followed by a mandatory farm visit, might have dissuaded some farmers from participating. This illustrates the difficulty to implement a detailed and time consuming survey in a population of farmers previously unknown. Connecting the data collected to the BPHS and Real Welfare database resulted in additional selection bias, as only 28 of the 40 fattening pig farms who participated could be found in both databases. This highlights the considerable room for improvement in organisation of industry data needed in order to conduct secondary data analysis about pig farms based on several data sources. We succeeded to recruit farms of interest (large breeders-fatteners or specialized fattening pig farms with larger herds which produce most of the fattening pigs in Great Britain), but the final sample size was limited. Our results should therefore only be extrapolated with care to the whole population of pig farms. The outcome highlights the need in studies of this nature to find an optimal balance between the quantity of information per farm and the sample size. Considering the value of the output that could be produced, improving the possible connection between different data sources would be of great benefit for the pig industry in the UK.

### *2.5.2 Biosecurity in fattening and breeding herds*

The characteristics of the study farms in relation to the health and welfare indicators have been described in previous papers (Sanchez-Vazquez et al., 2012 ; Pandolfi et al., 2017a, b), and the results for our sample were consistent with these reports. However, Biocheck.UGent™ was used for the first time in the UK. Biosecurity comprises a set of measures targeting the protection of pig herds from the introduction and spread of infectious diseases (Amasset al., 1999; Beal et al., 2008; Boklund 2009; FAO, 2010). This tool has previously been used in different farm studies and several other countries (Laanen et al., 2010, 2013; Postma et al., 2016a,b), and its reliability to quantify and compare biosecurity between pig herds has been demonstrated by Laanen et al. (2010). Our study suggests room for improvement in certain measures of biosecurity for pig farms in Great Britain compared to other countries but also within British herds since there were some farms with lower scores than the others. Moreover, the mean internal biosecurity score was lower than the mean external biosecurity score, as in previous studies (Laanen et al., 2013; Backhans et al., 2015; Postma et al., 2016a), and the scores for some sub-categories of the internal biosecurity score were lower compared to others. This illustrates the possible improvement that can be made through better cleaning and disinfection around farrowing and in the nursery, and through the implementation of biosecurity measures between compartments to avoid disease spreading inside the farm. A higher external biosecurity score can be explained because the farmers were generally aware about the risk of contamination and the threat of diseases from outside the farms, especially for the diseases regulated by control programs (Casal et al. 2007; Nöremark et al., 2016. In contrast, the lower internal biosecurity score indicates that the risk of contamination inside the farm, arising through daily management practices, seemed to be underestimated by the farmers. Garthford et al. (2013) showed that there is little concern about risk from unseen diseases. Vets should use their authoritative position to promote better internal biosecurity and good awareness of disease risks by transferring knowledge about biosecurity (Garthford et al., 2013, Laanen et al., 2014), and special attention should be given when other animals are present in the farm as this was associated with lower biosecurity scores.

In the univariate analyses, internal biosecurity scores were higher for larger herds of fattening pigs and specialized fattening farms, while total biosecurity score was strongly correlated to measures between compartments and the use of equipment, and cleaning and disinfection, suggesting a good AIAO system for the farms that obtained a higher total biosecurity score. Generally, specialized fattening pig herds are more likely to have larger pig herds and to adopt an AIAO system, which contributes to good biosecurity (FAO, 2010; Marquer et al., 2014; Niemi et al., 2016). However, internal biosecurity was not significantly different for specialized fattening farms in the multivariate analysis; pointing to the influence of other factors, such as stockmanship or age of the building or type of equipment. This suggests room for improvement of the level of biosecurity which does not depend only on farm type.

Breeding farms had lower internal biosecurity compared to fattening pig farms. The total biosecurity score of breeding farms was strongly correlated to the internal biosecurity score and the cleaning and disinfection scores, suggesting that hygienic measures were the cornerstone of the breeding farms achieving a high level of biosecurity. Measures between compartments and the use of equipment, which largely refer to piglet manipulation, mixing of piglets from different sources, proper use of overalls, cleaning of boots, hands and materials (Laanen et al. 2013), had one of the lowest scores, highlighting areas where farms could seek biosecurity improvement (Postma et al., 2016a).

The type of building may impair the implementation of internal biosecurity measures such as AIAO or an increase of space allowance, and the perceived cost of the biosecurity measures might also influence the likelihood of adopting these measures (Niemi et al, 2016). Several studies have shown the reluctance of the farmers to adopt certain measures considered to be difficult to implement or with lack of trust in their effectiveness or relevance (Gunn et al., 2008; Heffernan et al., 2008), but the increase of awareness regarding specific biosecurity measures should encourage the popularization of all biosecurity measures or any beneficial changes in the management. Despite possible structural limitations, Laanen et al. (2013) suggest that the improvement of internal biosecurity constitutes a good starting point, which was confirmed by this study. Indeed, internal biosecurity also had a lower score compared to external biosecurity.

### *2.5.3 The inter-connections between biosecurity, health, welfare and performance*

The results of correlation coefficients and the PCA were used in combination to understand the interconnection between biosecurity, health, welfare and performance.

#### *2.5.3.1 The inter-connections between health and welfare*

Several expected intra-category correlations for welfare outcomes and health indicators were identified. Previous studies have highlighted the connection between different pig pathologies (Sanchez-Vazquez et al., 2012) and different welfare outcomes (Munsterhjelm et al., 2015a; Pandolfi et al., 2017b). Prevalence of enzootic pneumonia and pleuritic lesions were highly correlated in the present dataset; similar risk factors and associations between *ep* and *pl* have been reported in several studies (Jager et al., 2009, 2012; Sanchez-Vazquez et al., 2010; Meyns et al., 2011). However, none of these lung lesions had a strong correlation with the other, less prevalent, health indicators. This is not surprising as all these health conditions might have different risk factors and result from different pathogens.

Our results showed that a higher level of tail biting could be concomitantly identified by the two different schemes (BPHS, Real Welfare), suggesting a certain accuracy to identify on-farm tail-biting problems in abattoir screening. All welfare outcomes measured on farm were correlated to some of the BPHS lesions, suggesting potential common risk factors or biological connection between health and welfare (Sanchez-Vazquez et al., 2012). The prevalence of lameness and severe tail lesions was associated to the prevalence of EP-like lesions. Previous studies have demonstrated that the prevalence of tail lesions tends to increase the risk of infection leading to acute phase protein elevation and abscesses (Heinonen et al., 2010) and lung lesions (Van Staaveren et al., 2015). The prevalence of pyaemia was correlated to the prevalence of severe tail lesions, but also lameness and severe body marks. The economic impact of pyaemia has been discussed in the literature and it has been reported as an important cause of condemnation at the slaughterhouse (Chiew et al., 1991). Our study suggests that the prevalence of pyaemia could also be used as a proxy to alert to possible on farm welfare issues; as suggested by Sanchez-Vazquez et al., (2012) the presence of one pathology could motivate investigations for other issues.

#### *2.5.3.2 The interconnections between health, welfare and performance*

The positive correlation identified between **FCR** and **ADG** values was unexpected as better growth rates are usually associated with more efficient conversion of food to gain. However, the interaction between feed composition and environment on ADG and FCR does not preclude such a relationship (Douglas et al., 2015). The classification of the farms in different clusters and the correlations between variables enabled us to identify connections of parameters of health, welfare with performance. The percentage of carcasses showing EP-like lesions, pleurisy, peritonitis and tail-biting was higher for cluster 1 farms which also had lower **ADG**, although the differences were only statistically different between clusters for peritonitis. However, negative correlations were also found between pleurisy and **ADG.** A lower prevalence of EP-like lesions and pleurisy has been associated to lower performance in previous studies (Noyes et al; 1990; Regula et al., 2000; Sanchez-Vazquez et al., 2011; Brewster et al., 2017) and confirms the connection between respiratory problems and poor pig performance. However, no associations were identified in the present study between BPHS lesions and mortality, as was also the case in a previous study where antibiotic usage was used as a health indicator (Postma et al., 2016b).

Stressors in the environment and stockmanship might impact productivity and animal welfare (Hemsworth, 2003), showing the closepossible interaction between environment, welfare and productivity. Farms in cluster 1, with the lowest **ADG,** also tended to have a higher prevalence of welfare issues, such as the proportion of pigs with severe body marks and tail lesions. This confirms the results of Sinisalo et al. (2012), who identified a better ADG for pigs without tail lesions and might explain the connection between lower welfare and economic losses (Harley et al., 2012). Moreover, a higher prevalence of lameness and pigs requiring hospitalization was correlated to higher mortality. The connection between welfare indicators and production performance is encouraging, as it suggests welfare improvement will not necessarily jeopardize performance. Better performance leading to better economic results has been identified as the main incentive to participate in a quality assurance scheme, while the distrust in economic advantages was the main barrier not to participate in these schemes (Bock and Van Huik, 2007).

#### *2.5.3.3 The inter-connections between biosecurity and health, welfare and performance*

The farms from cluster 1, with lower **ADG** and higher prevalence for some welfare and health indicators compared to the other clusters, also had lower biosecurity scores. Biosecurity appears of great importance to maintain good production results, health and welfare and, by extension, to protect the economy, the environment and the public health (Beale et al., 2008; Pritchard et al., 2005). A recent study showed that improvement of external and internal biosecurity, achieved over a period of several months, and better herd management have led breeding farms to reduce antibiotic usage and increase the number of piglets weaned (Postma et al., 2016a, 2017). This supports the idea that biosecurity should be a core objective of the pig industry. Several studies have shown that improvement in biosecurity, such as by implementing an AIAO system with good cleaning and disinfection, had beneficial impact on disease control and pig health (Scheidt et al. 1990; Amass and Clark., 1999; Andres et al., 2015; Postma et al, 2016a). Moreover, a cost reduction and decline in the percentage of mortality were achieved in another study after implementing biosecurity measures and reducing antibiotic usage (Rojo-Gimeno et al., 2016). The negative correlation between *ep, pl, hs, tail, ppa*, *abscess* and internal biosecurity in the present study further highlights the importance of a good biosecurity to reduce health issues.

In the present study, a higher total biosecurity score was significantly and positively correlated to **ADG**, **PBA** and **PW**. The level of biosecurity was associated to the number of piglets weaned in the study of Postma et al. (2016a), but not in the study of Backhans et al. (2015). Similarly to health indicators, biosecurity was not correlated to the percentage of mortality. A correlation between biosecurity and mortality was found in the study of Maes et al. (2004), but not in the most recent study of Laanen et al. (2013). Despite a high level of biosecurity in cluster 2, a higher level of mortality in fattening pigs was identified. This suggests that the increase of mortality is not only the consequence of infection, but may result from multiple factors.

Previous studies showed better welfare when internal biosecurity measures, such as reducing stocking density, have been implemented (Cornale et al., 2015; Munsterhjelm et al., 2015b). Moreover, good management and appropriate infrastructures in intensive systems are key elements for better welfare (Gade, 2002), just as for implementing biosecurity measures (Laaneen et al., 2013). Farms from cluster 1 with low biosecurity and higher level of severe tail lesions and body marks had lower performance, confirming that poor animal welfare tends to appear in a context of lower biosecurity. Surprisingly, farms from cluster 3 with good biosecurity score had a higher level of pigs requiring hospitalization and lameness. Moreover, higher biosecurity scores were correlated overall to a higher prevalence of pigs requiring hospitalization, suggesting that good management of hospital pens cannot be inferred from a good biosecurity level, and that other factors like stockmanship and good management practices might have a great impact on animal welfare (Hemsworth, 2003). Our analysis also showed that an increase in internal biosecurity score was associated with a reduction of prevalence of severe tail lesions. These observations confirm previous results where a higher biosecurity level was associated with healthier animals and better welfare (Postma et al., 2016a,b).

## 2.6 Conclusions

This study highlights the challenges associated with connecting different data sources and conducting relevant analysis for the livestock (pig) industry.

Pig farmers prioritise internal biosecurity, which was generally lower and strongly connected to the overall level of biosecurity. While the biosecurity can be improved by taking further measures or adopting new habits, this study also suggests possible limitations in farm infrastructures which do not allow the implementation of AIAOand a small impact of biosecurity regarding issues like mortality, prevalence of lameness and pigs requiring hospitalization.

The associations identified between health indicators, welfare outcomes and production performance appear as a compelling reason to consider the improvement of animal welfare asone of the main objective of the pig industry. Facilitating the data collection and the connections between different sources of information related to biosecurity, health, welfare and performance would be of importance for the pig industry. This could be beneficial to determine the priority measures that should be adopted to sustain effective pig production.

# Chapter 3 The “Real Welfare” Scheme: benchmarking welfare outcomes for commercially farmed pigs

## 3.1 Abstract

Animal welfare standards have been incorporated in EU legislation and in Farm Assurance schemes, based on scientific information and aiming to safeguard the welfare of the species concerned. Recently, emphasis has shifted from resource-based measures of welfare to animal-based measures, which are considered to assess more accurately the welfare status. The data used in this analysis were collected from April 2013 to May 2016 through the “Real Welfare” scheme in order to assess on-farm pig welfare, as required for those finishing pigs under the UK Red Tractor Assurance Scheme. The assessment involved five main mandatory measures (percentage of pigs requiring hospitalization, percentage of lame pigs, percentage of pigs with severe tail lesions, percentage of pigs with severe body marks and enrichment use ratio) and optional secondary measures (percentage of pigs with mild tail lesions, percentage of pigs with dirty tails, percentage of pigs with mild body marks, percentage of pigs with dirty bodies) recorded at each farm visit, with associated information about the environment and the enrichment in the farms. For the complete database, a sample of pens was assessed from 1 928 farm units. Repeated measures were taken in the same farm unit over time, giving a total of 112 240 records at pen level. These concerned a total of 13 480 289 pigs present on the farm during the assessments, with 5 463 348 pigs directly assessed using the “Real Welfare” protocol. The three most common enrichment types were straw, chain and plastic objects. The main substrate was straw which was present in 67.9% of the farms. Compared to 2013, a significant increase of pens with undocked-tail pigs, substrates and objects was observed over time ($p<0.05$). The upper quartile prevalence was <0.2% for all of the four main physical outcomes, and 15% for mild body marks. The percentage of pigs that would benefit from being in a hospital pen was positively correlated to the percentage of lame pigs, and the absence of tail lesions was positively correlated with the absence of body marks ($p<0.05$, $R>0.3$). When comparing the following years to 2013, the results of this study demonstrate a reduction of the prevalence of animal-based measures of welfare problems in mainstream herds. This is partially due to the decline over years of the prevalence of the different welfare outcomes for the farms with a prevalence above the $90^{th}$ percentile in 2013.

## 3.2 Introduction

Several different groups in society take an interest in farm animal welfare with different perspectives taken (Fraser, 2003). Animal welfare is protected by legislation under which inspections are carried out annually (European Council 1998). Additional safeguards are increasingly adopted through the mechanism of Farm Assurance Schemes, which incorporate welfare standards and adopt third-party inspection procedures to verify compliance (Veissier *et al.,* 2008) to create a brand based on the 'best' animal health and welfare standards. Historically, both legislation and Assurance Schemes have adopted resource-based measures of welfare but limitations appear when it comes to understanding the true welfare state of individual animals (Webster et al., 2004). For this reason, there has been a growing trend for the adoption of animal-based measures, sometimes called welfare outcome measures, which rely on measurements made directly on the animals themselves irrespective of their keeping conditions (EFSA, 2012). Such measures are now recognized as a better alternative to assess animal welfare across different environments (Whay et al.*,* 2003).The application of this approach on farms was pioneered by the EU Welfare Quality® project (Blokhuis *et al.,* 2010). Farmers also place great importance on animal welfare and perceive a relationship between good welfare and good animal performance (Hubbard et al., 2007). However, on-farm assessments of welfare outcomes are subject to many practical constraints, and must be quick, cheap and sufficiently flexible to adapt to different production systems and be meaningful for the end user (Edwards, 2007). Simplified versions, relying on so-called iceberg indicators, are consequently being investigated (Heath et al.*,* 2014). Munsterhjelm et al. (2015a), by establishing the number and composition of possible sub-scales within the animal-based measures using Principal Component Analysis, showed that different animal welfare issues could be captured with a short list of animal-based measures. The British pig industry has been very proactive in consideration of animal welfare and was the first to adopt Farm Assurance at a national level (Whittemore, 1995; FAWC, 2001). In 2006 they commissioned a project to investigate the feasibility of adopting welfare outcome assessments on British pig farms (Mullan et al., 2009a, 2009b, 2011a and 2011b). Following pilot studies, a protocol was adopted as part of the Red Tractor Assurance Scheme for finisher herds. The objective of this chapter is to report the prevalence of five main welfare outcomes for the mainstream finisher pig herds of the UK (excluding hospital pens which were not recorded by the Real Welfare scheme) for the first three years of this scheme. This represents the first long term, nation-wide benchmarking of welfare outcomes for pigs – or any other species - on commercial farms at this scale. This study also describes the changes over calendar years of the different measures of welfare and the farm population involved through different variables related to farm environment and management.

## 3.3 Materials and Methods

### 3.1.3 Data and data management

The data used in this analysis were collected from April 2013 to May 2016 in order to assess on-farm pig welfare through the “Real Welfare” assessment scheme, as required for those finishing pigs under the Red Tractor Assurance Scheme. The data were collected using a standardised protocol, owned and managed by the Agriculture and Horticulture Development Board (AHDB). The welfare of the pigs was assessed by vets from 89 different veterinary practices carrying out quarterly health and welfare inspections for the Red Tractor Scheme. The data are collected to inform the farm health plan, assess animal welfare and inform pig farmers of the general trends in welfare parameters in their herds. Although the welfare outcomes themselves are not audited by scheme providers, the completion of actions agreed between the veterinarian and the producer to address any issues is included in audits. Before undertaking the additional “Real Welfare” audits, all vets underwent the same online and practical training in the assessment of the designated welfare outcomes (http://pork.ahdb.org.uk/health-welfare/welfare/real-welfare/real-welfare-vets/). The assessment involved five main measures (Appendix B.1 & Table B2), chosen after stakeholder consultation to capture the most important welfare issues for the industry, using protocols developed and piloted in a previous research project (Mullan et al., 2009a, 2009b and 2011a) which assessed the sampling strategy, the interdependence, the variation and the reliability of the outcome measures. The measures were recorded from a sample of finishing pigs from the mainstream herd (i.e. excluding those in hospital pens). The number of pens assessed at each visit and the type of pens were selected to be representative of the farm. The sampling used was a multistage sampling. At the first level, all farms that belong to the Red Tractor Assurance Scheme were sampled. At the second level, several pens were randomly selected on each farm in order to represent approximately one third of the pig places present in the farm. At the third level, all pigs in the pens were assessed for the prevalence of lameness and pigs requiring hospitalization. A random sample of pigs were further assessed for tail lesions and body marks (all pigs in the pen if there were fewer than 25 pigs, 25 pigs if there were up to 100 pigs, or 50 pigs if there were more than 100 pigs, and chosen to be representative of the pen) (Appendix B.1).

**Table 3.1** Measurements used in the assessment. Each pig in the sample selected was classified into one of the several levels for each measurement (the classification for Enrichment use only concerns the active pigs of the sample). Therefore, a proportion of pigs per pens could be calculated for each measurement. Detailed definition is given in Appendix B.2.

| Measurements for individual pigs | | Definitions |
|---|---|---|
| Pigs requiring hospitalization | | |
| | Yes | Pigs that would benefit from removal to a hospital pen |
| | No | Pigs that would not benefit from removal to a hospital pen. |
| Lame pigs | | |
| | Lame | Pigs with signs of lameness |
| | Non lame | Pigs without any sign of lameness |
| Pigs with tail lesions | | |
| | Severe | Pigs with severe tail lesions. Proportion of tail has been removed by biting or tail is swollen or held oddly, or scab covering whole tip or fresh blood visible |
| | Mild | Pigs with mild tail lesions |
| | No lesions | Pigs without any of the above lesions |
| | Dirty | Pigs dirty enough to obscure potential mild lesions |
| Pigs with body marks | | |
| | Severe | Pigs with severe body marks extending into deeper layers of skin or lesions covering a large percentage of skin |
| | Mild | Pigs with mild body marks |
| | No lesions | Pigs without any of the above body marks |
| | Dirty | Pigs dirty enough to obscure potential mild body marks |
| Enrichment use | | |
| | Enrichment | Pigs interacting with enrichment in the pen |
| | Other | Pigs interacting with other pen features or pen mates |

In addition to the welfare outcome measures, additional information about the sampled pens was also recorded during the visit, such as pen size and type, aspects of feed provision, enrichment and tail docking practices as shown in Table 3.2.

**Table 3.2** Variables collected by the veterinarians at pen level during the Real Welfare assessment.

| Variables | Categories |
|---|---|
| Pen size | small <30 pigs<br>medium ≥30 to <200 pigs<br>large ≥200 |
| Pen type | indoor (kennels, open + internal divisions or open plan)<br>outdoor (shelter + field )<br>in&outdoor (trowbridge or kennel + yard)<br>other |
| Ventilation | natural<br>powered |
| Feed form | pellets<br>meal<br>liquid |
| Feed availability | ad libitum<br>restricted |
| Feeder type | floor<br>hopper<br>trough |
| Tail docking | docked tails<br>undocked tails |
| Tail length | tail lengths ≤0.5 (pens with docked tails, smaller than half the original length)<br>tail lengths >0.5 (pens with undocked tail, tails longer than half the original length or mixed tail lengths) |
| Enrichment | substrate(s) only (straw or other substrates)<br>object(s) only (chains, plastic objects or other objects)<br>substrate(s) and object(s)<br>no enrichment |

The quantity of straw could be assessed as restricted (portions dispensed throughout the day), low (less than 5cm depth or less than 50% lying area covered), medium (depth of >5cm over 75% of lying area) and deep (covers >75% pen floor, depth 30cm+). The default qualification “medium” for the quantity of straw was used in case the quantity was not mentioned. Therefore, only the pens directly assessed by the vet without default classification were kept, leaving 74 596 pens with data on the quantity of straw. Only the farms with the mention “none seen", indicating the absence of visible enrichment in the pen at the time of the assessment, were considered as without enrichment. The mention "none seen", as distinct from a missing entry, was recorded only from June 2014 (sample of 76 002 pens).

The database was checked for mismatches and outliers. The different types of enrichment were transformed in dummy data in order to record the presence or the absence of each of the categories. From the date of the assessment, the calendar year and the season were extracted. Four seasons (Spring (March, April, May), Summer (June, July, August), Autumn (September, October, November), and Winter (December, January, February)) were identified from the date of assessment. All the measures reported in Table 3.1 were transformed into percentages, based on the total number of pigs assessed in the pen. Enrichment use was calculated as a ratio based on the following formula:

$$Enrichment\ use\ ratio = \frac{Number\ of\ active\ pigs\ interacting\ with\ the\ enrichment}{Number\ of\ active\ pigs\ interacting\ with\ pen\ features\ or\ pen\ mates\ or\ with\ the\ enrichment}$$

For the complete database, a sample of pens was assessed from 1 928 farm units. In some cases one 'farm unit' could consist of farms at several different locations. Repeated measures were taken in the same farm units over time, giving 112 240 records at pen level. These concerned a total of 13 480 289 pigs present in the farm during the assessments, with 5 463 348 pigs directly assessed using the "Real Welfare" protocol.

Over the period of scheme implementation, the recording of tail lesions and body marks underwent some changes. After an initial 8 month period, a review of the functioning of the scheme decided that the recording of the enrichment use, minor tail lesions (dirty and mild tail lesions) and minor body marks (dirty and mild body marks) should become optional. However, the recording of the severe lesions continued to be mandatory. The vet could therefore decide to report either only the severe lesions or both the minor and the severe ones. The initial period from April 2013 to November 2013 included 9 153 pen records from 1 108 farms and the database over the 4 calendar years which included pens with recording of both severe and minor lesions and body marks included 28 247 pen records from 1 293 farms.

### *3.2.3 Data analysis*

#### *3.1.1.1 Descriptive analysis of the farm characteristics and the welfare outcomes*

Data processing and data analysis was carried out using Microsoft Access Office Professional Plus 2010, Microsoft Excel Office Professional Plus 2010 and RStudio for R-3.1.0 software for Windows (64 bit). The herd size of the farms was described at farm level. For all the farms a description was undertaken at pen level for the variables related to the environment, the feed and for the different types of enrichment, since these could vary within farm. In order to investigate the association of the type of enrichment and the different measures related to environment of the pigs, Chi square tests or Fisher tests were used. A descriptive analysis was conducted for the percentage of pens and pigs with undocked tails and tails of different length. In order to better understand the association between tail docking and the different measures related to the environment of the pigs, Chi square tests or Fisher tests were used. Environmental features may be associated with tail lesions but also with tail docking, making it difficult to discriminate the independent impact of environmental features and tail docking on tail lesions. To assess the change of use of enrichment (Substrates and Objects) and the proportion of pens with undocked-tail pigs over years, Generalized Linear Mixed Models were used. In the first model, the binary variable was pens with undocked tails vs pens with mixed length tails or docked tails. The presence or absence of substrates in the pens was considered as the dependent variable in the second model and the presence or absence of objects was considered as the dependent variable in the third model. For these three models, the variable "year" was considered as a fixed effect and the farm unit was considered a random effect. A descriptive analysis was conducted for the percentage of animals showing the different levels of each measure of welfare at farm and pen level. The pens in which the minor lesions were not recorded were excluded from calculations of the mean of the dirty and mild tail lesions and body marks. However, dirty pigs might have mild lesions covered by the dirtiness, making the classification of minor lesions less exclusive. The variability between pens within the same farm was calculated as the intra-farm variance for the five mandatory welfare outcomes (lame pigs, pigs requiring hospitalization, severe tail lesions, severe body marks, enrichment ratio use). The inter-pen and inter-farm variance was also calculated for the annual rolling average to provide a wider view of the differences, instead of focussing on one specific time point which might not reflect appropriately the welfare status in the farm.

#### *3.3.2.1 Seasonal influences and annual averages of the welfare outcomes*

The changes over calendar years of the different measures of welfare were assessed with a Generalized Linear Mixed Model in an analysis performed at pen level. The variable "year" was considered as a fixed effect. The years 2014, 2015 and 2016 were compared to the year 2013. Despite the fact that we did not compare the years 2014 with 2015, 2014 with 2016 or 2015 with 2016, the value of the odds ratios provides an overview of relative differences between all years compared to 2013.The farm unit (Farm) was considered as a random effect as different pens could belong to the same farm. In order to reduce the information bias, the interaction between the veterinary practice that performed the assessment and the farm was also added as a random effect. Five different analyses were performed, considering the five mandatory welfare outcomes as dependent variables. In order to identify the changes in the measures of welfare over the different seasons, the same analyses were performed for the variable “season”. To look specifically at changes over time for farms initially having the highest prevalence of outcomes, farms with a prevalence of a specific welfare outcome above the 90th percentile in 2013 were selected separately according to each welfare outcome considered, i.e. the proportion of lame pigs, the proportion of pigs requiring hospitalization, the proportion of pigs with severe tail lesions and the proportion of pigs with severe body marks. As the values of the welfare outcomes were not normally distributed, a Friedman test was then used to assess the differences between years for these selected farms. Farm identification was used as a blocking variable. In order to understand whether individual farms showed consistency in welfare outcomes over years, Kendall’s tau-b correlations were calculated between the average percentages of each year for the main welfare outcomes.

#### *3.3.2.2 Correlation between the measures of welfare*

In order to understand the associations between the five mandatory measures of welfare, the correlation coefficients between these measures were calculated. As data were not normally distributed, Spearman's rank correlation coefficients were calculated for all the variables at pen level. The correlation between pigs with mild lesions and dirty pigs and of these with the five main measures of welfare, was performed using the whole database, but excluding all the pens without any record of the minor lesions, and separately on the database of the start-up period (April 2013-November 2013).

## 3.4 Results

### *3.1.4 Farm characteristics, enrichment and tail docking*

The population of interest included mainly pigs raised indoors. The minimum herd size (pig places) was 12 and the maximum 24 000 with a mean of 1 542. Thus, most of the farms might be considered as commercial scale pig farms: Fifty percent of the herds had 498 to 1 586 pigs in the farm unit during the visit and 1 810 holdings had ≥300 pig places. A breakdown of the housing and feeding practices in the study population is shown in Table 3.3. The three most common enrichment types were straw, chain and plastic (Table 3.4). Only 3.7% of the pigs had both enrichment types in the pens (substrates and objects) but this corresponds to 14.5% of the farms. Substrates were more common than objects with 62.0% of pigs (69% of the farms) with one or more substrates; and 31.9% of the pigs (52.5% of the farms) with one or more objects. The main substrate was straw which was present in 67.9% of the farms (Appendix B.3). For the pens where quantity was specified, 41.6% of the pigs (65.4% of the farms) had medium or deep straw quantity (Appendix B.4). Compared to 2013, a significant increase of pens with substrates was observed ($P$ <0.05) in 2014, 2015 and 2016, and this was also the case for pens with objects (Table 3.5).

**Table 3.3** Characteristics of the sample - descriptors of the environment and feeding of the pigs at pen level

| Variables | | | Number of pens | % | Number of pigs assessed | % |
|---|---|---|---|---|---|---|
| Pen type | | | | | | |
| | Indoors | | | | | |
| | | Kennels | 11 579 | 10.32 | 270 676 | 4.95 |
| | | Open + internal divisions | 35 252 | 31.41 | 1 527 574 | 27.96 |
| | | Open plan | 56 767 | 50.58 | 3 288 664 | 60.2 |
| | In&outdoors | | | | | |
| | | Trobridge | 3 584 | 3.19 | 84 224 | 1.54 |
| | | Kennel + yard | 2 088 | 1.86 | 66 698 | 1.22 |
| | Outdoors | (Shelter + field ) | 1 942 | 1.73 | 198 957 | 3.64 |
| | Other | | 585 | 0.52 | 26 246 | 0.48 |
| | Missing values | | 443 | 0.39 | 309 | <0.01 |
| Ventilation type | | | | | | |
| | | Natural | 83 572 | 74.74 | 4 570 736 | 83.66 |
| | | Powered | 27 385 | 24.49 | 830 028 | 15.19 |
| | | Missing values | 1 283 | 0.77 | 62 584 | 1.15 |
| Pen size | | | | | | |
| | | Large (≥200) | 6 180 | 5.50 | 1 863 606 | 34.11 |
| | | Medium (≥30-200) | 65 579 | 58.43 | 2 406 862 | 44.05 |
| | | Small (<30) | 40 481 | 36.07 | 1 192 880 | 21.83 |

| Variables | | Number of pens | % | Number of pigs assessed | % |
|---|---|---|---|---|---|
| Feed form | | | | | |
| | Liquid | 18 161 | 16.18 | 521 066 | 9.54 |
| | Meal | 25 649 | 22.85 | 853 848 | 15.63 |
| | Pellet | 68 404 | 60.95 | 4 088 125 | 74.83 |
| | Missing values | 26 | 0.02 | 309 | 0.01 |
| Feed | | | | | |
| | Ad libitum | 101 123 | 90.1 | 5 211 662 | 95.39 |
| | Restricted | 11 091 | 9.88 | 251 377 | 4.6 |
| | Missing values | 26 | 0.02 | 309 | 0.01 |
| Feeder type | | | | | |
| | Floor | 1 377 | 1.23 | 26 161 | 0.48 |
| | Hopper | 88 910 | 79.21 | 4 710 744 | 86.22 |
| | Trough | 21 927 | 19.54 | 726 134 | 13.29 |
| | Missing values | 26 | 0.02 | 309 | 0.01 |

**Table 3.4** Characteristics of the sample - Number and percentage of pens and pigs with each enrichment type reported.

| | Percentage of pens with the enrichment of interest | Number of pens | Percentage of pigs assessed with the enrichment of interest | Number of pigs |
|---|---|---|---|---|
| Straw | 44.7 | 50 136 | 60.8 | 3 320 398 |
| Other substrates | 1.41 | 1 588 | 2.46 | 134 313 |
| Chain | 24.2 | 27 196 | 16.4 | 894 112 |
| Plastic objects | 33.0 | 37 003 | 21.4 | 1 171 330 |
| Other objects | 8.92 | 10 014 | 7.09 | 387 608 |
| Enrichment not seen[1] | 2.71 | 2 058 | 1.73 | 65 613 |

[1]: based on 76002 pens and 3790879 pigs from June 2014 to May2016

The Chi and Fisher tests showed that all the variables related to the enrichment and the environment (pen size, pen type, ventilation type, feed form, feed availability, feeder type, straw, other substrate, chain, plastics, other object) were associated ($P$<0.05). The proportion of pens fed with liquid feed and with powered ventilation was higher for the category of pens without straw. The proportion of small pens was lower and the proportion of large pens was higher in the category of pens with straw ($P$ <0.05).

The percentage of pigs assessed with tails undocked was 24.25% and 70.43% of the pigs had their tails docked, with the remaining small percentage of pigs (5.31%) from pens where undocked and docked pigs were mixed (0.01 of the pigs had no data). The proportion of pens with undocked pigs and the proportion of pigs with different tail lengths are reported in Appendix B.5 and B.6 respectively. The result of the Chi square or Fisher tests showed that all measures related to the environment were associated with tail docking ($P$ <0.05) suggesting a potential confounding effect of tail docking with the environment on the measures of welfare. Pens with tail docked pigs were less commonly found outside, in large pens and in pens with natural ventilation (Appendix B.7). The percentage of pigs with undocked tails tended to be higher in pens with substrates (Appendix B.8). Compared to 2013, a significant increase of pens with undocked-tail pigs was observed over time ($P$ <0.05) (Table 3.5). The data from 2016 only concern a part of the year and the changes for 2016 should be re-assessed after review of the data until the end of 2016.

### *3.2.4 Descriptive analysis of the welfare outcomes*

The descriptive analysis of the welfare outcomes (Table 3.6) shows some outcomes with high maximum values during individual visits of certain farms. However the median and upper quartiles both have very much lower values, highlighting that high percentages for the different welfare outcomes were not very frequent. The descriptive analysis based on annual rolling averages also shows much smaller values (Appendix B.9). The description at pen level of the welfare outcomes for the complete database and the start-up period is presented in the Appendix B.10 and B.11. The mean values of the intra-farm variance were 0.46 for pigs requiring hospitalization, 1.22 for lame pigs, 2.2 for pigs with severe tail lesions, 2.89 for pigs with severe body marks and 0.025 for enrichment use ratio. The minimum and maximum values indicate that this variance differed greatly between farms (Appendix B.12).

**Table 3.5** Odds ratio, confidence intervals and p-values. Absence of tail docking, and the presence of enrichment at pen level were the dependent variables and the year was the independent variable in a model that considered the effect of farm.

| | Tail undocked | | | | Substrates | | | | Objects | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Odds | CI95% | | P values | Odds | CI95% | | P values | Odds | CI95% | | P values |
| Year | | | | | | | | | | | | |
| 2013 | *(Intercept)* | | | | *(Intercept)* | | | | *(Intercept)* | | | |
| 2014 | 1.481 | 1.316 | 1.667 | <0.001 | 1.811 | 1.723 | 1.902 | <0.001 | 2.440 | 2.314 | 2.573 | <0.001 |
| 2015 | 1.066 | 0.946 | 1.202 | 0.29 | 2.483 | 2.359 | 2.614 | <0.001 | 2.139 | 2.027 | 2.257 | <0.001 |
| 2016 | 1.318 | 1.120 | 1.551 | <0.001 | 3.151 | 2.924 | 3.394 | <0.001 | 2.749 | 2.546 | 2.968 | <0.001 |

**Table 3.6** Description of the Welfare outcomes at farm level (% of pigs in the pen or ratio).

| | Mean | SD | 1st Quartile | Median | 3rd Quartile | Min | Max |
|---|---|---|---|---|---|---|---|
| Pigs requiring hospitalization[1] (%) | 0.07 | 0.26 | 0 | 0 | 0 | 0 | 8.3 |
| Lame pigs[1] (%) | 0.18 | 0.60 | 0 | 0 | 0.16 | 0 | 40.5 |
| Enrichment use ratio[1] | 0.50 | 0.27 | 0.29 | 0.51 | 0.69 | 0 | 1 |
| Severe tail lesions[1] (%) | 0.14 | 0.69 | 0 | 0 | 0 | 0 | 25.2 |
| Mild tail lesions[1] (%) | 1.34 | 2.76 | 0 | 0 | 1.52 | 0 | 33.3 |
| Dirty tail[1] (%) | 6.22 | 14.80 | 0 | 0 | 3.59 | 0 | 100 |
| Severe body marks[1] (%) | 0.26 | 1.11 | 0 | 0 | 0 | 0 | 36.3 |
| Mild body marks[1] (%) | 11.00 | 13.10 | 2 | 6.59 | 15.20 | 0 | 95 |
| Dirty body[1] (%) | 4.00 | 12.40 | 0 | 0 | 0.67 | 0 | 100 |

[1]: values based on individual visits

### *3.3.4 Trends over time*

Compared to 2013, a significant decrease of the proportion of lame pigs and pigs requiring hospitalization was observed in 2014, 2015 and 2016 ($P$ <0.05). Compared to 2013, a significant increase of the proportion of pigs with severe tail lesions and severe body marks was observed in 2014 but also in 2015 for the severe tail lesions ($P$ <0.05). However, no significant differences were observed in 2016 compared to 2013 for the proportion of severe tail lesions ($P$ >0.05) and a significant decrease was observed in 2015 and 2016 for severe body marks ($P$ <0.05). Compared to 2013, no increase of the enrichment use ratio was identified in 2014 ($P$>0.05), but further increases were identified in 2015 and 2016 ($P$ <0.05) (Table 3.7). Any conclusion for 2016 needs to wait until the data for the full year are available. Figures 3.1 and 3.2 show the monthly averages for the different welfare outcomes over the 36 months. The value of the 90th percentile was used to select the farms with the highest prevalence for each of the welfare outcomes in 2013 and the mean values for these selected farms in each subsequent year are reported in Appendix B.13 and B.14. The means for each welfare outcome for the group of farms selected decreased over years. The Friedman test showed significant improvement between years (P<0.001) for all welfare outcomes. The Kendall's tau-b correlation coefficient showed that some welfare outcomes were correlated by farm between two consecutive years (tau>0.3, $P$ <0.05), but these correlations were weakened over longer periods, suggesting that farms changed their relative ranking over time, but that change could be slow for some parameters (Appendix B.15, B.16, B.17 and B.18).

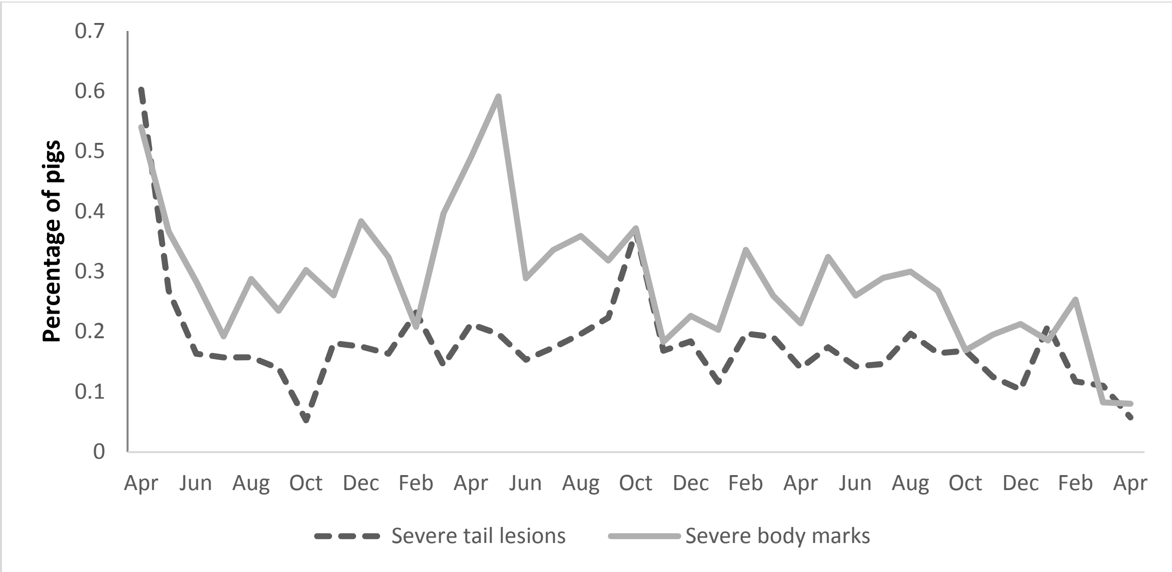



**Figure 3.1** The mean prevalence of pigs with severe tail lesions and severe body marks per month over the 36 months of data collection (April 2013 –2016).

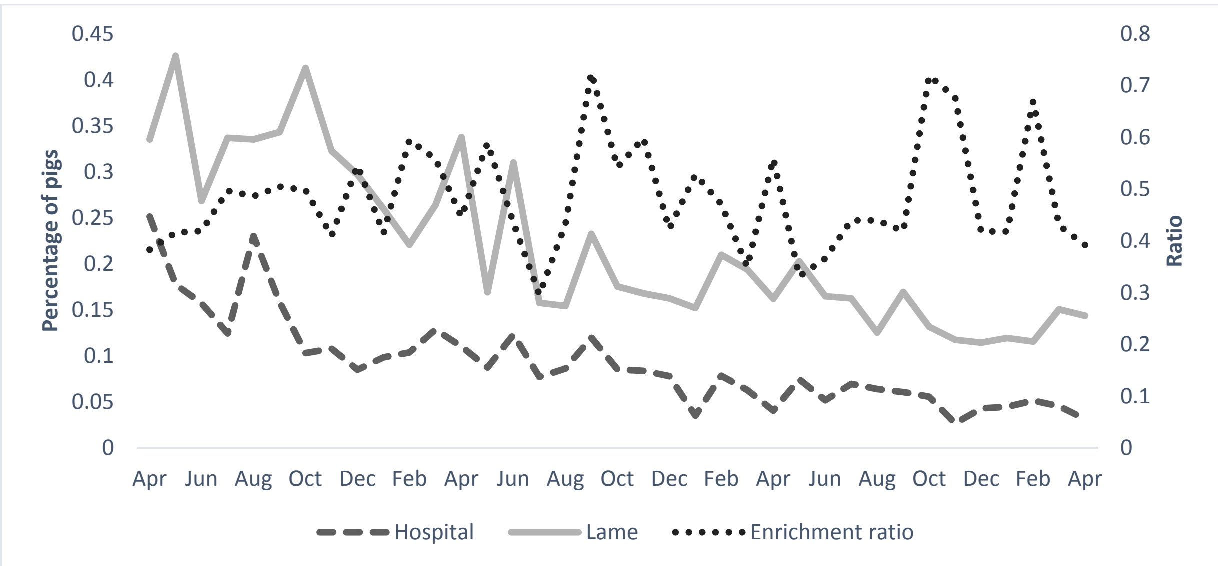



**Figure 3.2** The mean prevalence of lame pigs and pigs requiring hospitalization, and the mean enrichment use ratio per month over the 36 months of data collection (April 2013 – 2016).

**Table 3.7** Odds ratio, confidence intervals and P-value for all pens included in the study. The proportion of lame pigs, pigs requiring hospitalization, the proportion of pig with severe tail lesions, the proportion of pigs with severe body marks and the proportion of pigs that interacts with the enrichment were the dependent variables and the year was the independent variable in a model that considered the farm as a random effect. The years 2014, 2015 and 2016 were compared to the year 2013

| | | Odds ratio | CI95% | | P value |
|---|---|---|---|---|---|
| Lame pigs | Year | | | | |
| | 2013 | *Intercept* | | | |
| | 2014 | 0.547 | 0.516 | 0.579 | <0.001 |
| | 2015 | 0.382 | 0.359 | 0.407 | <0.001 |
| | 2016 | 0.298 | 0.268 | 0.331 | <0.001 |
| Pigs requiring hospitalization | | | | | |
| | 2013 | *Intercept* | | | |
| | 2014 | 0.651 | 0.591 | 0.716 | <0.001 |
| | 2015 | 0.364 | 0.327 | 0.406 | <0.001 |
| | 2016 | 0.297 | 0.248 | 0.356 | <0.001 |
| Severe tail lesions | | | | | |
| | 2013 | *Intercept* | | | |
| | 2014 | 1.331 | 1.211 | 1.463 | <0.001 |
| | 2015 | 1.287 | 1.167 | 1.419 | <0.001 |
| | 2016 | 1.108 | 0.958 | 1.280 | 0.166 |
| Severe body marks | | | | | |
| | 2013 | *Intercept* | | | |
| | 2014 | 1.129 | 1.057 | 1.206 | <0.001 |
| | 2015 | 0.872 | 0.813 | 0.935 | <0.001 |
| | 2016 | 0.533 | 0.472 | 0.601 | <0.001 |
| Enrichment use ratio | | | | | |
| | 2013 | *Intercept* | | | |
| | 2014 | 1.053 | 0.973 | 1.140 | 0.199 |
| | 2015 | 1.422 | 1.292 | 1.564 | <0.001 |
| | 2016 | 1.295 | 1.071 | 1.566 | <0.001 |

### *3.4.4 Seasonal influence*

Prevalence of lame pigs and pigs that would benefit from being in a hospital pen were significantly higher in spring than in summer, autumn and winter ($P < 0.05$). Prevalence of severe body marks was also significantly higher in spring than in autumn and winter ($P < 0.05$)

and a tendency (P=0.09) for a lower prevalence of severe tail lesions was also observed in summer. Compared to spring, a significant increase in the enrichment use ratio was observed in autum and winter ($P<0.05$) (Appendix B.19 and B.20).

### *3.5.4 Correlation between the measures of welfare*

The percentage of pigs that would benefit from being in a hospital pen was positively correlated to the percentage of lame pigs, and the absence of tail lesions was positively correlated with the absence of body marks ($P<0.05$, $R>0.3$) (Appendix B.21). For the two periods considered (the start-up period from April 2013 to November 2013 and the total period from 2013 to 2016), the correlations of mild tail lesions and body marks were similar. The percentage of pigs with a dirty tail was positively correlated with the percentage of pigs with a dirty body (Appendix B.22 and B.23).

## 3.5 Discussion

### *3.1.5 Description of the population of interest and limitations*

The objective of this study was to assess the welfare of pigs in commercial pig finishing enterprises in the UK (excluding any pigs in hospital pens) through five animal-based measures and to assess the changes in these measures over time and season. The study also represented an upstream task to describe farm characteristics and welfare outcomes in preparation for future risk factor analysis. To our knowledge, the data collected represent the largest dataset available on animal-based welfare measures for finisher pigs existing in the world. This scale necessitated use of many different vets for data collection, and Temple et al. (2013) reported the possibility of a lack of intra and inter-observer reliability in assessments repeated over the time. However, another study of Temple et al. (2012) showed that the inclusion of inter-observer effects did not impact on the outputs of the different measures, and the measures of lameness in pigs by trained observers showed consistency in the study of Main et al. (2000). The standardized procedure and the training provided to the individual vets was designed to minimise observer bias, and the inclusion of the interaction of the veterinary practice and the farm (Farm:Vet) reduced the possible information bias in this study. The number of holdings with 300 pig places or more was 1 810. Therefore, this sample represented around 83% of the 2 200 pig holdings with 300 finishing pigs or more present in the UK (DEFRA 2012), and can be considered as representative of the commercial farms present in the UK. Moreover, as suggested by Mullan et al. (2009b), estimation of the low prevalence of the welfare outcomes can only be achieved with very large sample size and the scheme provided a large number of data for accurate descriptive analysis.

### *3.2.5 Comparison of the benchmarks for the welfare outcomes*

No correlations were found between the proportion of pigs withlameness, body marks and tail lesions, as in a previous study (Whay et al., 2007), indicating no redundancy in the data collected. Whilst there are no comparable national databases of this scale for comparative purposes, the benchmarks can be compared to different results obtained previously in the UK by the National Animal Disease Animal Service (NADIS) or from other countries where the Welfare Quality® animal welfare assessment system has been applied across a large sample of farms. In this study, the average prevalence of lameness at farm level was 0.2%. The average prevalence of tail lesions at farm level was 0.5 % if both severe and mild lesions are considered, and the average prevalence of body marks at farm level was 0.26% if only severe body marks were assessed. These prevalences were slightly lower or comparable to the prevalences reported by NADIS (2007-2011) (lameness (0.2 to 0.6%) and severe and mild tail lesions (1.2%), to the lameness prevalence reported in UK by Kilbride et al. (2009) (mild to severe posture (1.1%) and gait problems (1.4%)) and to the prevalence of finisher pig lameness (0.2%, 1.2%, 0.2%) or tail biting (8.8%, 2.4%, 1.1%, 0.9%) reported in other countries of Europe (Whay et al., 2007; Courboulay et al., 2009; Temple et al., 2011; Temple et al., 2012 respectively). In both the “Real Welfare” and Welfare Quality® protocols, milder forms of lameness are not recorded and pigs in hospital pens are excluded from study. The prevalences reported therefore do not fully reflect the overall welfare impact of lameness, but take account of the way in which lame pigs are being managed on the farm. A different definition of body wounds was used in the Welfare Quality® protocol (considering more than 10 lesions in two body zones or more than 15 in a single zone), but the definition can be considered close to the definition of severe body marks in this study (Appendix B.2). A lack of representativeness of the whole population of finisher pig farms in smaller scale studies might explain the higher prevalence in previous studies, but it also raises the question of potential under-reporting in large scale projects like those detailed above. This highlights the importance of sustaining the motivation of assessors in order to avoid under-reporting.

### *3.3.5 Changes over time*

All welfare outcomes referring to lesions or sickness in the mainstream herd (excluding hospital pens), except the tail lesions, decreased over years. The reduction of the recorded prevalence might be the result of a better management of sick/injured pigs which have been moved to hospital pens. Whether there is a real reduction of the prevalence, or better management of hospital pens, it is known that benchmarking of health and welfare measures can lead to greater awareness and motivation to improve (Tremetsberger et al., 2015). For the farms with initially higher prevalence of welfare outcomes (above 90th percentile), the reduction for all welfare outcomes also suggests improvement of the welfare status in the mainstream herd or better management of the sick pigs following the implementation of the scheme. Recording the proportion of pigs in hospital pens and any changes over time would help to give a better overview of the welfare status of the farms and the hospital pen management. The increase of use of some forms of enrichment over the years showed some parallel trends with the decrease of the prevalence of welfare outcomes over the same period. This suggests a possible positive impact of enrichment on welfare outcomes but the causal relationship could not be inferred in this analysis. Prevalence of tail lesions did not show significant reduction over time but the complex interactions between enrichment provision and prevalence of undocked tails will have influenced this result. Enrichments might have been used post hoc to control tail biting problems arising from other environmental or management issues, particularly in undocked groups, so that the substrate provision alone might not show a simple causal relationship.

A number of the welfare outcome measures were observed to show a significant seasonal difference, as was also identified in a Finnish study on animal-based welfare-measures (Munsterhjelm et al., 2015b). This might be explained by the changes that occur in the environment over the seasons, such as variation in temperature or humidity, and subsequent impact on pigs. This knowledge is important when designing sampling strategies for farm audits. A decrease of the prevalence of physical injury in autumn and winter, and over years, corresponded to an increase of the interaction of the animal with the enrichment during the same period. The association between these changes needs to be more critically assessed in further study where the proportion of pigs located in hospital pens would be included in any survey and also in experimental studies allowing better control of the causal factors. It cannot be assumed that the relationship between season and welfare outcome measures is causal until proven.

### *3.4.5 Variability within and between farms*

As mentioned in the studies of Temple et al. (2011, 2013) and Whay et al. (2007), animal-based measures of welfare show variability both within and between farms. This highlights the importance of an appropriate sampling strategy. The prevalence of welfare outcomes at farm level ranged between 0 and 40.5 %, but the extreme values were unusual and the vast majority of the farms did not present any problems or showed a very low prevalence in the mainstream herd (i.e. excluding any pigs in hospital pens). The reasons for the variability seen intra- and inter-farm in animal-based measures of welfare need to be assessed through the identification of risk factors that tend to increase the prevalence of disorders in certain farms and understanding of the multifactorial impact of housing, nutrition and management practices (Averos et al., 2010; Taylor et al. 2012).

### 3.6 Conclusion

The “Real Welfare” initiative is a unique national industry scheme designed to benchmark welfare outcomes on finishing pig farms, promote welfare improvement through regular visits in the farm by trained vets and demonstrate good management by recording animal-based and resource-based measures. The results from the first three years of the scheme demonstrate a reduction in the prevalence of most animal-based measures of welfare after the first year of the implementation of the scheme and the accompanying regular welfare assessments implemented during the first year. However, since pigs in hospital pens were excluded from the assessment, only animals in the mainstream herds were assessed. Further research is needed to understand if the reduction in prevalence of animal-based welfare issues is attributable to better management of sick or injured pigs that have been moved to hospital pens or better attention to animal welfare in the mainstream herd. However, the baseline data provided highlight the value of this initiative, and the large database generated by the scheme will be a valuable source of information for future risk assessment investigations.

# Chapter 4: The "Real Welfare" scheme: Identification of risk and protective factors for welfare outcomes in commercial pig farms in the UK

## 4.1 Abstract

From 2013 to 2016, animal-based measures were collected as part of the "Real Welfare" protocol adopted by the Red Tractor Pigs Assurance Scheme to assess the welfare in finisher pig herds in the UK. Trained veterinarians from 89 veterinary practices assessed 112 241 pens (hospital pens excluded) from 1 928 farms using a multistage sampling protocol, and collected data about pig welfare, management and farm environment on 5 463 348 pigs. Multivariable analyses were conducted for five main welfare outcomes: the proportion of lame pigs, pigs requiring hospitalization or with severe tail lesions or with severe body marks and the enrichment use ratio (number of active pigs interacting with the enrichment/ total number of active pigs). Additionally, a multiple correspondence analysis (MCA) was conducted to analyse systematic patterns of variations of environmental characteristics and improve understanding of the connection between welfare outcomes and environment. The prevalence of the 4 welfare outcomes and the mean enrichment use ratio differed between pen types ($P<0.05$), with a higher mean prevalence of lame pigs (0.39%) but lower mean prevalence of pigs requiring hospitalization (0.07%), severe tail lesions (0.07%) and severe body marks (0.12%) in outdoor pens. In&outdoor pens had the highest mean prevalence of the measured outcomes ($P<0.05$). After adjusting for the farm, date and pen type, the proportion of lame pigs, pigs requiring hospitalization or those with severe tail lesions were less prevalent in large pens ($P<0.01$), pens with substrates ($P\leq0.05$) and pens fed with meal ($P\leq0.05$), while enrichment use ratio was higher with substrates ($P<0.001$). Moreover, pigs requiring hospitalization and severe body marks were more prevalent in pens with powered compared to natural ventilation ($P<0.05$). On the MCA graph, higher prevalences of lameness and pigs requiring hospitalization (> 1, 5 and 10% respectively) were located in the same direction as lower enrichment use ratio, liquid feed, trough feeding, floor feeding, restricted feed and in&outdoor pens. Results suggested that these higher prevalences were not only connected to a particular system, but that all welfare outcomes were also connected to several inappropriate features in the environment. This study suggests several protective factors resulting in animal welfare improvement and highlights the importance of considering the environment as a whole because of potential factor combinations and confounds. A better understanding of influences on welfare requires better control of the confounding factors. However, the results

of this study can be used to support evidence-based advice and future formulation of standards for good practice.

## 4.2 Introduction

Animal-based measures have been suggested to be more appropriate and easier to interpret than resource-based measures to assess animal welfare (Whay et al., 2007). These measures, also called welfare outcomes, rely on measurements made on the animals themselves and are being adopted by Farm Assurance Schemes to benchmark animal welfare and promote welfare-friendly management (Blokhuis et al., 2010). Following pilot studies, the "Real Welfare" protocol for welfare outcome assessment was adopted by the Red Tractor Assurance Scheme for finisher pig herds in the UK. The welfare data were collected in conjunction with other data about enrichment provision, management practices and farm environment. Over 3 years, more than 90% of English pig farms were regularly visited (Pandolfi et al., 2017). This high population coverage and the probability sampling methodology permit scientifically-grounded estimates from the survey for the whole population of interest (Turner, 2003), and a previous descriptive analysis established mean values for five main welfare outcomes and their changes over time (Pandolfi et al., 2017).

The data also constitute a valuable resource to identify risk factors related to the welfare outcomes. Risk or protective factors for tail biting, lameness or body lesions have been identified in previous studies (Hunter et al., 2001; Schroder-Petersen et al., 2001; Moinard et al., 2003; Van De Weerd et al., 2006; Temple et al., 2012; Munsterhjelm et al., 2015a). However, such studies generally refer either to experimental situations or farm samples which are not sufficiently large or representative to extrapolate the conclusions to the whole national population of pigs. Therefore, the data collected through the "Real Welfare" initiative provided the first opportunity to conduct a risk factor analysis on a large sample of finishing pig farms which can be considered as fully representative of the finishing pig farms present in the UK.

The objective of this study was to assess the multifactorial aspects of welfare issues by the identification of risk and protective factors at pen level, among variables related to pig environment and management, for five main welfare indicators: the proportion of lame pigs, pigs requiring hospitalisation or with severe tail lesions or severe body marks and the enrichment use. In the first instance, we identified risk factors for the 5 welfare outcomes with multivariable analyses. Subsequently, we used a multiple correspondence analysis to confirm and refine the results of the multivariable analyses and identify the relationship between pen environment and the severity of the different welfare outcomes. Finally, we interpreted the results to highlight the risk and protective factors which can be used to identify pen features connected to welfare issues and the critical points that should be the focus of veterinarians and farmers to improve the welfare of pigs in their care.

## 4.3 Materials and methods

### *4.3.1 Data and data management*

The collection and management of the data used for this analysis have been described in detail in a previous publication (Pandolfi et al., 2017). The data were collected from April 2013 to May 2016 in order to assess on-farm pig welfare through the “Real Welfare” assessment protocol, as required for those finishing pigs under the Red Tractor Pigs Assurance Scheme. The assessment involved five main measures (Table 4.1) taken from a sample of pens on each farm during quarterly veterinary visits by trained vets from 89 different veterinary practices who underwent the same online and practical training. Hospital pens were excluded from the assessment. Each pig was classified as having, or not having one of the lesions reported in Table 4.1 and all the measures were transformed into percentages, based on the total number of pigs assessed in the pen. Enrichment use was calculated as a ratio based on the following formula:

$$Enrichment\ use\ ratio = \frac{Number\ of\ active\ pigs\ interacting\ with\ the\ enrichment}{Number\ of\ active\ pigs\ interacting\ with\ pen\ features\ or\ pen\ mates\ or\ with\ the\ enrichment}$$

**Table 4.1** Measurements used by the veterinarians to assess pig welfare. Each pig in the sample selected was classified into one of the several levels for each measurement (the classification for enrichment use ratio only concerned the active pigs of the sample).

| Measurements | Levels |
|---|---|
| **Pigs requiring hospitalization** | **yes**: Any pigs seen in the sampled pens that would benefit from being separated into a hospital pen. (The nature of the health condition and the pen environment will affect this measure). Some types of pigs which may benefit from being in a hospital pen include pigs who are sick, injured or lame and are unable to compete for resources, being bullied/ tail bitten or would benefit from access to bedding that is more comfortable than that available in the pen.<br>**no**: Pigs that would not benefit from removal to a hospital pen. |

| Measurements | Levels |
|---|---|
| **Lame pigs** | **lame**: Pigs with signs of lameness. Includes any pig that when standing will not bear full weight on the affected limb and/or appears to be standing on its toes. When moving there is a shortened stride with minimum or no weight-bearing on the affected limb and a swagger of the hind quarters. May still be able to trot and gallop.<br>**Non lame**: Pigs without any sign of lameness |
| **Pigs with tail lesions** | **severe**: Pigs with severe tail lesions<br>Proportion of tail has been removed by biting, or tail is swollen or held oddly, or scab covering whole tip or fresh blood visible<br>**mild**: Pigs with mild tail lesions<br>Linear lesion extending 1cm or more, or scabs/lesions greater than 0.5cm diameter, or swelling visible<br>**no lesions**: Pigs without any of the above lesions<br>**dirty**: Pigs dirty enough to obscure potential mild lesions but not the severe ones. Tail end or whole tail is soiled making assessment of lesions difficult. |
| **Pigs with body marks** | **severe**: Pigs with severe body marks<br>Lesion is larger than 5x5cm diameter, or lesion extends into deeper layers of skin, or lesions cover a large percentage of skin (>25%)<br>**mild**: Pigs with mild body marks<br>Linear lesion longer than 10cm or if there are 3 or more 3cm lesions or if there is a circular area larger than 1cm diameter<br>**no lesions**: Pigs without any of the above body marks<br>**dirty**: Pigs dirty enough to obscure potential mild body marks but not the severe ones. The pig is soiled with > a handsize (15cm x 10cm) of fresh/old slurry/urine/faeces, or mud which is dense enough to conceal lesions. |
| **Enrichment use ratio (optional)** | **enrichment**: Pigs interacting with enrichment in the pen. Number of standing or sitting pigs investigating a manipulable material, i.e. substrates or toy provided as enrichment.<br>**other**: Pigs interacting with other pens features or pen mates. Number of standing or sitting pigs manipulating other pigs, pen fittings, pen floor or muck. |

Additional information about the sampled pens was also recorded during the visit (Table 4.2). The farm, from which the pens were sampled, and the date of the assessment were recorded for all pens.

**Table 4.2** Variables collected by the veterinarians at pen level during the Real Welfare assessment.

| Variables | Categories |
|---|---|
| Pen size | small <30 pigs<br>medium ≥30 to <200 pigs<br>large ≥200 |
| Pen type | indoor (kennels, open + internal divisions or open plan)<br>outdoor (shelter + field )<br>in&outdoor (trobridge or kennel + yard)<br>other |
| Ventilation | natural<br>powered |
| Feed form | pellets<br>meal<br>liquid |
| Feed availability | ad libitum<br>restricted |
| Feeder type | floor<br>hopper<br>trough |
| Tail docking | docked tails<br>undocked tails |
| Tail length | tail lengths ≤0.5 (pens with docked tails, smaller than half the original length)<br>tail lengths >0.5 (pens with undocked tail, tails longer than half the original length or mixed tail lengths) |
| Pig weight | <30kg<br>30-50kg<br>>50kg |
| Enrichment | substrate(s) only (straw or other substrates)<br>object(s) only (chains, plastic objects or other objects)<br>substrate(s) and object(s)<br>no enrichment |

For the complete database, a sample of pens was assessed from 1 928 farm units. Repeated measures were taken in the same farm unit over three years, giving 112 240 records at pen level. The Real Welfare protocol was used to assess the prevalence of lameness and pigs requiring hospitalization on 5 463 348 pigs, the prevalence of body marks and tail lesions on 2 952 561 pigs and the enrichment use ratio (which was optional during the assessment) on 497 724 pigs.

### *4.3.2 Sampling*

The sampling used was a multistage sampling. At the first level, all farms that finish pigs and belong to the Red Tractor Pigs Assurance Scheme were sampled. At the second level, several pens were randomly selected within each farm in order to be representative of the finisher pig places present in the farm (see Pandolfi et al., 2017 for pen sampling details, which are documented in full on the Scheme website (http://pork.ahdb.org.uk/health-welfare/welfare/real-welfare/real-welfare-vets/). The assessments were carried out two to four times per year. For units of 300 finisher places or less, a minimum of 300 pigs were sampled each year, but for units of 900 finisher places or more, a total of 900 pigs were sampled per year. For units of between 300 and 900 finisher places, an equivalent representative proportion was sampled. As pen size could be different between farms and the number of pigs required depended on herd size, the number of pens selected differed between farms. At the third level, selected pens were assessed for all lame pigs and pigs requiring hospitalization and a random sample of pigs in the pen was further assessed for tail lesions and body marks (all pigs in the pen if there were fewer than 25 pigs, 25 pigs if there were up to 100 pigs, or 50 pigs if there were more than 100 pigs, and chosen to be representative of the pen). All the active pigs in the pens were assessed for enrichment use.

A retrospective power calculation was carried out for each welfare outcome, using the following equation (Teerenstra et al., 2008):

Deff= (1+ICC (m-1)

n'/Deff=n

$$n=Z^2 \frac{(Z_{\alpha/2}+Z_{\beta})^2\sigma 2}{e^2}$$

The calculation was made for a desired margin of error (e) of 10% and 20% in the mean percentage of the welfare outcome and based on the actual sample size. We calculated the power of the analysis based on the sample size by accounting for the clustering effect of pens within farms. Therefore, we estimated the sample size n as the result of the actual sample size n' (the number of pens designated in the protocol) divided by the design effect Deff and we calculated the power based on the value of n. ICC is the intraclass correlation between pens within a farm and m the average number of pens per farm. The value of $\sigma^2$ (the population variance of the welfare outcome), e (margin of error) and ICC (intraclass correlation) were estimated from the descriptive analysis (Pandolfi et al., 2017). Z is the value from a standard normal distribution corresponding to the desired confidence level, with α as the type I error (Z=1.96 for 95% CI) and β as the power of the analysis.

### *4.3.3 Data analysis*

#### *4.3.3.1 Influence of the environment on the welfare outcomes*

First, the prevalence of the 5 main welfare outcomes was calculated for each pen and each pen type.. The distribution of the 5 main welfare outcomes was assessed for normality through the histograms. Kruskall Wallis tests with a Bonferonni correction were used to assess the differences between pen types. The influence of the other variables related to the environment on the different measures of welfare was assessed with a Generalized Linear Mixed Model in an analysis performed at pen level. Five different models were built, considering respectively as dependent variables: the proportion of pigs that would benefit from removal to a hospital pen, the proportion of lame pigs, the proportion of pigs with severe tail lesions, the proportion of pigs with severe body marks, the proportion of active pigs that interact with the enrichment in preference to other exploratory activities. The sampling date, nested in farm unit, and the pen type were considered as random effects. Although different pens could belong to the same farm, differences might exist between the different visits over time or season and the changes that might occur over time are farm specific (Courboulay et al., 2009; Pandolfi et al., 2017). For the five models, the independent variables considered were the variables: pen size, ventilation type, weight of the pigs, feed availability, feed form and feeder type, enrichment. Data were dichotomised to give categories with and without substrates, objects, substrates+objects, or no enrichment for the multivariable analyses. The variables were dichotomized in order to ease the interpretation of the multivariable analysis. For the model with the proportion of pigs with severe tail lesions, the variable pig weight was transformed as follows (pigs≤50kg, pigs>50 kg) to solve a problem of quasi-complete separation. The influence of the variables tail docking and length of the tails were also assessed when the dependent variable was the proportion of pigs with severe tail lesions, the proportion of pigs with severe body marks, or enrichment use ratio. Similarly, the influence of enrichment use ratio was assessed when the dependent variable was the proportion of pigs with severe tail lesions or the proportion of pigs with severe body marks.

Univariate analyses were initially carried out. All of the dependent variables with $P<0.1$ were retained for the multivariable analyses. Associations between dependent variables were identified in the previous descriptive analysis, suggesting that the individual contribution of each covariate is difficult to assess (Tu et al., 2012). In order to diagnose the potential problem of multicollinearity, the variance inflation factor (VIF) was calculated. Based on this result, the variables with VIF≥5 were removed to create the final model (Rogerson, 2001). The variables in the final model with $P \leq 0.05$ were considered significant.

#### *4.3.3.2 Multiple correspondence analysis*

A multiple correspondence analysis (MCA) was conducted to analyse systematic patterns of variations of environmental characteristics in the pig farms and illustrate the relationship between these. The decomposition of the inertia on the two first factorial axes (F1 and F2), considered as the most discriminating, was used to eliminate the variables with a low absolute contribution. As no standard value has been strictly defined (Messad, 2012), we eliminated variables under a subjectively chosen limit of 500 (5% of the total absolute contribution of 10 000). After this selection, the contributions of the variables to each factorial axis and the plot of MCA were used to interpret each factorial axis. In order to better understand the connection between the environment and farm practice and the welfare outcomes, the five welfare outcomes were transformed into categorical variables and considered as supplementary variables in the MCA. For each welfare outcome, a new categorical variable was created based on the prevalence of these welfare outcomes. These variables had two categories namely presence (at least one pig in the pen) or absence (no pigs in the pen). The position on the MCA graph of the welfare outcomes helped to interpret the association with environmental variables.

Moreover, in order to understand the relationship between the magnitude of prevalence of the four physical welfare outcomes and the environment, we dichotomized each welfare outcome several times based, not only on the presence of the welfare outcome in the pen but also on different thresholds (outcome 0.5%, 1%, 5% and 10% higher or lower than the mean) to create additional categorical variables with two categories. Following a similar logic, the enrichment use ratio was also dichotomized based on different thresholds (0.75, 0.50, 0.20, 0.10). These increasing thresholds were arbitrarily chosen to assess if the position on the factorial axes changed. After the transformation, these 28 supplementary variables were plotted on the MCA graph for interpretation.

In order to confirm differences in prevalence of the welfare outcomes according to their position on the MCA graph, a t-test was used to compare the mean of each of the five outcomes between the pens with negative coordinates and those with positive coordinates on F1. Moreover, since the different variables representing lameness and pigs requiring hospitalization above different limits (0.5%, 1%, 5%, 10%) showed different positions on the

MCA graph (moving from upper left to upper right quadrant), a t-test was used to assess if the mean prevalence of lameness and pigs requiring hospitalization for pens with positions in the upper right quadrant (positive coordinates on F1 and positive coordinates on F2) was higher than the mean prevalence of all other pens.

Data processing was carried out using Microsoft Access Office Professional Plus 2010, Microsoft Excel Office Professional Plus 2010 and RStudio for R-3.1.0 software for Windows (64 bit) to create the dataset at pens level and perform the analyses.

## 4.4 Results

### *4.4.1 Sample size*

After adjusting the sample size by accounting for the design effect, the power of the analyses with an accepted margin of error of 10% of the real population mean was 72.2% for pigs requiring hospitalization, 42.8% for lameness, 30.9% for severe tail lesions, 46.0% severe body marks and 100% for enrichment use ratio. With an accepted margin of error of 20% of the real population mean, it was 99.9% for pigs requiring hospitalization, 94.5% for lameness, 83.2% for severe tail lesions, 96.1% severe body marks and 100% for enrichment use ratio. The values of σ, e, ICC, m, N and Deff for each welfare outcome can be found in Appendix C1.

### *4.4.2 Influence of the environment on the welfare outcomes*

Extensive descriptive results have been presented in Chapter 3. At pen level, the mean and standard deviation of prevalence of pigs requiring hospitalization was 0.07% (±0.26), the prevalence of lame pigs was 0.18% (±0.60), the prevalence of severe tail lesions was 0.14% (±0.69), the prevalence of severe body marks was 0.26% (±1.11) and the mean enrichment ratio was 0.50% (±0.27).

#### *4.4.2.1 Lameness*

The mean prevalence of lameness was 0.20% (±1.28) in indoor pens, 0.39% (±1.40) in outdoor pens, 0.30% (±1.45) in in&outdoor pens and 0.23% (±2.28) in other pens. The mean prevalence was significantly lower in indoor pens compared to outdoor (P<0.01) and in&outdoor pens (P=0.03) and significantly higher in outdoor pens compared to in&outdoor pens (P<0.01) and other pens (P<0.01). All VIF were between 1 and 2. Compared to the pigs fed on meal, the proportion of lame pigs was higher in pens fed on liquid feed (P<0.001) and pellets (P=0.03). The proportion of lame pigs was also higher in small (P<0.001) and medium pens (P<0.001) compared to large pens. Pens with pigs that weighed between 30 and 50kg had less lameness than those with pigs over 50kg (P=0.003). The proportion of lame pigs was also lower when substrates were present (P=0.012) but was higher when substrates and objects were both present (P<0.001) (Table 4.3).

**Table 4.3** Results of the multivariable analysis of data collected in 112 240 pens between 2013 and 2016 in pig farms in the UK. A generalized linear mixed model was used to identify the impact of environment, feed and enrichment on the proportion of lame pigs at pen level.

| variables | levels | Odds | 95% CI | | P values |
|---|---|---|---|---|---|
| Substrates | no substrates | *Baseline* | | | |
| | substrates | 0.87 | 0.79 | 0.97 | **0.012** |
| Objects | no objects | *Baseline* | | | |
| | objects | 0.89 | 0.79 | 1.01 | 0.069 |
| Substrates+objects | no objects + substrates | *Baseline* | | | |
| | objects + substrates | 1.46 | 1.18 | 1.81 | **<0.001** |
| Ventilation type | natural ventilation | *Baseline* | | | |
| | powered ventilation | 1.05 | 0.93 | 1.19 | 0.431 |
| Weight | weight >50kg | *Baseline* | | | |
| | weight <30kg | 1.48 | 0.66 | 3.35 | 0.343 |
| | weight 30-50kg | 0.80 | 0.69 | 0.92 | **0.003** |
| Feed form | meal | *Baseline* | | | |
| | liquid | 1.63 | 1.29 | 2.05 | **<0.001** |
| | pellets | 1.21 | 1.02 | 1.43 | **0.027** |
| Feed availability | ad libitum | *Baseline* | | | |
| | restricted | 1.13 | 0.92 | 1.38 | 0.238 |
| Pen size | large pens | *Baseline* | | | |
| | small pens | 2.05 | 1.81 | 2.32 | **<0.001** |
| | medium pens | 1.54 | 1.39 | 1.71 | **<0.001** |

#### 4.4.2.2 *Pigs requiring hospitalization*

The mean prevalence of pigs requiring hospitalization was 0.08% (±0.79) in indoor pens, 0.07% (±0.44) in outdoor pens, 0.13% (±0.87) in in&outdoor pens and 0.09% (±0.66) in other pens. The mean prevalence was significantly lower in outdoor pens compared to in&outdoor pens (P<0.01) and indoor pens (P<0.01). The mean prevalence was significantly lower in indoor pens compared to in&outdoor pens (P=0.02) and other pens (P=0.03). All VIF were between 1.53 and 2.31. The proportion of pigs requiring hospitalization was higher when the pigs were fed with liquid feed (P<0.001) or pellets (P=0.001) compared to pigs fed with meal. This outcome was also more prevalent in pens with powered ventilation (P=0.01) compared to natural ventilation, and in small (P<0.001) and medium pens (P<0.001) compared to large pens. The proportion of pigs requiring hospitalization also tended to be smaller when substrates were present (P=0.050) (Table 4.4).

**Table 4.4** Results of the multivariable analysis of data collected in 112 240 pens between 2013 and 2016 in pig farms in the UK. A generalized linear mixed model was used to identify the impact of environment, feed and enrichment on the proportion of pigs requiring hospitalization at pen level.

| variables | levels | Odds | 95% CI | | P values |
|---|---|---|---|---|---|
| Substrates | no substrates | *Baseline* | | | |
| | substrates | 0.86 | 0.73 | 1.00 | **0.050** |
| Objects | no objects | *Baseline* | | | |
| | objects | 0.88 | 0.75 | 1.08 | 0.133 |
| Ventilation type | natural ventilation | *Baseline* | | | |
| | powered ventilation | 1.25 | 1.06 | 1.48 | **0.010** |
| Pen size | large pens | *Baseline* | | | |
| | small pens | 2.62 | 2.18 | 3.15 | **<0.001** |
| | medium pens | 1.89 | 1.61 | 2.23 | **<0.001** |
| Feed form | meal | *Baseline* | | | |
| | liquid | 1.58 | 1.21 | 2.06 | **<0.001** |
| | pellets | 1.38 | 1.13 | 1.68 | **0.001** |

#### *4.4.2.3 Severe tail lesions*

The mean prevalence of severe tail lesions was 0.17% (±1.60) in indoor pens, 0.07% (±0.93) in outdoor pens, 0.22% (±1.85) in in&outdoor pens and 0.22% (±1.27) in other pens. The mean prevalence was significantly lower in outdoor pens compared to indoor ($P=0.05$), in&outdoor pens ($P<0.01$) and other pens ($P<0.01$). All VIF were between 1.01 and 2.79 except feeder type, which had VIF>5 and was removed from the final model. The proportion of severe tail lesions was higher when the pigs were fed with liquid feed ($P=0.026$) or pellets ($P=0.003$) compared to pigs fed with meal. The proportion of pigs with severe tail lesions was higher in small pens ($P=0.042$) and medium size pens ($P<0.001$) compared to large pens. The proportion of pigs with severe tail lesions was also more prevalent for pigs with a weight over 50kg compared to those under 50kg ($P=0.004$). The proportion of pigs with severe tail lesions was lower when substrates were present ($P=0.012$), but was higher when substrates and objects were both present ($P<0.001$). Finally, severe tail lesions were less prevalent in pens with pigs with tail longer than half of the undocked size ($P=0.046$) (Table 4.5).

**Table 4.5** Results of the multivariable analysis of data collected in 112 240 pens between 2013 and 2016 in pig farms in the UK. A generalized linear mixed model was used to identify the impact of environment, feed and enrichment on the proportion of pigs with severe tail lesions at pen level.

| variables | levels | Odds | 95% CI | | P values |
|---|---|---|---|---|---|
| Substrates | no substrates | *Baseline* | | | |
| | substrates | 0.76 | 0.62 | 0.94 | **0.012** |
| Objects | no objects | *Baseline* | | | |
| | Objects | 0.88 | 0.70 | 1.11 | 0.275 |
| Substrates+objects | no objects+substrates | *Baseline* | | | |
| | objects+substrates | 2.16 | 1.53 | 3.06 | **<0.001** |
| Ventilation type | natural ventilation | *Baseline* | | | |
| | powered ventilation | 1.09 | 0.92 | 1.29 | 0.321 |
| Pen size | large pens | *Baseline* | | | |
| | small pens | 1.24 | 1.01 | 1.52 | **0.042** |
| | medium pens | 1.40 | 1.17 | 1.68 | **<0.001** |
| Weight | weight ≤50kg | *Baseline* | | | |
| | weight >50kg | 1.39 | 1.12 | 1.74 | **0.004** |
| Feed form | Meal | *Baseline* | | | |
| | Liquid | 1.48 | 1.05 | 2.10 | **0.026** |
| | Pellets | 1.50 | 1.14 | 1.97 | **0.003** |
| Tail length | tail lengths ≤ 0.5 | *Baseline* | | | |
| | tail lengths >0.5 | 0.82 | 0.68 | 1.00 | **0.046** |

#### *4.4.2.4 Severe body marks*

The mean prevalence of severe body marks was 0.29% (±1.96) in indoor pens, 0.12% (±0.84) in outdoor pens, 0.33% (±2.05) in in&outdoor pens and 0.24% (±1.43) in other pens. The mean prevalence was significantly lower in outdoor pens compared to in&outdoor pens

(P=0.05). All VIF were between 1 and 1.23. The proportion of pigs with severe body marks was lower in pens with restricted feed (P<0.001) compared to ad libitum feed but higher in pens with powered ventilation (P<0.001) compared to natural ventilation. This outcome was also more prevalent for pens of pigs with a weight between 30-50kg (P<0.001) compared to those over 50kg.  The proportion of pigs with severe body lesions was lower for pigs with tails longer than half of the original length (P=0.046) (Table 4.6).

**Table 4.6** Results of the multivariable analysis of data collected in 112 240 pens between 2013 and 2016 in pig farms in the UK. A generalized linear mixed model was used to identify the impact of environment, feed and enrichment on the proportion of pigs with severe body marks at pen level.

| variables | levels | Odds | 95% CI | | P values |
|---|---|---|---|---|---|
| Objects | no objects | *Baseline* | | | |
| | Objects | 1.10 | 0.97 | 1.24 | 0.128 |
| Ventilation type | natural ventilation | *Baseline* | | | |
| | powered ventilation | 1.51 | 1.33 | 1.73 | **<0.001** |
| Weight | weight >50kg | *Baseline* | | | |
| | weight <30kg | 0.73 | 0.25 | 2.15 | 0.566 |
| | weight 30-50kg | 1.45 | 1.20 | 1.75 | **<0.001** |
| Feed availability | ad libitum | *Baseline* | | | |
| | restricted | 0.55 | 0.40 | 0.75 | **<0.001** |
| Tail docking | docked tails | *Baseline* | | | |
| | undocked tails | 0.90 | 0.67 | 1.20 | 0.460 |
| Tail length | tail lengths ≤0.5 | *Baseline* | | | |
| | tail lengths >0.5 | 0.83 | 0.68 | 1.00 | **0.046** |

#### *4.4.2.5 Enrichment use ratio*

The mean ratio was 0.47 (±0.36) in indoor pens, 0.67 (±0.35) in outdoor pens, 0.40 (±0.39) in in&outdoor pens and 0.37 (±0.32) in other pens. The mean ratio was significantly lower in indoor pens, in&outdoor pens and other pens compared to outdoor (P<0.001). The mean ratio was significantly higher in indoor pens compared to in&outdoor pens (P<0.001). All VIF were between 1 and 2.08. The enrichment use ratio tended to be lower in pens fed with liquid feed (P=0.046) compared to the pens fed with meal. The enrichment use ratio was lower in pens with powered ventilation compared to natural ventilation (P<0.001), in small (P<0.001) and medium pens (P<0.001) compared to large pens. The pigs that weighed between 30-50 kg showed more relative interaction with the enrichment than the pigs over 50kg (P<0.001).The proportion of pigs that interacted with enrichment instead of other pigs or pen fittings was higher when substrates were present in the pen (P<0.001) and when the tails of the pigs were not docked (P=0.017) (Table 4.7).

**Table 4.7** Results of the multivariable analysis of data collected in 112 240 pens between 2013 and 2016 in pig farms in the UK. A generalized linear mixed model was used to identify the impact of environment, feed and enrichment on the enrichment use ratio (proportion of pigs that interact with the enrichment in comparison to other exploratory activities).

| variables | levels | Odds | CI 95% | | P values |
|---|---|---|---|---|---|
| Substrates | no substrates | *Baseline* | | | |
| | substrates | 1.187 | 1.086 | 1.299 | **<0.001** |
| Objects | no objects | *Baseline* | | | |
| | objects | 0.92 | 0.84 | 1.01 | 0.093 |
| Ventilation type | natural ventilation | *Baseline* | | | |
| | powered ventilation | 0.74 | 0.65 | 0.84 | **<0.001** |
| Pen size | large pens | *Baseline* | | | |
| | small pens | 0.65 | 0.59 | 0.73 | **<0.001** |
| | medium pens | 0.81 | 0.74 | 0.88 | **<0.001** |
| Weight | weight >50kg | *Baseline* | | | |
| | weight <30kg | 1.37 | 0.73 | 2.59 | 0.332 |
| | weight 30-50kg | 1.33 | 1.17 | 1.51 | **<0.001** |
| Feed form | meal | *Baseline* | | | |
| | liquid | 0.78 | 0.62 | 0.99 | **0.045** |
| | pellets | 0.99 | 0.83 | 1.19 | 0.945 |
| Feed availability | ad libitum | *Baseline* | | | |
| | restricted | 0.92 | 0.75 | 1.13 | 0.448 |
| Tail docking | docked tails | *Baseline* | | | |
| | undocked tails | 1.22 | 1.04 | 1.43 | **0.017** |

### *4.4.3 Multiple Correspondence Analysis*

After a first decomposition of the inertia, the variables related to some pen types, some enrichments, ventilation type, feed type, feed availability, feeder type, tail docking, and tail lengths were selected for the analysis (because inertia>500) and transformed into dichotomized variables for the analysis (Appendix C.3). The two first factorial axes, after running the MCA, represented 39.6% of the total inertia, with 23.5% explained by the first factorial axis (F1) and 16.2% explained by the second one (F2) (Appendix C.2). The absolute contributions are reported in Appendix C.3. Figure 4.1 shows the patterns of farm characteristics. The MCA revealed that certain categories of the variables considered seem to be connected as they appear close to each other and are in the same direction on the graph. The use of liquid feed was related to restricted feed and distribution of the feed in a trough. The feed distributed on the floor was related to in&outdoor pens. Having short-tail pigs was related to the presence of plastic objects, pens without straw and powered ventilation. Having pigs with undocked or long tails was related to the presence of straw, the absence of plastic objects and natural ventilation. Undocked pigs, pens with straw and natural ventilation and feeding with meal or pellets had negative coordinates on the horizontal axis (F1) while pens with powered ventilated systems, liquid feed, without straw, with tail docked pigs and plastic objects for enrichment had positive coordinates on the horizontal axis (F1).

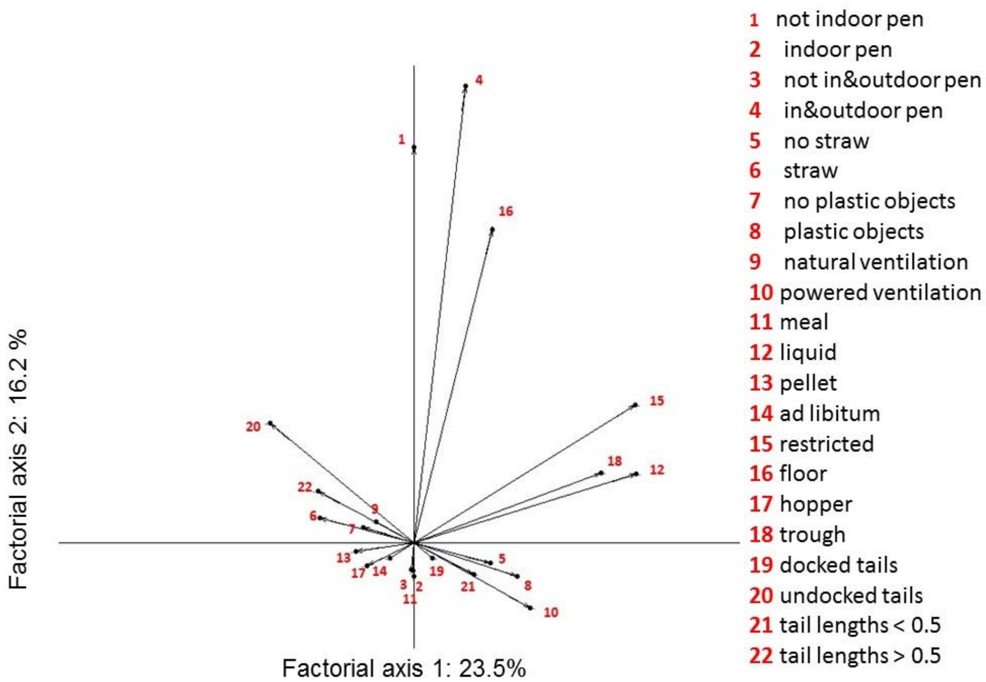



**Figure 4.1** Graphical solution of the Multiple Correspondence Analysis (MCA) at pen-level including 112,240 pig pens, 2013-2016, UK. MCA was used to analyse the pattern of relationships of several categorical variables related to the environment. The two first factorial were used to reduce the dimensionality of the data and simplify the interpretation. The two first factorial axes represented 39.6% of the total inertia (total variance of all variables included in the analysis), with 23.5% explained by the first factorial axis (F1) and 16.2% explained by the second one (F2) (Appendix C.2).

The variables representing the welfares outcomes were plotted on the MCA graph as supplementary variables. The presence, or a prevalence higher than the mean, for lameness and pigs requiring hospitalization were represented close to each other and to the variables "no plastic objects" and "natural ventilation". The presence, or a prevalence higher than the mean, for severe tail lesions and body marks were represented close to each other and close to the variable "tail docked" and in the same direction as "tail lengths <0.5" and "no straw" (Appendix C.4 & C.5).

Figure 4.2 shows that the coordinates of the variables representing a percentage of lameness or pigs requiring hospitalization higher than 0.5%, 1%, 5% and 10% shift progressively from the negative to the positive side of the factorial axis F1. The variables representing the enrichment use ratio below the different limits tended to have positive coordinates on the factorial axis F1 (Appendix C.6). This observation suggests different associations with the environmental variables according to the magnitude of lameness and pigs requiring hospitalization within a pen. Although lower percentage values were still close to each other and to the variable “no plastic objects” and “natural ventilation”, the variables representing higher incidences (1, 5 and 10%) and low enrichment use ratio were located in the same direction as liquid feed, trough feeder, floor feeding, restricted feed and in&outdoor pens. The variables “severe body marks >10%” and “severe tail lesions >10%” were still close to “no straw” and “docked tail pigs” and remained in a similar position to the lower percentages (Figure 4.2).

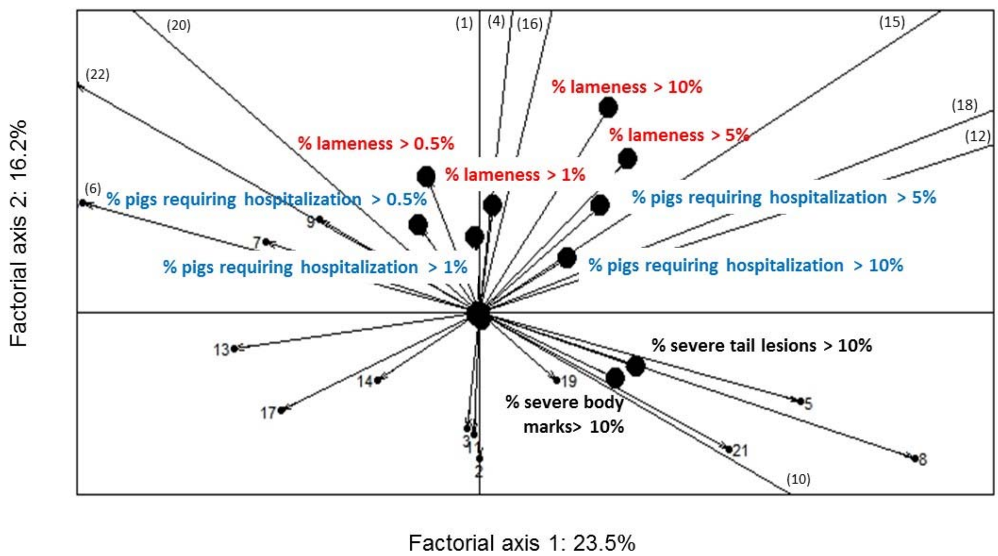



**Figure 4.2** Partial representation of the Figure 4.1 plot with the addition of the supplementary variables related to different prevalences of lameness, pigs requiring hospitalization, tail lesions and body marks on the first and second factorial axis of the MCA graph, along with the active variables and the axes connecting the variables (number in bracket on the MCA graph): not indoor pen (1), indoor pen (2), not in&outdoor outdoor pen (3), in&outdoor pen (4), no straw (5), straw (6), no plastic objects (7), plastic objects (8), natural ventilation (9), powered ventilation (10), meal feeding (11), liquid feed (12), pellets feeding (13), feed always available (ad libitum) (14), restricted feed (15), floor feeding (16), hopper feeding (17), trough feeding (18), docked tails (19), undocked tails (20), tail lengths <0.5 (21) and tail lengths >0.5 (22).

The results of t-tests showed that the pens with positive coordinates on F1 had a higher mean percentage of severe tail lesions ($P<0.001$, mean=0.20) than the pens with negative coordinates on F1 (mean=0.14). The pens with positive coordinates on F1 also had higher mean percentage of severe body marks ($P<0.001$, mean=0.34) than the pens with negative coordinates on F1 (mean=0.22). In contrast, the pens with negative coordinates on F1 had higher mean percentage of lameness ($P<0.001$, mean=0.22) than the pens with positive coordinates on F1 (mean=0.19). The pens with negative coordinates on F1 did not differ in the mean percentage of pigs requiring hospitalization ($P>0.05$, mean=0.08) from the pens with positive coordinates on F1 (mean=0.09). The pens with negative coordinates on F1 had higher enrichment use ratio ($P<0.001$, mean=0.53) than the pens with positive coordinates on F1 (mean=0.36). Furthermore, results of t-tests showed that the pens with both positive coordinates on F1 and positive coordinates on F2 had a higher mean percentage of lameness ($P<0.001$, mean=0.33) than the other pens (mean=0.19) and higher mean percentage of pigs requiring hospitalization ($P<0.01$, mean=0.10) compared to other pens (mean=0.08) .

## 4.5 Discussion

The objective of the study was to identify risk and protective factors for five main welfare indicators collected on UK pig farms. The large sample size and the longitudinal nature of the data provided a good representativeness of commercial pig farms in the UK. As highlighted by Mullan et al. (2009a), a satisfactory estimation of the low prevalence of the welfare outcomes can only be achieved with very large sample size.

### *4.5.1 Sampling and limitations*

Our choice to conduct the analysis at pen level was supported by the results of Taylor at al. (2012), who found no differences in tail biting between systems at farm level but some differences for descriptors at pen level. The analysis showed that good power could be achieved when a margin of error of maximum 20% from the real population mean for the different welfare outcomes was accepted. When a margin of error of maximum 10% from the real population mean for the different welfare outcomes was accepted, attemping to increase the confidence in the results, the power of the analysis was more limited, especially for lameness, severe body marks and severe tail lesions. In multivariable analysis, the P-value assesses the strength of the associations between the dependent variables and the potential risk factors. As the P-value reflects both the size of the sample and the magnitude of the effect (Blumenthal et al., 2001), nationwide collection of large datasets is more effective than small samples to reject the null hypothesis and highlight differences. Although several different assessors collected the data, information bias was thought to be limited as they all received the same formal training. However, this does not exclude potential mistakes in the data recorded by the observers. Several studies have shown good inter-observer reliability of similar welfare outcome data recorded by trained assessors (Main et al., 2000; Mullan et al., 2011a).

The sampling was organized to select, as randomly as possible, pens and pigs representative of the farms. Although it is possible that selection bias might have occurred in the first stage, since only Assurance Scheme members were represented, Red Tractor members represent more than 90% of the pig farmers in England. We used a model that controlled for unknown confounding factors connected to farm, time and pen type and the multivariable analysis also permitted us to produce odds ratios adjusted for the other covariates in the model. To account for the many correlations between variables, we calculated the VIF associated with their inclusion. While a VIF < 5 is considered as acceptable (Rogerson et al., 2001), the inclusion of variables with a VIF between 1 and 5 might led to some misinterpretations for unrepresentative samples (Vatcheva et al., 2016). However, the large sample and the combined MCA allowed a better interpretation of the results.

It must be highlighted that the assessments relate only to pens in the mainstream herd, with the exclusion of hospital pens. This is likely to reduce the estimate of the total prevalence of problems at farm level, since with good management any seriously sick/injured pigs would be moved to hospital pens. Therefore, our assessment was of the association of different variables with a reduction of detrimental welfare outcomes in the mainstream herd, as a consequence of either a general improvement of welfare in the whole farm or better management of sick animals and hospital pens.

### *4.5.2 Associations between variables*

The association between variables, and the potential confounding effects arising from this, have been highlighted in previous studies (Munsterhjelm et al., 2015a). In this study, at least two sets of interconnected variables were apparent. One set represented variables more connected to conventional housing systems (restricted liquid feeding in troughs, and unbedded, controlled-environment systems with object enrichment), while the other set were connected to farms that have implemented supplementary "welfare-friendly" initiatives (straw, undocked tails). Moreover, the different welfare outcome measures did not all co-locate on the MCA plot; a connection appeared between lameness and pigs requiring hospitalization, which differed from severe body marks and severe tail lesions that were located in the opposite quadrant. The proportion of lame pigs and pigs requiring hospitalization had been previously found to be associated in this dataset (Pandolfi et al., 2017), but results contrast with those of Munsterhjelm et al. (2015b), who also excluded hospital pens from their analysis and found a connection between wounds and lameness.

#### *4.5.3 Pen type and farming system*

As suggested by Gade (2002), both intensive and more extensive systems present advantages and disadvantages for animal health and welfare. In the current study, only the prevalence of lameness tended to be higher outdoors, and this was higher also in in&outdoor compared to indoor pens. The prevalence of pigs requiring hospitalization, severe tail biting damage and severe body marks were lower in outdoor pens and the highest prevalence was observed in in&outdoor pens. Contrary to our study, higher prevalence of tail biting, skin lesions and other health issues in abattoir data were identified in pigs from organic/free range systems in Danish herds (Kongsted and Sørensen, 2010; Alban et al., 2015), but the studies referred to all lesions, not specifically the severe ones, and only compared the system without considering other environmental parameters. Moreover, Walker et al. (2006) showed that outdoor pens do not completely prevent tail biting, but pigs more frequently presented moderate wounds with low grade infection. According to the review of Schroder-Petersen et al. (2001), indoor and outdoor temperatures both influence tail biting, such that the combination of variability in both might further increase risk; this suggests that the greater problems seen in in&outdoor pens may relate to control of the thermal environment experienced by the animal.

As reported by D'Eath et al. (2014), welfare issues such as tail biting do not have a single cause, making the comparison between systems too simplistic. The MCA helped to clarify the complexity of the association between welfare outcomes and the environment. While the lower prevalence of lameness and pigs requiring hospitalization showed a certain degree of connection with "welfare friendly pens", the higher prevalence (above 1, 5 or 10%) was connected to in&outdoor pens, but also to liquid feed and restricted feed in troughs or on the floor. Thus, while a low prevalence of lameness or foot lesions can be expected with outdoor soil (Kilbride et al., 2009a; Kilbride et al., 2009b), the prevalence of welfare outcomes may not be only connected to a specific housing system. The complex interaction between welfare issues and the different variables might reveal endemic problems which constantly expose the animal to several inappropriate features in the environment or problems connected to management practices.

The possible confounding effect between pen types and unrecorded risk factors such as health status, previous rearing environment and other management practices (Schroder-Petersen et al., 2001; Taylor et al., 2012; D'Eath et al., 2014), dampness and dirtiness (Geers et al., 1990; Von Borell et al., 1998, Smulders et al., 2006; van de Weerd et al., 2009), and floor type (Gentry et al., 2002; Straw et al., 2006; Kilbride et al., 2009a) should be further explored. For example, pigs requiring hospitalization and with severe body marks were found more commonly in pens with powered ventilation. Draughts resulting in changed level of activity and dirtiness, high concentrations of dust and irritant gases or inadequate temperature are several risk factors that might be associated to powered ventilation of poor quality and affect pig health or welfare (Defra, 2003, Taylor et al., 2012; D'Eath et al., 2014; Michiels et al., 2015). Furthermore, although large pens were associated with lower prevalence of lameness, for pigs requiring hospitalization and with severe tail lesions, the pen size variable might indirectly measure the impact of space allowance, as bigger functional area per pig might be expected in larger pens and has been associated to a decrease of tail lesions (Munsterhjelm et al., 2015a). Moreover, an experimental study showed no differences in lameness with different pen size alone (Vermeer et al., 2014), suggesting that the increase of welfare outcomes is not only connected to the pen size but to several parameters in the environment, such as pen floor type, level of dirtiness or enrichment provision. One study found that farmers with larger herds had better knowledge about hospital pen requirement (Thomsen et al., 2016). Farmer perception regarding pig sickness and requirement for hospitalisation is likely to differ between individuals. The perception of hospitalisation need may also be confounded with production circumstances and the degree of physical, thermal and social challenge provided by the home pen.

### *4.5.4 Feed*

Similarly to previous studies (Van de Weerd et al., 2009; Temple et al., 2012), pens with pigs fed with meal had lower prevalence of lameness, pigs requiring hospitalization and severe tail lesions in comparison with pigs fed liquid feed or pellets. The association of pelleted feed

(Hunter et al., 2001) and liquid feeding (Temple et al., 2012) with an increase of tail biting has been reported in previous studies and might be explained by a better gut health with meal feeding (Taylor et al., 2010). Substrate, meal feed and large pens were associated in our previous study (Pandolfi et al., 2017), supporting the multifactorial aspect of welfare issues. Feeding systems was also associated with other parameters in the environment which might be more directly connected to certain welfare outcomes, such as lameness.

### *4.5.5 Enrichment and tail docking*

Pens with substrates had a lower prevalence of lameness, pigs requiring hospitalization and severe tail lesions, consistent with previous studies (Courboulay et al., 2009; Van de Weerd et al., 2009; Temple et al., 2012; Munsterhjelm et al., 2015a). This might be due to better confort provided by straw bedding and the positive impact of straw on animal behaviour. However, enrichment type was not associated with severe body marks, as previously suggested by other studies (Van de Weerd et al., 2006; Temple et al., 2012). Although provision of substrates showed a positive impact on most welfare outcomes, objects were not associated with a positive effect but very few pens had no reported enrichment against which they could be compared. Many studies have suggested that substrates are more used by pigs and thus more effective to reduce inappropriate behaviors towards pen mates, compared to different objects (Bracke et al., 2006; Van De Weerd et al., 2006, 2009; Scott et al., 2007, 2009). However, enrichment with wooden objects or hanging toys has shown positive impact in some studies (Scott et al., 2009; Cornale et al., 2015). Despite some differences, straw-bedded and conventional systems with slats or concrete floors have also shown similarity in some animal based measures (Guy et al., 2002; Taylor et al., 2012; Temple et al., 2012), suggesting that the substrate alone might not always be able to solve welfare issues. Surprisingly, an increase in lameness and severe tail lesions, which previous studies have indicated can be inter-related through infection (Niemi et al., 2012; Munsterhjelm et al., 2015b), were associated with the presence of objects combined with substrates. This raises the question about the confounding effect of substrates associated to objects, as multiple enrichments might have been used post hoc to control problems such as tail biting arising from other environmental and management issues (Niemi et al., 2012; Munsterhjelm et al., 2015b).

Substrate provision tended to be associated with a decrease of prevalence of severe tail lesions and farms with this system are less likely to dock tails. The causality of the link between tail docking/tail length and tail biting cannot be inferred, since farms choosing not to dock tails, or to dock to a longer length, are likely to be those which have previously experienced little tail biting and therefore have lower risk systems for rearing long tailed pigs. However, the MCA indicated a certain degree of connection between docked tails, tail lengths under 0.5, absence of straw and higher prevalence of severe tail lesions and body marks. This confirms conclusions from the earlier study of Moinard et al. (2003) and more recent review of D'Eath et al. (2014) which suggested that tail docking, which is used to reduce tail biting risk, may not be totally effective on its own.

### *4.5.6 Practical recommendations*

The decrease of lameness in younger pigs, consistent with a previous study (Temple et al., 2012), and the increase of tail biting in older pigs suggests a benefit overall in targeting pigs over 50kg for farm welfare assessment. Severe body marks were more prevalent in younger pigs, as suggested by Temple et al. (2012). Young pigs are more likely to have been recently mixed during group formation and particular attention should be given regarding body marks after regrouping.

Outdoor pigs seem to be m ore suceptible to lameness and the detection of lame pigs should be a focal point in outdoor systems. However, the outdoor system showed its benefits by improving the other welfare outcomes such as reducing the prevalence of tail biting. In&outdoor pens, smaller pens and powered ventilation tended to promote a higher prevalence of lameness, pig requiring hospitalization and severe body marks.

The requirement for pigs to be removed to hospital pens comes from avoidance of further damage, contagion or to remove the pigs from a competitive environment to protect their welfare (White, 2009). In order to avoid welfare issues, quicker hospitalization or intervention should be considered in pens considered at risk.

Feeding system and the use of substrates, and their consequence for pig behavior and health, should be discussed between farmer and veterinarian as potential solutions to reduce lameness, pigs requiring hospitalization or tail biting. However, the whole environment should be reviewed and appropriate space and features provided to ensure that the needs of the animals are fully met.

## 4.6 Conclusions

Pen type, ventilation system, pen size, enrichment and feed were all associated with an impact on welfare outcomes. While the provision of substrate showed a positive impact on several welfare outcomes, tail docking does not seem to be effective on its own to reduce tail biting prevalence. Veterinarians and farmers should give particular attention to pen environment and feeding system to improve animal welfare in all farming systems. This study highlights individual risk factors which can be considered to improve animal welfare, but also indicates the need to consider the environment as a whole because of potential factor combinations and confounds. The "Real Welfare" assessments carried out as part of farm assurance provide a unique opportunity to conduct a risk factor analysis on a large scale database from which to derive practical advice and support future formulation of standards for good practice. The need for large samples to assess risk factors for welfare outcomes with low prevalence and high variability between pens and farms should encourage the collection of additional data in the future.

# Chapter 5 Risk factors associated with the different categories of piglet perinatal mortality in French farms

## 5.1 Abstract

We aimed to identify mortality patterns in French farms and to establish risk factors associated with different categories of piglet perinatal mortality that occurs during the first 48h of life. After exclusion of farms with missing data, the analyses were performed, at farm level, 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.

## 5.2 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 (2013), although different causes of piglet 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., 2010; 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 in their farm. 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.

## 5.3 Materials and methods

### *5.3.1 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 were self-reported by the farmer, thereby creating a broad range of inclusion criteria. 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 48h of life.

### *5.3.2 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 high levels of perinatal mortality. 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 Appendix D.1 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. Therefore the sample size was considered adequate for the purposes of this study.

### 5.3.3 Piglet necropsy

A necropsy was carried out by trained vet in the CCPA 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 Appendix D.2.

### 5.3.4 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.

#### 5.3.4.1 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.

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

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 and avoid bias of the percentages of the different categories of piglet death at farm level, 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; leaving 146 farms in the sample.

#### *5.3.4.2 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 5.1). A season (spring, summer, autumn, or winter) was assigned to the piglet based on its date of birth.

**Table 5.1** Categories and definitons of piglet perinatal mortality.

| Categories | Definitions |
|---|---|
| Non-viable | Piglets < 800g 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 |

### *5.3.5 Data analysis*

For each continuous variable, at farm and piglet level, the median, the first and third quartile, minimum and 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, region C with 500000-1000000 pigs, region B with 200000-50000 pigs, region A with <200000 pigs), Season and Time of death (night/day) (Appendix D.3).

#### *5.3.5.1 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 profiles: 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., 2015b).

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 variables 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 three 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).

#### *5.3.5.2 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 hours, for which we had limited data. Therefore, the analysis focused on the comparison of each of the seven 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. Seven models were used– 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 seven 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 (≤1031g) vs above the mean (>1031g)) and the parity was grouped in three categories (Parity1 to 2, Parity 3 to 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≤ 0.25 were selected for the multivariate models. Variables not significant in the multivariate model, which increased the value of 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 800g 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 fetal death on the basis of the crown-rump length transformation developed by Ullrey (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).

## 5.4 Results

### *5.4.1 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 7,928 that died before farrowing or within the 48h 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). In this sample, moore 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 5.2.

**Table 5.2 Descriptive analysis of the categories of perinatal mortality at farm level:** Median, 1st 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 | 1st 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 |

### *5.4.2 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).

### *5.4.3 Principal Components Analysis*

The results showed that four components had an Eigenvalue higher than 1. The first three components were retained in the model as the Eigenvalue of the fourth component was very close to 1. These three components explained 62.76 % of the total variance for the eight variables of the dataset (Appendix D.4). 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% (Apppendix D.5). The absolute and the relative contributions of the variables for each component are reported in Appendix D.6.

### *5.4.4 Ascending Hierarchical Classification*

A partition into three 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 three clusters instead of a higher partition, suggested this to be the best classification (Appendix D.7)

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 (Figure 5.1). 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.

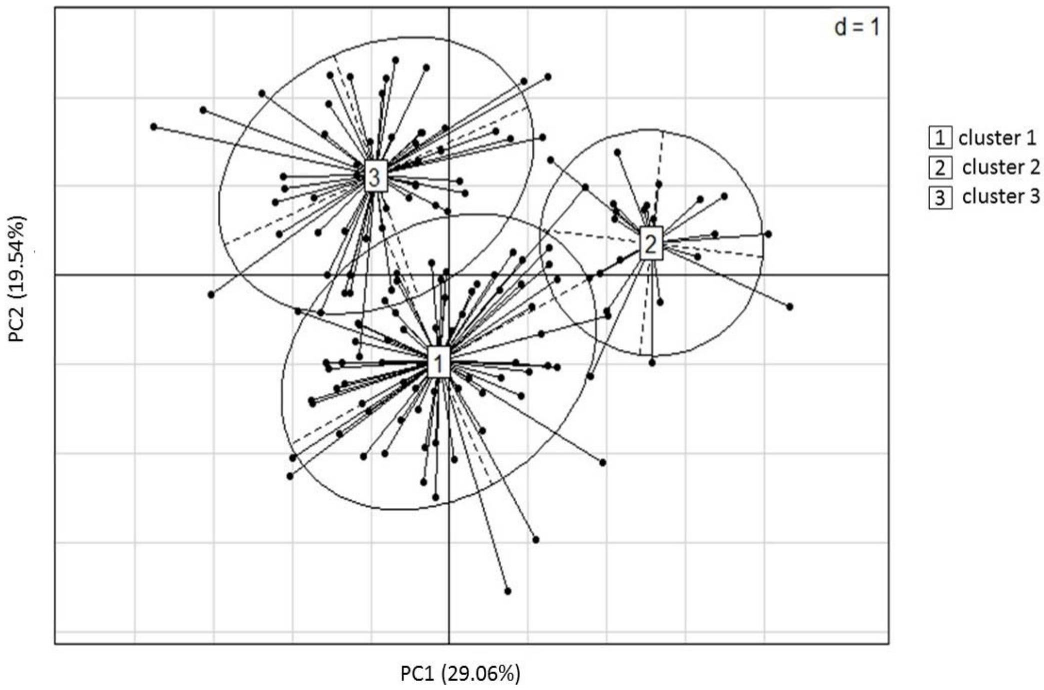



**Figure 5.1** Three different clusters of farms were identified by Ascendant Hierarchical Clustering (AHC) in a sample of French pig farms and represented on the factorial plane 1-2 of the Principal Component Analysis (x-axis: Principal Component 1 (PC1), y-axis: Principal Component 2 (PC2)). The percentage 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.

The description of the variables used for the PCA and the additional continuous variables for each cluster can be seen in Table 5.3. The test values used to compare the mean of the continuous variables, or the proportion for categorical variables, in the cluster and the total sample enabled the evaluation of additional differences between clusters. The percentage of piglets dying from acute disease was significantly higher for cluster 1 and significantly lower for cluster 2. The percentage of piglets dying from 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.

**Table 5.3** 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*

### 5.4.5 Descriptive analysis at piglet level

After removing the outliers, 7761 piglets that died before farrowing or within the 48h 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 piglets was 1031g with a standard deviation of 437.9g. 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 5.4.

**Table 5.4** Categorical explanatory variables used for the multivariable analysis of the 7 categories of perinatal mortality considered at piglet level in French farms.

| Variables | Levels | n (piglets) | % | Variables | Levels | 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 | | | | |

The six mortality categories considered in the analysis represented 84.41% of the total perinatal mortality (Table 5.5).

**Table 5.5** 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%) |

### *5.4.6 Risk factor analysis*

#### *5.4.6.1 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 to 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 5.6).

#### *5.4.6.2 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~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 5.6).

#### *5.4.6.3 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 to 5 compared to parities 1 and 2 (Table 5.6).

#### *5.4.6.4 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 5.6).

#### *5.4.6.5 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 5.7).

#### *5.4.6.6 Starvation*

Piglets were less likely to die with signs of starvation than being classified in another category in parities 3 to 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 5.7).

#### *5.4.6.7 Other categories*

Piglets were more likely to be classified in “other categories” than in the six main categories of piglet death in parities 3 to 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 5.7).

### *5.4.7 Weight by category*

The mean weights, the standard deviations (SD) and the number of piglets (N) for each category are reported in Table 5.8. 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 ($P<0.05$).

**Table 5.6** Multivariate analysis at piglet level for the categories: Early sepsis, Non-viable, Death during farrowing, and Mummified. Odds 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** | **Odds ratios** | **CI 95%** | | ***P-values*** | **Odds ratios** | **CI 95%** | | ***P-values*** | **Odds ratios** | **CI 95%** | | ***P-values*** | **Odds 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 |
| M[1] | Day | *NT* | | | | *NT* | | | | *Baseline* | | | | *NT* | | | |
| | Night | | | | | | | | | 0.853 | 0.753 | 0.966 | 0.012 | | | | |
| W[1] | <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 |
| N[1] | DEATH | *NT* | | | | 0.950 | 0.923 | 0.977 | <0.001 | *NT* | | | | 0.880 | 0.850 | 0.911 | <0.001 |
| O[1] | 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 |
| S[1] | 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 |
| P[1] | 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 |
| L[1] | LITTER | *NT* | | | | *NT* | | | | *NT* | | | | *NT* | | | |

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

[1] M: Moment of the death during the day, W: Weight, N: Number of death in the litter, O: Other piglets death from the same cause, S: Season, P: Parity, L: Litter size

**Table 5.7** Multivariate analysis at piglet level for the categories: Crushing, Starvation and Other. Odds 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 | Odds ratio | CI 95% | | P-values | Odds ratios | CI 95% | | P-values | Odds 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%

**Table 5.8** Mean and Standard deviation of the weight (g) per category of mortality. Each mean weight which was 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 (Pvalue<0.05, with Bonferroni correction)*

### *5.4.8 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 fetal 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 (Appendix D.8).

## 5.5 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 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.

### *5.5.1 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 preweaning mortality (20.0%) (IFIP-GTTT, 2014). It should be noted however, that our analysis only considered deaths in the first 48 hours 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.

#### *5.5.1.1 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 Odds 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.

#### *5.5.1.2 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.

### *5.5.2 Risk factors*

#### *5.5.2.1 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).

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., 2013a). 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., 2010). 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.

#### *5.5.2.2 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 1kg, but 45% with a weight higher than 1.4kg (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 (Cozler et al., 2002; Herpin et al., 2002). Limitation of the placental area by the larger 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. (2010) who highlighted the fact that other daylight activities might stress the sows during 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 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 to 5 than in parities 1 or 2. This is in agreement with other studies in which the risk of stillbirth was higher for sows of parity above 4 who usually farrow bigger litters (Lucia et al., 2002; Borges et al., 2005).

#### *5.5.2.3 Mummified piglets*

The distribution of the length of the mummies did not show the bimodal distribution found in a previous study (Vanderhaeghe et al., 2010) 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 the current 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).

#### *5.5.2.4 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 (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; hyperprolific 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 to 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). Selective culling adopted by farmers will tend to reducethe number of older parity sows with inappropriate maternal behaviour which could lead to crushing.

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, 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.

### *5.5.3 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 those regions of France which make an important contribution to national 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 such as pen and floor type or maternal behavior (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 especially the sow housing 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 and larger average litter size. 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.

## 5.6 Conclusion

Through the comparison of the different categories of mortality and the classification of the farms according to their perinatal mortality problem, this study provides new insights into the problem of piglet mortality during the first 48h after farrowing. 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 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.

# Chapter 6 Impact of neonate management on different categories of piglet mortality in French farms

## 6.1 Abstract

To identify different piglet management strategies and assess their impact on the prevalence and causes of piglet mortality, 58 farms participating in a piglet necropsy study of 3487 piglets between 2009 and 2015 completed a retrospective questionnaire on farm characteristics and management practices. The major categories of mortality after birth were starvation, crushing and non-viable piglets, accounting for 36% of all death causes. A Multiple Correspondence Analysis and Ascendent Hierarchical Clustering identified three clusters of farms, corresponding to 3 different piglet management strategies. Cluster 3 farms (88% of the farms) widely supported both suckling and thermoregulation, tended not to have rules for cross-fostering of bigger piglets and did not cross-foster smaller piglets or mainly cross-fostered them to multiparous sows. We used multinomial regression to assess differences in farm characteristics between clusters using Cluster 3 as a reference: Cluster 1 was more likely to have sows with respiratory problems, vaccinate against circovirus and had slightly smaller piglets ($P < 0.05$) and Cluster 2 farms had a higher number of batches, fewer farrowing units built prior to 2000, spread faecal material less often in the quarantine area and more often employed vaginal palpation before injecting oxytocin ($P < 0.05$). Using generalized linear mixed models, the proportions of piglets which died from starvation, crushing or low viability were only significantly higher in Cluster 1 compared to Cluster 3 ($P < 0.05$). Supporting good thermoregulation and providing piglet assistance can help at reducing piglet mortality post birth, but a strategy which supports better sow management, including vaginal palpation before resorting to an oxytocine injection and selecting sows to retain within the herd according to the number of piglets weaned, might be similarly effective.

## 6.2 Introduction

Crushing, starvation and piglet immaturity have been reported as the main causes of death of live born piglets (Edwards, 2002; Herpin et al., 2002; Pandolfi et al., 2017). Farrowing management, piglet management strategies, environment and genetics all influence risk of piglet death (Rehfeldt and Kuhn, 2006; Alonso-Spilsbury et al., 2007; Canario et al., 2007; Beaulieu et al., 2010). Several studies have demonstrated a positive impact of attitude toward animals, postpartum piglet assistance to obtain colostrum or support for piglet thermoregulation on piglet survival (Andersen et al., 2009; Kauppinen et al., 2012; Rosvold et al., 2017). However, most studies have not specifically focussed on farms where piglet perinatal mortality is an issue. The variables which impact piglet survival are often inter-related and difficult to isolate and interpret in an observational study (Pfeiffer et al., 2010, Edwards and Baxter, 2014), resulting in a limited control of the confounding effects (Westin et al., 2015, Rosvold et al., 2017). Studies also often only investigate risk factors for overall piglet mortality (Panzardi et al., 2013; Rosvold et al., 2017), whilst in studies which investigated specific causes of death, the misclassification of dead piglets has been raised as a particular issue (Kilbride et al., 2012; Westin et al., 2015).

Therefore, by considering a large set of variables, our study aimed to describe different piglet management strategies in a sample of farms with perinatal mortality problems. Based on necropsy and standardized methodology, we assessed the impact of these strategies on piglet mortality and, more specifically, on the prevalence of non-viable piglets, starvation and crushing. In order to consider the multifactorial nature of piglet mortality, in this analysis we accounted for covariates related to farm characteristics and sow management, and compared the farm characteristics associated with the different piglet management strategies.

## 6.3 Materials and Methods

### *6.3.1 Data and sampling*

The study analysed data on piglet perinatal mortality collected from post mortem investigations carried out by CCPA-DELTAVIT, a French consulting company for animal nutrition and health, in combination with data derived from a phone survey conducted from November 2015 to January 2016. Since investigations began in 2004, 177 farms with perinatal piglet mortality issues have participated in the CCPA audit. A total of 81 farms which participated in the audit between 2009 and 2015 were requested to complete a retrospective questionnaire; 58 agreed to participate. The questionnaire included 31 variables related to piglet management strategies (Table 6.1) and additional variables regarding general farm characteristics and sow management (Table 6.2, 6.3 & 6.4). Some of these variables have been recognized in recent literature reviews as risk factors for piglet mortality (Kirkden et al. 2013b; Muns et al., 2016) and were used to adjust the different models which assessed the impact of piglet management on piglet mortality (Table 6.3 & 6.4). The questionnaire was tested with a small number of French farms and was modified by removing or reformulating some questions.

On average, 20 sows were selected in each farm and all the dead piglets of these sows (born dead and dead in the first 48 hours) were collected for necropsy. This represented 3487 piglets in total. Average parity, total number of piglets born, number and weight of piglets dead were recorded. Each piglet was classified into one of 15 categories of death based on a decision tree (Appendix E.2). “Non-viable” piglets were not necropsied and were classified in this category only according to piglet weight.

### *6.3.2 Data analysis*

#### *6.3.2.1 Prevalence of different categories of death*

Descriptive analyses were conducted to describe, at farm level, the percentage of the total piglet deaths represented by each specific category of mortality. We focussed on the prevalence, at piglet level, of the main mortality categories post-birth (starvation, crushing, non-viable), part of the 6 main categories of death identified in our previous study (Pandolfi et al., 2017).

#### *6.3.2.2 Piglet management strategy*

We hypothesized that different piglet management strategies might be associated with different categories of piglet mortality. Multiple correspondence analysis (MCA) and Ascendant Hierarchical Clustering (AHC) were used to identify different piglet management strategies based on the 31 variables from the questionnaire chosen to be related to piglet care (Table 6.1). The methodology is described in Appendix E.1.

**Table 6.1** Variables selected from a retrospective questionnaire to be indicators of the piglet management strategy in 58 French farms experiencing piglet mortality problems.

| Variables | Levels | Variables | Levels |
|---|---|---|---|
| Providing help to piglets after birth[1] | yes | Day of iron administration | day 1 |
| | no | | > day 1 |
| Frequency of help[1] | never | Iron administration[1] | injection |
| | rarely | | oral |
| | sometimes | | |
| | often | Transfer piglets to sow | yes |
| | always | from another batch | no |
| Type of piglet | none | Teeth clipping | yes |
| assistance[1] | assist suckling | | no |
| | move under heating lamp | | |
| | Other support for thermoregulation | Teeth grinding | yes |
| | at least 2 of the 3 propositions | | no |
| | | Piglet castration | yes |
| Providing help for suckling | never | | no |
| | put on the udder | | |
| | shift suckling | Tail docking | yes |
| Providing dry powder or | never | | no |
| equivalent in the farrowing crate | at the beginning of farrowing | | |
| | at the end of farrowing | Day of tail docking | day 1 |
| | | | > day 1 |

| Variables | Levels | Variables | Levels |
|---|---|---|---|
| Rules for piglet cross-fostering | no rules | | |
| | transfer mainly bigger piglets | Treat piglets against parasites | yes |
| | transfer mainly smaller piglets | during the first week | no |
| Transfer of the bigger piglets[1] (crossfostering) | no transfer | Treat piglets with antibiotic | yes |
| | no rules | during the first week | no |
| | to primiparous sow | | |
| | to multiparous sow | | |
| | | Treat piglets with anti-inflammatory | yes |
| Transfer of the smaller | no transfer | during the first week[1] | no |
| piglets[1] (crossfostering) | no rules | | |
| | to primiparous sow | Start extra-feed for piglets | ≤ 5 days |
| | to multiparous sow | | > 5 days |
| Cross-fostering | yes | Type of extra feed | solid |
| if heterogeneous litter | no | | liquid |
| Cross-fostering | yes | Age at weaning | ≤21 days |
| if large litter | no | | >21 days |
| Cross-fostering: sow selection based on parity | yes | Start heating lamp | 1 day before farrowing |
| | no | | > 1 day before |

| Variables | Levels | Variables | Levels |
| --- | --- | --- | --- |
| Crossfostering: sow selection based on maternal behaviour | yes<br>no | Heating in creep area or heating pad | yes<br>no |
| Period of fostering | day of birth<br>day after birth<br>2 days after birth or more | Number of lamps at birth[1] | 1<br>2<br>3 |
| | | Position of the heating lamp[1] | posterior<br>side<br>both |

[1] variables with an absolute contribution above 700 for one of the first 3 factorial axes of the MCA.

#### *6.3.2.3 Farm characteristics*

In order to assess general farm characteristics associated with each piglet management strategy, we assessed the association between the clusters and a set of continuous and categorical variables representing different farm characteristics using separate multinomial logistic regressions. The cluster was the dependant multinomial variable and the reference category was the Cluster 3 with the majority of farms. The difference between clusters was considered significant if $P < 0.05$. The independent variables were either continuous or categorical (Table 6.2). Additional variables, relevant for piglet survival, were also considered as independent variables in the model (Table 6.3 & 6.4).

**Table 6.2** Categorical variables representing different farm characteristics compared between the clusters of farms with different piglet management strategies.

| **Continuous variables** | |
|---|---|
| Number of sow batches in the farm (bach systems) | Length of cleaning period in the farrowing unit |
| Number of sows | Length of cleaning period in the gestation unit |
| Number of fattening pigs | Length of cleaning period in the serving unit |
| Date of construction of the farrowing unit | |
| Date of construction of the gestation unit | |
| Date of construction of the serving unit | |

| **Categorical variables** | **Levels** | **Categorical variables** | **Levels** |
|---|---|---|---|
| Region category (the region of farm location was classified in 5 categories according to pig population in the region) | E: >2 million pigs | Water source | borehole |
| | D: 1-2 million pigs | | mains |
| | C: 0.5-1 million pigs | | well |
| | B: 0.2-0.5 million pigs | | |
| | A: <0.2 million pigs | Faecal material of the herd spread in the quarantine | yes |
| | | | no |
| Farm type | specialized breeder | | |
| | breeder-fatteners | Sows or piglets of the mainstream herd placed in the quarantine | yes |
| | | | no |
| Cooperative type | specialized in pigs | | |
| | not specialized in pigs | Floor in farrowing unit | slatted |
| | | | partially slatted |
| | | | solid concrete |
| System for recording data | none | | |
| | GTT (Gestion Technique Economique) | | |

| Categorical variables | Levels |
|---|---|
| Sow gestation pens | tethers and sow stalls<br>groups |
| Breed selected for prolificity | yes<br>no |
| Breed selected for maternal capacity | yes<br>no |
| Breed selected for robustness | yes<br>no |
| Breed selected for number of piglets weaned | yes<br>no |
| Breed selected because routinely used in the past | yes<br>no |
| Breed selected for quality of the fattening pigs | yes<br>no |
| Breed selected by the cooperative | yes<br>no |

| Categorical variables | Levels |
|---|---|
| Floor in gestation unit | slatted<br>partially slatted<br>solid concrete |
| Floor in serving unit | slatted<br>partially slatted<br>solid concrete |
| Frequency of lameness in sow | never<br>sometimes<br>often<br>always |
| Frequency of respiratory disorder in sow | never<br>sometimes<br>often<br>always |
| Frequency of abortion | never<br>sometimes<br>often<br>always |
| Frequency of vaginal discharge | never<br>sometimes<br>Often<br>always |

| Categorical variables | Levels | Categorical variables | Levels |
|---|---|---|---|
| Vaccination of the sows against Mycoplasma pneumoniae | yes<br>no | Frequency of hypogalactia | never<br>sometimes<br>Often<br>always |
| Vaccination of the sows against PRRS | yes<br>no | | |
| Vaccination of the sows against Actinobacillus pleuropneumoniae | yes<br>no | Frequency of dystocia | never<br>sometimes<br>often<br>always |
| Vaccination of the sows against Escherichia coli | yes<br>no | | |
| Vaccination of the sows against atrophic rhinitis | yes<br>no | | |

#### *6.3.2.4 Impact of piglet management strategy*

To assess whether the piglet management strategy used by the farm impacted on piglet mortality, generalized linear models were used. The cluster was the independent variable. The dependent variable was the total proportion of dead piglets (stillborn and postnatal) for the first model, the proportion of all piglets born which died of starvation for the second model, the proportion of all piglets born which died of crushing for the third model and the proportion of all piglets born which were non-viable for the fourth model. We then examined if other known risk factors might have explained the association between the proportion of the different categories of piglet perinatal mortality and piglet management strategies. The four previously described models were further adjusted (using generalized linear mixed models) for other covariates that are relevant, according to the literature, for piglet survival (Muns et al., 2016) (Table 6.3, 6.4 & 6.5). In total, 20 models were developed; five for each category of death (total piglet deaths, starvation, crushing and non-viable piglets): one model not adjusted, one model adjusted for average parity and average litter size, one model adjusted for average parity, average litter size and stockmanship (training given, sows per employee), one model adjusted for average parity, average litter size and biosecurity score, one model adjusted for average parity, average litter size and a farrowing management score. The association was considered significant if $P < 0.05$. As the model could not converge with all variables related to farrowing management or biosecurity included as covariates, a score for each of these elements was established for the analysis. This scoring system summarized all the variables under a unique score which was used as a covariate in the fourth and fifth models for each category of perinatal death (Table 6.4 & 6.5). The associations between the different covariates were assessed before the analysis using Pearson or Spearman correlations between continuous variables and Anova or Kruskall-Wallis tests for the association between continuous and categorical variables. If two covariates were correlated one of them was excluded from the model.

**Table 6.3** Variables, collected in the farm survey, which were selected for their potential influence on the prevalence of different categories of piglet death.

| Continuous variables | Definition | |
|---|---|---|
| Litter size | average litter size for all sows sampled in the farm | |
| Parity | average parity for all sows sampled in the farm | |
| Sows per employee | number of sows per employee in the farm | |
| Farrowing unit entry | average number of days before farrowing that the sows are transferred to the farrowing unit | |
| **Categorical variables** | **Definition** | **Levels** |
| Training | frequency of the training received by employees | more than once a year<br>once a year<br>less than once a year |

**Table 6.4** Biosecurity scores based on variables collected in the farm survey, which were selected for their potential influence on the prevalence of different categories of piglet death. A score of 1 was attributed if the practice was favourable and a score of 0 was attributed if the practice was not favourable. The total scores were considered as covariates in the different models which assess the association between piglet management and piglet mortality

| Biosecurity score | | |
|---|---|---|
| Variables | Levels | Scores |
| Quarantine | no | 0 |
| | yes | 1 |
| Change boots at entry | rarely or never | 0 |
| | always or often | 1 |
| Cleaning hands at entry | rarely or never | 0 |
| | always or often | 1 |
| Change clothes at entry | rarely or never | 0 |
| | always or often | 1 |
| Vehicles go inside the farm | yes | 0 |
| | no | 1 |
| Clear boundary around the farm | no | 0 |
| | yes | 1 |
| Total score range | | 0 to 6 |

**Table 6.5** farrowing scores based on variables collected in the farm survey, which were selected for their potential influence on the prevalence of different categories of piglet death. A score of 1 was attributed if the practice was favourable and a score of 0 was attributed if the practice was not favourable. The total scores were considered as covariates in the different models which assess the association between piglet management and piglet mortality

| Farrowing score | | |
|---|---|---|
| Variables | Levels | Scores |
| Temperature in farrowing room | >24 °C | 0 |
| | <24 °C | 1 |
| Vaginal palpation before injecting oxytocin | no | 0 |
| | yes | 1 |
| Dose of oxytocin | ≥ 1.5cc | 0 |
| | ≤ 1cc | 1 |
| Farrowing induction | <114 days of pregnancy | 0 |
| | ≥ 114 days of pregnancy | 1 |
| Sergotonine© | before or during the farrowing | 0 |
| | after farrowing | 1 |
| Monitoring farrowing | never or rarely | 0 |
| | often or always | 1 |
| Total score range | | 0 to 6 |

Microsoft Excel 2010, Microsoft Access 2010 and Rstudio (R version 3.1.0) software packages were used for data management and analysis.

## 6.4 Results

### *6.4.1 Descriptive analysis*

Table 6.6 describes the percentage of the total piglet mortality for each category of mortality at farm level. On average, non-viable piglets represented 20.3%, crushing 8.52% and starvation 7.55% of piglet deaths at farm level.

**Table 6.6** The percentage of the total piglet mortality represented by each category of piglet death in a sample of 58 French farms experiencing piglet mortality problems.

| | min | 1st quartile | median | 3rd quartile | max | mean | SD |
|---|---|---|---|---|---|---|---|
| Anemia | 0 | 0 | 0 | 2.81 | 8.11 | 1.40 | 1.98 |
| Starvation | 0 | 3.62 | 6.94 | 11.6 | 19.6 | 7.55 | 5.11 |
| Dehydration enteritis | 0 | 0 | 0 | 0.78 | 10.14 | 1.09 | 2.34 |
| Crushing | 0 | 3.82 | 8.10 | 11.4 | 27.3 | 8.52 | 6.45 |
| Unknown | 0 | 0 | 1.53 | 2.86 | 23.8 | 2.09 | 3.47 |
| Early sepsis | 0 | 8.57 | 12.2 | 24.1 | 48.6 | 15.9 | 10.7 |
| Acute disease | 0 | 0 | 2.49 | 5.34 | 20.0 | 3.56 | 3.87 |
| Malformation | 0 | 0 | 0 | 1.19 | 5.00 | 0.61 | 1.13 |
| Mummification | 0 | 4.25 | 8.33 | 12.5 | 40.5 | 9.04 | 7.17 |
| Death before farrowing | 0 | 1.69 | 3.55 | 7.52 | 22.9 | 5.08 | 4.80 |
| Death during farrowing | 2.08 | 15.0 | 19.7 | 29.5 | 65.8 | 23.3 | 13.5 |
| Non-viable | 0 | 13.6 | 18.8 | 24.9 | 43.4 | 20.3 | 9.61 |
| Splayleg | 0 | 0 | 0 | 0 | 8.00 | 0.67 | 1.77 |
| Killed by the sow | 0 | 0 | 0 | 1.01 | 10.7 | 0.70 | 1.72 |
| Killed by the farmer | 0 | 0 | 0 | 0 | 1.54 | 0.04 | 0.23 |
| Total piglet mortality | 10.2 | 17.5 | 20.1 | 24.1 | 37.3 | 20.9 | 5.59 |

### *6.4.2 Piglet management strategies*

The results of the MCA and AHC were used to identify different piglet management strategies (Table 6.1). After the decomposition of the inertia, 9 variables with an absolute contribution equal to or above 700 were included in the MCA. The three first factorial axes, after running the MCA with the selected variables, represented 33.0% of the total inertia with 12.8% explained by the first (F1), 10.9% explained by the second (F2) and 9.31% explained by the third factorial axis (F3) (Appendix E.3). The absolute contribution for each individual level of the variables is reported in Appendix E.4. A partition into three clusters was determined as the best option (Figure 6.1), giving three distinguishable piglet management strategies. The farms and the variables related to piglet management were projected on the same graph (Appendix E.8, E.9 &

E.10) and coordinates of these variables (Appendix E.5) were used to interpret the piglet management strategy of each cluster of farms.

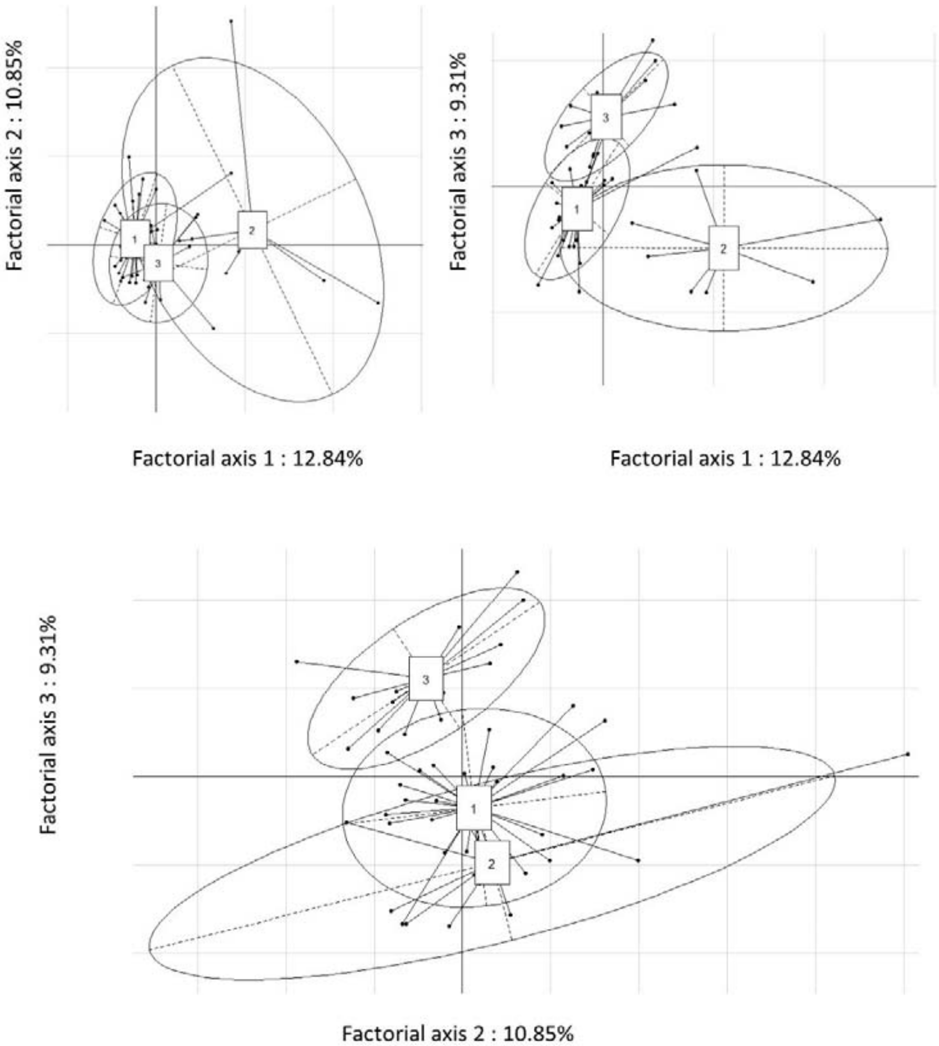



**Figure 6.1** Plots of the farms on the first, the second and the third factorial axes. Three clusters of farms were identified using Ascendant Hierarchical Clustering (AHC) based on the results of a Multiple Correspondence Analysis (MCA) of the values of nine variables related to piglet management.

The farms of the Cluster 1 were on the negative side of F1 and on the negative side of F3, close to the variables: “anti-inflammatory: yes”, “number of lamps at birth: 1”, “position of the heating lamp: posterior", "position of the heating lamp: side", "type of piglet assistance: suckling", "type of piglet assistance: other", "transfer of the smaller to primiparous", "transfer of the bigger to multiparous". We can conclude that the strategy adopted by these farms seemed to provide some assistance to piglets, but supplementary heating provision was limited and only 50% of the farms provided support for both suckling and thermoregulation. They also tended to cross-foster smaller piglets to primiparous sows (59%) and bigger piglets to multiparous sows (50% of the farms) or did not have rules of cross-fostering for bigger piglets (50% of the farms) (Table 6.7, Appendix E.5, E8, E.9 & E.10).

The farms of Cluster 2 were mainly on the positive side of F1 and negative side of F3, close to the variables: "frequency of help: never", "frequency of help: rarely", "type of piglet assistance: none", "Help piglet after birth: no", "transfer of the smaller: no rules", "transfer of the bigger: no transfer", "number of lamps at birth: 3". We can conclude that the main characteristic of this cluster was the low assistance given to piglets after birth but several sources of supplementary heating. The small number of farms did not allow a good interpretation of the variables: "transfer of the smaller piglets", "transfer of the bigger piglets" (Table 6.7, Appendix E.5, E8, E.9 & E.10).

The farms of Cluster 3 were mainly on the positive side of F3 represented cluster 3 close to thevariables: "number of lamps at birth: 3", "position of the heating lamp: both (side and posterior)", "frequency of help: often", "frequency of help: always", "type of piglet assistance: at least 2 of the 3 propositions", "type of piglet assistance: move under heating lamp", "transfer of the bigger: primiparous", "transfer of the bigger: no transfer", transfer of the bigger: no rules", transfer of the smaller: multiparous", "transfer of the smaller: no transfer". The farms of this cluster seemed to provide regular help to the piglets, 88% of the farms of this cluster provided help for both suckling and thermoregulation and provided several sources of supplementary heating. A higher percentage of farms transferred smaller piglets to multiparous (47%) and transferred bigger piglets without specific rules (53%) (Table 6.7, Appendix E.5, E8, E.9 & E.10).

**Table 6.7** Mean and standard deviation for the different categories of piglet mortality for each farm cluster and frequency of each sublevel of the variables related to the piglet management strategies for the 3 different clusters identified with an MCA and AHC analysis. (The higher number of farms for each parameters is marked in bold for the categorical variables)

| **Variables** | **Cluster 1(n=35)** | **Cluster 2(n=7)** | **Cluster 3 (n=17)** |
|---|---|---|---|
| Total piglet mortality (%) | 21.8 (±5.51) | 21.9 (±6.07) | 19.4 (±5.42) |
| Starvation (% of total born) | 2.23 (±1.27) | 1.47 (±1.23) | 1.01 (±0.86) |
| Starvation (% of total piglet deaths) | 9.96 (±4.81) | 6.73 (±5.53) | 5.28 (±4.20) |
| Crushing (% of total born) | 2.27 (±1.35) | 1.67 (±1.29) | 1.43 (±1.47) |
| Crushing (% of total piglet deaths) | 10.9 (±7.21) | 7.44 (±5.56) | 6.42 (±5.19) |
| Non-viable piglets (% of total born) | 5.16 (±3.14) | 4.40 (±3.50) | 3.84 (±2.46) |
| Non-viable piglets (% of total piglet deaths) | 21.9 (±8.52) | 18.9 (±11.94) | 19.2 (±9.84) |

| **Variables** | **Levels** | **Number of farms** | **%** | **Number of farms** | **%** | **Number of farms** | **%** |
|---|---|---|---|---|---|---|---|
| Help piglet after birth | yes | **31** | 91.2 | 1 | 14.3 | **17** | 100 |
| | no | 1 | 2.94 | **6** | 85.7 | 0 | 0 |
| | missing | 2 | 5.88 | 0 | 0 | 0 | 0 |
| Frequency of help | never | 0 | 0 | 2 | 28.6 | 0 | 0 |
| | rarely | 0 | 0 | 1 | 14.3 | 0 | 0 |
| | sometimes | **21** | 61.8 | **3** | 42.9 | 4 | 23.5 |
| | often | 12 | 35.3 | 1 | 14.3 | **8** | 47.1 |
| | always | 0 | 0 | 0 | 0 | 5 | 29.4 |
| | missing | 1 | 2.94 | 0 | 0 | 0 | 0 |

| Variables | Levels | Number of farms | % | Number of farms | % | Number of farms | % |
|---|---|---|---|---|---|---|---|
| Type of piglet assistance | none | 0 | 0 | **5** | 71.4 | 0 | 0 |
| | suckling | 8 | 23.5 | 1 | 14.3 | 0 | 0 |
| | move under heating lamp | 7 | 20.6 | 1 | 14.3 | 2 | 11.8 |
| | other | 1 | 2.94 | 0 | 0 | 0 | 0 |
| | at least 2 of the 3 propositions* | **17** | 50.0 | 0 | 0 | **15** | 88.2 |
| | missing | 1 | 2.94 | 0 | 0 | 0 | 0 |
| Cross-fostering of the smaller piglets | no transfer | 0 | 0 | 0 | 0 | 3 | 17.6 |
| | no rules | 4 | 11.8 | 1 | 14.3 | 0 | 0 |
| | to primiparous | **20** | 58.8 | 3 | 42.9 | 6 | 35.3 |
| | to multiparous | 9 | 26.5 | 3 | 42.9 | **8** | 47.1 |
| | missing | 1 | 2.94 | 0 | 0 | 0 | 0 |
| Cross-fostering of the bigger piglets | no transfer | 0 | 0 | 1 | 14.3 | 1 | 5.88 |
| | no rules | **15** | 44.1 | 1 | 14.3 | **9** | 52.9 |
| | to primiparous | 0 | 0 | 1 | 14.3 | 3 | 17.6 |
| | to multiparous | **15** | 44.1 | **3** | 42.9 | 4 | 23.5 |
| | missing | 0 | 0 | 1 | 14.3 | 0 | 0 |
| Anti-inflammatory | yes | 3 | 8.82 | 0 | 0 | 0 | 0 |
| | no | **31** | 91.2 | **7** | 100 | **17** | 100 |
| | missing | 0 | 0 | 0 | 0 | 0 | 0 |

| Variables | Levels | Number of farms | % | Number of farms | % | Number of farms | % |
|---|---|---|---|---|---|---|---|
| Iron administration | injection | **28** | 82.4 | **6** | 85.7 | **15** | 88.2 |
| | oral | 5 | 14.7 | 1 | 14.3 | 2 | 11.8 |
| | missing | 1 | 2.94 | 0 | 0 | 0 | 0 |
| Number of lamps at birth | 1 | **18** | 52.9 | 1 | 14.3 | 1 | 5.88 |
| | 2 | 13 | 38.2 | **5** | 71.4 | **13** | 76.5 |
| | 3 | 1 | 2.94 | 1 | 14.3 | 2 | 11.8 |
| | missing | 2 | 5.88 | 0 | 0 | 1 | 5.88 |
| Position of the heating lamp | posterior | **19** | 55.9 | **4** | 57.1 | 1 | 5.88 |
| | side | 10 | 29.4 | 1 | 14.3 | 3 | 17.6 |
| | both | 3 | 8.82 | 2 | 28.6 | **12** | 70.6 |
| | missing | 2 | 5.88 | 0 | 0 | 1 | 5.88 |

### *6.4.3 Farm characteristics associated with piglet management strategies*

Table 6.8 presents the farm characteristics significantly associated to a specific piglet management strategy cluster. The farms from Cluster 1 were more likely to have a respiratory problem amongst their sows, vaccinated more often against circovirus and had slightly smaller piglets than farms from cluster 3 ($P < 0.05$). The farms from Cluster 2 had a higher number of batches, fewer farrowing units built before 2000, less often spread faecal material in the quarantine, more often employed vaginal palpation before injecting oxytocin and were more likely to select a breed based on the number of piglets weaned ($P < 0.05$).

**Table 6.8** Odds ratios, confidence interval and P values for the multinomial models used to assess the differences in farm management and characteristics for different farm clusters based on their piglet management strategies.

| | Cluster 3 | Cluster 1 | Cluster 2 |
|---|---|---|---|
| Number of batches | | | |
| Odds ratios | *baseline* | 1.01 | 1.12 |
| CI 95% | | 0.92-1.12 | 1.00-1.25 |
| P value | | 0.738 | 0.046[a] |
| Mean number of batches | 8.39 | 8.96 | 13.6 |
| Year of construction of the farrowing unit: <2000 (ref: >=2000) | | | |
| Odds ratios | *baseline* | 0.78 | 0.11 |
| CI 95% | | 0.23-2.60 | 0.02-0.65 |
| P value | | 0.683 | 0.015[a] |
| number of farms with farrowing unit built before 2000 | 16(70%) | 16(64%) | 2(20%) |
| Breed selected for number of piglet weaned: yes (ref= no) | | | |
| Odds ratios | *baseline* | 3.32 | 7.00 |
| CI 95% | | 0.60-18.5 | 1.02-47.97 |
| P value | | 0.171 | 0.048[a] |
| number of farms where breed selected for number of piglet weaned | 2(9%) | 6(24%) | 4(40%) |
| Average weight of the dead piglets | | | |
| Odds ratios | *baseline* | 0.99 | 1.00 |
| CI 95% | | 0.99-0.99 | 1.00-1.00 |
| P value | | <0.01 [a] | <0.01 [a] |
| Average weight of the dead piglets (g) | 1057 | 1042 | 1094 |

| | Cluster 3 | Cluster 1 | Cluster 2 |
|---|---|---|---|
| Vaginal palpation before injecting oxytocin: often (ref=never or sometimes) | | | |
| Odds ratios | *baseline* | 3.53 | 12.50 |
| CI 95% | | 0.63-19.83 | 1.76-88.73 |
| P value | | 0.152 | 0.012 [a] |
| Number of farms which are often practicing vaginal palpation before injecting oxytocin | 2(9%) | 6(24%) | 5(50%) |
| Faecal material of the herd spread in the quarantine: yes (ref= no) | | | |
| Odds ratios | *baseline* | 0.45 | 0.15 |
| CI 95% | | 0.10-2.07 | 0.03-0.85 |
| P value | | 0.305 | 0.032 [a] |
| number of farms which spread faecal material in the quarantine | 20(87%) | 18(72%) | 5(50%) |
| Respiratory disorders : Yes (ref=no or rarely) | | | |
| Odds ratios | *baseline* | 5.64 | 0.74 |
| CI 95% | | 1.32-24.17 | 0.07-8.13 |
| P value | | 0.020 [a] | 0.806 |
| number of farms with respiratory issues | 3(13%) | 11(44%) | 1(10%) |
| Vaccine against circovirus: yes (ref=no) | | | |
| Odds ratios | *baseline* | 4.82 | 1.86 |
| CI 95% | | 1.46-16.40 | 0.42-8.47 |
| P value | | 0.012 [a] | 0.414 |
| Number of farms which vaccinate the sows against circovirus | 8(35%) | 18(72%) | 5(50%) |

[a] significantly different than Cluster 3 ($P < 0.05$). No letter: cluster does not differ from Cluster 3 ($P > 0.05$)

### 6.4.4 *Impact of the different management strategies on piglet mortality*

No associations were found between the different covariates considered for this analysis. The description of each covariate and variables used to create the scores is reported in Appendix E.6 & E.7. Total piglet mortality from all causes was significantly higher in Cluster 1 compared to cluster 3 (P < 0.05) but the difference between clusters was no longer significant when covariates were added, despite a tendency to remain different between Clusters 1 and 3 (0.1> P > 0.05), suggesting that differences in total piglet mortality are also associated with risk factors other than piglet management (Table 6.9).

**Table 6.9** Comparison of the impact of piglet management strategies adopted by different farm clusters on total piglet mortality. The ratios were generated by different generalized linear mixed models with the total proportion of dead piglets as the dependent variable and the cluster partition as the independent variable. The odds ratios for Clusters 1 and 2 use Cluster 3 as the baseline.

| | | Odds ratios | CI 95% | | P values |
|---|---|---|---|---|---|
| Model 1[a] | Cluster 3 | *baseline* | | | |
| | Cluster 1 | 1.13 | 1.04 | 1.26 | <0.01[f] |
| | Cluster 2 | 1.12 | 1.00 | 1.24 | 0.05 |
| Model 2[b] | Cluster 3 | *baseline* | | | |
| | Cluster 1 | 1.20 | 0.99 | 1.45 | 0.06 |
| | Cluster 2 | 1.07 | 0.84 | 1.37 | 0.57 |
| Model 3[c] | Cluster 3 | *baseline* | | | |
| | Cluster 1 | 1.19 | 0.97 | 1.46 | 0.08 |
| | Cluster 2 | 1.04 | 0.80 | 1.36 | 0.75 |
| Model 4[d] | Cluster 3 | *baseline* | | | |
| | Cluster 1 | 1.20 | 0.99 | 1.45 | 0.06 |
| | Cluster 2 | 1.04 | 0.82 | 1.32 | 0.75 |
| Model 5[e] | Cluster 3 | *baseline* | | | |
| | Cluster 1 | 1.20 | 0.98 | 1.46 | 0.08 |
| | Cluster 2 | 1.07 | 0.82 | 1.38 | 0.62 |

[a] model not adjusted

[b] model adjusted for parity and litter size

[c] model adjusted for parity, litter size and stockmanship.

[d] model adjusted for parity, litter size and biosecurity score

[e] model adjusted for parity, litter size and farrowing management score

[f] Significantly different from Cluster 3 (P < 0.05). No letter if no significant difference from Cluster 3 (P > 0.05)

The proportion of piglets dying from starvation amongst the number of piglets born was significantly higher in Cluster 1 compared to Cluster 3, even after considering the adjustment for average parity, average litter size, stockmanship, biosecurity score and farrowing management score ($P < 0.05$). The percentage of piglets dying from starvation was significantly higher in Cluster 2 compared to Cluster 3 only after considering the adjustment for litter size, parity and biosecurity score ($P < 0.05$) (Table 6.10).

**Table 6.10** Comparison of the impact of piglet management strategies adopted by different farm clusters on the percentage of piglets dying from starvation. The ratios were generated by different generalized linear mixed models with the proportion of all piglets born which died of starvation as dependent variable and the cluster partition as independent variable. The odds ratios for Clusters 1 and 2 use Cluster 3 as the baseline.

| | | Odds ratios | CI 95% | | P values |
|---|---|---|---|---|---|
| Model 1[a] | Cluster 3 | *baseline* | | | |
| | Cluster 1 | 2.11 | 1.60 | 2.81 | <0.01 [f] |
| | Cluster 2 | 1.38 | 0.93 | 2.03 | 0.106 |
| Model 2[b] | Cluster 3 | *baseline* | | | |
| | Cluster 1 | 2.18 | 1.45 | 3.28 | <0.01 [f] |
| | Cluster 2 | 1.47 | 0.86 | 2.54 | 0.161 |
| Model 3[c] | Cluster 3 | *baseline* | | | |
| | Cluster 1 | 2.25 | 1.49 | 3.41 | <0.01 [f] |
| | Cluster 2 | 1.41 | 0.80 | 2.47 | 0.233 |
| Model 4[d] | Cluster 3 | *baseline* | | | |
| | Cluster 1 | 2.36 | 1.59 | 3.49 | <0.01 [f] |
| | Cluster 2 | 1.73 | 1.01 | 2.97 | 0.046 [f] |
| Model 5[e] | Cluster 3 | *baseline* | | | |
| | Cluster 1 | 2.29 | 1.49 | 3.53 | <0.01 [f] |
| | Cluster 2 | 1.26 | 0.71 | 2.26 | 0.429 |

[a] model not adjusted

[b] model adjusted for parity and litter size

[c] model adjusted for parity, litter size and stockmanship.

[d] model adjusted for parity, litter size and biosecurity score

[e] model adjusted for parity, litter size and farrowing management score

[f] Significantly different from Cluster 3 ($P < 0.05$). No letter if no significant difference from Cluster 3 ($P > 0.05$)

The proportion of piglets dying from crushing amongst the number of piglet born was significantly higher in Cluster 1 compared to Cluster 3, even after considering the adjustment for average parity, average litter size, stockmanship, biosecurity score and farrowing management score ($P < 0.05$) (Table 6.11).

**Table 6.11** Comparison of the impact of piglet management strategies adopted by different farm clusters on the percentage of piglets dying from crushing. The ratios were generated by different generalized linear mixed models with the proportion of all piglets born which died of crushing as dependent variable and the cluster partition as independent variable. The odds ratios for Clusters 1 and 2 use Cluster 3 as the baseline.

| | | Odds ratios | CI 95% | | P values |
|---|---|---|---|---|---|
| Model 1[a] | Cluster 3 | *baseline* | | | |
| | Cluster 1 | 1.54 | 1.21 | 1.98 | < 0.01 [f] |
| | Cluster 2 | 1.11 | 0.78 | 1.57 | 0.542 |
| Model 2[b] | Cluster 3 | *baseline* | | | |
| | Cluster 1 | 1.75 | 1.10 | 2.78 | 0.018 [f] |
| | Cluster 2 | 1.23 | 0.66 | 2.29 | 0.515 |
| Model 3[c] | Cluster 3 | *baseline* | | | |
| | Cluster 1 | 1.86 | 1.18 | 2.91 | < 0.01 [f] |
| | Cluster 2 | 1.13 | 0.62 | 2.06 | 0.688 |
| Model 4[d] | Cluster 3 | *baseline* | | | |
| | Cluster 1 | 1.81 | 1.12 | 2.95 | 0.016 [f] |
| | Cluster 2 | 1.36 | 0.70 | 2.64 | 0.366 |
| Model 5[e] | Cluster 3 | *baseline* | | | |
| | Cluster 1 | 1.80 | 1.13 | 2.86 | 0.013 [f] |
| | Cluster 2 | 1.16 | 0.64 | 2.11 | 0.621 |

[a] model not adjusted

[b] model adjusted for parity and litter size

[c] model adjusted for parity, litter size and stockmanship.

[d] model adjusted for parity, litter size and biosecurity score

[e] model adjusted for parity, litter size and farrowing management score

[f] Significantly different from Cluster 3 ($P < 0.05$). No letter if no significant difference from Cluster 3 ($P > 0.05$)

The proportion of dead piglets classed as non-viable amongst the number of piglets born was also significantly higher in Cluster 1 compared to Cluster 3 when adjusting for all different covariates additional to average parity and average litter size (P < 0.05) (Table 6.12).

**Table 6.12** Comparison of the impact of piglet management strategies adopted by different farm clusters on the percentage of piglets classed as non-viable piglets. The ratios were generated by different generalized linear mixed models with the proportion of all piglets born which were non-viable as dependent variable and the cluster partition as independent variable. The odds ratios for Clusters 1 and 2 use Cluster 3 as the baseline.

| | | Odds ratios | CI 95% | | P values |
|---|---|---|---|---|---|
| Model 1[a] | Cluster 3 | *baseline* | | | |
| | Cluster 1 | 1.30 | 1.11 | 1.53 | <0.01 [f] |
| | Cluster 2 | 1.15 | 0.92 | 1.43 | 0.218 |
| Model 2[b] | Cluster 3 | *baseline* | | | |
| | Cluster 1 | 1.41 | 0.98 | 2.03 | 0.061 |
| | Cluster 2 | 1.00 | 0.61 | 1.64 | 0.996 |
| Model 3[c] | Cluster 3 | *baseline* | | | |
| | Cluster 1 | 1.45 | 1.02 | 2.06 | 0.038 [f] |
| | Cluster 2 | 0.83 | 0.50 | 1.38 | 0.473 |
| Model 4[d] | Cluster 3 | *baseline* | | | |
| | Cluster 1 | 1.45 | 1.00 | 2.11 | 0.048 [f] |
| | Cluster 2 | 0.91 | 0.55 | 1.51 | 0.724 |
| Model 5[e] | Cluster 3 | *baseline* | | | |
| | Cluster 1 | 1.48 | 1.01 | 2.17 | 0.045 [f] |
| | Cluster 2 | 1.07 | 0.64 | 1.80 | 0.791 |

[a] model not adjusted

[b] model adjusted for parity and litter size

[c] model adjusted for parity, litter size and stockmanship.

[d] model adjusted for parity, litter size and biosecurity score

[e] model adjusted for parity, litter size and farrowing management score

[f] Significantly different from Cluster 3 (P < 0.05). No letter if no significant difference from Cluster 3 (P > 0.05)

## 6.5 Discussion

Piglet perinatal mortality is a complex problem with a multifactorial nature encountered in many pig farms (Kirkden et al., 2013b). The majority of deaths occur in the first few days after birth from a range of causes (Panzardi et al., 2013). Crushing, starvation and piglet immaturity are the main causes of death of live born piglets (Herpin et al., 1996; Herpin et al., 2002), with these causes being more prevalent for some farm types than others (Pandolfi et al., 2017c). Several studies have shown that mortality of piglets born alive can be reduced if good management routines are adopted (Andersen et al., 2007; Rosvold et al., 2017). The aims of this study were to: 1) identify different piglet management strategies used by farms which experience perinatal mortality problems, 2) identify the characteristics of farms associated with each piglet management strategy and 3) assess the impact of these strategies on different categories of piglet death: total mortality, starvation, crushing and non-viable piglets. We identified three clusters of farms with different piglet management strategies. The differences between clusters appeared to be related to a number of different aspects of management, discussed below.

### *6.5.1 Provision of supplementary heating*

Farms in Clusters 2 & 3 preferentially used two heating lamps or more, providing a good microclimate for the neonatal piglets (Muirhead and Alexander, 1997; Kirkden et al., 2013b, Edwards and Baxter, 2014). Piglets usually prefer to lie close to the sow udder during the first two days after birth (Berg et al., 2006), attracted by thermal and olfactory cues (Rohde Parfet and Gonyou, 1991). This highlights the importance of providing an environment which allows good thermoregulation and teat accessibility to reduce the mortality of the weakest piglets and respect natural piglet and sow behaviour. While no significant differences were identified between Clusters 2 & 3, in Cluster 3 the levels of total mortality, starvation, crushing and non-viable piglet were reduced compared to Cluster 1. In Cluster 1 only one heating lamp was generally used and placed posterior to the sow.

### *6.5.2 Provision of assistance to neonatal piglets*

Cluster 3 adopted a strategy which provided more frequent and diverse help to the piglets; supporting both suckling and thermoregulation. This might suggest better stockmanship in this cluster of farms. A previous study showed that drying the piglets and placing them at the udder reduced the time between birth and the first suckle and facilitated achievement of <10 %

mortality in loose housing (Vasdal et al., 2011). While farms in both Cluster 1 & 3 helped piglets after birth, the farms of Cluster 1 helped mainly for the suckling or thermoregulation, but not systematically both at the same time. The proportion of piglets dying from starvation, crushing and non-viable piglets was significantly smaller in Cluster 3 compared to 1, suggesting that only encouraging piglet suckling or supporting thermoregulation might not be sufficient to improve piglet survival. Indeed, Muns et al. (2015) showed the lack of success of split suckling, while Vasdal et al. (2011) showed that the interval between birth and first suckle was reduced when piglets were dried and placed close to the udder, but the level of mortality was higher when they were just placed close to the udder. The increase in prevalence of crushing, starvation and non-viable piglets in Cluster 1 compared to 3 was unaffected by the different covariates; suggesting the importance of piglet management for piglets born alive (Muns et al., 2016; Rosvold et al., 2017). Farms from Cluster 2 tended to provide little help to the piglets and the proportion of piglets dying from starvation was only higher in Cluster 2 compared to Cluster 3 when adjusting for parity, litter size and biosecurity. This suggests that the importance of piglet assistance might be conditional to other parameters, such as the environment or sow management. Although the level of total mortality was not significantly different between clusters, that is perhaps not surprising given how the farms were selected, namely all farms selected had perinatal mortality issues. Equally, it is not surprising that other parameters related to the sows and the environment can have a bigger influence on the total piglet deaths including stillbirth, than management strategies employed for the newborn piglets (Weber et al., 2009; Kirkden et al., 2013b; Westin et al., 2015).

### *6.5.3 Piglet size and cross-fostering*

The farms in Cluster 3 tended to show more flexibility when cross-fostering bigger piglets, did not cross-foster smaller piglets or mostly transfered them to multiparous sows. The absence of fixed rules for cross-forstering gives the opportunity to consider several parameters related to the sow, the piglet and the environment to guarantee the sucess of the practice and might explain better piglet survival in this cluster. Kikden et al. (2013b) recommend a litter-by-litter decision making, involving stockperson expertise, as pre-defined rules might not be sufficient. Another study also showed the impact of farmer management routines around farrowing on piglet survival (Rosvold et al., 2017). However, this also suggests the necessity for a good level of expertise, good training of the farm staff and suitable working conditions, such as a low-stress environment that encourages low-stress interactions with animal and to make the appropriate choices during cross-fostering (Coleman et al., 1998; Coleman et al., 2000; Coleman and Hemsworth, 2014). In Cluster 1, the dead piglets tended to be slightly smaller, which might reflect a lower birthweight or an earlier age of death, and the rules for cross-fostering seemed to prioritize the transfer of smaller piglets to primiparous sows. Many studies have reported that low birth weight impairs piglet survival (Herpin et al., 1996; Panzardi et al., 2013); the social environment will disadvantage low birth weight piglets and competition will increase their risk of starvation (Edwards and Baxter, 2014). Moreover, one study showed lower performance for piglets with low birth weight and transfer to primiparous sows during crossfostering (Ferrari et al., 2014).

### *6.5.4 Farrowing accommodation and sow management*

The farrowing units, on average, were more recently constructed in Cluster 2, and more modern equipment in a new housing system might improve sow health and piglet survival (Gu et al., 2010; Muns et al., 2016). The confounding effect of sow management or stockperson skills in recently constructed buildings need to be assessed in further studies. The farms from Cluster 2 tended also to select their sow breed based on the number of piglets weaned, putting some genetic emphasis on reducing mortality. This might result in lower piglet mortality, as Knecht et al. (2015) and Quesnel et al. (2008) showed that a higher number of piglets born alive and piglets weaned could be achieved with specific breeds or genetic lines. Moreover, regular vaginal palpation before injecting oxytocin practiced by these farmers might illustrate more careful management during farrowing. This suggests the importance of such precautions when oxytocin is routinely used during farrowing management and, therefore, the importance of stockmanship. While Vanderhaeghe et al. (2010) suggested an increased risk of stillbirth following vaginal palpation but not with the use of oxytocin, Kirkden et al. (2013b) highlighted the lack of discrimination between routine administration and the use of oxytocin to treat dystocia. Moreover, other studies have shown that administering the wrong dose of oxytocin at the wrong time could have a negative impact on piglet survival (Mota-Rojas et al., 2002; Mota-Rojas et al., 2006). Therefore, practicing manual assistance when indicated might improve piglet survival and avoid misuse of oxytocin. Despite the lack of piglet assistance, the farms in Cluster 2 might therefore have improved piglet survival due to better infrastructure and sow management.

### *6.5.5 Health status of the farm*

Cluster 1 farms reported greater respiratory problems in sows and a higher frequency of vaccination against circovirus (PCV2) for the sows compared to Cluster 3. PCV2, in combination with other agents such as Porcine Reproductive and Respiratory syndrome (PRRS), swine influenza virus or Mycoplasma hyopneumoniae, can be responsible for respiratory symptoms (Afghah et al., 2016). Moreover, PRRS involves both respiratory and problems of fertility in the sow and weaker piglets at birth (Christianson et al., 1993), while PCV2 vaccination has been considered particularly relevant in herds positive for PRRS (da Silva et al., 2014). More data are needed to better explore the impact of the prevalence of specific sow disease status of the farm on the prevalence of piglet deaths.

The higher level of starvation in Cluster 2 compared to Cluster 3 after considering the average parity, average litter size and biosecurity score may suggest that piglet handling could be an important parameter for certain parities, hyperprolific sows and farms with a low level of biosecurity (Westin et al., 2015; Muns et al., 2016). The higher average number of batches in the farm (batch system) found in Cluster 2 might suggest higher likelihood of low biosecurity in this cluster. Systems with 20-21 batches generally allow more flexibility in management, but may show some weaknesses regarding sanitary measures (Allouchery, 2010). Finally, these farms tended to less often spread faecal material in the quarantine. Acclimatizing the gilts to herd pathogens by introducing cull sows or manure during the latter part of the quarantine period has been recognized as a good practice to build immunity (Kraeling and Webel, 2015), but the positive or negative impact of quarantine management on sow health and piglet survival would also need to be investigated in future studies.

### *6.5.6 Limitations and bias in the study*

The farms in this study were not randomly sampled and were self-defined as having perinatal mortality problems. Therefore, the results of this analysis should be only extended with care to the whole population of French pig farms due to the limitations of the sampling strategy. Further analyses are required to identify whether similar piglet management strategies can be identified in a random sample of farms and to assess the impact of these strategies on piglet mortality. While the data on mortality are based on a multistage sampling, where sows and piglets were sampled randomly and dead piglets were classified into different categories based on standardised necropsy (Pandolfi et al., 2017c), the phone interview might have been subject to information bias which we could not verify by a proper farm visit. However, the methodology used allowed a better control of the cofounding effects. The extensive background of information collected during the study allowed the models to be adjusted for several variables known as risk factors for piglet mortality and also to describe the farm characteristics associated with the different piglet management strategies. Despite the simplification of using a scoring system for farrowing management and biosecurity, this was useful to control for potential confounding effects.

## 6.6 Conclusion

Supporting good thermoregulation and providing piglet assistance can be an easy way to reduce perinatal piglet mortality after birth, by increasing the level of help provided to the underweight and immature piglets and at the same time improving colostrum intake and thermoregulation. However, the absence of differences in the prevalence of total piglet mortality after adjusting for several important other risk factors highlights the importance of other variables related to the environment and sow health and management to reduce piglet mortality as a whole, which includes a significant proportion of pigs already dead at birth. Moreover, a strategy which supports better sow management and an appropriate farrowing environment might be as effective as providing piglet assistance to weaker piglets if the sanitary status of the herd is not compromised. Improvement of piglet care should be targetted in farms where starvation, crushing and non-viable underweight piglets have been identified as important causes of piglet death.

# Chapter 7 : General discussion

The different studies included in this thesis have illustrated the possibility of conducting secondary data analysis on industry databases holding information in order to address the problem of production diseases. The studies have highlighted the need to value the data collected by the pig industry in order to achieve better resource efficiency in scientific research, which in turn can produce outputs to improve the sustainability of pig farming. Combining data collected by the pig industry with additional on-farm data, such as that collected with the Biocheck-UGhent$^{TM}$ or from retrospective surveys designed for the purpose of specific research questions, appeared to be a valuable methodology to improve the value of industry databases, but also to advance the knowledge regarding health and welfare issues related to pig farm intensification. This also provides opportunities to conduct analyses within a restricted amount of time and at reasonable cost. The different studies conducted in this thesis have led to the identification of risk factors related to health and welfare issues and have enabled estimation of the prevalence of welfare outcomes in commercial pig farms and the relative proportion of the different categories of piglet perinatal mortality in farms with piglet mortality issues. Furthermore, the studies illustrate an approach to study production diseases in a more integrated manner and to identify possible solutions to reduce the impact of such diseases. However, several limitations regarding secondary data analysis have been identified, revealing the challenge of collecting and combining data from different sources for the purposes of scientific research.

## 7.1 The challenge of conducting secondary data analysis

### *7.1.1 Secondary data analysis: New opportunities and compromises*

Electronic data archives and improvements in technology have made various types of data collected on farm, by veterinary consultancies or quality assurance schemes, easily accessible for research purposes (Boslaugh, 2007; Johnston, 2014; Vanderwaal et al., 2017). The first challenge for conducting secondary data analyses was the identification of data sources containing the data of interest. This is especially challenging as data are usually collected by many different governmental and private organizations, and for different purposes. This thesis offers the opportunity to describe and comment on a strategy used to locate and analyse secondary data collected by the pig industry.

The studies were designed according to the data we expected to find in various industry databases holding information and were then further adapted according to the data actually available and the quality of these data. Multiple-source secondary data usually require combination of data from the same population or with specific connections in space and time (Saunders et al., 2009). As suggested by Boslaugh (2007), secondary data analysis is "achieving a fit between your research question and the data you choose to analyse". Secondary data are collected neither for the purpose of research nor regarding a specific study design (Boslaugh, 2007; Tripathy, 2013). Therefore, it is not surprising that several different data sources needed to be located to assemble the data required to conduct our analyses and answer our research questions.

### *7.1.2 Locating data for secondary data analysis*

To conduct secondary data analysis, researchers need to establish whether the expected data are available and to locate the data sources (Saunders et al., 2009). The data can be located through scientific publications, public reports and various online information (Boslaugh, 2007). After defining a way to assess production disease in pig farms through several indicators of health, welfare and performance, the second challenge was to locate the data of interest in different databases held by the pig industry. The data were used to address several research questions previously defined: How do different indicators of production diseases relate to each other? Is there a pattern that can be defined regarding production diseases, welfare and performance? What are the main categories of piglet mortality and can we find different mortality patterns in different farms? Can we identify risk factors related to the increase of prevalence of some of these indicators (i.e. welfare indicators and categories of perinatal piglet death)?

Our studies demonstrate that these research questions could be answered by combining existing data sources. Moreover, instead of greatly modifying the research questions originally defined, the combination of existing data with supplementary data collected from additional surveys and on-farm data collection appeared to be a possible way to enhance the value of existing data. The data of the pig industry of the UK are of interest, as several studies have proved the value of the BPHS abattoir-related data to identify pig pathologies (Sanchez-Vasquez et al., 2012, Brewster et al., 2017); most of these pathologies can be considered as outcomes of production diseases. Moreover, the uniqueness of the Real Welfare database represented a good opportunity to conduct analysis on animal welfare outcomes (as indicators of production diseases) on a large scale database representative of the pig farms in the UK.

As none of the industry databases holding data about pig performance could claim to have national representativeness, the performance data had to be individually collected in each pig farm and this probably represents the weaker part of the research. Discrepancies might occur between farms due to feeding strategy, the weight range over which feed conversion is measured and the manner in which the necessary information is collected and used to assess feed efficiency (Patience et al., 2015). This represents one of the main biases when comparing results between farms, suggesting that a better standardization in performance data recording would lead to more accurate analysis and better estimation of the national performance of the pig industry. As suggested by Rocadembosch et al. (2016), reliable performance indicators will help to quantify the impact of swine disease and its associated cost.

Different challenges appear when using multi-source data. Apart from locating the variables targeted in different databases, the selected databases should make it possible to apply an appropriate sampling methodology.

### *7.1.3 Sampling methodology*

The first step was to assess the possibility to access the full database of pig farms in Great Britain with the objective of selecting a sample of pig farms representative of the national population of commercial pig farms. Although we had access to the full database of pig farms in Great Britain and were able to select a sample representative of commercial pig farms, conducting further analyses on this representative sample appeared to be very challenging. The willingness of farmers to participate in gathering the required data was one of the main selection biases that drastically reduced our initial sample size and impaired its representativeness. In general, farmers are regularly approached to reply to different questionnaires. This activity is time consuming and the farmers might not perceive the benefit of spending time on this request, especially if they do not receive some advice or information in return. Despite the access to pig population census data, farmers will always be free to decide not to answer supplementary requests, making it impossible to achieve sample representativeness and potentially creating distortion in means, variance and multivariate coefficients (Gobo, 2004). Therefore, rather than random sampling, alternative methodologies should be considered in order to assess the representativeness of the sample population. This could be achieved by collecting key farm characteristics and comparing these characteristics between the sample set and the population of interest. Geographical location and the number of fattening and breeding pigs are characteristics than can be easily identified, both in the national database and for the selected sample of pig farms. Without the possibility of randomly selecting pig farms in cross sectional studies, using statistical analysis to compare such characteristics between the sample and the population of interest could therefore be an alternative method to better describe the sample selected. Considering the limitations for selecting a representative sample in its classical sense, we chose to demonstrate similarity between the farm sample and the pig farms in the whole population.

The question of the representativeness and generalizability of a sample has been discussed in previous publications. It has been widely suggested that only polls and surveys use representative samples (Gobo, 2004). The representativeness will also depend on the research design and the sampling methodology used to produce unbiased estimates (Turner, 2003). A series of biases affect the representativeness of the sample, usually classified as information bias, selection bias and confoundings (Schlomer et al., 2013; Materia et al., 2015; Kravanen et al., 2016). Moreover, Gobo (2004) highlighted the limitation in the concept of representativeness in multivariable analyses, as the representativeness of a sample based on one variable does not guarantee the representativeness of this sample for other variables. Considering the complexity to achieve a random sampling and the difficulty to avoid biases, judgemental and non-probability samples are still widely used (Turner, 2003) and alternative methodologies, such as theoretical sampling used in "grounded theory study", sometimes replace probability samples (Gobo, 2004; Sbanari et al., 2011). Grounded theory studies move from the particular to the general in order to develop hypotheses and the results are expressed as substantive theory (Sbanari et al., 2011). Theoretical sampling methodology tries to achieve a certain representativeness of the population without following statistical logic. These examples, and the difficulty to operate a probability sampling, should encourage the development of scientifically grounded sampling methodologies, adapted to the field of agriculture, which circumvent the current problem of population representativeness. Moreover, the lack of population representativeness often represents a barrier to publish in high impact journals. However, instead of opposing the studies that do not achieve representativeness with the ones that pretend to achieve it, the peer review process should encourage the researcher to critically assess the representativeness of the sample used in their study, without the fear of seeing their manuscript then criticized or even rejected on the basis of this criterion. This could be achieved by a review process which does not particularly focus on population representativeness as the main criterion to assess the quality of a research methodology.

Despite using a sample not representative of the whole population of French pig farms in the study conducted about piglet mortality, the identification of the three groups of farms based on different mortality patterns, could represent the first step of a grounded theory study which then needs to be completed by further studies that challenge this primary classification. Collecting other samples, raising new questions and identifying gaps in the knowledge will allow, over a cumulative process, strengthening of the theory that emerges from this primary study (Sbanari et al., 2011). This may open new perspectives for future studies by identifying the gaps present in the previous ones. The value of the output can be retrospectively assessed by comparing the results with further studies that could address the same research questions with larger datasets or by reproducing the methodology in different contexts (Schlomer et al., 2013).

This illustrates how the methodology of analysis might be much more important than achieving sample representativeness for the emergence of new hypotheses. In the same way, the inter-connection identified between health, welfare, performance and biosecurity in the sample of commercial pig farms emphasized the possible development of theory and hypotheses based on a restricted number of farms but using a standardized methodology. Breaking down the data collected to classify farms into groups also facilitates the comparison and, similarly, this classification can be challenged in future studies based on different samples, larger datasets or conducted in different contexts. Therefore, these observations suggest that original methodology used on a restricted sample and the conduct of additional studies in the future, which address the weaknesses identified in the primary study to validate the observations, might equally advance scientific knowledge and its potential practical application.

#### *7.1.4 Connecting different datasets*

The data available in a single database might not enable a research question to be answered. Connecting different databases might be a necessary alternative in order to gather the required information and conduct the appropriate analyses. Therefore, any difficulty in connecting these data sources can be very limiting. Vanderwaal et al. (2017) highlighted the difficulty of aggregating data from different sources that can be organised in different temporal and spatial scales, with discrepancies in the data structure and vocabulary. For the data collected about pig farms, this generally means that individual pigs or individual farms should be recognizable in all databases by a similar system of identification. This difficulty can eventually be circumvented by accounting for several characteristics present in all databases which enable the appropriate match, but this increases the complexity of the process. While we based our sample on the CPH number that recognizes individual farms, some data identified only the batch number (several batch numbers are recorded for individual farms and represent the successive herds that belong to this farm over the different production cycles). In this case the recognition of the pig holdings can be undertaken through several other characteristics.

After locating the data, collecting and using these data usually require researchers to sign confidentiality agreements which provide different guidelines on how to preserve confidentiality of the farmers, and on the way in which the data can be used and analysed. This should be respected at each step of the study until the publication of the results, and more particularly when establishing the connection between multiple data sources. Considering the obligation of respecting confidentiality agreements, making the connections between data sources can be extremely challenging (Tripathy et al., 2013; Vanderwaal et al., 2017). Moreover, the need for several steps to connect two data sources, which can only be achieved by the data holders for confidentially reasons, is time consuming and represents a disadvantage for both the person who requests the data and the person who shares it. Adopting a similar system of identification of the farm or batch in all databases held by the pig industry, independent of the level at which the data are collected, would ease the connection between different data sources. Based on the difficulty encountered in their study, Sprague et al (2016) suggested that data usability can be improved by adopting several standardized metadata practices, such as creating a common system for data validation, settling global rules of registration and parametrizing data entry. This could help to merge and identify data from multiple sources. Data formats, universally recognized, could enhance the connectivity of the data sources (Vanderwaal et al., 2017)

The possibility of connecting different data sources related to pig farming is poorly known at the moment. Moreover, precise methodologies to achieve such connections are not always detailed in scientific publication. Sprague et al (2017) provide detailed information about the difficulty to connect data from multiple sources, but the problems exposed are not always transferable to other research fields. General advice regarding how to conduct a secondary data analysis is currently present in the literature (Boslaugh, 2007; Schlomer et al, 2013), but the concrete application of this advice can be elusive when applied to a specific problem in a particular field of research.

This highlights the importance of reporting the difficulties encountered in secondary data analysis, or for connecting multiple data sources, and the way that these have been overcome in research about agriculture and animal health. In order to improve the access to different databases, and encourage the use of the information recorded by different organizations, scientific journals should encourage the researchers who conduct secondary analysis to mention this clearly in their publications (Koo et al., 2016). The journals should also encourage precise description of the methodology used to collect and connect the data sources and operate the data management. Sharing such information may open new perspective for other researchers and the outputs from secondary data analysis might also be beneficial for the industry.

In our analysis regarding different indicators of production diseases, the difficulty to connect the datasets had an impact on the sample size. The impossibility of identifying all the farms selected in the BPHS and Real Welfare databases (both are AHDB projects), was surprising as the producers were initially contacted through AHDB. This outcome illustrates how multiple steps to connect different datasets can severely impair the sample size. Therefore, simplifying these connections and developing alternative methodology to increase the sample size might also drastically reduce the selection bias and help to maintain accuracy in the analysis. This would lead to improved quality of outputs that could subsequently be generalized to the full population of pig farms.

#### *7.1.5 Assessing data quality and producing valuable outputs*

The studies conducted in this thesis highlight the possibility to collect data from industry-held databases with sufficient quality to then conduct appropriate data management and reply to research questions. First of all, the data themselves should enable research objectives to be met. Selecting data which are the most appropriate for the purpose of the research is crucial because the purpose of the data collection might not match the research needs, or the research question might require additional data or the combination of several datasets (Smith et al., 2011b). Therefore, the quality of the data should be assessed according to the objective of the research and the expected outputs.

Furthermore, reliable data are a key element for decision making in animal health (Dohoo, 2015). After identifying reliable sources of information, the data management conducted on the different datasets will enable data quality to be assessed. Different issues are generally identified during this process. The large amount of missing data can be one of the major issues arising from secondary data analysis (Dohoo, 2015; Sprague et al., 2017). For the data collected from the Real Welfare Scheme, a substantial amount of data was missing. On 112240 pens, the missing data for the different pen characteristics varied from few dozen to over one thousand. In contrast, in the study related to piglet mortality, and according to the variable considered, data were generally missing for no more than one or two farms. Most of the missing data in the Real Welfare dataset arose from the inability to connect different databases when attempting to connect data about health, welfare and performance. However, we also imputed missing entries about health and welfare using the iterative PCA algorithm. Missing data can be a major issue (Boslaugh et al., 2007) that can lead to biased estimates and misinterpretation of the influence of different risk factors (Dohoo, 2015) and such information should therefore systematically appear in the methodology.

Data can also be inaccurate, imprecise and multiple errors can arise from a poor data management and greatly impair the quality of the dataset. Some errors, such as biogically impossible values or inappropriate entries were found in the datasets collected for the different studies. This generally led to additional missing data, as accurate corrections were rarely possible. This highlights the importance of data validation after data collection (Emanuelson and Egenvall, 2013; Dohoo, 2015; Vanderwaal et al., 2017). A quality control system improves the quality of the dataset and, therefore, the quality of the output from secondary data analysis (Vanderwaal et al., 2017). Specific methods are adapted for the validation of secondary data (Ennanuelson and Egenvall, 2013). One of the advantages of coupling several data sources is the possibility to perform data validation through variables that are recorded in more than one dataset and check the discrepancies between datasets. The level of standardization in data collection and the structure of the dataset will be of great importance. Unstructured datasets might be limiting and the possibility to achieve the required data management, which enables the researchers to conduct analyses, will determine the usefulness of the data collected (Vanderwall et al., 2017). The lack of standardization of the collected data might drastically reduce the chance of using the information for scientific purposes.  Good data management represents a critical part of any study and data management of secondary data requires numerous operations. While part of these operations were succinctly explained, the inclusion of more details about the procedure to collect, combine and transform the data would ensure better reproducibility of the data management (Williams et al., 2017). This could become a mandatory requirement for studies based on secondary data, clearly explained in the author guidelines of scientific journals.  Moreover, there is a new focus on data management plans for grant applications, aiming to emphasize the importance of data sharing and long term data management or upstream activities which can impact data quality (Williams et al., 2017). This demonstrates that a new paradigm is opening up in scientific research, with challenges that move progressively from organizing data collection to extracting, preserving and sharing the information from the large amount of data already available.

As suggested by Vanderwaal et al (2017), the increase in data volume and accessibility move the challenge from collecting data toward creating scientific value from the collected datasets. This value depends on the quality of the data, the originality of the analysis and the translation of the output of this analysis into practical advice. The quality of the datasets from BPHS, the Real Welfare Scheme and the CCPA group represented a unique opportunity to conduct secondary data analyses in a short period of time and in a cost-effective way. All these data were collected over several years with a standardized methodology and represented the only possibility in a restricted amount of time to assess the prevalence of pig welfare outcomes at national level, and also to develop a new approach to piglet mortality issues.

The opportunity of secondary data analysis highlights the need to strengthen the communication between scientists and pig industry information holders. The increasing amount of data collected presents new challenges for collecting and analysing data, which could severely impact the opportunity to conduct original research if we fail to meet these challenges by giving an inappropriate response. This can be achieved by improving the level of standardization and automation of the data management and providing the appropriate tools to increase data utility (Vanderwaal et al., 2017). Secondary data analysis represents a possibility to strengthen the link between pig production stakeholders and research by closing the gap between the objectives of the scientists and the interests of the industry. In this thesis, we highlighted the possibility to conduct original research with secondary data which improved the understanding of production diseases and should be beneficial for the pig industry.

## 7.2 Improvement in the understanding of production diseases

### *7.2.1 Using indicators for production diseases*

The studies conducted on production diseases through several chosen indicators illustrate the usefulness of the data collected through voluntary monitoring systems and how these data can be used to assess animal health, welfare and performance as indirect measures of production diseases

(Correia-Gomes et al., 2017). Assessing production diseases can be challenging as they include numerous pathologies and syndromes. We have selected several indicators to provide a synthetic definition of production diseases. By assessing the level of connection between indicators of health, welfare and performance, and identifying different risk factors for these indicators, we intended to study production diseases in a more integrated manner.

Investigating diseases through performance indicators is not new and appeared to be a useful tool to investigate pig health (Holt et al., 2011; Alarcon et al., 2013) but also disease outbreaks. For example, during investigation of salmon anaemia and Schmallenberg virus infections, the mortality and the milk production respectively were used to identify the disease outbreaks and investigate potential risk factors (Mc Clure et al., 2005; Roberts et al., 2014).

In contrast, the estimation of animal welfare over the whole national pig population through animal-based welfare outcomes is relatively new. Scientifically validated tools to assess animal welfare became essential in order to meet consumer demand and the changes in the legislation regarding animal welfare. The consumer definition of meat quality includes different aspects: food safety, animal welfare, environment, healthiness, organoleptic properties and lifestyle (Wood et al., 1998) and animal welfare has become an indicator of other important food attributes (Gemma and Aikaterini, 2002). European Council Directives and Commission Directives provide rules for pig care at different stages of life, for environmental requirements and for stockmanship in order to improve animal welfare (Caporale et al., 2005). The global concern about animal welfare has encouraged the development of international standards on animal welfare (OIE, 2016) and progressively raised the question of welfare equivalence in trade agreements (Thiermann and Babcock, 2005). This became a prominent issue in the recent post Brexit trade agreement considerations, with the possibility of cheaper, but lower welfare, product exported from countries with different production methods (AHDB, 2016). Such considerations highlight the need to clearly define welfare through different indicators and to develop a tool to assess and compare animal welfare in different systems and countries. While creating a system of assessment through Farm Assurance schemes represents a first step, the validity of such assessment should be evaluated with a scientifically grounded methodology. The analysis conducted on the Real Welfare Scheme database in Chapter 3 highlighted the changes which occurred over time and seasons but also according to different features in the farm environment. Having a better understanding of these changes will help to establish practical recommendations that can be implemented by farmers and veterinarians in order to improve animal welfare, but also remind them of the necessity to closely look at the pigs and their pen environment to understand the potential issues affecting health and welfare in their own herd.

The different studies conducted in this thesis demonstrated that indicators of health, welfare and performance are able to reveal subclinical diseases, usually connected to the inflammatory reaction and a decrease in performance, without the expression of clinical signs (Grutzer et al., 2014; Pomorskat et al., 2014). These indicators can precede clinical disease or reflect chronic sub-clinical diseases giving rise to characteristic carcass lesions at the abattoir. A higher prevalence of such lesions at the abattoir is generally associated with a reduction in performance and an increase in the cost of pig production (Correia-Gomes et al., 2017). Moreover, the connections between indicators of health, welfare and performance suggest that abattoir lesions could be used as a proxy to detect other diseases or welfare issues in a resource-efficient surveillance system (Sanchez-Vazquez et al., 2012). The connections identified between the different indicators should encourage improvement in the data management to efficiently combine these data, especially across the datasets owned by the same organization. An improvement of data utility will enable assessment of the changes over time and space in quasi real-time and will facilitate both ongoing surveillance and the analyses conducted on these data, leading to better understanding of the problem of production diseases as a whole.

Assessing production diseases through simple indicators can also be limiting. Taken alone, simple indicators may over-simplify the identification of health, welfare and performance issues and the understanding of such issues might require more elaborate analyses. We have attempted to adopt a wider perspective on animal welfare and piglet mortality by using simple indicators but also seeing the complex patterns underneath these issues. By identifying patterns in welfare and piglet mortality outcomes and connecting these particular patterns to different aspects of the environment, we have demonstrated the necessity to consider the multifactorial aspects of these different issues. The analyses aimed to design a more integrated approach, where a particular issue is never considered on its own but in parallel with connected health or welfare issues, performance and several aspects of the environment. This came from the concept that strategies to improve health, welfare and performance should not be targeted to solve one particular problem, but should be seen as a reorganization which attempts to create a new balance. Several indicators could be similarly or differently impacted by management practices and features in the environment, which requires a more sophisticated understanding of risk factors for production diseases.

### *7.2.2 Identification of risk factors for health, welfare and performance*

Secondary data analyses provided the opportunity to better understand production diseases by identifying risk factors for animal welfare and the interconnection between health, welfare, performance and biosecurity. Voluntary monitoring systems, by increasing the sensitivity to detect health conditions, not only those related to public health, improve the surveillance of disease outbreaks and endemic diseases (Correia-Gomes et al., 2017). This allows early detection of changing health condition and provision of feedback on this to the farmers (Sanchez-Vazquez, 2011, 2012). However, risk-based planning to reduce diseases should be based on data analyses which consider the multifactorial aspect of such diseases. Our analyses have demonstrated the importance of several risk factors related to pig management and environment. Identifying these risk factors enables implementation of a strategy to improve animal health, welfare and performance in commercial pig farms. Moreover, capturing these risk factors through analyses which consider welfare or piglet mortality in a more integrated manner has permitted the formulation of recommendations that not only focus on a specific aspect of the issue. It has been demonstrated that our animal production systems increase the risk of pathogen circulation through inappropriate biosecurity and biocontainment measures and inefficient waste management (Graham et al., 2008). Our study suggests that biosecurity is a key element of animal heath but also influences welfare and performance. While health and welfare monitoring systems enable a better control of production diseases, monitoring the level of biosecurity and the pen environment will help to identify known risk factors and implement the necessary changes to reduce production diseases. In situations where changes of certain environmental features cannot be easily implemented, for example when they are inherent to a specific production system, particular attention should be given to health and welfare issues known to be connected to this environment in order to quickly treat or hospitalize sick pigs. This will enable faster reaction to disease and welfare issues when they occur, and better hospital pen management, in order to minimize the potential impact on the animals concerned and on herd performance.

### *7.2.3 Strategies for early detection of production diseases and new opportunities for syndromic surveillance*

The connections identified between different indicators of health, welfare and performance can be used to identify proxy indicators for early problem detection and optimize the data collected by the pig industry. Sanchez-Vasquez et al. (2012) identified several connections between pathologies, suggesting that lesions discovered during abattoir inspections could be used as a proxy for risk-based farm surveillance. Similarly, carcass condemnations at the abattoir have been connected to different pig disease outbreaks in Canada, strengthening the idea of a syndromic surveillance system that could be implemented at the abattoir (Thomas-Bachli et al., 2014). Furthermore, the results of our research, and more specifically the connection of tail biting with pyemia, suggest that the connection between pig pathologies detectable at the abattoir and welfare outcomes might mean that such assessments are not only useful to detect health problems but could be extended to identify on-farm welfare issues. Additional analyses need to be conducted to assess the predictive values of pathologies detected at the abattoir and the possibility to use changes in their incidence as a signal to conduct further on-farm investigation. For example, the Real Welfare scheme could adopt this approach in conjunction with their current protocol, and additional assessments could be scheduled for farms estimated to be at risk of welfare and health issues. This may enable early detection of welfare issues and provision of the necessary support to the farms which face such problems.

Apart from data collected during abattoir meat inspection, our study suggests that production performance and biosecurity level, which can be directly measured on farm, might be equally used as tools for risk-based surveillance. Moreover, knowledge that different environmental variables and pig farming systems constitute risks for certain outcomes may be additionally used to focus the attention of the farmer and the vet on potential health and welfare issues in pig herds raised in these particular environments.

Better use of the data available through industry databases and voluntary schemes could be achieved through data pipelines that can collect information from different data sources and operate a quick and efficient treatment of this information in order to provide useful feedback to farmers and veterinarians (Vanderwaal et al., 2017).

## 7.3 Study limitations and opportunities for future research

The differences between data sources, and the multiple steps necessary to locate, collect and connect the different data sources, do not allow us to claim any possible generalization of the strategyused to conduct this secondary data analysis to routine industry use. However, this provided an opportunity to highlight possible challenges and identify valuable sources of information which could be helpful in future studies. Moreover, two different methods can be used when exploiting industry data: define a research question and seek the dataset containing the data of interest, or, conversely, seek an interesting dataset and thereafter formulate the research question (Boslaugh, 2007). We used the first methodology, which might appear more challenging, but is also closer to the definition of original research without limiting the creativity of the researchers, although we appreciate that the second methodology may become more prevalent given the electronic availability of data. Moreover, the demonstration of using complex data management and overcoming the challenge of connecting different datasets might be a good way to promote the value of industry databases holding information and encourage other scientists to use these data in future research.

The weakness of our sample, due to the necessity to combine three different datasets, suggests that a different methodology should be used that does not necessarily target population representativeness. Future secondary data analyses on the same topic should target a sampling methodology that prioritizes the connections between datasets and provides a larger sample size. This can be achieved, for example, by connecting all the data from the Real Welfare Scheme and BPHS as many farms belong to both schemes. This will enable future research to be conducted on larger datasets and will improve our understanding of the connections between health and welfare in commercial pig farms.

The high number of variables collected might require more original approaches in order to analyse the available data in the most integrated manner. For example, around 200 variables per farm were collected in our study regarding piglet mortality on French farms. While particular attention was given to piglet management, due to the ease of implementing potential changes, all the data collected need to be studied in a more integrated way with original methodology. The need for a switch toward new methodologies using computer programming has been suggested by Vanderwaal et al. (2017) and various methodologies to handle a large amount of variables have been implemented in different studies (Machado et al., 2015; Dijkstra, 2016). However, such methodologies require computing skills which are not inherent to epidemiologists and need to be developed in the future (Vanderwaal et al., 2017).

New studies should be conducted to better assess the data available, the optimal route to locate, collect and connect these data, and also to assess the quality of the data available. Our studies highlight the increasing opportunities offered by secondary data analysis and the need to implement strategies that exploit the data available.  Creating connections between different data sources relating to pig health, welfare and performance has opened a number of possibilities for research, which can also be updated as long as the different schemes and stakeholders continue to record the data. The studies also demonstrate the unique opportunity to conduct specific research that could not be conducted with classical data collection in a restricted amount of time. However, engaging in further discussion with the industry will encourage them to better adapt the data available for scientific research by standardizing the databases and to target missing information that could be useful to study specific issues. We urgently need to showcase the double benefit of secondary data analysis, for both research and industry. This collaboration would enable work to address the different issues faced by the pig industry, to meet consumer demand and to elaborate strategies to respond to market pressure. The results of secondary data analysis can be used to improve the sustainability of animal production, which can only be achieved if the production issues are treated in a more integrated way.

Finally, this study did not target to assess the impact on farmer motivation. This may require sociological analyses based on structural models that assess the attitude toward the scheme, the subjective norm and perceived behavioural control in order to assess the intention of the farmers regarding improvement of animal welfare. This is a complete different study that would be beneficial but was not conducted for this thesis.

### 7.4 Reducing production diseases as part of a sustainable intensification

The problem of antibiotic resistance, globalization and the trade in animal products all over the world, as well as the increasing concern about animal welfare in commercial farms, all require study of the impact of farming intensification, including the problem of production diseases. A better understanding of production diseases is essential to identify key elements for sustainable intensification.

The use of efficient production tools to enhance profitability can lead to important social and environmental consequences and impact severely on animal and public health, questioning the sustainability of such intensive agricultural systems (Mazoyer and Roudart, 2001). Sustainability has been the point of interest of recent agricultural policies. However, after considering the large range of ideas and initiatives existing in the agricultural landscape, farmer behaviours in relation to agro-environmental schemes support the idea of an agricultural industry which largely mixes ideas of productivism and post-productivism (Wilson, 2001). Sustainable intensification has been considered from different perspectives, aiming to find the best way to encourage sustainability but at the same time preserve the competitiveness of the most productive farming systems (Bowers, 1995). In the 1970's, a United Nations conference on the environment highlighted the contradiction between the intensive growth and the available resources (Chambert et al., 2008). The question about sustainability of intensive agriculture arose for the first time. What is the alternative to create an agricultural sector which is economically viable, respectful for the environment and allows acceptable social condition for the agricultural workers? Scientific and public opinion debate this subject with many contradictory opinions and a real gap between Northern European and developing countries (Wilson, 2001). Intensive agriculture was the response to food insecurity and impacted all actors, up and downstream in the supply chain. This system is dependent on our present economic system, which explains its market logic. Intensive farming remains an alternative to limit the land use for meat production, but the industrialization of animal production also impacts on the environment (Trienekens et al., 2009; Aiking, 2011, Mackenzie et al., 2015).

Considering the growth of the world's population and of their meat consumption, the abolition of intensive farming seems complicated or even impossible, but some modifications of this system to promote a better sustainability of intensive farming and a correlated environmental and economic efficiency should be considered (Chambert et al., 2008). This includes the need to rethink farming intensification and better understand the problem of production diseases. Policies might promote a change toward an ideology more respectful of the environment and animal welfare, giving less emphasis to the narrow idea of productivism. However, the problem of conceptualization of this transition makes it difficult to design a support policy for such a change, although this is necessary to support the market position of such agriculture. Farmer beliefs remain traditionally encompassed in market logic and might leave very little opportunity to think outside of this box (Meert et al., 2005). Therefore, scientific research that produces knowledge regarding the current challenges to health, welfare and performance should seek to produce practical recommendations which demonstrate the possibility to use secondary data as a way to strengthen the connection between scientific research and the pig industry, and to efficiently communicate the results of such research to the industry. This could provide better support to the industry and would help to promote the necessary changes to address the current problems in different pig production systems.

The different findings related to production disease also question how to define sustainable intensification. Considering that the environmental features and management practices which are most connected to farming intensification also lead to higher risk of production diseases, can pig production pursue intensification and sustainability at the same time? Some proofs of sustainable intensification, e.g. yield improvement on a fixed amount of land without adverse environmental impacts, are reported, but most of the time exclude livestock production that has important environmental impact (Firbank et al., 2013). Sustainable intensification remains difficult to define and different definitions, tools and data sources must be utilised to assess this sustainability and consider its multifactorial aspect (Barnes and Thomson, 2014). Current knowledge hardly provides proof of a clear existence of sustainable intensive pig farming but, at least, better health and welfare within intensive production should be considered as a way towards greater sustainability. Identification of risk factors for adverse outcomes might help to transform the way pigs are currently raised. Our analysis suggests that some commercial pig farms have better management which improves animal performance and welfare. This should not be taken as the exception, but as a reference for commercial pig farm standards. Rawles (2010) claimed that sustainability in agriculture should place a greater emphasis on animal welfare, based on the fact that sustainable development is ethically aspirational and the ethic should be applied on a large scale instead of just focussing on the inter-human topics. Moreover, sustainability should escape from the short-term economic priorities to build long term perspectives. This appears even more logical considering the close relationship between health, welfare and performance identified in our study and their major economic impact. Moreover, the target of economic efficiency has shown cut-backs in social welfare and economic growth and has been somewhat detrimental to the well-being of the population (Rawles, 2010). Ideally, food production systems should outstrip economic values which have failed to represent the complexity of our world and its interconnections (Rawles, 2010). In the past, the utopia of market regulation has illustrated its impact on society and the reaction of society to counter balance the negative effects of a system based on profits (Polanyi, 1944). The gap existing between the food we produce, the farming methods promoted by the economic system and the real expectations of the society should help to challenge our view of food production and undertake the necessary changes to promote better animal health and welfare.

# Appendix A: Connecting different data sources to assess the associations between biosecurity, health, welfare and performance in commercial pig farms in Great Britain (Chapter 2)

**Table A.1** Pearson[(*)] or Spearman correlations between biosecurity scores for 40 fattening pig farms visited in GB in 2015-16.

| | A[1] | B[1*] | C[1*] | D[1] | Es[1] | F[1] | EXT* | G[2] | H[2] | I[2] | J[2] | K[2] | L[2] | INT* | TOT[3]* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A[1] | 1 | | | | | | | | | | | | | | |
| B[1] | 0.27 | 1 | | | | | | | | | | | | | |
| C[1*] | 0.13 | 0.25 | 1 | | | | | | | | | | | | |
| D[1*] | 0.04 | **0.31** | **0.41** | 1 | | | | | | | | | | | |
| E[1] | -0.08 | 0.15 | **0.30** | 0.26 | 1 | | | | | | | | | | |
| F[1] | 0.04 | -0.10 | -0.23 | 0.00 | -0.12 | 1 | | | | | | | | | |
| EXT* | **0.35** | **0.63** | **0.70** | **0.67** | **0.55** | -0.01 | 1 | | | | | | | | |
| G[2] | 0.09 | 0.17 | 0.18 | 0.15 | 0.15 | 0.00 | 0.26 | 1 | | | | | | | |
| H[2] | 0.21 | 0.07 | -0.16 | 0.13 | -0.24 | 0.21 | -0.02 | -0.05 | 1 | | | | | | |
| I[2] | 0.09 | 0.27 | -0.02 | **0.31** | 0.04 | 0.10 | 0.24 | 0.20 | **0.42** | 1 | | | | | |
| J[2] | 0.12 | 0.18 | **0.31** | 0.28 | 0.26 | 0.12 | **0.46** | **0.42** | -0.13 | 0.11 | 1 | | | | |
| K[2] | 0.25 | 0.08 | **0.33** | **0.43** | **0.30** | 0.15 | **0.43** | 0.22 | -0.09 | 0.12 | 0.28 | 1 | | | |
| L[2] | 0.05 | 0.21 | 0.28 | 0.27 | **0.38** | -0.10 | **0.32** | **0.42** | **-0.31** | 0.07 | **0.32** | **0.55** | 1 | | |
| INT* | 0.14 | 0.24 | **0.43** | **0.45** | **0.46** | 0.08 | **0.61** | **0.55** | -0.27 | 0.13 | **0.61** | **0.75** | **0.84** | 1 | |
| TOT[3]* | 0.20 | **0.38** | **0.58** | **0.58** | **0.57** | 0.04 | **0.82** | **0.48** | -0.24 | 0.16 | **0.62** | **0.74** | **0.73** | **0.95** | 1 |

Significant correlations in bold: moderately correlated if coefficient $r > 0.3$ and $P < 0.05$, strongly correlated if $r > 0.6$ and $P < 0.05$

[1] External biosecurity (EXT) sub-categories scores: A. Purchase of animals and semen; B. Transport of animals, removal of manure/dead animals; C. Feed, water and equipment supply; D. Personnel and visitor; E. Vermin/bird control; F. Environment and region.

[2] Internal biosecurity (INT) sub-categories scores: G. Disease management; H. Farrowing period; I. Nursery, J. Fattening pigs; K. Measures between compartments and the use of equipment; L. Cleaning and disinfection.

[3]Total biosecurity(TOT)= mean (EXT+INT)

**Table A.2** Pearson[(*)] or Spearman correlations between biosecurity scores for 28 breeding pig farms visited in GB in 2015-16.

| | A[1] | B[1] | C[1*] | D[1*] | Es[1] | F[1] | EXT* | G[2] | H[2] | I[2] | J[2] | K[2] | L[2] | INT* | TOT[3]* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A[1] | 1 | | | | | | | | | | | | | | |
| B[1] | 0.20 | 1 | | | | | | | | | | | | | |
| C[1*] | -0.25 | -0.11 | 1 | | | | | | | | | | | | |
| D[1*] | -0.33 | 0.03 | 0.51 | 1 | | | | | | | | | | | |
| E[1] | -0.07 | 0.27 | 0.22 | 0.16 | 1 | | | | | | | | | | |
| F[1] | 0.15 | -0.21 | **-0.37** | -0.12 | **-0.56** | 1 | | | | | | | | | |
| EXT* | 0.04 | **0.39** | **0.62** | **0.66** | **0.53** | -0.28 | 1 | | | | | | | | |
| G[2] | 0.01 | -0.05 | 0.21 | **0.31** | 0.03 | -0.16 | 0.20 | 1 | | | | | | | |
| H[2] | 0.25 | -0.02 | -0.27 | -0.03 | -0.06 | 0.15 | -0.11 | -0.20 | 1 | | | | | | |
| I[2] | 0.08 | 0.24 | 0.18 | 0.29 | **0.51** | -0.18 | **0.43** | 0.28 | -0.17 | 1 | | | | | |
| J[2] | **0.35** | 0.12 | -0.11 | -0.11 | -0.07 | 0.26 | 0.09 | 0.01 | 0.00 | 0.28 | 1 | | | | |
| K[2] | 0.01 | -0.12 | 0.14 | 0.24 | 0.04 | 0.12 | 0.21 | 0.25 | -0.06 | **0.39** | 0.18 | 1 | | | |
| L[2] | -0.17 | 0.20 | 0.09 | 0.13 | 0.14 | -0.10 | 0.13 | **0.46** | -0.18 | 0.26 | 0.17 | 0.26 | 1 | | |
| INT* | -0.01 | 0.15 | 0.24 | **0.30** | 0.13 | 0.03 | **0.44** | **0.51** | -0.16 | **0.63** | **0.48** | **0.63** | **0.72** | 1 | |
| TOT[3]* | 0.00 | 0.25 | **0.44** | **0.50** | **0.34** | -0.12 | **0.75** | **0.47** | -0.14 | **0.68** | **0.38** | **0.58** | **0.75** | **0.87** | 1 |

Significant correlations in bold: moderately correlated if coefficient $r > 0.3$ and $P < 0.05$, strongly correlated if $r > 0.6$ and $P < 0.05$.

[1] External biosecurity (EXT) sub-categories scores: A. Purchase of animals and semen; B. Transport of animals, removal of manure/dead animals; C. Feed, water and equipment supply; D. Personnel and visitor; E. Vermin/bird control; F. Environment and region.

[2] Internal biosecurity (INT) sub-categories scores: G. Disease management; H. Farrowing period; I. Nursery, J. Fattening pigs; K. Measures between compartments and the use of equipment; L. Cleaning and disinfection.

[3]Total biosecurity(TOT)= mean (EXT+INT)

**Table A.3** Pearson(*) or Spearman correlations between biosecurity scores, health indicators, welfare outcomes and production performance for 40 fattening pig farms for 2015-2016.

| | EXT* | INT* | TOT* | **MOR** | **FCR** | **ADG*** | hosp | lam | stl | sbm | *ep* | *pl* | *pc* | *pt* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| EXT* | 1.00 | | | | | | | | | | | | | |
| INT* | **0.61** | 1.00 | | | | | | | | | | | | |
| TOT* | **0.82** | **0.95** | 1.00 | | | | | | | | | | | |
| **MOR** | -0.09 | 0.01 | -0.01 | 1.00 | | | | | | | | | | |
| **FCR** | 0.19 | **0.46** | **0.41** | 0.11 | 1.00 | | | | | | | | | |
| **ADG*** | **0.38** | 0.24 | **0.32** | **-0.40** | **0.40** | 1.00 | | | | | | | | |
| hosp | **0.36** | **0.47** | **0.46** | **0.34** | **0.30** | -0.16 | 1.00 | | | | | | | |
| lam | 0.10 | -0.02 | 0.05 | **0.67** | -0.20 | -0.22 | **0.45** | 1.00 | | | | | | |
| stl | -0.04 | **-0.31** | -0.18 | 0.28 | -0.14 | -0.22 | 0.18 | **0.32** | 1.00 | | | | | |
| sbm | 0.01 | -0.26 | -0.11 | 0.08 | -0.09 | **-0.56** | 0.22 | 0.06 | **0.45** | 1.00 | | | | |
| *ep* | 0.02 | **-0.38** | -0.28 | 0.06 | 0.02 | -0.16 | -0.27 | **0.35** | **0.34** | 0.07 | 1.00 | | | |
| *pl* | 0.01 | **-0.51** | **-0.45** | -0.06 | -0.04 | **-0.30** | -0.19 | -0.23 | 0.20 | 0.11 | **0.66** | 1.00 | | |
| *pc* | 0.15 | -0.19 | -0.12 | 0.15 | **0.42** | -0.09 | 0.28 | -0.13 | -0.08 | 0.29 | **0.36** | **0.55** | 1.00 | |
| *pt* | -0.02 | -0.27 | -0.19 | -0.25 | **-0.58** | -0.04 | -0.07 | 0.12 | 0.16 | **0.45** | 0.09 | 0.06 | -0.29 | 1.00 |
| *ms* | 0.14 | 0.07 | 0.15 | 0.25 | **0.39** | 0.12 | 0.11 | 0.20 | -0.16 | **0.53** | 0.11 | -0.04 | 0.09 | **0.36** |
| *hs* | **-0.39** | **-0.39** | **-0.39** | 0.05 | -0.11 | 0.21 | -0.28 | 0.25 | 0.08 | **0.37** | -0.07 | -0.02 | -0.04 | **0.49** |
| *pd* | -0.04 | -0.22 | -0.18 | 0.02 | -0.24 | -0.04 | -0.13 | 0.24 | 0.28 | **0.58** | 0.03 | 0.03 | -0.20 | **0.64** |
| *tail* | -0.29 | **-0.50** | **-0.45** | 0.17 | 0.04 | -0.21 | -0.24 | 0.15 | **0.38** | **0.58** | 0.16 | 0.18 | -0.02 | **0.37** |
| *viral* | 0.13 | 0.18 | 0.21 | 0.07 | 0.16 | 0.15 | 0.23 | -0.11 | -0.23 | -0.24 | 0.06 | -0.10 | -0.14 | 0.25 |
| *ppa* | -0.16 | **-0.34** | **-0.35** | -0.21 | 0.00 | 0.00 | 0.10 | 0.03 | -0.06 | 0.07 | **0.32** | **0.52** | 0.16 | **0.31** |
| *ppc* | -0.11 | 0.11 | 0.07 | **-0.31** | 0.27 | 0.15 | 0.18 | -0.25 | 0.03 | 0.18 | -0.05 | 0.12 | -0.10 | 0.03 |
| *abscess* | -0.08 | **-0.34** | -0.27 | **-0.33** | -0.02 | **0.44** | -0.18 | -0.29 | 0.14 | -0.17 | -0.05 | -0.02 | -0.01 | **0.42** |
| *pyaemia* | -0.06 | -0.27 | -0.22 | 0.05 | 0.16 | **0.30** | -0.02 | **0.33** | **0.32** | **0.41** | 0.08 | 0.06 | 0.05 | **0.39** |
| *ep score* | 0.04 | -0.16 | -0.05 | 0.00 | 0.06 | 0.02 | -0.13 | **0.52** | 0.30 | 0.15 | **0.79** | 0.26 | 0.18 | 0.23 |
| *pl score* | -0.11 | **-0.54** | **-0.51** | -0.12 | -0.15 | **-0.36** | -0.13 | -0.24 | 0.19 | 0.10 | **0.51** | **0.90** | **0.33** | 0.15 |
| *Pd score* | -0.05 | -0.22 | -0.18 | 0.00 | -0.24 | -0.04 | -0.10 | 0.21 | 0.23 | **0.57** | 0.01 | 0.04 | -0.20 | **0.64** |

| | *ms* | *hs* | *pd* | *tail* | *viral* | *ppa* | *ppc* | *abscess* | *Pyaemia* | *ep score* | *pl score* | *pd score* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| EXT* | | | | | | | | | | | | |
| INT* | | | | | | | | | | | | |
| TOT* | | | | | | | | | | | | |
| **MOR** | | | | | | | | | | | | |
| **FCR** | | | | | | | | | | | | |
| **ADG*** | | | | | | | | | | | | |
| hosp | | | | | | | | | | | | |
| lam | | | | | | | | | | | | |
| stl | | | | | | | | | | | | |
| sbm | | | | | | | | | | | | |
| *ep* | | | | | | | | | | | | |
| *pl* | | | | | | | | | | | | |
| *pc* | | | | | | | | | | | | |
| *pt* | | | | | | | | | | | | |
| *ms* | 1.00 | | | | | | | | | | | |
| *hs* | **0.39** | 1.00 | | | | | | | | | | |
| *pd* | **0.31** | **0.54** | 1.00 | | | | | | | | | |
| *tail* | 0.24 | **0.62** | **0.58** | 1.00 | | | | | | | | |
| *viral* | 0.27 | 0.11 | -0.11 | -0.02 | 1.00 | | | | | | | |
| *ppa* | **0.39** | 0.27 | 0.25 | 0.18 | 0.09 | 1.00 | | | | | | |
| *ppc* | 0.23 | 0.16 | -0.14 | -0.01 | 0.15 | **0.42** | 1.00 | | | | | |
| *abscess* | 0.24 | **0.34** | 0.11 | **0.37** | -0.01 | **0.32** | 0.21 | 1.00 | | | | |
| *pyaemia* | **0.58** | **0.59** | **0.44** | **0.51** | -0.08 | **0.51** | **0.34** | **0.62** | 1.00 | | | |
| *ep score* | 0.22 | 0.07 | 0.00 | 0.12 | 0.26 | 0.21 | -0.02 | 0.10 | 0.17 | 1.00 | | |
| *pl score* | -0.13 | -0.02 | 0.10 | 0.23 | -0.05 | **0.57** | 0.19 | 0.11 | 0.05 | 0.18 | 1.00 | |
| *Pd score* | **0.31** | **0.54** | **1.00** | **0.58** | -0.11 | 0.27 | -0.13 | 0.11 | 0.44 | -0.01 | 0.11 | 1.00 |

EXT: External biosecurity, INT: internal biosecurity score, TOT: total biosecurity score, **ADG**: Average daily weight gain, **FCR**: Feed conversion ratio, **MOR**: Mortality, hosp: pigs requiring hospitalization, lam: lameness, stl: severe tail lesions, sbm: severe body marks, *ep*: enzootic pneumonia, *pl*: pleurisy, *pc*: pericarditis, *pt*: peritonitis, *ms*: milk spot, *hs*: hepatic scarring, *pd*: papular dermatitis, *tail*: tail-bitten, *viral*: viral-type distribution, *ppa*: pleuropneumonia – acute, *ppc*: pleuropneumonia – chronic, *abscess: a*bscess, *pyaemia*: pyaemia, *ep score:* score enzootic pneumonia, *pl score*: score pleurisy, *pd score*: score papular dermatitis

**Table A.4** Pearson(*) or Spearman correlations between production performance and biosecurity scores for 28 breeding pig farms for 2015-2016.

| | EXT* | INT* | TOT* | **PB*** | **PBA*** | **PW*** |
|---|---|---|---|---|---|---|
| EXT* | 1 | | | | | |
| INT* | **0.44** | 1 | | | | |
| TOT* | **0.75** | **0.87** | 1 | | | |
| **PB*** | 0.11 | **0.33** | 0.29 | 1 | | |
| **PBA*** | 0.15 | 0.4 | **0.36** | **0.93** | 1 | |
| **PW*** | 0.28 | **0.43** | **0.44** | **0.73** | **0.86** | 1 |

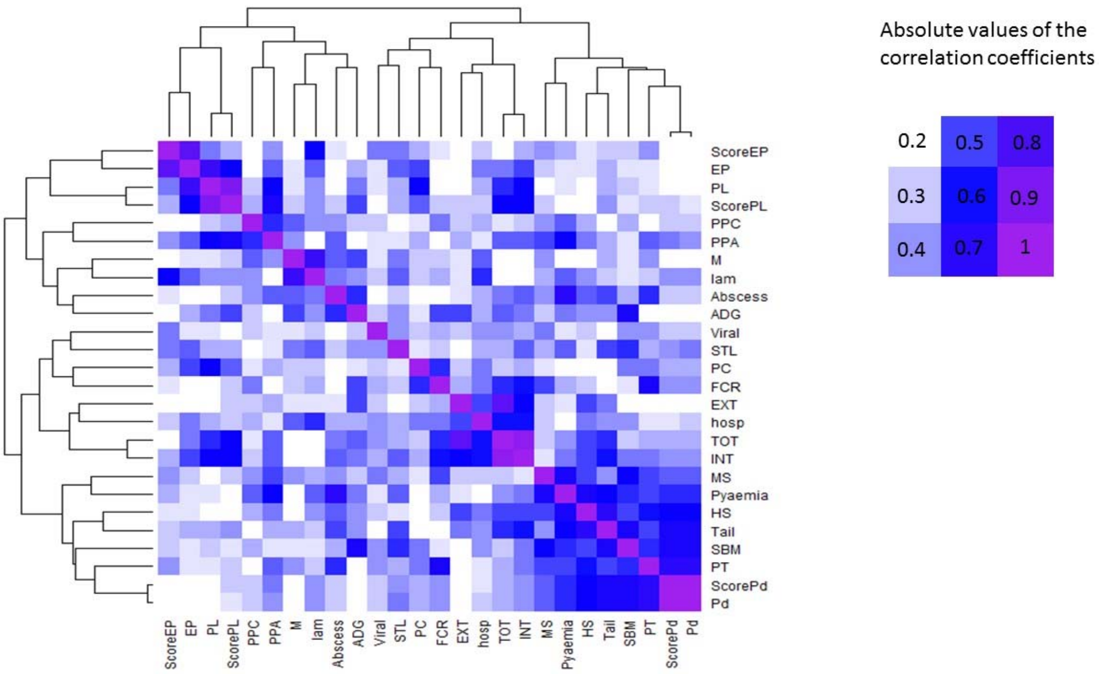



**Figure A.5** Correlation matrix: Correlations between welfare outcomes, production performance, health indicators and biosecurity scores for 40 fattening pig farms for 2015-2016. The more intense is the blue colour, the stronger is the correlation between two variables.

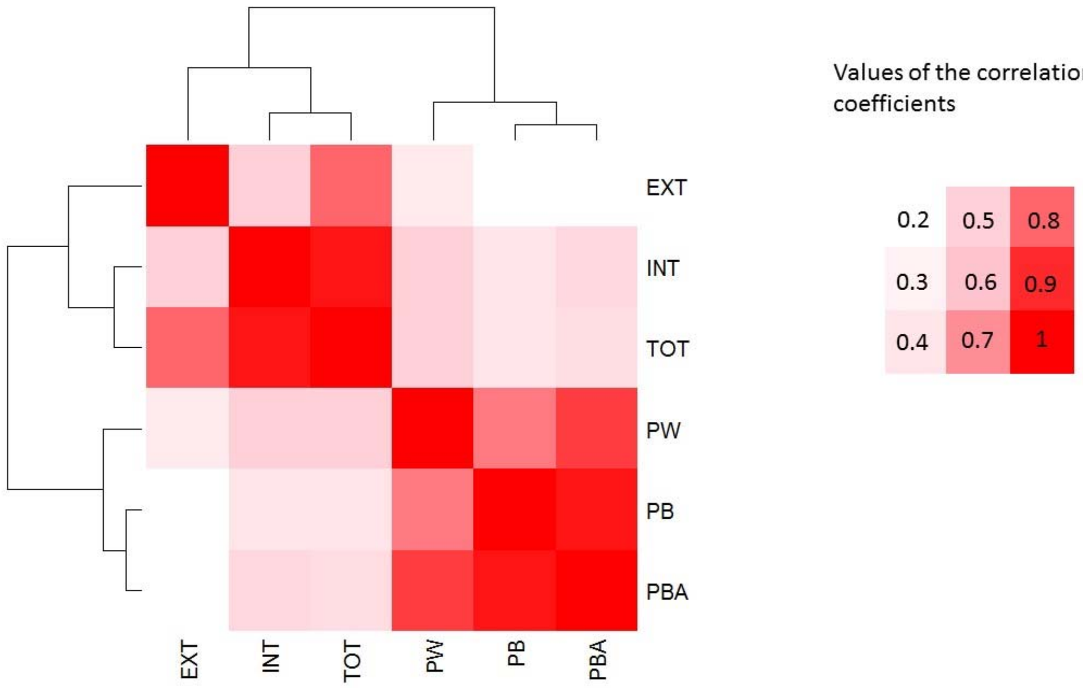



**Figure A.6** Correlation matrix: Correlations between production performance and biosecurity scores for 28 breeding pig farms for 2015-2016. The more intense is the red colour, the stronger is the correlation between two variables.

# Appendix B: The "Real Welfare" Scheme: benchmarking welfare outcomes for commercially farmed pigs (Chapter 3)

**Appendix B.1** Sampling and data collection.

The number of assessments (2 to 4) depended on pig flow and they were carried out during quarterly visits from the farm veterinarian. All participating veterinarians were required to be members of the Pig Veterinary Society. All vets wishing to carry out these assessments were required to undergo online and practical training to ensure standardisation of recording [http://pork.ahdb.org.uk/health-welfare/welfare/real-welfare/real-welfare-vets/]. The assessment involved 5 main measures. Full details of the measurement protocol can be found at [http://pork.ahdb.org.uk/health-welfare/welfare/real-welfare/]. Tail lesions and body marks were assessed on a sample of pigs per pen but pigs requiring hospitalization, lame pigs and enrichment use were assessed for all pigs in the selected pens as this method improved the accuracy of the recording of these welfare outcomes which usually occur at low prevalence. The number of pens assessed at each visit was selected to be representative of the farm and to comply with the number of pigs required to be assessed each year for tail lesions and body marks. For units of 300 finisher places or less, a minimum of 300 pigs should be sampled each year, but for units of 900 finisher places or more, a total of 900 pigs should be sampled per year. For units of between 300 to 900 finisher places, an equivalent representative proportion should be sampled. The sampling of pigs within a pen was as follows: all pigs in the pen if there were fewer than 25 pigs, 25 pigs if there were up to 100 pigs in the pen, or 50 pigs if there were more than 100 pigs in the pen. Sampling more pigs than this per pen was allowed at the vets' discretion and if the total number of pigs required to be sampled on farm could not be reached (for instance if a farm had only few pens, but with many pigs). In case the necessary number of pigs was not reached, therefore, the recommendation was to divide the number of pigs needed from a pen type by the number of pens available (eg if 150 pigs were needed from two pens of 100, sample 150/2 = 75 pigs per pen). Data were preferentially collected from pigs of ≥50kg liveweight, but if there were not enough pigs for the sample then pigs of ≥30kg liveweight were also included in the sample.

**Table B.2** Measurements used in the assessment. Each pig in the sample selected was classified into one of the several levels for each measurement (the classification for enrichment use only concerns the active pigs of the sample).

| Measurements | Definitions |
|---|---|
| Pigs requiring hospitalization | |
| Yes | Any pigs seen in the sampled pens that would benefit from being separated into a hospital pen. (The nature of the health condition and the pen environment will affect this measure). Some types of pigs which may benefit from being in a hospital pen include pigs which are sick, injured or lame and are unable to compete for resources, being bullied/ tail bitten or would benefit from access to bedding that is more comfortable than that available in the pen. |
| No | Pigs that would not benefit from removal to a hospital pen. |
| Lame pigs | |
| Lame | Pigs with signs of lameness. Include any pig that, when standing, will not bear full weight on the affected limb and/or appears to be standing on its toes. When moving there is a shortened stride with minimum or no weight-bearing on the affected limb and a swagger of the hind quarters. May still be able to trot and gallop. |
| Non lame | Pigs without any sign of lameness |
| Pigs with tail lesions | |
| Severe | Pigs with severe tail lesions. Proportion of tail has been removed by biting, or tail is swollen or held oddly, or scab covering whole tip or fresh blood visible |
| Mild | Pigs with mild tail lesions. Linear lesion extending 1cm or more, or scabs/lesions greater than 0.5cm diameter, or swelling visible |
| No lesions | Pigs without any of the above lesions |
| Dirty | Pigs dirty enough to obscure potential mild lesions but not the severe ones. Tail end or whole tail is soiled making assessment of mild lesions difficult. |
| Pigs with body marks | |
| Severe | Pigs with severe body marks. Lesion is larger than 5x5cm diameter, or lesion extends into deeper layers of skin, or lesions cover a large percentage of skin (>25%) |
| Mild | Pigs with mild body marks. Linear lesion longer than 10cm or if there are 3 or more 3cm lesions or if there is a circular area larger than 1cm diameter |
| No lesions | Pigs without any of the above body marks |
| Dirty | Pigs dirty enough to obscure potential mild body marks but not the severe ones. The pig is soiled with > a handsize (15cm x 10cm) of fresh/old slurry/urine/faeces, or mud which is dense enough to conceal mild lesions. |
| Enrichment use | |
| Enrichment | Pigs interacting with enrichment in the pen. Number of standing or sitting pigs investigating a manipulable material, i.e. substrate or toy provided as enrichment. |
| Other | Pigs interacting with other pens features or pen mates. Number of standing or sitting pigs manipulating other pigs, pen fittings, pen floor or muck. |

**Table B.3** Number of pens and pigs in the study population with objects and/or substrates for enrichment.

| | Farms | Percentage | Pens | Percentage | Pigs | Percentage |
|---|---|---|---|---|---|---|
| Substrates and Objects | 279 | 14.5 | 3 111 | 2.8 | 204 580 | 3.7 |
| Substrates[1] | 1 330 | 69.0 | 51 234 | 45.6 | 3 386 964 | 62.0 |
| Including Straw | 1 310 | 67.9 | 50 136 | 44.7 | 3 320 398 | 60.8 |
| Objects[2] | 1 012 | 52.5 | 51 826 | 46.2 | 1 740 123 | 31.9 |
| Total | 1 928 | 100 | 112 240 | 100 | 5 463 348 | 100 |

[1]Pens with substrates (with or without objects)
[2]Pens with objects (with or without substrates)

**Table B.4** Qualification of quantity provided for the substrates present in the pens.

| Enrichment | | Number of Pens | Percentage of all pens with straw | Number of pigs | Percentage of all pigs with straw |
|---|---|---|---|---|---|
| Straw | | | | | |
| | Restricted | 439 | 1.18 | 12 466 | 0.53 |
| | Low | 4 617 | 12.38 | 148 853 | 6.27 |
| | Medium | 17 055 | 45.75 | 872 111 | 36.76 |
| | Deep | 6 306 | 19.91 | 659 317 | 27.79 |
| | Deep and medium[2] | 21 | 0.06 | 1 184 | 0.05 |
| | Low and deep or restricted or medium[2] | 73 | 0.20 | 2 583 | 0.11 |
| | Not qualified | 8 771 | 23.53 | 676 158 | 28.50 |
| Total straw[1] | | 37 282 | 100 | 2 372 672 | 100 |
| Total without straw[1] | | 37 314 | - | 1 310 650 | - |

[1]Based on a subset of assessments of 74 596 pens reporting qualification of amount
[2]Two qualifications were recorded for the straw (the straw bedding was not uniform)

**Table B.5** Proportion of pens and pigs in the study population with undocked tails.

| Tails | Number of pens | % | Number of pigs | % |
|---|---|---|---|---|
| Docked | 96 009 | 85.54 | 3 847 672 | 70.43 |
| Mixed | 3 628 | 3.23 | 290 433 | 5.31 |
| Undocked | 12 584 | 11.21 | 1 324 936 | 24.25 |
| Not recorded | 19 | 0.02 | 307 | 0.01 |
| Total | 112 240 | 100.00 | 5 463 348 | 100.00 |

**Table B.6** Tail lengths (proportion of tail remaining) for the pens and pigs in the study population.

| Length | Number of pens | % | Number of pigs | % |
|---|---|---|---|---|
| <0.33 | 38 934 | 34.69 | 1 539 023 | 28.17 |
| ~0.5 | 30 379 | 27.07 | 1 259 775 | 23.05 |
| >0.5 | 24 040 | 21.41 | 962 980 | 17.63 |
| Mix of lengths | 5 272 | 4.70 | 263 595 | 4.83 |
| Undocked | 12 584 | 11.21 | 1 324 936 | 24.25 |
| Not recorded | 1 031 | 0.92 | 113 039 | 2.07 |
| Total | 112 240 | 100 | 5 463 348 | 100 |

**Table B.7** Proportion of pens with undocked pigs according to the environment. Data collected at pen level from April 2013 to May 2016.

| Categories | Number of Pens | | | Number of pigs | |
|---|---|---|---|---|---|
| | Docked | Mixed | Undocked | Undocked | % undocked in the sub-category |
| Pen type | | | | | |
| Indoor | 89 868 | 3 436 | 10 289 | 1 118 087 | 22.0 |
| In&outdoor | 5 350 | 129 | 610 | 21 146 | 14.0 |
| Other type | 478 | 39 | 68 | 7 515 | 28.6 |
| Outdoor | 301 | 24 | 1617 | 178 265 | 89.6 |
| Pen size | | | | | |
| Large | 3 205 | 466 | 2 509 | 787 034 | 42.2 |
| Medium | 33 213 | 1 682 | 5 573 | 76 413 | 6.4 |
| Small | 59 591 | 1 480 | 4 502 | 461 489 | 19.2 |
| Ventilation | | | | | |
| Natural | 68 554 | 3 420 | 11 585 | 1 267 719 | 23.20 |
| Powered | 26 332 | 182 | 885 | 41 201 | 0.75 |

**Table B.8** Proportion of pens with undocked tail pigs according to the enrichment. Data collected at pen level from April 2013 to May 2016.

| Categories | Number of Pens | | | Number of pigs | |
|---|---|---|---|---|---|
| | Docked | Mixed | Undocked | Undocked | % |
| Substrate | 39 123 | 2 638 | 9 462 | 1 063 415 | 31.2 |
| No Substrate | 56 886 | 990 | 3 122 | 261 521 | 12.6 |

**Table B.9** Description of welfare outcomes at farm level (% of pigs or ratio).

| Welfare outcomes | Mean | SD | 1st Quartile | Median | 3rd Quartile | Min | Max |
|---|---|---|---|---|---|---|---|
| Pigs requiring hospitalization[1] | 0.001 | 0.002 | 0 | 0 | 0 | 0 | 0.05 |
| Lame pigs[1] | 0.002 | 0.005 | 0 | 0 | 0.002 | 0 | 0.19 |
| Severe tail lesions[1] | 0.001 | 0.006 | 0 | 0 | 0 | 0 | 0.15 |
| Severe body marks[1] | 0.002 | 0.009 | 0 | 0 | 0 | 0 | 0.15 |
| Enrichment ratio[1] | 0.505 | 0.261 | 0.318 | 0.512 | 0.680 | 0 | 1.00 |

[1]: Values based on annual rolling averages

**Table B.10** Description of the Welfare outcomes at pen level (% of pigs or ratio) (April 2013-May 2016).

| Average percentage | Mean | SD | 1st Quartile | Median | 3rd Quartile | Min | Max |
|---|---|---|---|---|---|---|---|
| Pigs requiring hospitalization | 0.09 | 0.79 | 0 | 0 | 0 | 0 | 50 |
| Lame pigs | 0.21 | 1.30 | 0 | 0 | 0 | 0 | 100 |
| Enrichment use ratio | 0.47 | 0.36 | 0.11 | 0.47 | 0.75 | 0 | 1 |
| Severe tail lesions | 0.17 | 1.61 | 0 | 0 | 0 | 0 | 100 |
| Mild tail lesions[1] | 1.45 | 4.79 | 0 | 0 | 0 | 0 | 100 |
| Dirty tail[1] | 5.70 | 15.87 | 0 | 0 | 0 | 0 | 100 |
| Severe body marks | 0.28 | 1.94 | 0 | 0 | 0 | 0 | 100 |
| Mild body marks[1] | 11.00 | 15.22 | 0 | 5.55 | 16 | 0 | 100 |
| Dirty body[1] | 3.33 | 12.96 | 0 | 0 | 0 | 0 | 100 |

[1]Includes only the pens where mild lesions were assessed

**Table B.11** Description of the Welfare outcomes at pen level (% of pigs or ratio) (April 2013-November 2013).

| Percentage | Mean | SD | 1st Quartile | Median | 3rd Quartile | Min | Max |
|---|---|---|---|---|---|---|---|
| Pigs requiring hospitalization | 0.15 | 1.06 | 0 | 0 | 0 | 0 | 33.3 |
| Lame pigs | 0.36 | 1.88 | 0 | 0 | 0 | 0 | 100 |
| Enrichment use ratio | 0.47 | 0.36 | 0 | 0.50 | 0.75 | 0 | 1 |
| Severe tail lesions | 0.16 | 1.51 | 0 | 0 | 0 | 0 | 52.9 |
| Mild tail lesions | 1.72 | 5.23 | 0 | 0 | 0 | 0 | 100 |
| Dirty tail | 5.63 | 14.96 | 0 | 0 | 0 | 0 | 100 |
| Severe body marks | 0.27 | 2.05 | 0 | 0 | 0 | 0 | 100 |
| Mild body marks | 13.00 | 16.36 | 0 | 8 | 20 | 0 | 100 |
| Dirty body | 3.03 | 11.95 | 0 | 0 | 0 | 0 | 100 |

**Table B.12** Variance inter-pen in the same farm (intra farm): Mean value, minimum and maximum in the pig population of farms studied.

| | mean values of the intra-farm variances | Min | Max |
|---|---|---|---|
| Pigs requiring hospitalization % | 0.46 | 0 | 35.3 |
| Lame pigs % | 1.22 | 0 | 206.9 |
| Severe tail lesions % | 2.20 | 0 | 581.3 |
| Severe body marks % | 2.89 | 0 | 338.4 |
| Enrichment use ratio | 0.025 | 0 | 0.094 |

**Table B.13** Four groups of farms (one for each welfare outcome) were selected with a prevalence above the 90th percentile in 2013. The mean and the standard deviation (SD) of each welfare outcome for these groups of selected farms were calculated for each year from 2013 to 2016. The result of the Friedman test is reported for each group of farms.

| | | Mean values of the welfare outcomes for the selected farms | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 90th Percentiles | Mean 2013 | SD 2013 | Mean 2014 | SD 2014 | Mean 2015 | SD 2015 | Mean 2016 | SD 2016 | P value Friedman test |
| Lame pigs | 0.954 | 1.944 | 1.326 | 0.700 | 0.763 | 0.340 | 0.410 | 0.291 | 0.523 | <0.001 |
| Pigs requiring hospitalization | 0.382 | 0.759 | 0.456 | 0.119 | 0.215 | 0.062 | 0.126 | 0.065 | 0.167 | <0.001 |
| Pigs with severe tail lesions | 0.333 | 1.083 | 1.196 | 0.426 | 0.711 | 0.298 | 0.801 | 0.354 | 1.650 | <0.001 |
| Pigs with severe body marks | 0.605 | 2.157 | 1.904 | 0.807 | 1.645 | 0.714 | 2.091 | 0.293 | 0.821 | <0.001 |

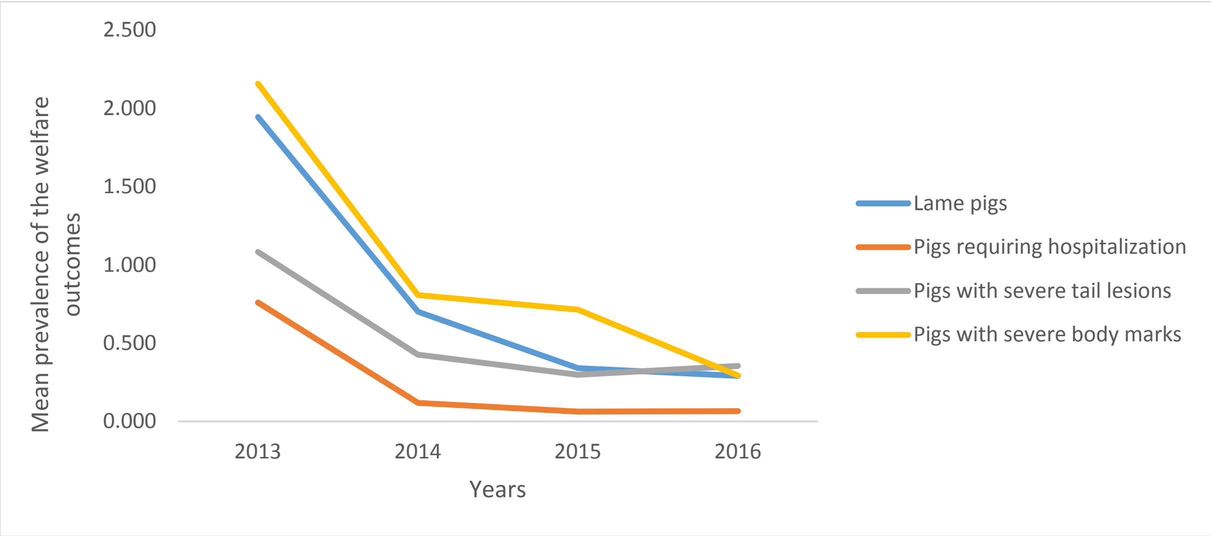



**Figure B.14** Means of welfare outcomes for the farms above the value of 90th percentile in 2013.

**Table B.15** Kendall's tau-b correlation coefficient between the average percentages of lame pigs for individual farms in each year.

| | 2013 | 2014 | 2015 | 2016 |
|---|---|---|---|---|
| 2013 | 1.000 | | | |
| 2014 | 0.360[1] | 1.000 | | |
| 2015 | 0.299 | 0.444[1] | 1.000 | |
| 2016 | 0.239 | 0.316 | 0.371[1] | 1.000 |

[1]Considered significant P<0.05 tau>0.3

**Table B.16** Kendall's tau-b correlation coefficient between the average percentages of pigs requiring hospitalization for individual farms in each.
year.

| | 2013 | 2014 | 2015 | 2016 |
|---|---|---|---|---|
| 2013 | 1.000 | | | |
| 2014 | 0.108 | 1.000 | | |
| 2015 | 0.103 | 0.302[1] | 1.000 | |
| 2016 | 0.125 | 0.133 | 0.190 | 1.000 |

[1]Considered significant P<0.05 tau>0.3

**Table B.17** Kendall's tau-b correlation coefficient between the average percentages of severe tail lesions for individual farms in each year.
year.

| | 2013 | 2014 | 2015 | 2016 |
|---|---|---|---|---|
| 2013 | 1.000 | | | |
| 2014 | 0.199 | 1.000 | | |
| 2015 | 0.180 | 0.260 | 1.000 | |
| 2016 | 0.134 | 0.125 | 0.242 | 1.000 |

[1]Considered significant P<0.05 tau>0.3

**Table B.18** Kendall's tau-b correlation coefficient between the average percentages of severe body marks for individual farms in each year.

| | 2013 | 2014 | 2015 | 2016 |
|---|---|---|---|---|
| 2013 | 1.000 | | | |
| 2014 | 0.323[1] | 1.000 | | |
| 2015 | 0.217 | 0.394[1] | 1.000 | |
| 2016 | 0.146 | 0.213 | 0.328[1] | 1.000 |

[1]Considered significant P<0.05 tau>0.3

**Table B.19** Odds ratio, confidence intervals and p-value. The proportion of lame pigs and pigs requiring hospitalization were the dependent variables and the season was the independent variable in a model that considered the farm as a random effect.

| | Lame pigs | | | | Pigs requiring hospitalization | | | |
|---|---|---|---|---|---|---|---|---|
| | Odds ratios | CI95% | | P values | Odds ratios | CI95% | | P values |
| Spring | Intercept | | | | Intercept | | | |
| Summer | 0.775 | 0.718 | 0.837 | **<0.001** | 0.866 | 0.767 | 0.978 | **0.021** |
| Autumn | 0.825 | 0.766 | 0.889 | **<0.001** | 0.842 | 0.749 | 0.948 | **0.004** |
| Winter | 0.847 | 0.789 | 0.910 | **<0.001** | 0.831 | 0.741 | 0.931 | **0.001** |

**Table B.20** Odds ratio, confidence intervals and p-value. The proportion of pig with severe tail lesions, the proportion of pigs with severe body marks and the proportion of pigs that interacted with the enrichment were the dependent variables and the season was the independent variable in a model that considered the farm as a random effect.

| | Severe tail lesions | | | | Severe body marks | | | | Enrichment use ratio | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Odds ratios | CI95% | | P values | Odds ratios | CI95% | | P values | Odds ratios | CI95% | | P values |
| Spring | Intercept | | | | Intercept | | | | Intercept | | | |
| Summer | 0.915 | 0.826 | 1.015 | 0.093 | 0.956 | 0.882 | 1.036 | **0.276** | 0.925 | 0.842 | 1.016 | 0.105 |
| Autumn | 1.019 | 0.926 | 1.121 | 0.705 | 0.822 | 0.759 | 0.891 | **<0.001** | 1.313 | 1.194 | 1.443 | **<0.001** |
| Winter | 1.018 | 0.923 | 1.123 | 0.714 | 0.911 | 0.844 | 0.984 | **0.018** | 1.373 | 1.240 | 1.521 | **<0.001** |

**Table B.21** Correlations between percentage of the different measures of pig welfare for all pens.

| | Hospital | Lame | Severe tail lesions | Severe body marks | Ratio | Absence of tail lesions | Absence of body marks |
|---|---|---|---|---|---|---|---|
| Pigs requiring hospitalization | 1.00 | | | | | | |
| Lame pigs | **0.33**[1] | 1.00 | | | | | |
| Severe tail lesions | 0.19 | 0.05 | 1.00 | | | | |
| Severe body marks | 0.04 | 0.01 | 0.05 | 1.00 | | | |
| Enrichment use ratio | 0.01 | 0.02 | -0.02 | 0.00 | 1.00 | | |
| Absence of tail lesions | -0.11 | -0.04 | -0.21 | -0.04 | 0.01 | 1.00 | |
| Absence of body marks | -0.09 | -0.06 | -0.02 | -0.15 | 0.03 | **0.35**[1] | 1.00 |

[1] $P<0.05$ $R>0.3$ or $<-0.3$

**Table B.22** Correlation of the different measures of welfare (%) for the pens which received an assessment for both severe and minor lesions and body marks over the whole 3-year assessment period.

| | Mild marks | Mild tail lesions | Dirty tail | Dirty body | Hospital | Lame | Severe tail lesions | Severe body marks | Ratio | No tail lesions | No body marks |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Mild marks | 1.00 | | | | | | | | | | |
| Mild tail lesions | 0.20 | 1.00 | | | | | | | | | |
| Dirty tail | 0.11 | 0.19 | 1.00 | | | | | | | | |
| Dirty body | -0.01 | 0.12 | **0.49**[1] | 1.00 | | | | | | | |
| Pigs requiring hospitalization | 0.08 | 0.09 | 0.08 | 0.05 | 1.00 | | | | | | |
| Lame pigs | 0.05 | 0.05 | 0.02 | 0.04 | **0.34**[1] | 1.00 | | | | | |
| Severe tail lesions | 0.03 | 0.21 | 0.03 | 0.00 | 0.20 | 0.06 | 1.00 | | | | |
| Severe body marks | 0.09 | 0.04 | 0.02 | -0.02 | 0.04 | 0.01 | 0.03 | 1.00 | | | |
| Enrichment use ratio | -0.03 | -0.01 | 0.02 | 0.04 | 0.01 | 0.02 | -0.02 | -0.01 | 1.00 | | |
| No Lesions | -0.17 | **-0.64**[1] | **-0.81**[1] | **-0.42**[1] | -0.11 | -0.03 | -0.21 | -0.04 | 0.00 | 1.00 | |
| No body marks | **-0.87**[1] | -0.20 | -0.29 | **-0.38**[1] | -0.08 | -0.05 | -0.02 | -0.15 | 0.03 | **0.32**[1] | 1.00 |

[1] P<0.05 R>0.3 or <-0.3

**Table B.23** Correlation of the different measures of welfare (%) for the pens which received an assessment for both severe and minor lesions and body marks during the start-up assessment period (April 2013-Nov 2013).

| | Mild body marks | Mild tail lesions | Dirty tail | Dirty body | Hospital | Lame | Severe tail lesions | Severe body marks | Ratio | No tail lesions | No body marks |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Mild body marks | 1.00 | | | | | | | | | | |
| Mild tail lesions | 0.19 | 1.00 | | | | | | | | | |
| Dirty tail | 0.12 | 0.21 | 1.00 | | | | | | | | |
| Dirty body | -0.01 | 0.12 | 0.51[1] | 1.00 | | | | | | | |
| Pigs requiring hospitalization | 0.07 | 0.09 | 0.07 | 0.05 | 1.00 | | | | | | |
| Lame pigs | 0.04 | 0.04 | 0.02 | 0.05 | 0.34[1] | 1.00 | | | | | |
| Severe tail lesions | 0.04 | 0.21 | 0.04 | 0.00 | 0.21 | 0.06 | 1.00 | | | | |
| Severe body marks | 0.09 | 0.05 | 0.03 | 0.00 | 0.05 | 0.03 | 0.04 | 1.00 | | | |
| Enrichment use ratio | -0.03 | -0.01 | 0.03 | 0.04 | 0.02 | 0.02 | -0.02 | -0.01 | 1.00 | | |
| No tail lesions | -0.18 | -0.65[1] | -0.81[1] | -0.43[1] | -0.11 | -0.03 | -0.21 | -0.05 | 0.00 | 1.00 | |
| No body marks | -0.87[1] | -0.19 | -0.31[1] | -0.38[1] | -0.09 | -0.05 | -0.03 | -0.14 | 0.03 | 0.33[1] | 1.00 |

1 P<0.05 R>0.3 or <-0.3

# Appendix C: The “Real Welfare” scheme: Identification of risk and protective factors for welfare outcomes in commercial pig farms in the UK (Chapter 4)

**Table C.2** Results of sampling size calculations.

| | lameness | hospital pigs | severe tail lesions | severe body marks | enrichment use ratio |
|---|---|---|---|---|---|
| sigma (σ) (Standard deviation) | 1.30 | 0.79 | 1.61 | 1.94 | 0.36 |
| margin of error (e) (10% of the mean) | 0.021 | 0.009 | 0.017 | 0.028 | 0.047 |
| margin of error (e) (20% of the mean) | 0.042 | 0.018 | 0.034 | 0.056 | 0.094 |
| intraclass correlation (ICC) | 0.39 | 0.40 | 0.54 | 0.64 | 0.35 |
| average number of pens per farm (m) | 10 | 10 | 10 | 10 | 10 |
| actual sample size (N’) | 112 241 | 112 241 | 112 241 | 112 241 | 112 241 |
| design effect (Deff) | 4.51 | 4.60 | 5.86 | 6.76 | 4.15 |
| sample size (N) considering clustering effect | 24887.14 | 24400.22 | 19153.75 | 16603.70 | 27046.02 |
| power with e= 10% of the mean | 72.2% | 42.8% | 30.9% | 46.0% | 100% |
| power with e= 20% of the mean | 99.9% | 94.5% | 83.2% | 96.1% | 100% |

**Table C.2** Multiple Correspondence Analysis solution: eigen values, percentage of inertia and cumulative percentage inertia.

| components | eigen values | % | cumulative % |
|---|---|---|---|
| 1 | 0.284 | 23.5 | 23.5 |
| 2 | 0.196 | 16.2 | 39.6 |
| 3 | 0.171 | 14.1 | 53.8 |
| 4 | 0.113 | 9.3 | 63.1 |
| 5 | 0.100 | 8.2 | 71.3 |
| 6 | 0.091 | 7.5 | 78.8 |
| 7 | 0.078 | 6.5 | 85.3 |
| 8 | 0.050 | 4.1 | 89.4 |
| 9 | 0.042 | 3.5 | 92.9 |
| 10 | 0.040 | 3.3 | 96.2 |
| 11 | 0.021 | 1.7 | 97.9 |
| 12 | 0.015 | 1.3 | 99.2 |
| 13 | 0.005 | 0.5 | 99.7 |
| 14 | 0.001 | 0.1 | 99.8 |
| 15 | <0.001 | 0.1 | 99.9 |
| 16 | <0.001 | 0.1 | 100.0 |

**Table C.3** Absolute contribution to the inertia of the axis (per 10 000) for the first and the second factorial axes.

| | F1 | F2 |
|---|---|---|
| no indoor pen | 0 | 3294 |
| indoor pen | 0 | 274 |
| no in&outdoor pen | 2 | 178 |
| in&outdoor pen | 31 | 3100 |
| no straw | 651 | 64 |
| straw | 806 | 79 |
| no plastic objects | 353 | 50 |
| plastic objects | 718 | 102 |
| ventilation.natural | 204 | 96 |
| ventilation.power | 633 | 277 |
| feed.meal | 0 | 49 |
| feed.liquid | 1629 | 210 |
| feed.pellets | 427 | 10 |
| ad libitum | 108 | 56 |
| restricted | 988 | 512 |
| feeder.floor | 16 | 328 |
| feeder.hopper | 363 | 106 |
| feeder.trough | 1394 | 262 |
| docked tails | 60 | 57 |
| undocked tails | 474 | 450 |
| tail lengths <0.5 | 440 | 165 |
| tail lengths >0.5 | 703 | 281 |

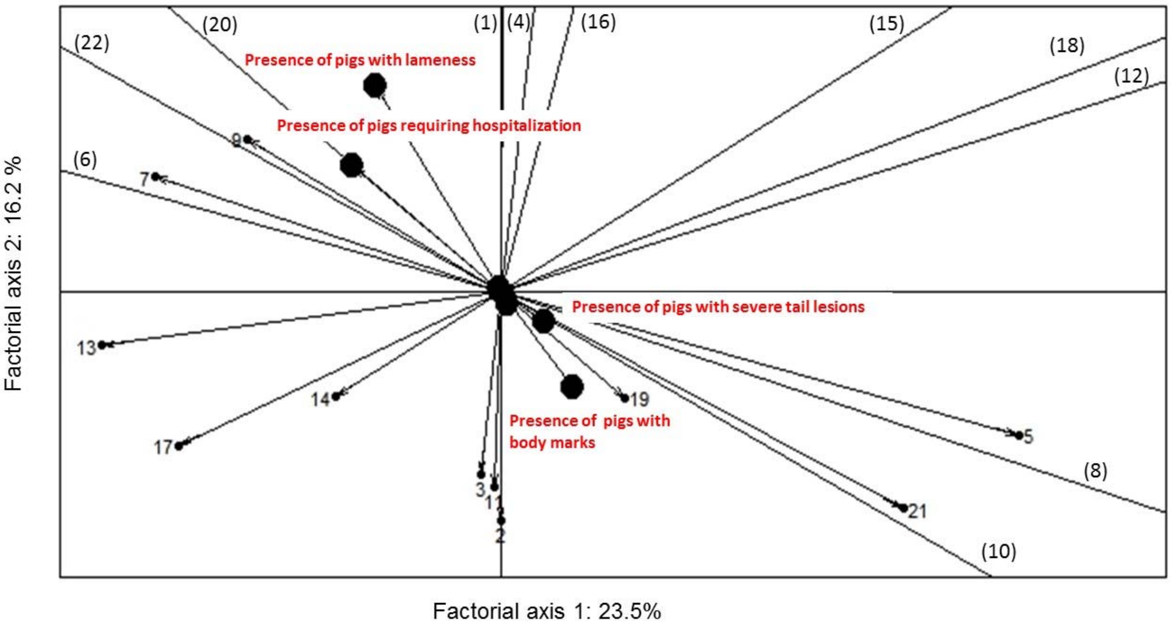



**Figure C.4** Partial representation of the Figure 1 plot with the addition of the supplementary variables (Presence of pigs requiring hospitalization, presence of lame pigs, presence of severe tail lesions, presence of severe body marks) on the first and second factorial axis of the MCA graph along with the active variables and the axes connecting the variables (number in bracket on the MCA graph): not indoor pen (1), indoor pen (2), not in&outdoor outdoor pen (3), in&outdoor pen (4), no straw (5), straw (6), no plastic objects (7), plastic objects (8), natural ventilation (9), powered ventilation (10), meal feeding (11), liquid feed (12), pellets feeding (13), feed always available (ad libitum) (14), restricted feed (15), floor feeding (16), hopper feeding (17), trough feeding (18), docked tails (19), undocked tails (20), tail lengths <0.5 (21) and tail lengths >0.5 (22).

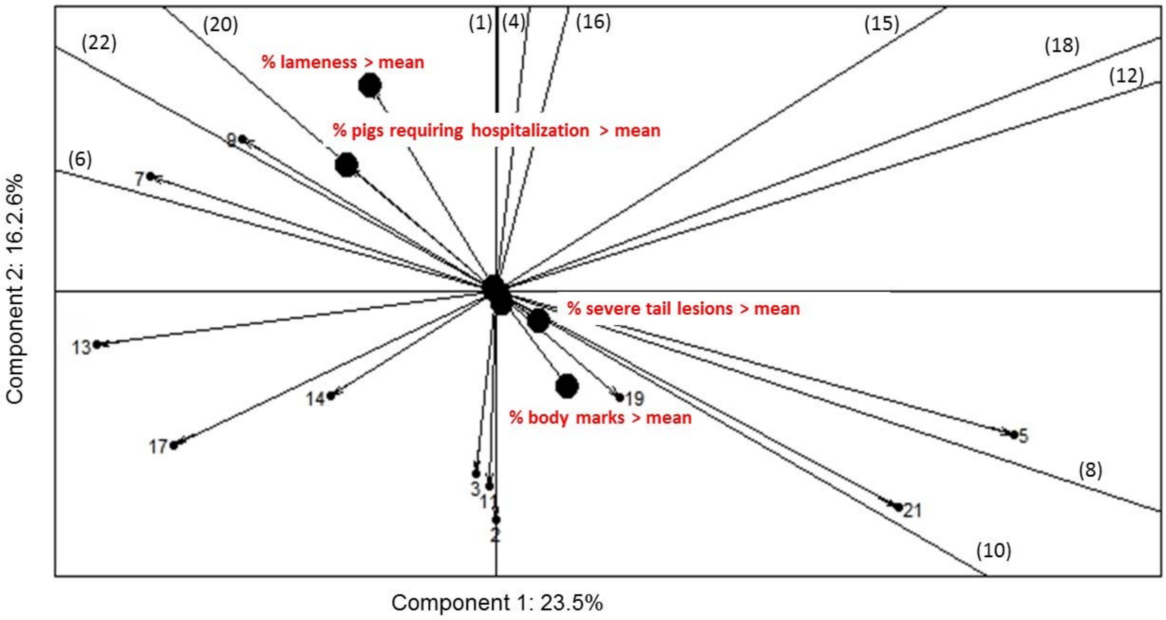



**Figure C.5** Partial Plot of the MCA showing the supplementary variables "% of lameness > mean", "% of pigs requiring hospitalization > mean ","% of severe tail lesions > mean" and "% of severe body marks > mean ", along with the active variables and the axes connecting the variables(number in bracket on the MCA graph): not indoor pen (1), indoor pen (2), not in&outdoor outdoor pen (3), in&outdoor pen (4), no straw (5), straw (6), no plastic objects (7), plastic objects (8), natural ventilation (9), powered ventilation (10), meal feeding (11), liquid feed (12), pellets feeding (13), feed always available (ad libitum) (14), restricted feed (15), floor feeding (16), hopper feeding (17), trough feeding (18), docked tails (19), undocked tails (20), tail lengths <0.5 (21) and tail lengths >0.5 (22).

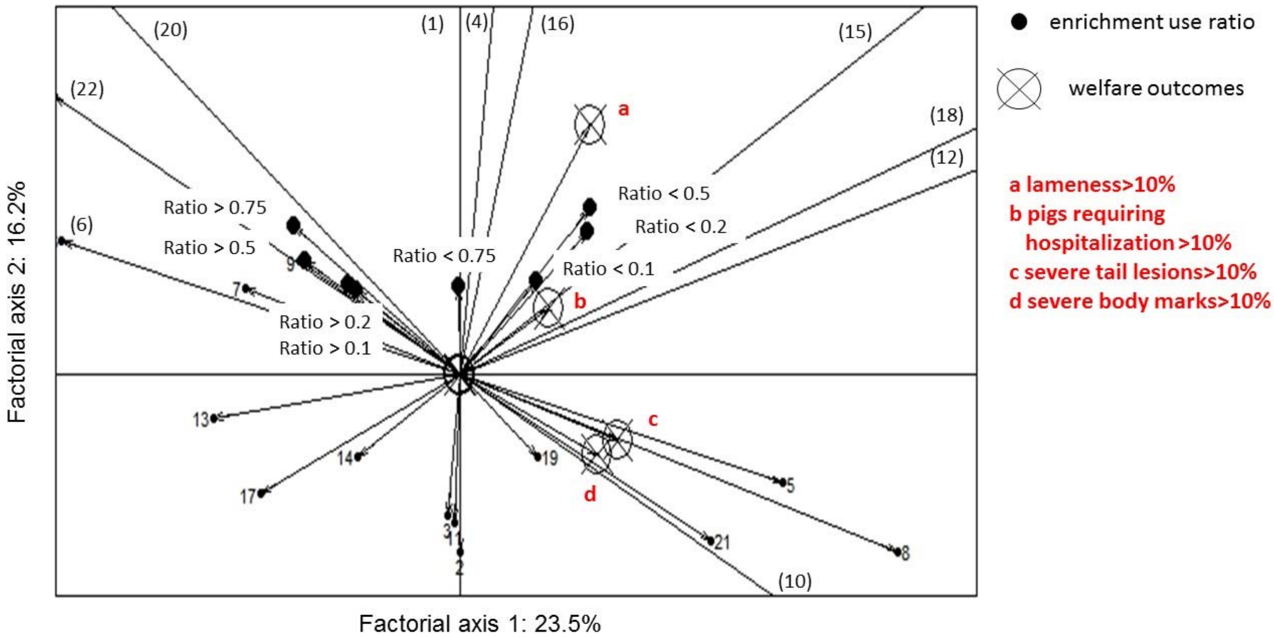



**Figure C.6** Partial representation of the Figure 1 plot with addition of the supplementary variables related to different levels of enrichment use ratio, and high prevalence of the outcomes lameness, pigs requiring hospitalization, tail lesions and body marks, on the first and second factorial axis of the MCA graph, along with the active variables and the axes connecting the variables (number in bracket on the MCA graph): not indoor pen (1), indoor pen (2), not in&outdoor outdoor pen (3), in&outdoor pen (4), no straw (5), straw (6), no plastic objects (7), plastic objects (8), natural ventilation (9), powered ventilation (10), meal feeding (11), liquid feed (12), pellets feeding (13), feed always available (ad libitum) (14), restricted feed (15), floor feeding (16), hopper feeding (17), trough feeding (18), docked tails (19), undocked tails (20), tail lengths <0.5 (21) and tail lengths >0.5 (22).

# Appendix D: Risk factors associated with the different categories of piglet perinatal mortality in French farms (Chapter 5)

**Appendix D.1** Sample size calculation

$$N' = N \times Deff$$

$$N = Z^2 \frac{p(1-p)}{e^2}$$

$$Deff = (1+ICC_p(m_p-1)) \times (1+ICC_s w(m_s-1))$$

$$w = (m_p ICC_p)/(1 + (m_p - 1)ICC_p))$$

Where: N' minimal sample size

N Sample size required to estimate a proportion in absence of intraclass correlation

Z Value from standard normal distribution corresponding to the desired confidence level (Z=1.96 for 95% CI)

p Estimated percentage of a particular category on the total number of dead piglets

e Level of precision

Deff Design effect which accounts for the clustering in litters and farms

$ICC_p$ Intraclass correlation between piglets within the litter, $ICC_s$ Intraclass correlation between sows within the farm

$m_p$ is the average number of dead piglet per litter, $m_s$ is the average number of sows per farm

A value of 40% for $p$ has been chosen according to the maximum values reported in the literature (Panzardi et al., 2013; Kilbride et al., 2012). The chosen level of precision $e$ was 5%. An $ICC_p$ of 0.4 and an $ICC_s$ of 0.4 were used, based on the maximum value found in different studies of piglet mortality or piglets disorders (McDermott and Schukken, 1994; Kilbride et al., 2012; Skampardonis et al., 2012; Kongsted et al., 2014; Iida et al, 2014). The value of $m_p$ was 3.5 and $m_s$ was 18.1.

**Table D.2** Categories of perinatal mortality: Definition of the categories of perinatal mortality and their classification based on the necropsy and the time of death.

| Categories | Definition |
|---|---|
| anaemia | Mature lungs, abrasion of the feet, death after farrowing, pale skin and mucosa, white porcelain colour of the body, no organ lesions visible during the necropsy |
| arthritis | Mature lungs, abrasion of the feet, death after farrowing, swelling joints, signs of arthritis during necropsy |
| 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 |
| dehydration/ enteritis | Mature lungs, abrasion of the feet, death after farrowing, significant quantity of liquid in the intestine, signs of dehydration, sticky sub-cutaneous tissue, urate crystals in the kidney |
| 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 |
| acute disease | Mature lungs, death after farrowing, pericarditis, pleurisy, abscess, peritonitis, signs of inflammation on the umbilical cord, gingivitis after teeth clipping, petechial bleeding |
| malformation | Death during or after farrowing, signs of malformation |
| splayleg | Mature lungs, death after farrowing, cause reported by the farmer, no organs lesions at the necropsy |
| killed by the sow | Mature lungs, death after farrowing, signs of bites |
| killed by the farmer | Mature lungs, death after farrowing, reported by the farmer, signs of cranial trauma |
| Unknown cause | None of the other causes were identified, problem of conservation of the body |
| 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 before farrowing | Incomplete lung maturation, lack of abrasion of the feet, more than 800g, no organ lesions visible during the necropsy, autolysis lesions |
| death during farrowing | Incomplete lungs 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 |
| non-viable piglet | piglets < 800g excluding mummified piglets |

**Table D.3** Data recorded at farm and piglet levels: Some of these data were selected as covariates in the binary logistic regression, to assess their impact on the proportion of piglet deaths at piglet levels (see main text and superscripts).

| Farm level | Piglet level |
|---|---|
| Holding number of farm | Holding number of farm |
| Average $Sow\ Parity$ $(AVGP)$ | Sow Parity [4] |
| Average Litter $size$ $(AVGL)$ | Litter size [4] |
| Average weight of the dead piglets[1] $(AVGW)$ | Weight of the dead piglet [4] |
| Region[3] | Region |
| Total dead piglets *(TPD)* | Season [4,6] |
| Total piglets born *(TPB)* | Sow ID |
| Number of piglets dead from each cause [2] | Number of deaths in the same litter [4] |
| Percentage of dead piglets attributed to each cause [1,2] | Number of littermates which died from the same cause [2,4] |
| Total piglet mortality (%) $(TPM)$ | Time of death (Day vs Night) [4,5] |
| Year *(Y)* | Length of the mummies |
| Season *(S)* | Year |

1 Calculation reported in Data management at farm level

2 Applied for all the causes reported in Table 1

3 For the analysis at farm level, the farms were classified according to the pig population in the region they belong to: E >2000000 pigs, D 1000000-2000000 pigs, C 500000-1000000 pigs, B 200000-500000 pigs, A<200000pigs

4 Covariates tested in the binary logistic regression

5 Day: Inside the working hours vs Night: Outside the working hours

6 Spring (February, March April), Summer (May June, July), Autumn (August, September, October), Winter (November, December, January)

**Table D.4** Proportion of the inertia explained by all the Components of the Principal Component Analysis (PCA) : Eigenvalues, Projected Inertia and Cumulative Projected Inertia (CPI) of the PCA used to select the number of components and to assess the percentage of variance of the active variables explained by the different Components.

| | Components | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| Eigenvalue | 2.32 | 1.56 | 1.13 | 1.07 | 0.87 | 0.69 | 0.23 | 0.12 |
| Projected inertia | 29.06 | 19.54 | 14.16 | 13.37 | 10.89 | 8.62 | 2.87 | 1.49 |
| CPI | 29.06 | 48.6 | 62.76 | 76.13 | 87.02 | 95.64 | 98.51 | 100 |

**Table D.5** Jackknife values and Bootstrapping of the 3 first components from the Principal Component Analysis (PCA): The jackknife estimate of standard error (Jack.SE), the jackknife estimate of bias (Jack.Bias) and the bootstrapping of the Eigenvalues of the 3 first components from the PCA were assessed to provide Confidence Intervals (CI).

| | Eigenvalues | Jack. SE | Jack.Bias | CI95% | | Cumulative Projected Inertia CI95% | |
|---|---|---|---|---|---|---|---|
| PC1 | 2.325 | 0.172 | 0.039 | 2.153 | 2.568 | 26.91 | 32.10 |
| PC2 | 1.563 | 0.133 | 0.042 | 1.399 | 1.813 | 44.39 | 54.76 |
| PC3 | 1.133 | 0.107 | 0.086 | 0.997 | 1.412 | 56.86 | 72.41 |

**Table D.6** Contribution of the active variables to the 3 first Components (PC) of the Principal Component Analysis (PCA): The absolute contributions of the variables of each component from the PCA and their relative contributions were used to identify which variables contributed the most to the different components.

| | Absolute contributions | | | Relative contributions | | |
|---|---|---|---|---|---|---|
| | PC1 | PC2 | PC3 | PC1 | PC2 | PC3 |
| starvation | 2.23 | 31.52 | 6.79 | -5.18 | -49.26 | 7.69 |
| crushing | 5.08 | 25.93 | 0.03 | -11.82 | -40.54 | 0.04 |
| early sepsis | 15.51 | 4.99 | 11.56 | 36.06 | 7.8 | 13.09 |
| mummified piglets | 5.91 | 6.58 | 28.44 | -13.73 | 10.29 | 32.21 |
| death during farrowing | 15.18 | 5.16 | 17.62 | 35.28 | 8.06 | -19.96 |
| non-viable piglets | 23.39 | 2.59 | 19.04 | -54.37 | 4.05 | -21.56 |
| average litter size | 2.41 | 12.53 | 15.61 | -5.6 | 19.59 | 17.68 |
| average weight | 30.29 | 10.69 | 0.92 | 70.42 | -16.71 | 1.04 |

**Figure D.7** Cluster Dendogram of French pig farms. Ward's method was the criterion applied in hierarchical cluster analysis: The longer branches for the partition into 3 clusters suggest a better differentiation of the different clusters.

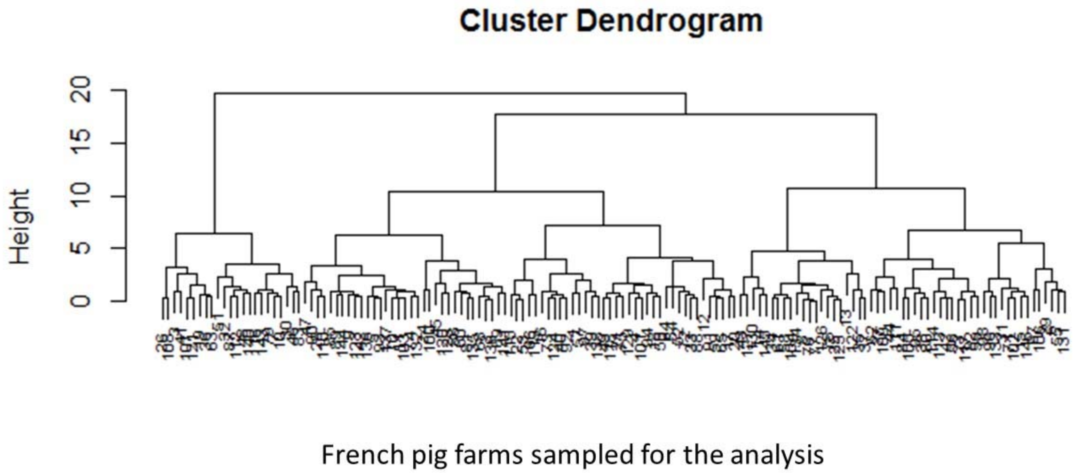
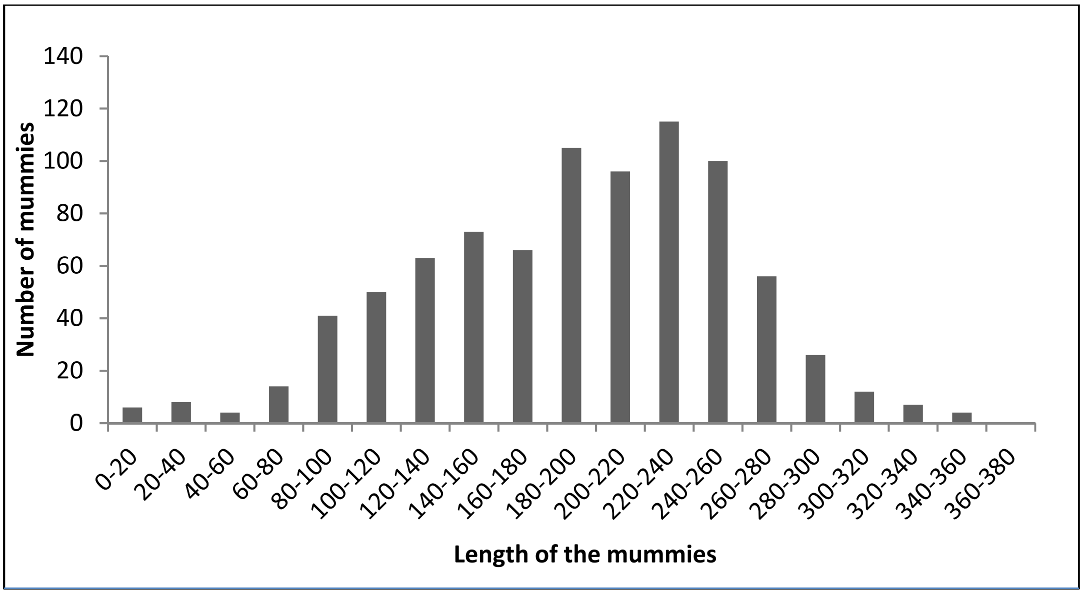


**Figure D.8** Distribution of the length (cm) of the mummified piglets from all sampled sows with mummified piglets.



# Appendix E: Impact of neonate management on different categories of piglet mortality in French farms (Chapter 6)

**Table E.1** Categories of perinatal mortality : Definition of the categories of perinatal mortality and their classification based on the necropsy and the time of death.

| Categories | Definition |
|---|---|
| anaemia | Mature lungs, abrasion of the feet, death after farrowing, pale skin and mucosa, white porcelain colour of the body, no organ lesions visible during the necropsy |
| arthritis | Mature lungs, abrasion of the feet, death after farrowing, swelling joints, signs of arthritis during necropsy |
| 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 |
| dehydration/ enteritis | Mature lungs, abrasion of the feet, death after farrowing, significant quantity of liquid in the intestine, signs of dehydration, sticky sub-cutaneous tissue, urate crystals in the kidney |
| 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 |
| acute disease | Mature lungs, death after farrowing, pericarditis, pleurisy, abscess, peritonitis, typical sepsis lesions, , petechial bleeding |
| malformation | Death during or after farrowing, signs of malformation |
| splayleg | Mature lungs, death after farrowing, cause reported by the farmer, no organs lesions at the necropsy |
| killed by the sow | Mature lungs, death after farrowing, signs of bites |
| killed by the farmer | Mature lungs, death after farrowing, reported by the farmer |
| Unknown cause | None of the other causes were identified, problem of conservation of the body |
| 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 before farrowing | Incomplete lung maturation, lack of abrasion of the feet, more than 800g, no organ lesions visible during the necropsy, autolysis lesions |
| death during farrowing | Incomplete lungs 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 |
| non-viable piglet | piglets < 800g excluding mummified piglets |

**Table E.2** Eigen values, projected inertia and cumulative projected inertia of the MCA of 9 variables related to piglet management on the first 3 factorial axes.

| | Factorial axis 1 | Factorial axis 2 | Factorial axis 3 |
|---|---|---|---|
| eigenvalues | 0.304 | 0.257 | 0.220 |
| projected inertia (%) | 12.84 | 10.85 | 9.31 |
| cumulative projected inertia | 12.84 | 23.69 | 33.00 |

**E.3** Absolute contributions for the three first factorial axes of the MCA of the levels of 9 variables related to piglet management.

| variables | F1 | F2 | F3 |
|---|---|---|---|
| transfer of the smaller: multiparous | 112 | 428 | 582 |
| transfer of the smaller: no transfer | 71 | 11 | 276 |
| transfer of the smaller: no rules | 65 | 154 | 97 |
| transfer of the smaller: primiparous | 89 | 454 | 456 |
| transfer of the bigger: multiparous | 12 | 25 | 399 |
| transfer of the bigger: no transfer | 1032 | 369 | 30 |
| transfer of the bigger: no rules | 127 | 110 | 127 |
| transfer of the bigger: primiparous | 306 | 0 | 352 |
| iron administration: injection | 2 | 235 | 11 |
| iron administration: oral | 10 | 1433 | 66 |
| anti-inflammatory: no | 7 | 2 | 12 |
| anti-inflammatory: yes | 133 | 30 | 227 |
| Help piglet after birth: no | 2005 | 156 | 448 |
| Help piglet after birth: yes | 276 | 43 | 62 |
| type of piglet assistance: suckling | 75 | 1144 | 532 |
| type of piglet assistance: at least 2 of the 3 propositions | 223 | 431 | 378 |
| type of piglet assistance: other | 10 | 33 | 276 |
| type of piglet assistance: none | 1694 | 116 | 708 |
| type of piglet assistance: move under heating lamp | 46 | 208 | 122 |
| frequency of help: never | 2014 | 163 | 207 |
| frequency of help: sometimes | 46 | 56 | 422 |
| frequency of help: rarely | 148 | 1850 | 6 |
| frequency of help: often | 140 | 41 | 249 |
| frequency of help: always | 42 | 247 | 579 |
| position of the heating lamp: both | 44 | 209 | 848 |
| position of the heating lamp: posterior | 331 | 52 | 1546 |
| position of the heating lamp: side | 84 | 124 | 33 |
| number of lamps at birth: 1 | 397 | 183 | 272 |
| number of lamps at birth: 2 | 102 | 541 | 7 |
| number of lamps at birth: 3 | 353 | 1151 | 671 |

**Table E.4** Coordinates on the first three factorial axes of the MCA.

| variables | F1 | F2 | F3 | Variable ID |
|---|---|---|---|---|
| transfer of the smaller: multiparous | 0.299 | 0.535 | 0.578 | 1 |
| transfer of the smaller: no transfer | -0.612 | -0.221 | 1.027 | 2 |
| transfer of the smaller: no rules | 0.455 | 0.643 | -0.472 | 3 |
| transfer of the smaller: primiparous | -0.221 | -0.458 | -0.425 | 4 |
| transfer of the bigger: multiparous | -0.093 | -0.124 | -0.457 | 5 |
| transfer of the bigger: no transfer | 2.860 | -1.573 | 0.415 | 6 |
| transfer of the bigger: no rules | -0.284 | 0.243 | 0.242 | 7 |
| transfer of the bigger: primiparous | 1.102 | 0.022 | 1.006 | 8 |
| iron administration: injection | 0.023 | -0.253 | -0.051 | 9 |
| iron administration: oral | -0.144 | 1.550 | 0.308 | 10 |
| anti-inflammatory: no | 0.046 | 0.020 | 0.051 | 11 |
| anti-inflammatory: yes | -0.838 | -0.365 | -0.932 | 12 |
| Help piglet after birth: no | 2.131 | 0.547 | -0.857 | 13 |
| Help piglet after birth: yes | -0.299 | -0.108 | 0.120 | 14 |
| type of piglet assistance: suckling | -0.364 | 1.305 | -0.824 | 15 |
| type of piglet assistance: at least 2 of the 3 propositions | -0.332 | -0.425 | 0.368 | 16 |
| type of piglet assistance: other | -0.398 | -0.668 | -1.780 | 17 |
| type of piglet assistance: none | 2.317 | -0.558 | -1.275 | 18 |
| type of piglet assistance: move under heating lamp | 0.271 | 0.528 | 0.375 | 19 |
| frequency of help: never | 3.996 | -1.046 | -1.090 | 20 |
| frequency of help: sometimes | -0.161 | 0.164 | -0.416 | 21 |
| frequency of help: rarely | 1.531 | 4.981 | 0.273 | 22 |
| frequency of help: often | -0.325 | -0.163 | 0.369 | 23 |
| frequency of help: always | 0.365 | -0.815 | 1.153 | 24 |
| position of the heating lamp: posterior | -0.171 | 0.342 | -0.637 | 25 |
| position of the heating lamp: both | 0.573 | -0.209 | 1.054 | 26 |
| position of the heating lamp: side | -0.297 | -0.332 | -0.160 | 27 |
| number of lamps at birth: 1 | -0.561 | 0.351 | -0.396 | 28 |
| number of lamps at birth: 2 | 0.229 | -0.484 | 0.049 | 29 |
| number of lamps at birth: 3 | 1.183 | 1.964 | 1.389 | 30 |

**Table E.6** Description of the continuous variables selected as covariates to adjust the models which assess the influence of different piglet management strategies on piglet mortality and different categories of piglet death.

| | min | 1st Q | median | mean | SD | 3rd Q | max |
|---|---|---|---|---|---|---|---|
| Average litter size | 13.13 | 15.10 | 15.93 | 15.90 | 1.20 | 16.73 | 18.21 |
| Average parity | 2.29 | 3.48 | 3.96 | 4.02 | 0.75 | 4.38 | 6.00 |
| Sows per employee | 7 | 98 | 125 | 153 | 104 | 201 | 650 |
| Biosecurity score | 1 | 4 | 5 | 4.76 | 1.23 | 6 | 6 |
| Farrowing score | 1 | 3 | 3 | 3.42 | 1.10 | 4 | 5 |

**Table E.7** Description of the categorical variable 'training' selected as covariates to adjust the models which assess the influence of different piglet management strategies on piglet mortality and different categories of piglet death.

| variables | level | number of farms | % |
|---|---|---|---|
| training | More than once a year | 12 | 20.7 |
| | less than once a year | 31 | 53.4 |
| | once a year | 12 | 20.7 |

**Figure E.8** MCA graph with the projection of piglet management variables and the farms on the first and second factorial axes. The squares with a number, pointed to by arrows, represent the piglet management variables (for key to the numbers see APPENDIX Table A4) and the black dots represent the farms of the sample.

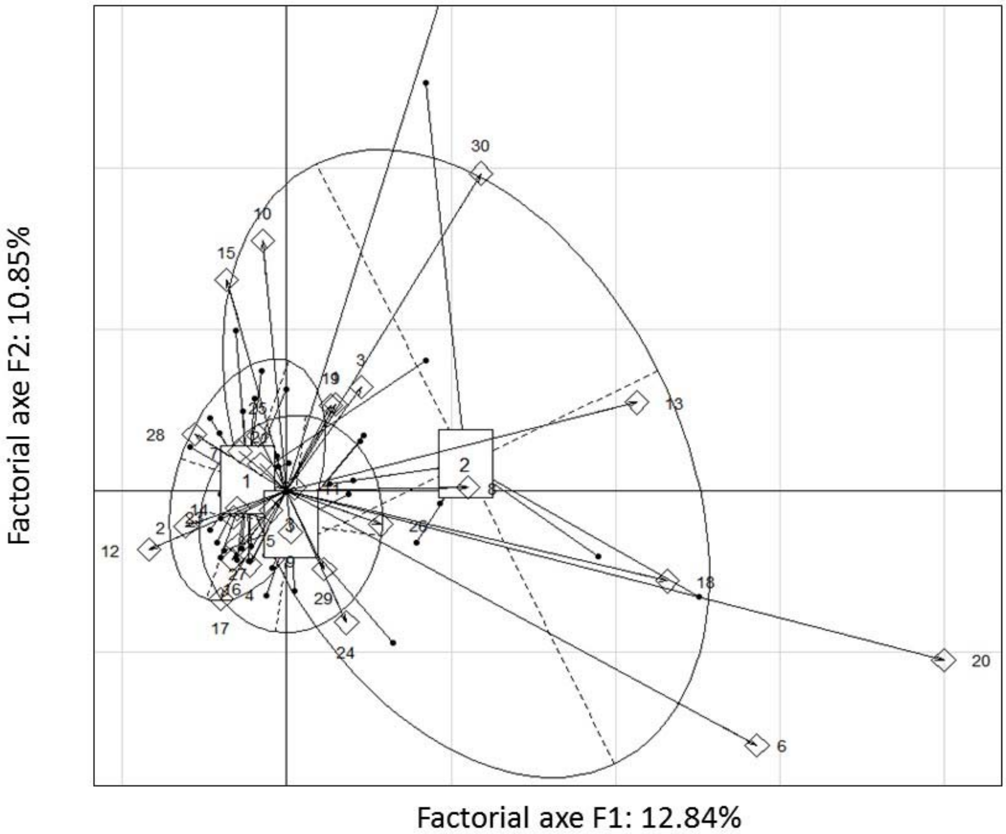


**Figure E.9** MCA graph with the projection of piglet management variables and the farms on the first and third factorial axes. The squares with a number, pointed to by the arrows, represent the piglet management variables ID (for key to the numbers see APPENDIX Table A4) and the black dots represent the farms of the sample.

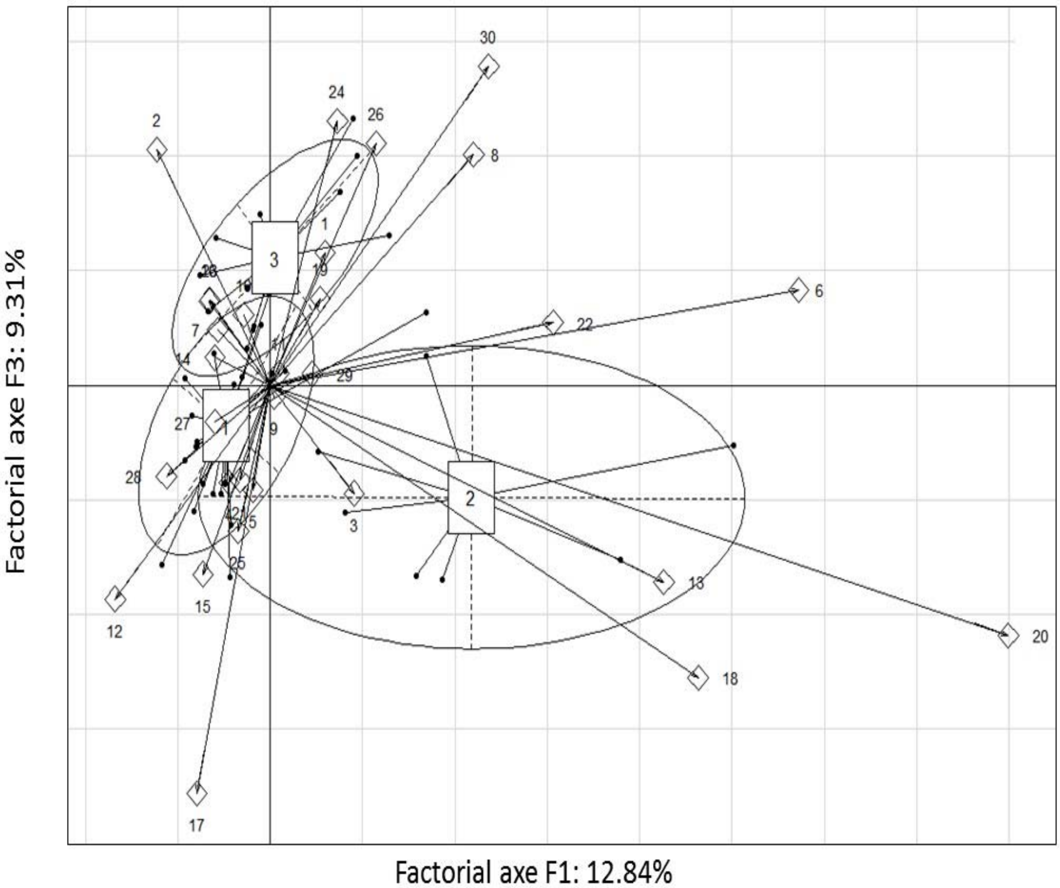
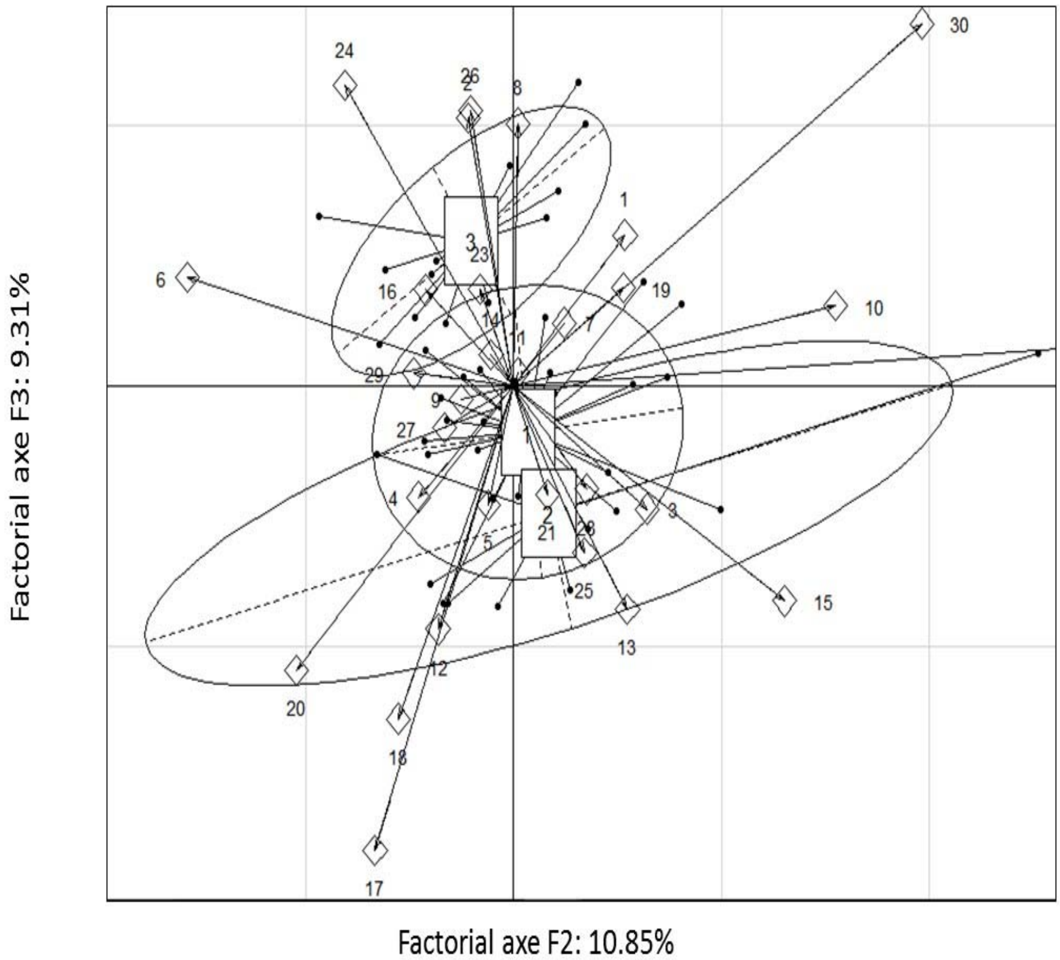


**Figure E.10** MCA graph with the projection of piglet management variables and the farms on the second and third factorial axes. The squares with a number, pointed to by the arrows, represent the piglet management variables ID (for key to the numbers see APPENDIX Table A4) and the black dots represent the farms of the sample.



# References


ADEWOLE, D. I., KIM, I. H. & NYACHOTI, C. M. 2016. Gut Health of Pigs: Challenge Models and Response Criteria with a Critical Analysis of the Effectiveness of Selected Feed Additives - A Review. Asian-Australasian Journal of Animal Sciences, 29, 909-924.

AFGHAH, Z., WEBB, B., MENG, X. J. & RAMAMOORTHY, S. 2017. Ten years of PCV2 vaccines and vaccination: Is eradication a possibility? Veterinary Microbiology, 206, 21-28.

AFONSO, A. & LINDBERG, A. 2014. Strengths and weaknesses of meat inspection as a contribution to animal health and welfare surveillance. Food Control, 39, 154-162.

AHDB. 2008. British Pig Health Scheme 2005-2008 http://pork.ahdb.org.uk/media/2717/british_pig_health_scheme_2005_-_2008.pdf

AHDB. 2010. Action for productivity. Porcine respiratory diseases complex 19

AHDB. 2014. 2014 pig cost of production in selected countries. AHDB market intelligence. http://pork.ahdb.org.uk/media/74797/cost-of-production-web-2014.pdf

AHDB. 2016. Will tariffs disrupt post-Brexit pork trade? Horizon. Market intelligence. 12 October 2016. https://ahdb.org.uk/documents/Horizon_Brexit_Analysis_Report-Oct2016.pdf

AHDB. 2017. Real Welfare. Baseline report: 2013-2016. Measuring welfare outcomes in pigs. http://pork.ahdb.org.uk/media/273110/real-welfare-report-2017.pdf

AIKING, H. 2011. Future Protein Supply. Trends in Food Science & Technology 22, 112-120.

ALARCON, P., RUSHTON, J. & WIELAND, B. 2013. Cost of post-weaning multi-systemic wasting syndrome and porcine circovirus type-2 subclinical infection in England An economic disease model. Preventive Veterinary Medicine, 110, 88-102.

ALARCON, P., VELASOVA, M., MASTIN, A., NEVEL, A., STARK, K. D. C. & WIELAND, B. 2011. Farm level risk factors associated with severity of post-weaning multi-systemic wasting syndrome. Preventive Veterinary Medicine, 101, 182-191.

ALBAN, L., PETERSEN, J. V. & BUSCH, M. E. 2015. A comparison between lesions found during meat inspection of finishing pigs raised under organic/free-range conditions and conventional, indoor conditions. Porcine Health Management, 1, 4.

ALLOUCHERY, H., 2010. Choisir sa conduite en Bandes. L'ABREUVOIR, Centre de Formation Elevage, 27400 CANAPPEVILLE. 217, 19-27.

ALONSO-SPILSBURY, M., RAMIREZ-NECOECHEA, R., GONZALEZ-LOZANO, M., MOTA-ROJAS, D. & TRUJILLO-ORTEGA, M.E. 2007. Piglet survival in early lactation: A review. Journal of Animal Veterinary Advances, 6, 76-86.

AMASS, S. F. & CLARK, L. K. 1999. Biosecurity considerations for pork production units. Swine Health and Production, 7, 217-228.

AMORY, J. R., MACKENZIE, A. M., ECKERSALL, P. D., STEAR, M. J. & PEARCE, G. P. 2007. Influence of rearing conditions and respiratory disease on haptoglobin levels in the pig at slaughter. Research in Veterinary Science, 83, 428-435.

ANDERSEN, I. L., HAUKVIK, I. A. & BØE, K. E. 2009. Drying and warming immediately after birth may reduce piglet mortality in loose-housed sows. Animal, 3, 592-597.

ANDERSEN, I. L., TAJET, G. M., HAUKVIK, I. A., KONGSRUD, S. & BØE, K. E. 2007. Relationship between postnatal piglet mortality, environmental factors and management around farrowing in herds with loose-housed, lactating sows. Acta Agriculturae Scandinavica, Section A — Animal Science, 57, 38-45.

ANDRES, V.M. & DAVIS, R.H. 2015. Biosecurity measures to control salmonella and other infectious agents in pig farms : a review. Comprehensive reviews in Food Science and Food Safety, 14, 317-335.

AVERÓS, X., BROSSARD, L., DOURMAD, J.-Y., DE GREEF, K. H., EDGE, H. L., EDWARDS, S. A. & MEUNIER-SALAÜN, M.-C. 2010. A meta-analysis of the combined effect of housing and environmental enrichment characteristics on the behaviour and performance of pigs. Applied Animal Behaviour Science, 127, 73-85.

BACKHANS, A., SJOLUND, M., LINDBERG, A. & EMANUELSON, U. 2015. Biosecurity level and health management practices in 60 Swedish farrow-to-finish herds. Acta Veterinaria Scandinavica, 57:14.

BARNES, A. P. & THOMSON, S. G. 2014. Measuring progress towards sustainable intensification: How far can secondary data go? Ecological Indicators, 36, 213-220.

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. Parasitology International, 64, 157-60.

BAXTER, E. & EDWARDS, S. A. 2016. Report of the Free Farrowing Workshop 2016, 2nd-3rd September, 2016, Belfast, NI

BEALE, R., FAIRBROTHER, J., INGLIS, A., TREBECK, D. 2008. One biosecurity. A working partnership. The independent review of australia's quarantine and biosecurity arrangements report for the Australian government. http://apo.org.au/system/files/2926/apo-nid2926-81841.pdf

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. Journal of Animal Science, 88, 2767-78.

BERG, S., ANDERSEN, I. L., TAJET, G. M., HAUKVIK, I. A., KONGSRUD, S. & BØE, K. E. 2007. Piglet use of the creep area and piglet mortality – effects of closing the piglets inside the creep area during sow feeding time in pens for individually loose-housed sows. Animal Science, 82, 277-281.

BESSE, P. 1989. Stabilité de l'Analyse en composantes principales par Ré-échantillonage, Approximation par la théorie des perturbations. Document N05-89 du laboratoire de Statistique et Probabilités de l'université Paul Sabatier de Toulouse.

BLOKHUIS, H. J., VEISSIER, I., MIELE, M. & JONES, B. 2010. The Welfare Quality® project and beyond: Safeguarding farm animal well-being. Acta Agriculturae Scandinavica, Section A — Animal Science, 60, 129-140.

BLUMENTHAL, U.J., FLEISHER, J.M., ESREY, S.A. & PEASEY, A. 2001. World Health Organization (WHO). Water Quality: Guidelines, Standards and Health: Epidemiology: a tool for the assessment of risk. IWA Publishing, London, UK

BOCK, B. B. & HUIK, M. M. V. 2007. Animal welfare: the attitudes and behaviour of European pig farmers. British Food Journal, 109, 931-944

BOKLUND, A., ALBAN, L., MORTENSEN, S. & HOUE, H. 2004. Biosecurity in 116 Danish fattening swineherds: descriptive results and factor analysis. Preventive Veterinary Medicine, 66, 49-62

BORGES, V. F., BERNARDI, M. L., BORTOLOZZO, F. P. & WENTZ, I. 2005. Risk factors for stillbirth and foetal mummification in four Brazilian swine herds. Preventive Veterinary Medicine, 70, 165-76. 9-62.

BOSLAUGH, S. 2007. Secondary Data Sources for Public Health. A Practical Guide. Cambridge University Press. New York. USA

BOTTOMS, K., POLJAK, Z., DEWEY, C., DEARDON, R., HOLTKAMP, D. & FRIENDSHIP, R. 2013. Evaluation of external biosecurity practices on southern Ontario sow farms. Preventive Veterinary Medicine, 109, 58-68.

BOWERS, J. 1995. Sustainability, Agriculture, and Agricultural Policy. Environment and Planning A, 27, 1231-1243.

BRACKE, M. B. M., HULSEGGE, B., KEELING, L. & BLOKHUIS, H. J. 2004. Decision support system with semantic model to assess the risk of tail biting in pigs. Applied Animal Behaviour Science, 87, 31-44.

BRACKE, M. B. M., ZONDERLAND, J. J., LENSKENS, P., SCHOUTEN, W. G. P., VERMEER, H., SPOOLDER, H. A. M., HENDRIKS, H. J. M. & HOPSTER, H. 2006. Formalised review of environmental enrichment for pigs in relation to political decision making. Applied Animal Behaviour Science, 98, 165-182.

BRAMBELL, F.W.R. 1965. Report of the Technical Committee to Enquire into the Welfare of Animals kept under Intensive Livestock Husbandry Systems. http://edepot.wur.nl/134379

BREWSTER, V. R., MAITI, H. C., TUCKER, A. W. & NEVEL, A. 2017. Associations between EP-like lesions and pleuritis and post trimming carcass weights of finishing pigs in England. Livestock Science, 201, 1-4.

BROWN, I. H. 2000. The epidemiology and evolution of influenza viruses in pigs. Veterinary Microbiology, 74, 29-46.

CALDARA, F. R., DOS SANTOS, L. S., MACHADO, S. T., MOI, M., DE ALENCAR NÄÄS, I., FOPPA, L., GARCIA, R. G. & DE KÁSSIA SILVA DOS SANTOS, R. 2014. Piglets' Surface Temperature Change at Different Weights at Birth. Asian-Australasian Journal of Animal Sciences, 27, 431-438.

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. Journées de Recherche Porcine 39, 273–280.

CAPORALE, V., ALESSANDRINI, B., DALLA VILLA, P. & DEL PAPA, S. 2005. Global perspectives on animal welfare: Europe. Revue Scientifique et Technique, 24, 567-77.

CASAL, J., DE MANUEL, A., MATEU, E. & MARTIN, M. 2007. Biosecurity measures on swine farms in Spain: Perceptions by farmers and their relationship to current on-farm measures. Preventive Veterinary Medicine, 82, 138-150.

CHAMBERT, T., DEFERT, F., GALAIS, B., PEGLION, M. & TRACOL, C. 2008. Étude d'un sujet de controverse: L'élevage intensif peut-il s'inscrire dans une agriculture durable? UE 16, Quart 4 Groupe 4a, Elevage intensif et agriculture durable, 1, 9.

CHIEW, K. T., CHUA, S. B. & SINGH, D. 1991. Pyaemia in pigs. British Veterinary Journal, 147, 256-69.

CHRISTIANSON, W. T., CHOI, C. S., COLLINS, J. E., MOLITOR, T. W., MORRISON, R. B. & JOO, H. S. 1993. Pathogenesis of porcine reproductive and respiratory syndrome virus infection in mid-gestation sows and fetuses. Canadian Journal of Veterinary Research, 57, 262-8.

CLARK, B., STEWART, G. B., PANZONE, L. A., KYRIAZAKIS, I. & FREWER, L. J. 2017. Citizens, consumers and farm animal welfare: A meta-analysis of willingness-to-pay studies. Food Policy, 68, 112-127.

COLEMAN, G.J. & HEMSWORTH, P.H. 2014. Training to improve stockperson beliefs and behaviour towards livestock enhances welfare and productivity. Revue Scientifique et Technique-OIE, 33, 131-137.

COLEMAN, G.J., HEMSWORTH, P.H. & HAY, M. 1998. Predicting stockperson behaviour towards pigs from attitudinal and job-related variables and empathy. Applied Animal Behaviour Science, 58, 63-75.

COLEMAN, G.J., HEMSWORTH, P.H., HAY, M. & COX, M. 2000. Modifying stockperson attitudes and behaviour towards pigs at a large commercial farm. Applied Animal Behaviour Science, 66, 11-20.

CORNALE, P., MACCHI, E., MIRETTI, S., RENNA, M., LUSSIANA, C., PERONA, G. & MIMOSI, A. 2015. Effects of stocking density and environmental enrichment on behavior and fecal corticosteroid levels of pigs under commercial farm conditions. Journal of Veterinary Behavior: Clinical Applications and Research, 10, 569-576.

CORREAS, I., OSORIO, F. A., STEFFEN, D., PATTNAIK, A. K. & VU, H. L. X. 2017. Cross reactivity of immune responses to porcine reproductive and respiratory syndrome virus infection. Vaccine, 35, 782-788.

CORREIA-GOMES, C., EZE, J. I., BOROBIA-BELSUÉ, J., TUCKER, A. W., SPARROW, D., STRACHAN, D. & GUNN, G. J. 2017. Voluntary monitoring systems for pig health and welfare in the UK: Comparative analysis of prevalence and temporal patterns of selected non-respiratory post mortem conditions. Preventive Veterinary Medicine, 146, 1-9.

COURBOULAY, V., EUGENE, A. & DELARUE, E. 2009. Welfare assessment in 82 pig farms: effect of animal age and floor type on behaviour and injuries in fattening pigs. Animal Welfare, 18, 515-521.

CRAWLEY, M.J. 2013. The R Book second edition, Chapter 11: Analysis of Variance, John Wiley and Son Ldt., Chichester, UK.

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. Applied Animal Behaviour Science, 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. Applied Animal Behaviour Science, 46, 175-192.

CROOKS, A. C., Hurd, H. S., Dargatz, D. A. & Hill, G. W. 1992. Economic Cost of Piglet Mortality in the farrowing to weaning phase: A report of the NAHMS National Swine Survey. Animal Health Insight, 9-14.

DA SILVA, N., CARRIQUIRY, A., O'NEILL, K., OPRIESSNIG, T. & O'CONNOR, A. M. 2014. Mixed treatment comparison meta-analysis of porcine circovirus type 2 (PCV2) vaccines used in piglets. Preventive Veterinary Medicine, 117, 413-24.

DAAF. 2008. One biosecurity a working partnership. The Independent Review of Australia's Quarantine and Biosecurity Arrangements Report to the Australian Government. http://www.agriculture.gov.au/about/publications/quarantine-biosecurity-report-and-preliminary-response

DE LANGE, F. M., DEWEY, C., STRAW, B. E, ZIMMERMAN, J., D'ALLAIRE, S. & TAYLOR, D. J. 2009. Management of growing-finishing pigs, Disease of swine. 9th ed. Ames, IA: Blackwell Publishing, Oxford, UK. Chapter 6

D'EATH, R. B., ARNOTT, G., TURNER, S. P., JENSEN, T., LAHRMANN, H. P., BUSCH, M. E., NIEMI, J. K., LAWRENCE, A. B. & SANDOE, P. 2014. Injurious tail biting in pigs: how can it be controlled in existing systems without tail docking? Animal, 8, 1479-97.

DEFRA, 2003. Code of recommendations for the Welfare of Livestock: Pigs. London, SW1A 2XX, 2003.

DEFRA, DAERA, Welsh Assembly Government, DRAH, RESAS. 2017. Agriculture in the UK 2016 https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/615965/AUK-2016-25may17i.pdf

DEWEY, C. E., WILSON, S., BUCK, P. & LEYENAAR, J. K. 1999. The reproductive performance of sows after PRRS vaccination depends on stage of gestation. Preventive Veterinary Medicine, 40, 233-41.

DEWULF, J. 2014. An online risk-based biosecurity scoring system for pig farms. Veterinary Ireland Journal, 4, 426-429.

DIJSKTRA, J. 2016. Modeling in animal science: an introduction to quantitative understanding and prediction. Animal and Science, big solutions for  grands challenges, ASAS, ADSA, CSAS, WSASAS joint annual meeting, 20 July 2016.

DOESCHL-WILSON, A. B., BRINDLE, W., EMMANS, G. & KYRIAZAKIS, I. 2009. Unravelling the relationship between animal growth and immune response during micro-parasitic infections. Plos One, 4, e7508.

DOHOO, I. R. 2015. Dealing with deficient and missing data. Preventive Veterinary Medicine, 122, 221-8.

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. Journal of Animal Science, 91, 4123-4132.

DOUGLAS, S. L., SZYSZKA, O., STODDART, K., EDWARDS, S. A. & KYRIAZAKIS, I. 2015. Animal and management factors influencing grower and finisher pig performance and efficiency in European systems: a meta-analysis. Animal, 9, 1210-20.

DREW, T. W. 2011. The emergence and evolution of swine viral diseases: to what extent have husbandry systems and global trade contributed to their distribution and diversity? Revue Scientifique Et Technique-OIE, 30, 95-106.

EDWARDS, S. A. 2002. Perinatal mortality in the pig: environmental or physiological solutions? Livestock Production Science, 78, 3–12.

EDWARDS, S. A. 2007. Experimental welfare assessment and on-farm application. Animal Welfare, 16, 111–115.

EDWARDS, S.A. & BAXTER, E.M. 2014. The gestating and lactating sow, Piglet mortality: causes and prevention, Wageningen Academic Publishers Books, Wageningen, Netherlands, 253-278.

ELBERS, A. R. W., TIELEN, M. J. M., SNIJDERS, J. M. A., CROMWIJK, W. A. J. & HUNNEMAN, W.A. 1992. Epidemiological studies on lesions in finishing pigs in the Netherlands. Preventive Veterinary Medicine, 14, 217-231.

EMANUELSON, U. & EGENVALL, A. 2014. The data - sources and validation. Preventive Veterinary Medicine, 113, 298-303.

ERIAN, I. & PHILLIPS, C. J. C. 2017. Public understanding and attitudes towards meat chicken production and relations to consumption. Animals, 7(3), 20.

ESCOBAR, M. P. & DEMERITT, D. 2015. Records, Regulation and the Practice of Animal Husbandry. How SAFE working paper 4, 27 March 2015. https://www.kcl.ac.uk/sspp/departments/geography/research/Research-Domains/Risk-and-Society/projects/howsafe/workshops/Records-paper-Howsafe-WP4.pdf

EUROPEAN COMMISSION, 2007a. Regulation (EC) No 1244/2007 of the European Parliament of 24 October 2007 amending Regulation (EC) No 2074/2005 as regards implementing measures for certain products of animal origin intended for human consumption and laying down specific rules on official controls for the inspection of meat (Text with EEA relevance). Official Journal of the European Union, L281:12–17.

EUROPEAN COMMISSION, 2007b. A new Animal Health Strategy for the European Union (2007-2013) where "Prevention is better than cure". European Commission Edition, Office for Official Publications of the European Communities, Luxembourg, pp. 1-26.

EUROPEAN COMMISSION. 2004. Regulation (EC) No 854/2004 of the European Parliament and of the Council of 29 April 2004 laying down specific rules for the organisation of official controls on products of animal origin intended for human consumption. Official Journal of the European Union, L226:111.

EUROPEAN COUNCIL, 1998. Council Directive 98/58/EC of 20 July 1998 concerning the protection of animals kept for farming purposes. Official Journal of the European Union, L221:111.

EUROPEAN FOOD SAFETY AUTHORITY (EFSA). 2007. Scientific opinion of the panel on animal health and welfare on a request from the commission on animal health and welfare in fattening pigs in relation to housing and husbandry. The EFSA Journal 564, 1-14.

EUROPEAN FOOD SAFETY AUTHORITY (EFSA). 2012. Statement on the use of animal based measures to assess the welfare of animals. The EFSA Journal, 10, 2767.

FAHRION, A. S., BEILAGE, E., NATHUES, H., DURR, S. & DOHERR, M. G. 2014. Evaluating perspectives for PRRS virus elimination from pig dense areas with a risk factor based herd index. Preventive Veterinary Medicine, 114, 247-58.

FAO. 1997. Marketing Research and Information Systems. Chapter 2: Secondary Sources Of Information. ISBN 92-5-103905-4 http://www.fao.org/docrep/w3241e/w3241e03.htm

FAO. 2010. Good practices for biosecurity in the pig sector – Issues and options in developing and transition countries. FAO Animal Production and Health Paper No. 169. Rome, FAO.

FARM ANIMAL WELFARE COUNCIL (FAWC). 2001. Interim report on the animal welfare implications of farm assurance schemes. FAWC, London, UK.

FELIN, E., JUKOLA, E., RAULO, S., HEINONEN, J. & FREDRIKSSON-AHOMAA, M. 2016. Current food chain information provides insufficient information for modern meat inspection of pigs. Preventive Veterinary Medicine, 127, 113-120.

FERRARI, C. V., SBARDELLA, P. E., BERNARDI, M. L., COUTINHO, M. L., VAZ, I. S., JR., 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. Preventive Veterinary Medicine, 114, 259-66.

FIRBANK, L. G., ELLIOTT, J., DRAKE, B., CAO, Y. & GOODAY, R. 2013. Evidence of sustainable intensification among British farms. Agriculture Ecosystems & Environment, 173, 58-65.

FISCHER, K., BRÜSSOW, K. &WÄHNER, M. 2005. The influence of the condition of the umbilical cord at birth on the vitality of newborn piglet. Biotechnology and Animal Husbandry 21, 191-194.

FOX N, HUNN A & MATHERS N. 2009. Sampling and Sample Size Calculation. The NIHR RDS for the East Midlands / Yorkshire & the Humber, 1-41

FRASER D. 2003. Assessing animal welfare at the farm and group level: the interplay of science and values. Animal Welfare 12, 433-443.

FRASER, D. 2008. Animal Welfare and the Intensification of Animal Production, P.B. Thompson Edition. The Ethics of Intensification, Springer Science + Business Media B.V., Chapter 12, 167-189

GADE, P. B. 2002. Welfare of animal production in intensive and organic systems with special reference to Danish organic pig production. Meat Science, 62, 353-8.

GARFORTH, C. J., BAILEY, A. P. & TRANTER, R. B. 2013. Farmers' attitudes to disease risk management in England: A comparative analysis of sheep and pig farmers. Preventive Veterinary Medicine, 110, 456-466.

GEERS, R., GOEDSEELS, V., PARDUYNS, G., NIJNS, P. & WOUTERS, P. 1990. Influence of floor type and surface temperature on the thermoregulatory behaviour of growing pigs. Journal of Agricultural Engineering Research, 45, 149-156.

GEMMA, C. H. & AIKATERINI, M. 2002. Consumer perception of organic food production and farm animal welfare. British Food Journal, 104, 287-299.

GENTRY, J. G., MCGLONE, J. J., BLANTON, J. R., JR. & MILLER, M. F. 2002. Alternative housing systems for pigs: influences on growth, composition, and pork quality. Journal of Animal Science, 80, 1781-90.

GILES, T. A., BELKHIRI, A., BARROW, P. A. & FOSTER, N. 2017. Molecular approaches to the diagnosis and monitoring of production diseases in pigs. Research in Veterinary Science, 114, 266-272.

GOBO, G. 2004. Qualitative Research Practice, Chapter 26, Sampling, Representativeness and Generalizability, Clive Seale, Giampietro Gobo, Jaber F. SAGE, London, UK. http://dx.doi.org/10.4135/9781848608191.d34

GOODWIN, R., HODGESON, R. G., WHITTLESTONE, P. & WOODHAMS, R.L. 1969. Some experiments relating to artificial immunity in enzootic pneumonia of pigs. Journal of Hygiene, 1969, 67, 465-476.

GOODWIN J. 2012.Secondary data analysis. SAGE, London, UK. http://dx.doi.org/10.4135/9781473963702

GOTTARDO, F., SCOLLO, A., CONTIERO, B., BOTTACINI, M., MAZZONI, C. & EDWARDS, S. A. 2017. Prevalence and risk factors for gastric ulceration in pigs slaughtered at 170 kg. Animal, In press.

GRADY, D. G., CUMMINGS, S. R. & HULLEY, S. B. 2013. Designing clinical research. Chapter 13 research using existing data. Lippincott Williams & Wilkins. Philadelphia. USA

GRAHAM, J. P., LEIBLER, J. H., PRICE, L. B., OTTE, J. M., PFEIFFER, D. U., TIENSIN, T. & SILBERGELD, E. K. 2008. The animal-human interface and infectious disease in industrial food animal production: rethinking biosecurity and biocontainment. Public Health Rep, 123, 282-299.

GRANDIN, T. 2014. Animal welfare and society concerns finding the missing link. Meat Science, 98, 461-469.

GRUTZNER, N., GEBHART, C. J., LAWHORN, B. D., SUCHODOLSKI, J. S. & STEINER, J. M. 2015. Serum folate, cobalamin, homocysteine and methylmalonic acid concentrations in pigs with acute, chronic or subclinical Lawsonia intracellularis infection. Veterinary Journal, 203, 320-5.

GU, Z., XIN, H., WANG, C., SHI, Z., LIU, Z., YANG, F., LIN, B., WANG, C. & LI, B. 2010. Effects of neoprene mat on diarrhea, mortality and foreleg abrasion of pre-weaning piglets. Preventive Veterinary Medicine, 95, 16-22.

GUNN, G. J., HEFFERNAN, C., HALL, M., MCLEOD, A. & HOVI, M. 2008. Measuring and comparing constraints to improved biosecurity amongst GB farmers, veterinarians and the auxiliary industries. Preventive Veterinary Medicine, 84, 310-23.

GUY, J. H., ROWLINSON, P., CHADWICK, J. P. & ELLIS, M. 2002. Behaviour of two genotypes of growing–finishing pig in three different housing systems. Applied Animal Behaviour Science, 75, 193-206.

HARLEY, S., MORE, S., BOYLE, L., CONNELL, N. O. & HANLON, A. 2012. Good animal welfare makes economic sense: potential of pig abattoir meat inspection as a welfare surveillance tool. Irish Veterinary Journal, 65, 11.

HEATH, C. A. E., BROWNE, W. J., MULLAN, S. & MAIN, D. C. J. 2014. Navigating the iceberg: reducing the number of parameters within the Welfare Quality® assessment protocol for dairy cows. Animal, 8, 1978-1986.

HEFFERNAN, C., NIELSEN, L., THOMSON, K. & GUNN, G. 2008. An exploration of the drivers to bio-security collective action among a sample of UK cattle and sheep farmers. Preventive Veterinary Medicine, 87, 358-72.

HEINONEN, M., ORRO, T., KOKKONEN, T., MUNSTERHJELM, C., PELTONIEMI, O. & VALROS, A. 2010. Tail biting induces a strong acute phase response and tail-end inflammation in finishing pigs. Veterinary Journal, 184, 303-7.

HEMSWORTH, P.H. 2003. Human-animal interactions in livestock production. Applied Animal Behaviour Science, 81, 185-198.

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. Journal of Animal Science, 71, 2645-53.

HERPIN, P., LE DIVIDICH, J., HULIN, J. C., 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. Journal of Animal Science, 74, 2067-75.

HERPIN, P., DAMON, M. & LE DIVIDICH, J. 2002. Development of thermoregulation and neonatal survival in pigs. Livestock Production Science, 78, 25-45.

HERSKIN, M. S., JENSEN, H. E., JESPERSEN, A., FORKMAN, B., JENSEN, M. B., CANIBE, N. & PEDERSEN, L. J. 2016. Impact of the amount of straw provided to pigs kept in intensive production conditions on the occurrence and severity of gastric ulceration at slaughter. Research in Veterinary Science, 104, 200-206.

HOLT, H. R., ALARCON, P., VELASOVA, M., PFEIFFER, D. U. & WIELAND, B. 2011. BPEX Pig Health Scheme: a useful monitoring system for respiratory disease control in pig farms? BMC Veterinary Research, 7, 82.

HOUŠKA, L., WOLFOVÁ, M., NAGY, I., CSÖRNYEI, Z. & KOMLÓSI I. 2010. Economic values for traits of pigs in Hungary. Czech Journal of Animal Science 55,139-148.

HUBBARD C, BOURLAKIS, M. & GARROD, G. 2007. Pig in the middle: farmers and the delivery of farm animal welfare standards. British Food Journal 109, 919-930.

HUNTER, E. J., JONES, T. A., GUISE, H. J., PENNY, R. H. C. & HOSTE, S. 2001. The relationship between tail biting in pigs, docking procedure and other management Practices. The Veterinary Journal, 161, 72-79.

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

IIDA, R., PINEIRO, C. & KOKETSU, Y. 2015. High lifetime and reproductive performance of sows on southern European Union commercial farms can be predicted by high numbers of pigs born alive in parity one. Journal of Animal Science, 93, 2501-8.

JACOBSON, M., AF SEGERSTAD, C. H., GUNNARSSON, A., FELLSTROM, C., KLINGENBERG, K. D., WALLGREN, P. & JENSEN-WAERN, M. 2003. Diarrhoea in the growing pig - a comparison of clinical, morphological and microbial findings between animals from good and poor performance herds. Research in Veterinary Science, 74, 163-169.

JAGER, H. C., MCKINLEY, T. J., WOOD, J. L., PEARCE, G. P., WILLIAMSON, S., STRUGNELL, B., DONE, S., HABERNOLL, H., PALZER, A. & TUCKER, A. W. 2012. Factors associated with pleurisy in pigs: a case-control analysis of slaughter pig data for England and Wales. PLoS One, 7, e29655.

JENSEN, K. H., JORGENSEN, L., HAUGEGAARD, S., HERSKIN, M. S., JENSEN, M. B., PEDERSEN, L. J. & CANIBE, N. 2017. The dose-response relationship between the amount of straw provided on the floor and gastric ulceration of pars oesophagea in growing pigs. Research in Veterinary Science, 112, 66-74.

JOHNSTON, M.P. 2014. Secondary Data Analysis: A method of which the time has come. Qualitative and Quantitative Methods in Libraries 3, 619-626.

JONES, B. A., GRACE, D., KOCK, R., ALONSO, S., RUSHTON, J., SAID, M. Y., MCKEEVER, D., MUTUA, F., YOUNG, J., MCDERMOTT, J. & PFEIFFER, D. U. 2013. Zoonosis emergence linked to agricultural intensification and environmental change. Proceedings of the National Academy of Sciences of the United States of America, 110, 8399-8404.

KAISER, H.F. 1960. The application of electronic computers to factor analysis. Educational and Psychological Measurements 20, 141-151. doi.org/10.1177/001316446002000116

KARVANEN, J., TOLONEN, H., HÄRKÄNEN, T., JOUSILAHTI, P. & KUULASMAA, K. Selection bias was reduced by recontacting nonparticipants. Journal of Clinical Epidemiology, 76, 209-217.

KAUPPINEN, T., VESALA, K. M. & VALROS, A. 2012. Farmer attitude toward improvement of animal welfare is correlated with piglet production parameters. Livestock Science, 143, 142-150.

KILBRIDE, A., GILLMAN, C., OSSENT, P. & GREEN, L. 2009a. Impact of flooring on the health and welfare of pigs. In Practice, 31, 390.

KILBRIDE, A. L., GILLMAN, C. E. & GREEN, L. E. 2009b. A cross-sectional study of the prevalence of lameness in finishing pigs, gilts and pregnant sows and associations with limb lesions and floor types on commercial farms in England. Animal Welfare, 18, 215-224.

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. Preventive Veterinary Medicine, 104, 281-91.

KIMMAN, T., HOEK, M. & DE JONG, M. C. M. 2013. Assessing and controlling health risks from animal husbandry. Njas-Wageningen Journal of Life Sciences, 66, 7-14.

KIRKDEN, R. D., BROOM, D. M. & ANDERSEN, I. L. 2013a. Piglet mortality: The impact of induction of farrowing using prostaglandins and oxytocin. Animal Reproduction Science, 138, 14-24.

KIRKDEN, R. D., BROOM, D. M. & ANDERSEN, I. L. 2013b. Invited review: piglet mortality: management solutions. Journal of Animal Science, 91, 3361-89.

KNECHT, D., SRODON, S., DUZINSKI & K. 2015. The impact of season, parity and breed on selected reproductive performance parameters of sows. Archives Animal Breeding, 58,49-56.

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. Journal of Animal Science 44, 620-637.

KOKETSU, Y., TANI, S. & IIDA, R. 2017. Factors for improving reproductive performance of sows and herd productivity in commercial breeding herds. Porcine Health Management, 3, 1.

KONGSTED, H. & SØRENSEN, J.T. 2010. Lesions found at routine meat inspection on finishing pigs. Veterinary Journal, 223, 21-26

KONGSTED, H., TOFT, N. & NIELSEN, J. P. 2014. Risk factors and epidemiological characteristics of new neonatal porcine diarrhoea syndrome in four Danish herds. BMC Veterinary Research, 10, 151. are associated with production system. Vet J http://dx.doi.org/10.1016/j.tvjl.2017.04.016

KOO, M. 2016. Reporting of secondary data analysis using routinely collected health data. European Journal of Internal Medicine, 34, e34.

KRAELING, R. R. & WEBEL, S. K. 2015. Current strategies for reproductive management of gilts and sows in North America. Journal of Animal Science and Biotechnology, 6, 3.

KYRIAZAKIS, I. & WHITTEMORE, C. T. 2006. Whittemore's Science and Practice of Pig Production, Third edition, Blackwell Publishing, Hoboken, États-Unis.

LAANEN, M., BEEK, J., RIBBENS, S., VANGROENWEGHE, F., MAES, D. & DEWULF, J. 2010. Biosecurity on pig herds: development of an on-line scoring system and the results of the first 99 participating herds. Vlaams Diergeneeskundig Tijdschrift, 79, 302-306.

LAANEN, M., PERSOONS, D., RIBBENS, S., DE JONG, E., CALLENS, B., STRUBBE, M., MAES, D. & DEWULF, J. 2013. Relationship between biosecurity and production/antimicrobial treatment characteristics in pig herds. Veterinary Journal, 198, 508-512.

LAANEN, M., MAES, D., HENDRIKSEN, C., GELAUDE, P., DE VLIEGHER, S., ROSSEEL, Y. & DEWULF, J. 2014. Pig, cattle and poultry farmers with a known interest in research have comparable perspectives on disease prevention and on-farm biosecurity. Preventive Veterinary Medicine, 115, 1-9.

LE COZLER, Y., GUYOMARC'H, C., PICHODO, X., QUINIO, P.-Y. & PELLOIS, H. 2002. Factors associated with stillborn and mummified piglets in high-prolific sows. Animal Research, 51, 261-268.

LEEN, F., VAN DEN BROEKE, A., AMPE, B., LAUWERS, L., VAN MEENSEL, J. & MILLET, S. 2017. Evaluation of performance models for farm-specific optimization of pig production. Livestock Science, 201, 99-108.

LUCIA, T., JR., CORREA, M. N., DESCHAMPS, J. C., BIANCHI, I., DONIN, M. A., MACHADO, A. C., MEINCKE, W. & MATHEUS, J. E. 2002. Risk factors for stillbirths in two swine farms in the south of Brazil. Preventive Veterinary Medicine, 53, 285-92.

LUNDMARK, F., BERG, C., SCHMID, O., BEHDADI, D. & ROCKLINSBERG, H. 2014. Intentions and Values in Animal Welfare Legislation and Standards. Journal of Agricultural & Environmental Ethics, 27, 991-1017.

MACHADO, G., MENDOZA, M. R. & CORBELLINI, L. G. 2015. What variables are important in predicting bovine viral diarrhea virus? A random forest approach. Veterinary Research, 46, 85.

MACKENZIE, S. G., LEINONEN, I., FERGUSON, N. & KYRIAZAKIS, I. 2015. Accounting for uncertainty in the quantification of the environmental impacts of Canadian pig farming systems. Journal of Animal Science, 93, 3130-3143.

MAES, D., LARRIESTRA, A., DEEN, J. & MORRISON, R. 2001. A retrospective study of mortality in grow-finish pigs in a multi-site production system. Journal of Swine Health and Production, 9, 267-273.

MAES, D. G., DUCHATEAU, L., LARRIESTRA, A., DEEN, J., MORRISON, R. B. & DE KRUIF, A. 2004. Risk factors for mortality in grow-finishing pigs in Belgium. Journal of Veterinary Medicine B. Infectious Disease and Veterinary Public Health, 51, 321-6.

MAGOWAN, E., MCCANN, M. E. E., BEATTIE, V. E., MCCRACKEN, K. J., HENRY, W., SMYTH, S., BRADFORD, R., GORDON, F. J. & MAYNE, C. S. 2007. Investigation of growth rate variation between commercial pig herds. Animal, 1, 1219-1226.

MAGOWAN, E., MOSS, B., GORDON, A. & MCCANN, E. 2010. Effect of average daily gain between weaning and slaughter (105 kg) on the meat quality of fast growing Landrace/Large White pigs. Agri-food and Biosciences Institute, 1-16

MAIN, D.C.J, CLEGG J, SPATZ, A. & GREEN, L.E. 2000. Repeatability of a lameness scoring system for finishing pigs. Veterinary Record 147, 574-576.

MAIN, D. C. J., WHAY, H. R., LEE, C. & WEBSTER, A. J. F. 2007. Formal animal-based welfare assessment in UK certification schemes. Animal Welfare, 16, 233-236.

MALDONADO, J., SEGALES, J., MARTINEZ-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. Veterinary Journal, 169, 454-6.

MANNING, L., BAINES, R. N. & CHADD, S. A. 2006. Quality assurance models in the food supply chain. British Food Journal, 108, 91-104.

MARQUER, P., RABADE, T. & FORTI R. 2014. Pig farming in the European Union: considerable variations from one Member State to another Eurostat. Statistic in focus 15/2014. ISSN: 2314-9647. Catalogue number: KS-SF-14-015-EN-N.

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. Journal of Swine Health Production 5, 49-56.

MARTINEAU, G. P. & MORVAN, H. 2010. Maladies d'élevage des porcs, 2nd Edition, Guides France Agricole, 18-19

MARTINEAU, G.P. & BADOUARD, B. 2009. Managing Highly Prolific Sows, London Swine Conference -Tools of the Trade 1-2 April.

MATERIA, V. C., PASCUCCI, S. & KOLYMPIRIS, C. 2015. Understanding the selection processes of public research projects in agriculture: The role of scientific merit. Food Policy, 56, 87-99.

MAZOYER, M., ROUDART, L. 2011. Histoire des agricultures du monde, du néolithique à la crise contemporaine, Edition du Seuil, Paris, France.

MCCLURE, C. A., HAMMELL, K. L. & DOHOO, I. R. 2005. Risk factors for outbreaks of infectious salmon anemia in farmed Atlantic salmon, Salmo salar. Preventive Veterinary Medicine, 72, 263-80.

MCDERMOTT, J. J. & SCHUKKEN, Y. H. 1994. A review of methods used to adjust for cluster effects in explanatory epidemiological studies of animal populations. Preventive Veterinary Medicine, 18, 155-173.

MEERT, H., VAN HUYLENBROECK, G. & VAN HECKE, E. 2001. Analysis of rural development policies based on different modes of economic integration, 73rd Seminar of the European Association of Agricultural Economists Ancona, policy experiences with rural development in a diversified Europe, 28-30 June 2001.

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? Applied Animal Behaviour Science, 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. Animal Reproduction Science, 60, 199-210.

MERIALDI, G., DOTTORI, M., BONILAURI, P., LUPPI, A., GOZIO, S., POZZI, P., SPAGGIARI, B. & MARTELLI, P. 2012. Survey of pleuritis and pulmonary lesions in pigs at abattoir with a focus on the extent of the condition and herd risk factors. Veterinary Journal, 193, 234-239.

MESA, H., CAMMACK, K. M., SAFRANSKI, T. J., GREEN, J. A. & LAMBERSON, W. R. 2012. Selection for placental efficiency in swine: conceptus development. Journal of Animal Science, 90, 4217-22.

MESSAD, S. 2012. Traitement statistique des données d'élevage Les méthodesd'analyses factorielles et de classification, Université de Montpellier. URLhttp://mon.univmontp2.fr/claroline/backends/download.php?url=L0FuYWx5c2VzTXVsdGl2YXJpZWVzLnBkZg%3D%3D&cidReset=true&cidReq=FMOM322.

MEYNS, T., VAN STEELANT, J., ROLLY, E., DEWULF, J., HAESEBROUCK, F. & MAES, D. 2011. A cross-sectional study of risk factors associated with pulmonary lesions in pigs at slaughter. Veterinary Journal, 187, 388-92.

MICHIELS, A., PIEPERS, S., ULENS, T., VAN RANSBEECK, N., DEL POZO SACRISTAN, R., SIERENS, A., HAESEBROUCK, F., DEMEYER, P. & MAES, D. 2015. Impact of particulate matter and ammonia on average daily weight gain, mortality and lung lesions in pigs. Preventive Veterinary Medicine, 121, 99-107.

MILLIGAN, B. N., FRASER, D. & KRAMER, D. L. 2001. Birth weight variation in the domestic pig: effects on offspring survival, weight gain and suckling behaviour. Applied Animal Behaviour Science, 73, 179-191.

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. Livestock Production Science, 76, 181-191.

MIRANDA-DE LA LAMA, G. C., SEPULVEDA, W. S., VILLARROEL, M. & MARIA, G. A. 2013. Attitudes of meat retailers to animal welfare in Spain. Meat Science, 95, 569-75.

MOINARD, C., MENDL, M., NICOL, C. J. & GREEN, L. E. 2003. A case control study of on-farm risk factors for tail biting in pigs. Applied Animal Behaviour Science, 81, 333-355.

MOTA-ROJAS, D., MARTINEZ-BURNES, J., TRUJILLO-ORTEGA, M. E., ALONSO-SPILSBURY, M. L., RAMIREZ-NECOECHEA, R. & LOPEZ, A. 2002. Effect of oxytocin treatment in sows on umbilical cord morphology, meconium staining, and neonatal mortality of piglets. American Journal of Veterinary Research, 63, 1571-4.

MOTA-ROJAS, D., TRUJILLO, M. E., MARTINEZ, J., ROSALES, A. M., OROZCO, H., RAMIREZ, R., SUMANO, H. & ALONSO-SPILSBURY, M. 2006. Comparative routes of oxytocin administration in crated farrowing sows and its effects on fetal and postnatal asphyxia. Animal Reproduction Science, 92, 123-43.

MOTA-ROJAS, D., VILLANUEVA-GARCÍA, D., VELAZQUEZ-ARMENTA, E. Y., NAVA-OCAMPO, A. A., 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. Biological Research, 40, 55-63.

MOTA-ROJAS, D., MARTINEZ-BURNES, J., VILLANUEVA-GARCIA, D., ROLDAN-SANTIAGO, P., TRUJILLO-ORTEGA, M.E., OROZCO-GREGORIO, H., BONILLA-JAIME, H. & LOPEZ-MAYAGOITIA, A. 2012. Animal welfare in the newborn piglet: a review. Veterinari Medicina 57, 338-349.

MUIRHEAD, M.R. & ALEXANDER, T.J.L. 1997. Managing pig health and the treatment of disease: A reference for the farm. 5M, Sheffield, UK.

MULLAN, S., BROWNE, W. J., EDWARDS, S. A., BUTTERWORTH, A., WHAY, H. R. & MAIN, D. C. J. 2009a. The effect of sampling strategy on the estimated prevalence of welfare outcome measures on finishing pig farms. Applied Animal Behaviour Science, 119, 39-48.

MULLAN, S., EDWARDS, S. A., BUTTERWORTH, A., WHAY, H. R. & MAIN, D. C. J. 2009b. Interdependence of welfare outcome measures and potential confounding factors on finishing pig farms. Applied Animal Behaviour Science, 121, 25-31.

MULLAN, S., EDWARDS, S. A., BUTTERWORTH, A., WHAY, H. R. & MAIN, D. C. 2011a. Inter-observer reliability testing of pig welfare outcome measures proposed for inclusion within farm assurance schemes. Veterinary Journal, 190, e100-9.

MULLAN, S., EDWARDS, S.A., BUTTERWORTH, A., WARD, M., WHAY, H.R. & MAIN, D.C.J. 2011b. Welfare science into practice: a successful case example of working with industry. Animal Welfare 20, 597-601.

MUNS, R., MANTECA, X. & GASA, J. 2015. Effect of different management techniques to enhance colostrum intake on piglets' growth and mortality. Animal Welfare, 24, 185-192.

MUNS, R., NUNTAPAITOON, M. & TUMMARUK, P. 2016. Non-infectious causes of pre-weaning mortality in piglets. Livestock Science, 184, 46-57.

MUNSTERHJELM, C., HEINONEN, M. & VALROS, A. 2015a. Application of the Welfare Quality (R) animal welfare assessment system in Finnish pig production, part I: Identification of principal components. Animal Welfare, 24, 151-160.

MUNSTERHJELM, C., HEINONEN, M. & VALROS, A. 2015b. Application of the Welfare Quality (R) animal welfare assessment system in Finnish pig production, part II: Associations between animal-based and environmental measures of welfare. Animal Welfare, 24, 161-172.

NADIS. NADIS Pig Graphs – May 2007 - March 2011. Retrieved on 1 June 2016 http://www.nadis.org.uk/media/69158/nadis%20pig%20graphs.pdf

NATHUES, H., ALARCON, P., RUSHTON, J., JOLIE, R., FIEBIG, K., JIMENEZ, M., GEURTS, V. & NATHUES, C. 2017. Cost of porcine reproductive and respiratory syndrome virus at individual farm level - An economic disease model. Preventive Veterinary Medicine, 142, 16-29.

NATHUES, H., WOESTE, H., DOEHRING, S., FAHRION, A. S., DOHERR, M. G. & BEILAGE, E. G. 2013. Herd specific risk factors for Mycoplasma hyopneumoniae infections in suckling pigs at the age of weaning. Acta Veterinaria Scandinavica, 55.

NEWMANN, E.J., KLIEBENSTEIN, J.B., JOHNSON, C.D., MABRY, J.W., BUSH, E.J., SEITZINGER, A.H., GREEN, A.L., ZIMMERMAN, J.J. 2005. Assessment of the economic impact of porcine reproductive and respiratory syndrome on swine production in the United States. Journal of Animal Veterinary Medicine Association, 227, 385-92.

NIELSEN, S. S., NIELSEN, G. B., DENWOOD, M. J., HAUGEGAARD, J. & HOUE, H. 2015. Comparison of recording of pericarditis and lung disorders at routine meat inspection with findings at systematic health monitoring in Danish finisher pigs. Acta Veterinaria Scandinavica, 57.

NIEMI, J.K., SINISALO, A., VALROS, A. & HEINONEN, M. 2012. New challenges for EU agricultura sector and rural areas. Which role for public policy? Market and policy-oriented incentives to provide animal welfare: The case of tail biting. Paper prepared for the 126thSeminar of European Association of Agricultural Economists. Capri (Italy), June 27-29, 2012

NIEMI JK, SAHLSTRÖM L, KYYRÖ J, LYYTIKÄINEN T, SINISALO A. 2016. Farm characteristics and perceptions regarding costs contribute to the adoption of biosecurity in Finnish pig and cattle farms. Review of Agricultural, Food and Environmental Studies doi:10.1007/s41130-016-0022-5

NIR, O. 2003. What are production diseases, and how do we manage them? Acta Veterinaria Scandinavica, 21-32.

NOREMARK, M., FROSSLING, J. & LEWERIN, S. S. 2013. A survey of visitors on Swedish livestock farms with reference to the spread of animal diseases. BMC Veterinary Research, 9, 184.

NÖREMARK, M., STERNBERG LEWERIN, S., ERNHOLM, L. & FRÖSSLING, J. 2016. Swedish Farmers' Opinions about Biosecurity and Their Intention to Make Professionals Use Clean Protective Clothing When Entering the Stable. Frontiers in Veterinary Science, 3, 46.

NOYES, E. P., FEENEY, D. A. & PIJOAN, C. 1990. Comparison of the effect of pneumonia detected during lifetime with pneumonia detected at slaughter on growth in swine. Journal of the American Veterinary Medical Association, 197, 1025-9.

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. Journal of Animal Science, 53, 195-203.

OIE. 2016. 4th OIE Global Conference on Animal welfare: towards a new global strategy on animal welfare. 85th OIE General Session in May 2017.

PANDOLFI, F., STODDART, K., WAINWRIGHT, N., KYRIAZAKIS, I. & EDWARDS, S. 2017a. The 'Real Welfare' scheme: Benchmarking welfare outcomes for commercially farmed pigs. Animal, 2, 1-9.

PANDOLFI, F., STODDART, K., WAINWRIGHT, N., KYRIAZAKIS, I. & EDWARDS S. 2017b. The "Real Welfare" Scheme: Identification of risk and protective factors for welfare outcomes in commercial pig farms in the UK. Preventive Veterinary Medicine, 146, 34-43.

PANDOLFI, F., EDWARDS, S.A., ROBERT, F. & KYRIAZAKIS, I. 2017c. Risk factors associated with the different categories of piglet perinatal mortality in French farms. Preventive Veterinary Medicine 137, 1-12.

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. Preventive Veterinary Medicine, 110, 206-13.

PATIENCE, J. F., ROSSONI-SERAO, M. C. & GUTIERREZ, N. A. 2015. A review of feed efficiency in swine: biology and application. Journal of Animal Science Biotechnology, 6, 33.

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. Applied Animal Behaviour Science, 96, 215-232.

PEET, B. 2002. Changing production requirements. London swine conference- Conquering the challenge: Emerging opportunities and challenges, 11-12 April 2002, London, UK.

PÈRE, M.C. & ETIENNE, M., 2000. Uterine blood flow in sows: Effects of pregnancy stage and litter size. Reproduction Nutrition Development, 40, 369-382.

PFEIFFER, D. 2010. Veterinary Epidemioloy : An Introduction pp 38-53. Wiley-Blackwell, Chichester, UK.

PICARDEAU, M., BERTHERAT, E., JANCLOES, M., SKOULOUDIS, A. N., DURSKI, K. & HARTSKEERL, R. A. 2014. Rapid tests for diagnosis of leptospirosis: Current tools and emerging technologies. Diagnostic Microbiology and Infectious Disease, 78, 1-8.

POLANYI, K. 1944. The Great Transformation. Beacon Press, Boston, USA.

POMORSKA-MOL, M., KWIT, K., MARKOWSKA-DANIEL, I., KOWALSKI, C. & PEJSAK, Z. 2014. Local and systemic immune response in pigs during subclinical and clinical swine influenza infection. Research in Veterinary Science, 97, 412-421.

POMORSKA-MOL, M., MARKOWSKA-DANIEL, I. & PEJSAK, Z. 2012. Acute phase protein response during subclinical infection of pigs with H1N1 swine influenza virus. Veterinary Microbiology, 159, 499-503.

POPA, A., DRAGHICI, M., POPA, M. & NICULITA, P. 2011. Consumer choice and food policy. A literature review. Journal of Environmental Protection and Ecology, 12, 708-717.

POSTMA, M., BACKHANS, A., COLLINEAU, L., LOESKEN, S., SJOLUND, M., BELLOC, C., EMANUELSON, U., BEILAGE, E. G., STARK, K. D. C., DEWULF, J. & CONSORTIUM, M. 2016a. The biosecurity status and its associations with production and management characteristics in farrow-to-finish pig herds. Animal, 10, 478-489.

POSTMA, M., BACKHANS, A., COLLINEAU, L., LOESKEN, S., SJOLUND, M., BELLOC, C., EMANUELSON, U., BEILAGE, E. G., OKHOLM-NIELSEN, K. D. C.,  STARK, K. D. C., DEWULF, J. & CONSORTIUM, M., Postma A., Backhans, L., Collineau, S., Loesken, M. 2016b. Evaluation of the relationship between the biosecurity status, production parameters, herd characteristics and antimicrobial usage in farrow-to-finish pig production in four EU countries. Porcine Health Management, 2:9.

POSTMA, M., SPEKSNIJDER, D. C., JAARSMA, A. D. C., VERHEIJ, T. J. M., WAGENAAR, J. A. & DEWULF, J. 2016c. Opinions of veterinarians on antimicrobial use in farm animals in Flanders and the Netherlands. Veterinary Record, 179, 68-+.

POSTMA, M., VANDERHAEGHEN, W., SARRAZIN, S., MAES, D. & DEWULF, J. 2017. Reducing Antimicrobial usage in pig production without jeopardizing production parameters. Zoonoses Public Health, 64, 63–74.

PRITCHARD, G., DENNIS, I. & WADDILOVE, J. 2005. Biosecurity: reducing disease risks to pig breeding herds. In Practice, 27, 230-237.

QUESNEL, H., BROSSARD, L., VALANCOGNE, A. & QUINIOU, N. 2008. Influence of some sow characteristics on within-litter variation of piglet birth weight. Animal, 2, 1842-1849.

RAWLES, K. 2010. Developing ethical, sustainable and compassionate food policies. The Meat Crisis: Developing More Sustainable Production and Consumption Earthscan, In Joyce D'Silva & John Webster edition, New York, USA.

RED TRACTOR ASSURANCE. 2014. Red Tractor Assurance for Farms – Pigs Scheme. http://assurance.redtractor.org.uk/contentfiles/Farmers-5615.pdf?_=635960611245183715

REGULA, G., LICHTENSTEIGER, C. A., MATEUS-PINILLA, N. E., SCHERBA, G., MILLER, G. Y. & WEIGEL, R. M. 2000. Comparison of serologic testing and slaughter evaluation for assessing the effects of subclinical infection on growth in pigs. Journal of the American Veterinary Medical Association, 217, 888-895.

REHFELDT, C. & KUHN, G. 2006. Consequences of birth weight for postnatal growth performance and carcass quality in pigs as related to myogenesis. Journal of Animal Science, 84 Suppl, E113-23.

RIEU, M. & ROGUET, C. 2012. Tendances de l'élevage porcin dans l'Union européenne: un modèle en pleine mutation. Journées Recherche Porcine, 44, 219-228

ROBERTS, H. C., ELBERS, A. R., CONRATHS, F. J., HOLSTEG, M., HOERETH-BOENTGEN, D., GETHMANN, J. & VAN SCHAIK, G. 2014. Response to an emerging vector-borne disease: surveillance and preparedness for Schmallenberg virus. Preventive Veterinary Medicine, 116, 341-9.

ROCADEMBOSCH, J., AMADOR, J., BERNAUS, J., FONT, J. & FRAILE, L. J. 2016. Production parameters and pig production cost: temporal evolution 2010-2014. Porcine Health Management, 2, 11.

ROGERSON, P. A. 2001. Statistical methods for geography. London: Sage

ROHDE PARFET, K.A. & GONYOU, H.W. 1991. Attraction of newborn piglets to auditory, visual, olfactory and tactile stimuli. Journal of Animal Science, 69, 125–133.

ROJO-GIMENO, C., POSTMA, M., DEWULF, J., HOGEVEEN, H., LAUWERS, L. & WAUTERS, E. 2016. Farm-economic analysis of reducing antimicrobial use whilst adopting improved management strategies on farrow-to-finish pig farms. Preventive Veterinary Medicine, 129, 74-87.

ROOTWELT, V., REKSEN, O., FARSTAD, W. & FRAMSTAD, T. 2013. Postpartum deaths: piglet, placental, and umbilical characteristics. Journal of Animal Science, 91, 2647-56.

ROSVOLD, E. M., KIELLAND, C., OCEPEK, M., FRAMSTAD, T., FREDRIKSEN, B., ANDERSEN-RANBERG, I., NÆSS, G. & ANDERSEN, I. L. 2017. Management routines influencing piglet survival in loose-housed sow herds. Livestock Science, 196, 1-6.

SAITONE, T.L. & SEXTON, R.J. 2017. Agri-food supply chain: evolution and performance with conflicting consumer and societal demands. European Review of Agricultural Economics, 1-24

SANCHEZ-VAZQUEZ, M. J., SMITH, R., GUNN, G. J., LEWIS, F. I., STRACHAN, W.D. & EDWARDS, S. A. 2010. The identification of risk factors for the presence of enzootic pneumonia-like lesions and pleurisy in slaughtered finishing pigs utilising existing British pig industry data. The Pig Journal, 63, 25-33.

SANCHEZ-VAZQUEZ, M. J., STRACHAN, W. D., ARMSTRONG, D., NIELEN, M. & GUNN, G. J. 2011. The British pig health schemes: integrated systems for large-scale pig abattoir lesion monitoring. Veterinary Record, 169, 413-U93.

SANCHEZ-VAZQUEZ, M. J., NIELEN, M., EDWARDS, S. A., GUNN, G. J. & LEWIS, F. I. 2012. Identifying associations between pig pathologies using a multi-dimensional machine learning methodology. BMC Veterinary Research, 8.

SAUNDERS, M., LEWIS P. & THORNHILL, A. 2009. Research methods for business students, Fifth edition, Pearson Education Limited, Harlow, UK

SBARAINI, A., CARTER, S. M., EVANS, R. W. & BLINKHORN, A. 2011. How to do a grounded theory study: a worked example of a study of dental practices. BMC Medical Research and Methodology, 11, 128.

SCHEIDT, A.B., CLINE, T.R., CLARK, L.K., MAYROSE, V.B., VAN ALSTINE, V.G., DIEKMAN, M.A. & SINGLETON, W.L. 1990. The effect of all-in-all-out growing-finishing on the health of pigs. Swine Health Production, 3, 202-205

SCHLOMER, B. J. & COPP, H. L. 2014. Secondary data analysis of large data sets in urology: successes and errors to avoid. Journal of Urology, 191, 587-96.

SCHRODER-PETERSEN, D. L. & SIMONSEN, H. B. 2001. Tail biting in pigs. Veterinary Journal, 162, 196-210

SCOLLO, A., GOTTARDO, F., CONTIERO, B., MAZZONI, C., LENEVEU, P. & EDWARDS, S. A. 2017. Benchmarking of pluck lesions at slaughter as a health monitoring tool for pigs slaughtered at 170kg (heavy pigs). Preventive Veterinary Medicine, 144, 20-28.

SCOTT, K., TAYLOR, L., GILL, B.P. & EDWARDS, S.A. 2007. Influence of different types of environmental enrichment on the behaviour of finishing pigs in two different housing systems - 2. Ratio of pigs to enrichment. Applied Animal Behaviour Science, 105, 51-58.

SCOTT, K., TAYLOR, L., GILL, B.P. & EDWARDS, S.A. 2009. Influence of different types of environmental enrichment on the behaviour of finishing pigs in two different housing systems - 3. Hanging toy versus rootable toy of the same material. Applied Animal Behaviour Science, 116, 186-190.

SEGURA-CORREA, J.C. & SOLORIO-RIVERA, J. L. 2007. Evaluation of three models and risk factors associated with stillborn piglets in Yucatan. Tecnica Pecuaria en Mexico, 45, 227-236.

SIBILA, M., ARAGON, V., FRAILE, L. & SEGALES, J. 2014. Comparison of four lung scoring systems for the assessment of the pathological outcomes derived from Actinobacillus pleuropneumoniae experimental infections. BMC Veterinary Research, 10.

SINISALO, A., NIEMI, J. K., HEINONEN, M. & VALROS, A. 2012. Tail biting and production performance in fattening pigs. Livestock Science, 143, 220-225.

SKAMPARDONIS, V., SOTIRAKI, S., KOSTOULAS, P. & LEONTIDES, L. 2012. Factors associated with the occurrence and level of Isospora suis oocyst excretion in nursing piglets of Greek farrow-to-finish herds. BMC Veterinary Research, 8, 228.

ŠKORJANC, D., BRUS, M. & POTOKAR, M.Č. 2007. Effect of Birth Weight and Sex on Pre-Weaning Growth Rate of Piglets. Archiv Tierzucht, 50, 476-486.

SMITH, R.P., SANCHEZ-VAZQUEZ, M.J., COOK, A.J. & EDWARDS, S.A. 2011a. Abattoir-based study investigating the association between gross pathological lesions and serological tests for Salmonella infection in pigs. Veterinary Record, 168, 240.

SMITH, A. K., AYANIAN, J. Z., COVINSKY, K. E., LANDON, B. E., MCCARTHY, E. P., WEE, C. C. & STEINMAN, M. A. 2011b. Conducting high-value secondary dataset analysis: an introductory guide and resources. Journal of General Internal Medicine, 26, 920-9.

SMULDERS, D., VERBEKE, G., MORMEDE, P. & GEERS, R. 2006. Validation of a behavioral observation tool to assess pig welfare. Physiology and Behaviour, 89, 438-47.

SPOOLDER, H., BRACKE, M., MUELLER-GRAF, C. & EDWARDS, S. A. 2011. Preparatory work for the future development of animal based measures for assessing the welfare of pigs. Report 2: Technical report of preparatory work for the future development of animal based measures for assessing the welfare of weaned, growing and fattening pigs including aspects related to space allowance, floor types, tail biting and need for tail docking. EFSA publication doi.org/10.2903/sp.efsa.2011.EN-181

SPRAGUE, L. A., OELSNER, G. P. & ARGUE, D. M. 2017. Challenges with secondary use of multi-source water-quality data in the United States. Water Research, 110, 252-261.

STARK, K. D. C., ALONSO, S., DADIOS, N., DUPUY, C., ELLERBROEK, L., GEORGIEV, M., HARDSTAFF, J., HUNEAU-SALAUN, A., LAUGIER, C., MATEUS, A., NIGSCH, A.,

STEINMANN, T., BLAHA, T. & MEEMKEN, D. 2014. A simplified evaluation system of surface-related lung lesions of pigs for official meat inspection under industrial slaughter conditions in Germany. BMC Veterinary Research, 10.

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. Journal of Animal Science, 91, 1562-1569.

STRAW, B.E., ZIMMERMAN, J.J., D'ALLAIRE, S. & TAYLOR, D.J., 2006. Disease of Swine. 9th Edition. Chapter 6: Disease of the Reproductive System, pp.127. Blackwell Publishing, Ames, USA.

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. Journal of Animal Science, 85, 1385-1392.

SVENDSEN, J. & STEEN SVENDSEN, L. 1997. Intensive (commercial) systems for breeding sows and piglets to weaning. Livestock Production Science, 49, 165-179.

TAYLOR, N. R., MAIN, D. C., MENDL, M. & EDWARDS, S. A. 2010. Tail-biting: a new perspective. Veterinary Journal, 186, 137-47.

TAYLOR, N. R., PARKER, R. M., MENDL, M., EDWARDS, S. A. & MAIN, D. C. 2012. Prevalence of risk factors for tail biting on commercial farms and intervention strategies. Veterinary Journal, 194, 77-83.

TEERENSTRA, S., MOERBEEK, M., VAN ACHTERBERG, T., PELZER, B.J. & BORM, G.F. 2008. Sample size calculations for 3-level cluster randomized. Clinical Trials, 5, 486–495.

TEMPLE, D., DALMAU, A., RUIZ DE LA TORRE, J.L., MANTECA, X. & VELARDE, A. 2011. Application of the Welfare Quality® protocol to assess finisher herds kept under intensive conditions in Spain. Journal of Veterinary Behaviour – Clinical Applications and Research 6, 138-149.

TEMPLE, D., COURBOULAY, V., VELARDE, A., DALMAU, A. & MANTECA, X. 2012. The welfare of growing pigs in five different production systems in France and Spain: assessment of health. Animal Welfare, 21, 257-271.

TEMPLE, D., MANTECA, X., DALMAU, A. & VELARDE, A. 2013. Assessment of test–retest reliability of animal-based measures on growing pig farms. Livestock Science 151, 35-45.

THIERMANN, A. B. & BABCOCK, S. 2005. Animal welfare and international trade. Revue Scientifique et Technique-OIE, 24, 747-55.

THOMAS-BACHLI, A. L., PEARL, D. L., FRIENDSHIP, R. M. & BERKE, O. 2014. Exploring relationships between whole carcass condemnation abattoir data, non-disease factors and disease outbreaks in swine herds in Ontario (2001–2007). BMC Research Notes, 7, 185.

THOMSEN, P. T., KLOTTRUP, A., STEINMETZ, H. & HERSKIN, M. S. 2016. Attitudes of Danish pig farmers towards requirements for hospital pens. Research in Veterinary Science, 106, 45-7

TILDESLEY, M. J. & KEELING, M. J. 2008. Modelling foot-and-mouth disease: A comparison between the UK and Denmark. Preventive Veterinary Medicine, 85, 107-124.

TOMA, B., DUFOUR, B., BÉNET, J.J., SANAA, M., SHAW, A. & MOUTOU, F. 2010. Épidémiologie appliquée à la lutte collective contre les maladies animales transmissibles majeures. Les biais. Maisons-Alfort: AEEMA. p. 239-241.

TREMETSBERGER, L., LEEB, C. & WINCKLER, C. 2015. Animal health and welfare planning improves udder health and cleanliness but not leg health in Austrian dairy herds. Journal of Dairy Science, 98, 6801-11.

TRIENEKENS, J., PETERSEN, B., WOGNUM, N. & BRINKMANN, D. 2009. European pork chains, diversity and quality challenges in consumer oriented production and distribution, Wageningen Academic Publishers, Wageningen, Netherlands. 1-69.

TRIPATHY, J. P. 2013. Secondary Data Analysis: Ethical Issues and Challenges. Iranian Journal of Public Health, 42, 1478-9.

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. Journal of Animal Science 56, 499-508.

TU, Y. K. & GILTHORPE, M.S. 2012. Statistical thinking in Epidemiology. Taylor and Francis Group LLC, Boca Raton, USA. 73-74.

TUCKER, A. W., MCKINLEY, T. J. & JAEGER, H. J. 2009. Pleurisy in Pigs: Associated risk factors and impact on health, welfare and performance. AHDB, 1-73

TURNER, A. G., 2003. Sampling strategies. United Nations Secreteriat. Statistics Division ESA/STAT/AC.93/2 Handbook on designing of Household Sample Surveys.

TUYTTENS, F. A. M., VANHONACKER, F., VAN POUCKE, E. & VERBEKE, W. 2010. Quantitative verification of the correspondence between the Welfare Quality (R) operational definition of farm animal welfare and the opinion of Flemish farmers, citizens and vegetarians. Livestock Science, 131, 108-114.

ULLREY, D.E., SPRAGUE, J.L., BECKER, D.E. & MILLER, E.R. 1965. Growth of the swine fetus. Journal of Animal Science 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. Preventive Veterinary Medicine 10, 119-130.

VAN DE WEERD, H.A., DOCKING, C.M., DAY, J.E.L., BREUER, K. & EDWARDS, S.A. 2006. Effects of species-relevant environmental enrichment on the behaviour and productivity of finishing pigs. Applied Animal Behaviour Science 99, 230-247.

VAN DE WEERD, H.A. & DAY, J.E.L. 2009. A review of environmental enrichment for pigs housed in intensive housing systems. Appl Anim Behav Sci 116, 1-20.

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. Livestock Production Science, 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. Animal Reproduction Science 75, 141-150.

VAN GREVENHOF, E. M., OTT, S., HAZELEGER, W., VAN WEEREN, P. R., BIJMA, P. & KEMP, B. 2011. The effects of housing system and feeding level on the joint-specific prevalence of osteochondrosis in fattening pigs. Livestock Science, 135, 53-61.

VAN STAAVEREN, N., VALE, A. P., MANZANILLA, E. G., TEIXEIRA, D. L., LEONARD, F. C., HANLON, A. & BOYLE, L. A. 2016. Relationship between tail lesions and lung health in slaughter pigs. Preventive Veterinary Medicine, 127, 21-26.

VANDERHAEGHE, C., DEWULF, J., DE VLIEGHER, S., PAPADOPOULOS, G. A., DE KRUIF, A. & MAES, D. 2010. Longitudinal field study to assess sow level risk factors associated with stillborn piglets. Animal Reproduction Science, 120, 78-83.

VANDERWAAL, K., MORRISON, R. B., NEUHAUSER, C., VILALTA, C. & PEREZ, A. M. 2017. Translating big data into smart data for veterinary epidemiology. Frontiers in Veterinary Science, 4**,** 110.

VANHONACKER, F., VERBEKE, W., VAN POUCKE, E. & TUYTTENS, F. A. M. 2008. Do citizens and farmers interpret the concept of farm animal welfare differently? Livestock Science, 116, 126-136.

VASDAL, G., GLÆRUM, M., MELIŠOVÁ, M., BØE, K., BROOM, D.M. & ANDERSEN, I. L. 2010. Increasing the piglets' use of the creep area –A battle against biology? Applied Animal Behaviour Science, 125, 96-102.

VASDAL, G., OSTENSEN, I., MELISOVA, M., BOZDECHOVA, B., ILLMANN, G., ANDERSEN, I.L. 2011. Management routines at the time of farrowing-effects on teat success and postnatal piglet mortality from loose housed sows. Livestock Science, 136, 225-231.

VATCHEVA, K.P.,LEE, M., MCCORMICK, J.B. & RAHBAR, M.H. 2016. Multicollinearity in Regression Analyses Conducted in Epidemiologic Studies. Epidemiology (Sunnyvale), 6, 1-20.

VEISSIER, I., BUTTERWORTH, A., BOCK, B. & ROE, E. 2008. European approaches to ensure good animal welfare. Applied Animal Behaviour Science 113, 279–297.

VERMEER, H. M., DE GREEF, K. H. & HOUWERS, H. W. J. 2014. Space allowance and pen size affect welfare indicators and performance of growing pigs under Comfort Class conditions. Livestock Science, 159, 79-86.

VON BORELL, E. & VAN DENWEGHE, S. 1998. Criteria for the assessment of pig housing. Pig News Infection, 19, 93N–6N.

WALKER, P.K. & BILKEI, G. 2006. Tail-biting in outdoor pig production. Veterinary Journal, 171, 367-369.

WANDA, S., SCHLEICHER, C., SCHERIAU, S., KOEFER, J. 2013. Austrian model approach to assess quality of post-mortem feedback-information systems in pigs. Safepork 2013 Proceding, 207-210.

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? Animal Behaviour, 51, 619-624.

WEBER, R., KEIL, N.M., FEHR, M. & HORAT, R. 2009. Factors affectingpiglet mortality in loose farrowing systems on commercial farms. Livestock Science, 124, 216-222.

WEBER, N. R., PEDERSEN, K. S., HANSEN, C. F., DENWOOD, M., HJULSAGER, C. K. & NIELSEN, J. P. 2017. Batch medication of intestinal infections in nursery pigs A randomised clinical trial on the efficacy of treatment strategy, type of antibiotic and bacterial load on average daily weight gain. Preventive Veterinary Medicine, 137, 69-76.

WEBSTER, A. J. F., MAIN, D. C. J. & WHAY, H. R. 2004. Welfare assessment: indices from clinical observation. Animal Welfare, 13, S93-S98.

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. Preventive Veterinary Medicine, 119, 141-152.

WHAY, H. R., MAIN, D. C. J., GREEN, L. E. & WEBSTER, A. J. F. 2003. Animal-based measures for the assessment of welfare state of dairy cattle, pigs and laying hens: Consensus of expert opinion. Animal Welfare, 12, 205-217.

WHAY, H. R., LEEB, C., MAINT, D. C. J., GREEN, L. E. & WEBSTER, A. J. F. 2007. Preliminary assessment of finishing pig welfare using animal-based measurements. Animal Welfare, 16, 209-211.

WHITE, M. 2009. Hospital pens and management of the compromised pig. Livestock, 14, 55-58.

WHITTEMORE, C.T. 1995. Response to the environmental and welfare imperatives by UK. Livestock Production Industries and Research Services. Journal of Agricultural and Environmental Ethics 8, 65-84

WILLEBERG, P., GERBOLA, M.A., PETERSEN, B.K., ANDERSEN & J.B. 1984. The Danish pig health scheme: Nation-wide computer-based abattoir surveillance and follow-up at the herdlevel. Preventive Veterinary Medicine, 3, 79-91.

WILLEBERG, P., WEDAM, J.M., GARDNER, I.A., HOLMES, J.C., MOUSING, J., KYRVAL, J., ENESE, C., ANDERSEN, S., LEONTIDES, L. 1997. A comparative study of visual and traditional post-mortem inspection of slaughter pigs: estimation of sensitivity, specificity and differences in non-detection rates. Épidémiologie et Santé Animale, 31-32.

WILLIAMS, M., BAGWELL, J. & NAHM ZOZUS, M. 2017. Data management plans: the missing perspective. Journal of Biomedical Informatics, 71, 130-142.

WILSON, G. A. 2001. From productivism to post-productivism … and back again? Exploring the (un)changed natural and mental landscapes of European agriculture. Transactions of the Institute of British Geographers, 26, 77-102.

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. Applied Animal Behaviour Science, 119, 49-55.

WOOD, J. D., HOLDER, J. S. & MAIN, D. C. 1998. Quality Assurance schemes. Meat Science, 49S1, S191-203.