Universitat Autònoma de Barcelona

Evaluation of current feeding and management practices in Irish pig production and future strategies for improvement

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Evaluation of current feeding and management practices in Irish pig production and future strategies for improvement

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Que la memòria titulada: "Evaluation of current feeding and management practices in Irish pig production and future strategies for improvement", presentada por Maria Rodrigues da Costa am la finalitat d'optar al grau de Doctor de Veterinària, há realitzada sota la seva direcció i, considerant-la finalitzada, autoritzen la seva presentació per qui sigui jutjada per la comissió correspondent.

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“The good thing about knowledge is that nobody can take it away from you.”

B. B. King

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Summary

Pig production is a very competitive industry with constant improvements in production efficiency. The Interpig benchmarking reports show that Ireland has lower production efficiency than the main pig producing countries in the EU. Thus, the Irish pig industry urgently needs coordinated actions to remain competitive and ensure its sustainability in the long term.

This dissertation aims to characterize biosecurity practices, feeding practices and respiratory disease in the Irish pig sector and to quantify their impact on productive performance. This analysis ultimately seeks to identify and help prioritize the aspects that need to be improved as a strategy to increase production efficiency and sustainability. Additionally, the work developed during this PhD has pursued three distinct outputs: 1) to produce peer-reviewed publications and this thesis document as the main research outputs, 2) to provide Irish pig farmers with feedback that allows them to improve their production efficiency, and 3) to develop collaborations with other national and international institutions that allow Teagasc to import and disseminate the knowledge that is needed in the Irish pig industry.

Because this document deals with data of very different nature like feeding systems and respiratory pathology, the literature review covers briefly the different areas studied in the three scientific chapters and the basic concepts needed for the integration of all the data. The methods used in the three chapters are repeated, to some extent, and the cohort of farms studied is the same to allow the direct comparison of the different factors studied in each chapter.

Chapter 4 focuses on biosecurity practices using the Biocheck.UGent™ scoring system in the studied cohort of farms. This chapter aims to describe biosecurity status on Irish pig farms, to investigate which biosecurity aspects are more critical in Irish farms, and to study the impact of such aspects on farm performance. The results showed that the Irish biosecurity scores as per the Biocheck.UGent™ were similar to other countries. External biosecurity is in general slightly better in Ireland than in other EU countries due to the particularities of the Irish farms. Internal biosecurity poses as the biggest liability of the Irish pig industry. The results suggest that practices related to the environment and region, feed, water and equipment supply, and the management of

the different stages, need to be addressed in poorly performing farms to improve productive performance.

In Chapter 5, the objective is to describe the feeding strategies used in gilts, sows (gestating and lactating) and pigs from weaning to slaughter in Irish pig farms, and to study the effects of such feeding practices on productive performance and feed cost. As expected, feeding practices differ greatly among Irish pig farms. Within the cohort of Irish farrow-to-finish farms studied, 42.9% are home-milling, 51.8% feed liquid diets to slaughter pigs and only 21.4% use phase-feeding for finishers. The studied feeding practices for sows and gilts explain 19% and 22% of sow culling and mortality, respectively. The feeding practices from weaning to slaughter explain 29 and 27% of the variability in ADG (g/day) and finisher mortality (%), and 39% of feed cost variability. Contrary to what the author expected, FCR is not greatly affected by the very different practices in each farm.

Finally, in Chapter 6, the objective is to describe the impact of respiratory disease in Irish pig production by 1) describing seroprevalence of the four main pathogens related to respiratory disease: Swine Influenza Virus (SIV), Porcine Reproductive and Respiratory Syndrome virus (PRRSv), *Mycoplasma hyopneumoniae* (MHyo) and *Actinobacillus pleuropneumoniae* (APP), 2) describing the prevalence of pleurisy, pneumonia, pericarditis and milk spots, and 3) estimating the impact of vaccination, serology and slaughterhouse checks on productive performance. The prevalence of SIV, PRRSv, MHyo and APP is similar and, in some cases, lower than that reported by other European countries. The prevalence of lung lesions at slaughter is variable and the national average prevalence for pleurisy and pneumonia figure is one of the lowest compared to those reported in peer-reviewed publications. At the same time, the prevalence of milk spots in the liver is unexpectedly high. The models to estimate productive performance from vaccination, serology and slaughter checks were able to explain the variability of weaner and finisher mortality by 26 and 20%, respectively, and ADFI, ADG and age at slaughter by 47, 40 and 41%, respectively.

The results showed that productive performance was more affected by respiratory disease compared to the impacts of biosecurity and feeding practices. To this result contribute many factors. Biosecurity and feeding strategies are directly manageable by farmers, while respiratory disease is not.

The priority aspects to improve in the Irish pig industry include internal biosecurity and management protocols, keeping accurate records to monitor on-farm health, welfare and productive performance and a closer collaboration between the team (farmer, veterinarian, nutritionist, advisor, etc) responsible for the management of each farm. Further studies are needed to identify other factors affecting feed cost and FCR.

Resum

La producció porcina moderna és cada vegada més competitiva i requereix una millora constant de la eficiència de producció. Segons els indicadors de Interpig, la industria porcina irlandesa presenta una eficiència de producció inferior als principals països productors europeus i necessita treballar de manera coordinada per millorar la seva eficiència i sostenibilitat en els propers anys.

Aquesta tesi te com a objectiu caracteritzar les pràctiques de bioseguretat, d'alimentació i de maneig de les malalties respiratòries en el sector porcí irlandès i quantificar el seu impacte sobre la productivitat de les granges. Així, aquest anàlisi identifica i prioritza els aspectes que han de ser adreçats com a estratègia per millorar la eficiència i la sostenibilitat del sector a Irlanda. A més, tota la feina desenvolupada en aquesta tesi persegueix 3 resultats concrets: 1) produir aquesta tesi i les publicacions indexades derivades com a principal resultat científic, 2) proporcionar al ramaders porcins irlandesos dades que els permetin millorar la seva productivitat de manera eficient, i 3) desenvolupar col·laboracions amb altres institucions nacionals i internacionals que permetin al Teagasc importar i disseminar el coneixement que la industria porcina irlandesa necessita.

Aquest document presenta dades de variables molt diferents, des de pràctiques d'alimentació fins a diagnòstic de malalties respiratòries. És per això que la revisió bibliogràfica inclou aspectes generals de les diferents àrees estudiades en els 3 capítols científics successius i els conceptes basics per a la integració de totes les dades. La metodologia utilitzada en els 3 capítols és similar i la cohort de granges utilitzada es la mateixa per facilitar la comparació directe dels diferents factors estudiats en cada capítol.

El capítol 4 està centrat en l'estudi de la bioseguretat en una cohort de granges de cicle tancat mitjançant la utilització del sistema de avaluació de risc Biocheck.UGent™. Aquest capítol descriu el nivell de bioseguretat a les granges porcines irlandeses per determinar quins aspectes són més importants en el cas irlandès i quins afecten més la productivitat de les granges. Els resultats mostren els nivells de bioseguretat a les granges irlandeses mesurats amb el sistema Biocheck.UGent™ són similars als de altres països. La bioseguretat externa és en general una mica millor que en altres països degut a determinades característiques de les granges irlandeses. La bioseguretat interna en canvi és un dels punts dèbils de les granges irlandeses.

L'entorn i la regió on estan situades les granges, el maneig de pinso, aigua i equipament, i el maneig dels animals a les diferent fases són punts que han de millorar-se a les granges amb baix rendiment.

El capítol 5 descriu les estratègies d'alimentació utilitzades per les llavores, les truges (gestants i lactants) i pels porcs en creixement/engreix a les granges irlandeses i els seus efectes a la productivitat i els costs d'alimentació. Com s'esperava, les pràctiques d'alimentació a les granges irlandeses son molt variables. Dintre de la cohort de granges estudiades un 42.9% de les granges fabriquen el seu propi pinso, un 51.8% utilitzen alimentació liquida a l'engreix i només un 21.4% utilitzen alimentació en fases a l'engreix. Les pràctiques d'alimentació de les truges i llavores expliquen el 19% i el 22% del sacrifici i de la mortalitat de les truges, respectivament. Les pràctiques d'alimentació al creixement i engreix expliquen un 29 i un 27% de la variabilitat del guany mig diari (g/dia) i de la mortalitat (%) al engreix, i un 39% dels cost d'alimentació. Al contrari del que s'esperava cap d les pràctiques d'alimentació estudiades va tenir cap efecte important a l'índex de conversió.

Finalment, el capítol 6 descriu l'impacte de les malalties respiratòries a les granges porcines irlandeses mitjançant 1) la seroprevalença dels quatre principals patògens involucrats: el virus de la grip porcina (SIV), el virus de la síndrome reproductiva i respiratòria porcina (PRRSv), Mycoplasma hyopneumoniae (MHyo) i Actinobacillus pleuropneumoniae (APP), 2) la prevalença de pleuritis, pneumònia, pericarditis i taques de llet, i 3) l'impacte de la vacunació, serologia i lesions a escorxador a la productivitat de granges porcines. La prevalença de SIV, PRRSv, MHyo i APP es similar, i en alguns casos menor, que la descrita en altres països europeus. La prevalença de lesions a escorxador és molt variable entre explotacions i la mitjana nacional de pleuritis i pneumònia és una de les més baixes descrites a les publicacions indexades. D'altra banda, la prevalença de taques de llet és molt més alta del que s'esperava. Els models per explicar l'efecte de la vacunació, la serologia i les lesions a escorxador sobre la productivitat expliquen el 26 i el 20% de la mortalitat al deslletament i al engreix, respectivament, i un 47, un 40 i un 41% de la ingesta diària, del guany mig diari i de l'edat al sacrifici, respectivament.

Els resultats mostren que la productivitat de les granges porcines irlandeses esta més afectada per les malalties respiratòries que per les pràctiques de bioseguretat o d'alimentació estudiades. Molts factors poden contribuir en aquest resultat, tanmateix, es possible que el ramader tingui més capacitat de canviar les pràctiques de bioseguretat i d’alimentació que el seu estat sanitari.

La industria porcina irlandesa ha de treballar determinats aspectes de la bioseguretat interna i els protocols de maneig a la vegada que necessita millorar els sistemes de recollida de dades relacionades amb la salut i benestar a la granja i la productivitat. A més es necessita una major col·laboració del equip a càrrec de la granja (ramader, veterinari, nutròleg, etc). Finalment, són necessaris més estudis per identificar els principals factors de l’alimentació que afecten la eficiència de conversió i els costs.

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Abbreviations

ADFI - Average daily feed intake.

ADG - Average daily gain.

AHDB - Agriculture and horticulture development board.

ANOVA - Analysis of variance.

APP - *Actinobacillus pleuropneumoniae.*

BPEX - British pig executive.

COMBAT - Comprehensive online management biosecurity assessment.

DAFM - Department of Agriculture, Food and the Marine.

ELISA - Enzyme-linked immunosorbent assay.

ePM - e-ProfitMonitor.

ESF - Electronic Sow Feeding.

EU - European Union.

FCR - Feed conversion ratio.

g – Grams.

kg – Kilograms.

Mhyo - *Mycoplasma hyopneumoniae*.

NAHMS - National Animal Health Monitoring Studies.

No. – Number.

OIE - Oficce International des Epizooties / World Organization for Animal Health.

PADRAP - Production animal disease risk assessment programme.

PCA - Principal components analysis.

PCV2 - Porcine circovirus type 2.

PEDv - Porcine epidemic diarrhoea virus.

PLF - Precision livestock farming.

PRDC - Porcine respiratory disease complex.

PRRSv - Porcine reproductive and respiratory syndrome virus.

RCT - Randomized control trials.

r_s - Spearman rank coefficient of correlation.

SIV - Swine Influenza virus.

UK - United Kingdom.

USA - United States of America.

VIF - Variance inflation criterion.

Chapter 1. General introduction

Pig production has been facing difficult times with high production costs threatening its sustainability. The intensification of production has been translated into bigger farms with higher health status and with standardized management protocols, ensuring farm efficiency and food safety and security (Whittemore and Kyriazakis, 2008). Nutrition is repeatedly pointed as the main driver for high production costs, accounting for up to 70% of them (Patience *et al.*, 2015). A good network of diagnostic resources and veterinary expertise are essential to keep animal health, diagnose and control disease outbreaks. At the same time, larger herds and higher health status make use of biosecurity measures and standardized management protocols to prevent the introduction and circulation of diseases, ensure welfare requirements, and increase growth and performance.

In Ireland, pig production is the third biggest agricultural activity in economic output (Department of Agriculture, Food and the Marine [DAFM], 2016), and there are approximately 149,900 breeding sows producing an estimate of 4,000,000 pigs per year (Central Statistics Office, 2017a). While these figures are small compared to other countries, the average herd size (average number of sows) is one of the largest in the European Union (EU; Eurostat, 2014) and the Irish pig industry is self-sufficient by 219% (Central Statistics Office, 2017a).

However, high production costs and a low level of technical development dictate the need to improve efficiency. The Irish industry identified nutrition, animal health and management as key inputs for productivity (DAFM, 2016). The feed cost in Ireland is one of the highest among the twenty countries belonging to the InterPIG network (Agriculture and Horticulture Development Board [AHDB], 2017) and the current price fluctuations mean that farmers must reduce their production costs to remain in the market. In parallel, the industry brought attention to the biggest challenges in the Irish setting, stating that addressing these issues would potentially "improve overall productivity whilst delivering a more consistent and improved product". The control of endemic diseases (i.e. Porcine Reproductive and Respiratory Syndrome virus - PRRSv), the prevention of introduction of exotic diseases, such as Porcine Epidemic Diarrhoea virus (PEDv), and the reduction of the use of antimicrobials figured as the main challenges (DAFM, 2016).

Nowadays, the gathering and use of information is the key for the fast progress of any industry. Teagasc, the Agricultural and Food Development Authority, is an Irish institute which aims to provide integrated research, advisory and training services (knowledge transfer) to the agriculture and food industry. The Pig Development Department holds a national database (Teagasc e-ProfitMonitor [ePM]) for production performance, comprehending data from more than one third of the Irish pig farms. However, no other farm information (i.e. feeding system, age of the facilities, herd health status and pig health protocols) is recorded in the system.

This dissertation aims to characterize the main factors affecting pig production in Ireland and to study their impact on productive performance. This analysis seeks to identify the aspects that need to be improved and future strategies to increase efficiency. Finally, all the work developed during this PhD thesis has pursued three distinct outputs: 1) to produce peer-reviewed publications as the main research output, 2) to provide Irish pig farmers with feedback that allows them to improve their efficiency, and 3) to develop collaborations with other national and international institutions that allow Teagasc to import and distribute the knowledge that is needed.

Chapter 2. Objectives

To assess the main factors affecting pig production in Ireland, three main areas were object of study: biosecurity, feeding practices and respiratory disease. These lack characterization on Irish pig farms, and that information is essential to address production challenges. In Chapter 3, the main aspects of these factors are reviewed.

To study the impact of these areas on farm productive performance, the following objectives were set:

1) Biosecurity practices
    a. To assess biosecurity practices in Irish pig farms, including internal and external biosecurity in Irish pig farms;
    b. To benchmark the biosecurity level on Irish pig farms against other EU countries;
    c. To estimate the effect of the different aspects of biosecurity on productive performance on Irish pig farms.
2) Feeding practices
    a. To assess the feeding practices of sows (gestating, lactating), gilts and pigs from weaning to slaughter in Irish pig farms;
    b. To estimate the effect of these feeding practices on productive performance and feed cost of Irish pig farms.
3) Respiratory diseases
    a. To assess the prevalence of four key respiratory pathogens (Swine Influenza Virus, Porcine Reproductive and Respiratory Syndrome, *Mycoplasma hyopneumoniae* and *Actinobacillus pleuropneumoniae*) in Irish pig farms;
    b. To assess the prevalence of pleurisy, pneumonia, pericarditis and milk spots on the liver in Irish finisher pigs at slaughter;
    c. To compare Irish pig respiratory health to that of other countries;
    d. To estimate the effect of respiratory disease on productive performance in Irish pig farms.

These objectives are addressed in Chapters 4, 5 and 6, respectively.

Finally, it matters to discuss the extent to which each area impacted on productive performance and draw conclusions on their relative importance. This discussion leads to the fulfilling of the last goal of this thesis, which was to suggest future strategies to improve pig production in Ireland, given the matters object of study. All of this is discussed in Chapter 7.

Chapter 3. Literature review

3.1. Biosecurity and management

In animal production, biosecurity is defined as the group of management and physical measures implemented to reduce the risk of introduction, establishment and spread of diseases to, from and within an animal population (Office International des Epizooties [OIE], 2017). This concept was developed in the context of intensive production and it pertains great relevance to preserve animal and human health. Likewise, biosecurity can be applied at a farm level, but also in regions, and countries. The wide nature of the concept gives room for different interpretations. Depner (2018) separates biosecurity in two main elements: the “hardware”, and the “software”. The hardware corresponds to the physical barriers and facilities aiming to reduce the risk of disease transmission. On the other hand, the software corresponds to the set of attitudes and behaviours to reduce that risk. Other authors subdivide biosecurity in two main components: external biosecurity and internal biosecurity (Dewulf and Van Immerseel, 2018). Traditionally, biosecurity is associated with the concept of external biosecurity, with it comprising the measures necessary to prevent the introduction of diseases into a herd. Recently, the measures to prevent diseases to spread once inside the herd were also considered, corresponding to internal biosecurity. These measures often overlap with management.

3.1.1. Why is biosecurity important?

Biosecurity is important due to its potential to control animal disease. Dewulf and Van Immerseel (2018) advocate that biosecurity is considered the foundation of all disease control programmes. In that light, the broad spectrum of management and physical measures required to apply a biosecurity plan dictate their priority before other preventive or curative measures. Its relation to improved production results and farm stability, and recently, the reduction of the use of antimicrobials underlines that importance (Laanen *et al.*, 2013; Postma *et al.*, 2016a; Postma *et al.*, 2016b). On the other hand, the overlapping concept of internal biosecurity with management also translates the relevance of biosecurity as the former is often stated as one of the most important factors in pig production (Ramirez and Karriker, 2012).

3.1.1.1. Prevention and biocontainment

The prevention of animal disease is the main pillar of biosecurity. Farm, national and international authorities implement biosecurity protocols on their premises or regions aiming to prevent the introduction of exotic or to control the spread of endemic diseases. The implementation of minimum biosecurity and management standards is nowadays required by many quality assurance schemes, as a measure to ensure food safety (Blaha, 2001). A few examples are the Irish Board Bia quality assurance scheme (https://www.bordbia.ie/) and the Red Tractor (https://assurance.redtractor.org.uk/) from the United Kingdom (UK). Both require minimum biosecurity practices (i.e. keeping log books for visitors, the disposition of footbaths before the entrance in the stables, wearing appropriate footwear and clothing, vermin and bird control measures and cleaning and disinfection). On the other hand, biocontainment is defined as the measures impeding diseases to spread to other farms from within a certain area or farm and it is usually associated with external biosecurity. The prevention and the biocontainment of animal diseases achieved by good biosecurity standards are essential tools for intensive livestock production, especially pigs and poultry.

3.1.1.2. Connection to health and the use of antimicrobials

Several studies have related the benefits of good biosecurity to pig health and to the reduction of use of antimicrobials (Laanen *et al.*, 2013; Postma *et al.*, 2016a; Postma *et al.*, 2016b). Establishing a good biosecurity protocol is an essential starting point to the maintenance of the farms' health status. This protocol should be designed conveying the main disease threats in the concerned area. Then, it is possible to apply other preventive plans and to address the health challenges endemic to the farm. Conversely, implementing curative measures without certifying the animals will be able to keep their new health status does not prevent new outbreaks. In other words, although the provision of antimicrobials as a curative plan is often necessary, it does not explain the incidence of disease. Thus, biosecurity and overlapping management routines should require attention every time there is a disease outbreak.

3.1.1.3. Connection to productive performance and farm stability

Better biosecurity is associated with better productive performance in consequence of a higher health status, or of a stabilized farm (Collineau *et al.*, 2017a; Dewulf and Van Immerseel, 2018; Postma *et al.*, 2016a). Yet, achieving better production results through single changes in biosecurity and management practices is difficult. In fact, a synergic effect of the combined application of these practices on production performance is likely. Moreover, there is a plenitude of other factors that may act as confounders when measuring the effect of biosecurity practices on performance. For instance, farms with similar biosecurity practices can have different health status, vaccination protocols and management routines, leading to disparate performance figures. Dionissopoulos *et al.* (2001) studied the effect of pig origin and health status on the performance on grower-finisher pigs. The authors concluded that, despite being reared under similar conditions and having similar genetic background, pigs originated from a minimal disease farm had considerably increased growth than pigs from a farm with known respiratory problems or pigs weaned early and sourced from multiple sow herds. On the other hand, farms with high health status and good production performance presumably have higher biosecurity standards, as supported by a study carried out in Belgium, France, Germany and Sweden (Collineau *et al.*, 2017a).

3.1.2. Biosecurity assessment and implementation plans

Over the years, many protocols have been developed to assess biosecurity on pig farms. These protocols intend to identify weaknesses related to external and internal biosecurity and they can be designed to investigate the risk of introduction or spread of pathogens in general or specific pathogenic agents. Biosecurity implementation plans should be developed from the results of biosecurity assessments, reinforcing measures identified as weaknesses.

Some biosecurity assessment protocols include the Production Animal Disease Risk Assessment Program (PADRAP), the Comprehensive Online Management Biosecurity Assessment Tool (COMBAT), the Biocheck.UGent™, and a recently developed risk scoring tool for Porcine Reproductive and Respiratory Syndrome virus (PRRSv) introduction developed in Spain. The PADRAP was developed by the American Association of Swine Veterinarians (AASV) and the College of Veterinary Medicine of Iowa State University (AASV, 2006). This tool has been available since 2006 and it was recently discontinued (July 2018). It aimed to measure and benchmark disease risks faced by the North American swine industry, focusing on PRRSv, although Bottoms *et al.* (2013) stresses that many of the practices addressed by this questionnaire “are relevant for assessing the likelihood of introduction of other contagious pathogens”. In 2017, with a similar approach to the PADRAP, Boehringer Ingelheim launched the COMBAT system for the identification and mitigation of risks associated with PRRSv introduction. This system is based on a five-step process to assess the main issues, analyse, visualize and benchmark the data and guide farmers to improve biosecurity and management practices. In Spain, a new risk assessment tool for improving biosecurity was recently developed by Allepuz *et al.* (2018). This tool estimates the risk of PRRSv introduction between different routes and it was designed using data from pig farms that were part of a voluntary program for PRRSv control in Northeast Spain.

3.1.2.1. Biocheck.UGent™

The Biocheck.UGent™ scoring system was developed in Gent University, Belgium (http://www.biocheck.ugent.be/). It is a scoring tool based on expert's opinions to quantify the risk of introduction and spread of diseases on pig farms. To the contrary of the other tools described, this scoring system does not focus on the risk introduction of a particular disease. Instead it assesses the (biosecurity and management) practices applied on farm and scores them according to their perceived risk/benefit as agreed by the experts. The tool subdivides biosecurity into external and internal biosecurity. Both subdivisions are subset in 12 categories covering several practices, as illustrated in Table 3.1. Each category score is given in a rank from 0 (worst scenario) to 100 (best scenario), according to the practices assessed. External and internal biosecurity scores were computed as an average of the scores achieved in the corresponding categories. The scoring tool also figures an overall biosecurity score which is the average of the external and internal biosecurity scores.

The tool has been implemented in several European countries: Belgium, France, Germany, Sweden, Denmark and The Netherlands (Filippitzi *et al.*, 2017; Kruse *et al.*, 2018; Laanen *et al.*, 2013; Postma *et al.*, 2016b), serving as a benchmarking reference. Some studies used this tool and the practices assessed in it to discuss alternative strategies for the use of antimicrobials (Collineau *et al.*, 2017b; Kruse *et al.*, 2018).

3.1.2.2. Benchmarking and on-farm application

The biosecurity assessments can serve several purposes like meeting requirements for quality assurance schemes, audit current practices on farm, and benchmark practices with other farmers, regions or countries. The regular application of such protocols allows the monitorization of changes in the biosecurity and management practices over time and helps to identify what activities should be recorded in log books (Amass and Clark, 1999). These also confer method and reproducibility to the regular checks that farmers, advisors and veterinarians must endure. Benchmarking biosecurity practices is useful to help farmers understand where they are positioned in comparison to their peers. At country level, the work by Bottoms *et al.* (2013) exemplify the usefulness of such assessments. The authors reported the assessment of biosecurity in several sow farms in the southern region of Ontario, Canada, and stated that the information gathered allowed "the implementation of biosecurity protocols in North American swine herds in general".

However, the difficulty in applying new practices lies in ensuring compliance with them. Dewulf and Van Immerseel (2018) discuss the need to carefully explain the benefits of each measure and the setbacks farmers face by perpetuating certain habits. Follow-up of these farms is very important to motivate farmers and to identify the goals achieved. Postma *et al.* (2017) studied the impact of management and biosecurity changes in the reduction of the use of antimicrobials in 61 Flemish farms and concluded that an important success factor was the use of a three-step approach: "check" - herd evaluation, "improve" - implementation of changes, and "reduce" - reduction of antimicrobials' usage.

3.1.2.3. Inter-country comparisons

When attempting international comparisons, the context of the pig industry and the legal rules applicable in each country must be recognized. For instance, Postma *et al.* (2016b) explained certain differences in biosecurity practices among four European countries based on country-specific legal rules. In a study relating the biosecurity practices in Denmark with productivity, antimicrobial use and vaccination, Kruse *et al.* (2018) expressed the need to interpret biosecurity and management results in the light of the correspondent national and regional contexts. Therefore, although the use of common assessment methods is the only way of ensuring valid comparisons, the results obtained should always be interpreted considering the farms' own national or regional context.

3.1.3. Validation of measures and its relative importance

Although literature asserts the connection of biosecurity to performance and to the reduction of the risk of introduction of disease, the validation of these benefits through research is difficult. In a review summarising the published literature on biosecurity, Amass and Clark (1999) state that few practices were effectively validated and calls for further investigation on the overall benefits of each measure on farm. Recently, Filippitzi *et al.* (2017) compared the implementation of biosecurity practices aimed to prevent disease introduction and spread in pig herds from six European countries and reviewed the transmission routes of 24 infectious pathogens as described in peer-reviewed literature. As a result, this publication compiles useful and up-to-date information to discriminate the relative importance of biosecurity measures according to the diseases of concern. Another approach is to study the impact that a set of measures had on a farm production performance or herd health and their financial return. A rare example of such a study is the work by Rojo-Gimeno *et al.* (2016), where the authors analysed the financial return obtained by farmers involved in a study to reduce antimicrobial usage through the improvement of management strategies, as advised by Postma *et al.* (2017).

Table 3.1. Description of the main practices covered by the Biocheck.UGent^{TM} scoring tool, developed by Gent University.

Biosecurity subdivision and category	**Description of main practices assessed**
External biosecurity	Measures to prevent the introduction of disease on to the farm.
Purchase of animals and semen	Purchase of gilts and piglets, quarantine procedures, semen purchase.
Transport of animals, removal of manure and dead animals	Cleaning, disinfection and emptiness of lorries, loading procedures, procedures for the removal of dead animals and manure.
Feed, water and equipment supply	Feed and water quality monitoring, feed supply, silos' cleaning, hygiene measures for material supply.
Personnel and visitors	Hygiene locks, hygiene requirements before entering the stables, check-in records, etc.
Vermin and bird control	Plagues control programs, free roaming of pets, placement of grids before air intakes.
Environment and region	Location of the farm and local pig density, distance to other pig farms and public roads.
Internal Biosecurity	Measures to prevent the spread of disease inside the farm.
Disease management	Vaccination and strategic treatments, regular assessment of disease status, regular veterinarian visits, handling of diseased animals.
Farrowing and suckling period	Cross-fostering practices and litter processing.
Nursery unit	All-in-all-out practices, mixing of weaners, pig densities, physical separation from sow unit, hygiene measures applied before entering this unit.
Fattening unit	All-in-all-out practices, mixing of pigs, pig densities.
Measures between compartments and the use of equipment	Change of clothes, hands' washing, disinfection baths, protocols for use and cleaning of equipment and its allocation to different stages.
Cleaning and disinfection	Protocols for cleaning, disinfection, rinsing and drying of the different stages, time empty between batches, cleaning and disinfection of corridors after moving pigs, presence and maintenance of footbaths.

3.2. Feeding practices

3.2.1. Importance of feed in pig production

Feed is one of the most important factors in pig production and it accounts for 60 to 70% of production costs (Patience *et al.*, 2015). As such, research has produced abundant literature on diverse feeding practices to increase feed efficiency and to minimize feed cost. However, these are not always synonyms. For example, increasing the energy concentration in-feed leads to higher feed efficiency, but it could also increase feed cost per pig (Patience *et al.*, 2015). While feed efficiency and feed cost are the main drivers for change, nowadays feed and its characteristics are also related to gut health and many authors discuss the potential role they could play in the reduction of antimicrobials' use in pig production. Environmental concerns may also condition feeding practices, especially concerning nitrogen and phosphorus excretion, and manure production.

3.2.2. Nutrition and animal feeding

An important distinction must be made between nutrition and animal feeding. The first refers to the feed composition, meaning the nutritional requirements, including energy, protein and mineral requirements of animals. The second encompasses the physical presentation of the feed, which will condition intake, digestibility and absorption. Feed can have great nutritional values, corresponding to the requirements of a pig, with a certain age and physiological state, but its physical properties may prevent the animal to take full advantage of those values.

3.2.3. Main feeding practices

The literature describes several feeding practices to increase feed efficiency and/or decrease feed cost. Diet quality and formulation, feed additives and supplementation, particle size, pelleting and feeder design are some of the many factors commonly associated with feed efficiency. Thus, the concept of feeding practices is very broad. As explained above, it matters to break down this in two categories: feeding practices related to nutrition, and feeding practices related to animal feeding. In this thesis, the effect of the most common feeding practices related to animal feeding are reviewed.

3.2.3.1. Feed origin

Producing pig feed on farm (home-milling) is generally considered cheaper than purchasing it, however this may not always be the case. With high feed cost, milling on farm can provide additional control over feed cost, especially if the farm produces some of the ingredients. Farmers may have direct access to ingredients avoiding transport costs and formulating diets in accordance to feedstuff prices and its availability. It may be also more flexible to use alternative ingredients. However, it can also have clear disadvantages. Diet formulation can be constrained by the technical capacity of the mill. The inclusion of ingredients in small proportions, vitamins or minerals may be prevented by the production scale and the mixing equipment. It is typical for home millers to have amino acids included in their premixes. Also, the addition of in-feed antibiotics to home-milled feed demands licensing by the competent authorities, in addition to the veterinary prescription. This feed is often offered to pigs as meal or mash, as opposed to pellets which require further processing. This saves the cost of pelleting but may also have consequences in feed efficiency. Phase-feeding may also be complicated by the manufacturing of the feed and its storage, conferring less flexibility in choosing diets when compared to purchasing feed. Conversely, buying feed offers the possibility to choose among a wide range of marketed complete feeds. Feed is more carefully formulated by nutritionists and ingredient quality is routinely controlled. It is also possible to achieve smaller particle sizes and pelleting is frequently an option, both contributing to increase feed digestibility and consequently, feed efficiency. However, feed cost are considerably higher, lowering the margin over feed. Despite its big impact on feed quality and costs, this aspect (feed origin) has been rarely researched and there is no scientific literature in this area.

3.2.3.2. Feed delivery

Feed can be delivered to pigs wet or dry. Before proceeding to major comparisons, a note should be made on the use of the term “liquid” or “wet” feeding. Wet feeding is a broader term, comprehending all types of feed delivery in which pigs are fed wet feed. This could correspond to liquid feeding, when diets are mixed and prepared before being sent to the feeders, or to other systems where diets are mixed in the feeders (like the Spotmix® system, from Schauer), or even to the case of pigs fed dry feed in wet/dry feeders. In this thesis, we refer to wet feeding. The comparisons on the effect of dry and wet feeding systems on the growth and efficiency of the pigs are many. It is accepted that feeding wet diets increase the average daily feed intake (ADFI, from 6 to 41%) and/or the average daily gain (ADG, from 5 up to 19%), although several studies report increases in feed conversion ratio (FCR, from 1 to 16%), when compared to pigs dry fed (British Pig Executive [BPEX], 2004; Gonyou and Lou, 2000; l'Anson *et al.*, 2012; Nyachoti *et al.*, 2004; Thaler and Nelssen, 1988). These differences are generally attributed to feed waste. Piglets and weaners may benefit the most from wet feed, especially because it is associated with increased intake and the consequential weight gain is beneficial to their performance in later stages (Chae, 2000; Kim *et al.*, 2001; Mahan *et al.*, 1998; Wolter and Ellis, 2001). Chae (2000) reviewed the impact of wet feeding on growth and carcass traits in pigs and concluded that bodyweight was more uniform in pigs wet fed than pigs fed dry feed. An advantage of feeding wet diets is the possibility of using by-products and fermentation (Missotten *et al.*, 2010). However, wet feed often requires more expertise, management and labour on feed preparation and delivery than dry feed. Concerns on the growth of moulds, spoilage or biofilms are also not negligible (DeRouchey and Richert, 2010). Other studies discuss the degradation of lysine and other aminoacids, especially in fermented wet feed as a reason for poorer efficiency in pigs fed these diets (Canibe *et al.*, 2007; Canibe and Jensen, 2012). Gastro-intestinal health and good gut microbiota are also associated with wet feed, as opposed to dry feed (BPEX, 2004). Wet feeding also substantially increases effluent production, deeming it not so advantageous in areas where manure is not profitable (BPEX, 2004; Russell *et al.*, 1996).

Discussions about the delivery methods often include feeder design. There is a wide variety of feeder designs available, for example wet/dry feeders (with drinkers incorporated), dry feeders and long troughs. All of these could be multi or single space and provide feed *ad libitum* (dry feed) or be connected to automated liquid feeding systems (electronic sensors or probe). Wet/dry feeders may be a confounder of the definition of wet and dry feeding systems stated before. This is so because dry feed, particularly dry meal can become wet-meal when fed in wet/dry feeders. In this case, pigs have access to drinkers in the feeder and mix freely the feed available with water from those drinkers. In fact, Gonyou and Lou (2000) suggested that wet/dry feeders may improve FCR when compared to single or multi-space feeders without drinkers, and this effect was seen by Agostini *et al.* (2014; 2015) when studying management factors affecting performance in Spanish farms. Conversely, Myers *et al.* (2013) studied the effects of diet form and feeder design in growth performance of finisher pigs and did not find any differences. In farms feeding wet diets, feeder design such as long troughs may present disadvantages when compared to probe feeding, where diets are prepared, mixed and fed more often and consequently providing fresher diets. Further on the effect of feeder design, Douglas *et al.* (2015) described the effect of feeder space in ADG, ADFI and FCR. These authors studied the management factors affecting grower and finisher performance in European systems using a meta-analysis. Another confounder is feed form. Pellets are often associated with dry feed. One more area to be looked at is feeding wet and dry intermittently until slaughter. Chae (2000) reported that pigs fed with wet diets in the grower stage and posteriorly fed with dry diets in the finisher stage had improved ADG and reduced FCR when compared to pigs fed dry diets from weaning to slaughter.

Although feed delivery is well researched in weaners and finishers, little is known on its effects in the other stages of pig production (i.e. sows) and or on the effect of alternating wet and dry diets until slaughter.

3.2.3.3. Feed form and particle size

In pig production, the most common feed forms are meal (or mash) and pellets. Most studies comparing meal and pellets agree that pellets lead to increased feed efficiency, which can range from 5 to 16%. This is supported by the studies of Ball *et al.* (2015); De Jong *et al.* (2015); Kjeldsen and Dahl (1999); I'Anson *et al.* (2012) and reviews on the matter (Flis *et al.*, 2014; Patience *et al.*, 2015; Saddoris-Clemons *et al.*, 2011). The authors agree that pelleting increases digestibility and the particle size is usually smaller than meal. Pellet quality (i.e. durability and homogeneity of feed ingredients) is of great relevance to achieve improved results (Myers *et al.*, 2013). In a study comparing meal against pelleted feed with equal diet formulation and particle size (660 µm) in finisher pigs, pellets increased ADG (6.25%) and decreased FCR (5.3%) in corn-soybean based diets. However, the same magnitude of that increase in ADG and the decrease in FCR was not observed in the second trial reported, where the diets were formulated using alternative ingredients (Potter *et al.*, 2009). The authors suggested that the quality of the pellets, which was affected by the diet formulation, could explain that inconsistency. Faucitano *et al.* (2006) studied the effect of feed form, meal frequency and pre-slaughter fasting and found that pigs fed pelleted diets had higher carcass yield (kill out percentage). Saddoris-Clemons *et al.* (2011) reviewed cost-effective feeding strategies pointing that the literature suggests pelleting increases feed efficiency due to better digestibility and reduced feed wastage. However, pelleting feed also has some disadvantages. Feeding pellets is recurrently stated as a risk factor for Salmonella infections in peer-reviewed publications from 1950 to 2005 (O'Connor *et al.*, 2008). Although the literature suggested such a connection, the authors advocate that most studies contained low to moderate evidences or that an insufficient number of animals was tested. Thus, the authors concluded that there should be a "low level of comfort" to claim that the association between pelleted feed and increased prevalence of Salmonella is "scientifically valid". More recently, Vukmirović *et al.* (2017) reviewed the importance of particle size and feed form in pig nutrition and explained that coarser (meal) feeds may have positive impacts on the prevalence of salmonella due to two mechanisms: 1) the decrease of pH in stomach and 2) a slower passage rate and a denser consistency of stomach content, creating a barrier for bacteria. Also, pelleting the feed might not be feasible when using alternative ingredients, according to Saddoris-Clemons *et al.* (2011). These authors state that the cost of pelleting the feed is usually overcome by the increased feed efficiency.

One of the biggest setbacks in the studies comparing meal to pellets is the confounding effect of particle size and pellet quality. Smaller particle size increases the digestibility of the feed by exposing a larger surface of feed to digestive enzymes (Vukmirović *et al.*, 2017). This increased digestibility is transported to pelleted feed once pelleting feed requires smaller particle sizes compared to meal or mash, which can have coarser particles. At the same time, the literature points that particle sizes smaller than 600 µm are linked to gastric ulceration (Saddoris-Clemons *et al.*, 2011). Thus, the connection between stomach ulceration and keratinization and smaller particle sizes is also found in pelleted feed. On the other hand, if pellet quality is good, it explains the increased efficiency between meal diets and pelleted diets; however, if it is poor, it may even decrease feed efficiency. This could be related to the fact that high quality pellets do not endure excessive breakage or generate fine particles and, thus, decrease feed wastage. Stark (1994) suggested that pellet quality is mainly affected by diet formula, particle size and conditioning. Similar to the suggestion of alternating wet and dry diets, De Jong *et al.* (2015) reported that rotating meal and pellet diets was beneficial on FCR and reduced the incidence of gastric ulcers.

3.2.3.4. Feeding frequency

In production systems where finisher pigs are slaughtered around 110-130kg, pigs are often fed *ad libitum*. The genetic evolution seen in pigs over the past 20 years explains that pigs grow leaner than before and justifies this approach. In dry feeding systems, feeders are adjusted to allow sensibly 20% of feed in the troughs, allowing pigs to eat *ad libitum*, without wasting feed. In wet feeding systems, a probe is often used feeding the pigs several times per day (up to 20 times). However, the feeding frequencies of sows (gestating and lactating) and gilts are often subject to debate. Gilts development demands dosing feed to achieve maturity and weight while avoiding fat deposition

(Stalder *et al.*, 2000). Gestating sows are often offered limited amounts of food to avoid over-feeding and increases in Body Condition Score (BSC) that would be detrimental to the gestation and farrowing (Solà-Oriol and Gasa, 2017). To meet that goal, farmers may choose to feed sows one or two times per day, or more often. This will also depend on the feeding system available. In the case of the Electronic Sow Feeders (ESF), sows are a fed specific amount per day, but they can manage their own intake each time they visit the feeder. The same is not possible for group-housed sows fed manually. Competition for feed dictates that dominant sows eat first and control feeding times of other sows. In lactating sows, feeding frequency could be a strategy and it is important to stimulate intake.

3.2.3.5. Feeding program at weaning

The provision of pre-starter, starter and link diets aim to progressively adapt the piglet and weaner pigs to plant-based diets. Creep diets are the first diets provided to piglets, introducing them to solid feed and facilitating the transition to weaner diets. These diets are usually very palatable and easy to digest. Fraser *et al.* (1994) and Okai *et al.* (1976) observed that feeding complex and enriched creep feeds stimulate pre-weaning intake and, although the intake is still very low, some studies have shown that this practice can increase weaning weight, reduce the weight loss associated with weaning, stimulate post-weaning feed intake, and post-weaning performance (Bruininx *et al.*, 2002; Sulabo *et al.*, 2010). Also, to prepare for the diet transition at weaning, creep can also stimulate the production of digestive enzymes which facilitate that process (de Passillé *et al.*, 1989; Johnson *et al.*, 2012). Kuller *et al.* (2007) noticed that pigs that ate creep feed before weaning had higher small intestinal net absorption capacity four days after weaning. Further, Fraser *et al.* (1994) noted that lighter pigs tended to use more creep feed, although creep intake varies greatly between litter mates and no strong relationship could be observed between intake and adaptation at weaning at four weeks. However, the same authors concluded that the advantage of providing creep feed was its tendency to increase weaning weight, which, according to Okai *et al.* (1976), is more important than weaning age in determining the pig's response to starter diets of different complexity post-weaning.

A possible confounder for the beneficial effects of creep feeding are cross-fostering practices. Huting *et al.* (2017) studied the consequences of cross-fostering and creep provision on performance to slaughter and noticed that homogenising litters by bodyweight was beneficial for piglets born lighter but prejudicial for piglets born heavy, with this disadvantage maintained up to slaughter.

As discussed in the feed delivery, feeding wet starters was reported to increase intake, which is manifestly beneficial for post-weaned pigs, but feed efficiency was lower, mainly due to feed wastage (Thaler and Nelssen, 1988). Several studies discuss the effects of starter feeding length on performance with disparate results. Mahan *et al.* (1998) reported that feeding starter for two weeks was better than feeding starter for one week, although Hogberg and Zimmerman (1978) found no effects on subsequent performance between pigs fed starter until 29 or 35 kg of body weight. Recently, Huting *et al.* (2018) noticed that different starter formulas (20% higher in essential amino acids or high energy ratio vs. standard formula) did not influence post-weaning performance, while Muns and Magowan (2018) suggested that starter diets improve gut structure after weaning. The authors studied the effect of creep feed intake and starter diet allowance on the piglet's gut morphology and growth performance after weaning and found that pigs fed higher amounts of starter (2 kg per pig per day against 6 kg per pig per day) had increased ADG and live weight from weaning to 16 weeks after weaning, and lower FCR in the first six weeks after weaning. This increased performance was related to higher villi height and crypt depth in the small intestine. Thus, starter diet formulation, feed form, feed allowance and length are factors affecting the impact of starter diets on productive performance.

3.2.3.6. Feeding program in finishers

Phase-feeding was developed to take advantage of the different rates in protein deposition that shift with age. Younger pigs require diets with higher levels of nutrients, especially regarding their protein requirements and are, therefore, costlier than the diets for older piglets (Saddoris-Clemons *et al.*, 2011). Using this principle, it is possible to formulate several diets to meet the requirements of different age groups, minimizing over- and underfeeding and consequently decreasing feed cost (Han *et al.*, 2000). However, Brossard *et al.* (2009) suggested that for diets formulated to supply 110% of lysine requirements, ADG, ADFI and FCR did not differ with an increased number of diets. Similarly, Menegat *et al.* (2017) trialled phase feeding strategies and lysine specifications in finisher diets and their effects on growth performance and concluded that "feeding lysine levels for maximum growth and efficiency in either a two or four phase feeding program results in the same growth performance and feed cost". Phase-feeding has potential to reduce nutrients excretion, such as nitrogen and phosphorus and this reduction should be the first step to reduce environmental impact of pig production (Han *et al.*, 2000).

Recently, the concept of precision feeding was defined as the approach to improve the utilization of nitrogen, phosphorus and other nutrients to reduce feed cost and nutrient excretion (Pomar *et al.*, 2009). In that context, Andretta *et al.* (2017) compared precision feeding by group and precision feeding by individual in the grower-finisher stage with conventional feeding, concluding that both systems were efficacious in reducing the environmental impact. These studies highlight the potential of precision livestock farming in pig production.

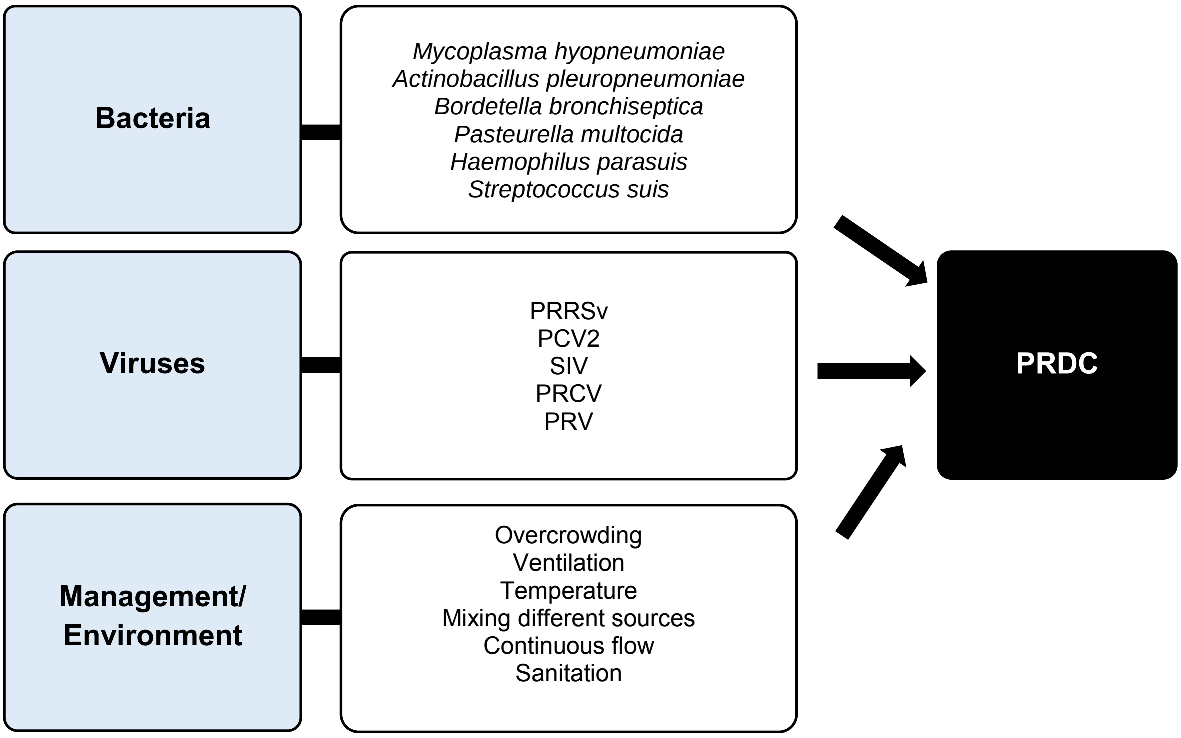
3.3. Respiratory diseases

3.3.1. Importance

Respiratory disease is one of the most important health issues in pig production (Brockmeier *et al.*, 2002). As an example of its relevance, in the United States of America (USA), the National Animal Health Monitoring System (NAHMS, 2015) reported that in 2012 that respiratory disease was the main death cause in nursery pigs (~50%) and in grower/finisher pigs (~70%). Although no studies of this kind were reported in Ireland, a 2014 farm survey pointed respiratory disease as the main reason for the use of antibiotics in pig farms (Pereira do Vale, unpublished data). The potential detrimental effect of respiratory disease has grown over the course of the last years with the intensification of production and keeping animals in indoors (VanAlstine, 2012). The combination of primary and opportunistic infectious agents, and other environmental risk factors characterizes the Porcine Respiratory Disease Complex (PRDC, Brockmeier *et al.*, 2002; Maes, 2010; Sibila *et al.*, 2009), Figure 3.1.

Environmental risk factors include dust, especially in farms with small particle (feed) size, higher ammonia levels, poor ventilation and high stocking densities. These can increase the pressure of infection and facilitate transmission. The primary infectious agents are those capable of overcoming the host defences, causing infections (Brockmeier *et al.*, 2002). Once these infections are established, opportunistic or secondary infectious agents complicate them, which is when most the economic losses happen (Maes, 2010; Thacker, 2001; VanAlstine, 2012). Among the primary agents, there are Porcine Reproductive and Respiratory Syndrome virus (PRRSv), Swine Influenza Virus (SIV), Porcine Circovirus type 2 (PCV2), *Mycoplasma hyopneumoniae* (MHyo), *Bordetella Bronchiseptica* and *Actinobacillus pleuropneumoniae* (APP). Some opportunistic agents are *Pasteurella Multocida*, *Haemophilus parasuis*, *Streptococcus suis*, and *Actinobacillus suis* (Choi *et al.*, 2003; Maes, 2010; Sibila *et al.*, 2009; Thacker, 2001). The relative importance of each of these pathogens in PRDC or, in other words, the aetiology of PRDC, varies between countries, regions, farms (production systems) and over time (Brockmeier *et al.*, 2002; Thacker and Minion, 2012).

Figure 3.1. Different factors playing a role in the development of Porcine Respiratory Disease Complex (PRDC, adapted from Brockmeier *et al.*, 2002).



Legend: PRRSv – Porcine Reproductive and Respiratory virus; Porcine Circovirus type 2; Swine Influenza virus; Porcine Respiratory Corona virus; Pseudorabies virus.

3.3.2. Main respiratory diseases impacting on pig production

The impact of each disease on pig health and on the overall farm performance is linked to its epidemiology, morbidity and mortality. Likewise, it is important to understand those under the light of the primary PRDC agents. Here we briefly review of the epidemiology, transmission routes, pathogenesis, clinical symptoms and lesions, diagnostics and prophylaxis of SIV, PRRSv, MHyo and APP infections. Although PCV2 is of great importance for the development of PRDC, the large majority of farms have vaccination programmes in place, controlling its effects. On the other hand, the prevalence and consequently the importance of atrophic rhinitis (corresponding to *Bordetella Bronchiseptica* and or *Pasteurella Multocida* infections) has decreased over the years. For instance, van Staaveren *et al.* (2018) described the prevalence of health and welfare lesions in 31 farrow-to-finish Irish farms, accounting for 12% of all the pigs in Ireland and did not find any pigs with evidence of twisted or shortened snouts, the most common sign of infection of Atrophic Rhinitis. Giving meaning to the PRDC, several interactions between primary agents have been reported throughout the years (Chae, 2016; Luehrs *et al.*, 2017; Opriessnig *et al.*, 2006; Pileri *et al.*, 2017; Pol *et al.*, 1997; Thacker, 2001; Thacker *et al.*, 1999; Thacker *et al.*, 2001; Thanawongnuwech *et al.*, 2000). The extent and circumstances of those interactions are, however, too broad to fit the purpose of this review.

3.3.2.1. Swine Influenza Virus (SIV)

The Swine Influeza Virus (SIV) is distributed world-wide and it has seasonality (winter), although it can be isolated from samples collected throughout the year (Choi *et al.*, 2003). It affects mostly newly weaned pigs and finishers. In 2009, a pandemic with H1N1 caused severe losses due to high morbidity and low mortality. The pigs play a major role in the reassortment and transmission of Influenza virus due to the possibility of co-infections by avian, swine and human influenza viruses (Brown, 2000).

Torremorell *et al.* (2012) described the complexity of SIV transmission due to its dependencies on pig flow, vaccination, animal movements and population dynamics. For instance, SIV virus is mostly transmitted through direct contact and aerosols, but indirect transmission may also be of relevance. SIV replication is mostly confined to the epithelial cells (cilia) of the upper and lower respiratory tract, damaging them and facilitating colonization by other pathogens (Brockmeier *et al.*, 2002), hence its importance in the scope of PRDC.

The clinical symptoms can appear suddenly, including cough, laboured breathing, fever, lethargy and anorexia, high morbidity (> 50%) and it disappears after approximately a week (5 to 7 days) with the improvement of the clinical signs (Brockmeier *et al.*, 2002; Reeth and Nauwynck, 2000; Van Reeth *et al.*, 2012). Lung lesions characteristic of this infection include purplish-red lesions and mottled areas in the cranioventral lobes of the lungs (Brockmeier *et al.*, 2002; Van Reeth *et al.*, 2012). Common findings at histological level are epithelial disruption and attenuation in the bronchioles and interstitial pneumonia, while mild to moderate peribronchiolar and perivascular lymphocytic infiltrations are also reported (Van Reeth *et al.*, 2012; Vincent *et al.*, 1997).

The diagnosis is done through anamnesis, clinical signs - although these two without the support of laboratorial diagnostics lead to a presumptive diagnosis -, and virus detection (PCR) or virus isolation, serology, and immunofluorescence of certain lung cuts (Torremorell *et al.*, 2012; Van Reeth *et al.*, 2012). The control of SIV lies mainly on vaccination protocols in sows, which lead to a passive immunity of piglets up to nursery age. The loss of passive immunity explains disease outbreaks in pigs from 12 to 24 weeks of age (Brockmeier *et al.*, 2002). Thus, vaccination of pigs in the nursery or in later stages depends on the impact SIV has on each farm, and this practice is not so common (Van Reeth *et al.*, 2012).

3.3.2.2. Porcine Reproductive and Respiratory Syndrome virus (PRRSv)

The Porcine Reproductive and Respiratory Syndrome virus (PRRSv) is a virus of the family *Arteriviridae* which has high genetic, antigenic and virulent variability among isolates (Brockmeier *et al.*, 2002). It was discovered in the 1980's in the USA and shortly after in Germany (Lunney *et al.*, 2010; Zimmerman *et al.*, 2012) and it has since become what some authors consider to be the most prevalent pig disease in the world (Lunney *et al.*, 2010), with huge economic impact (Nathues *et al.*, 2017; Neumann *et al.*, 2005). It is distributed world-wide with two main genotypes being recognized: the European (Type 1) and the North-American (Type 2) genotype (Mateu and Diaz, 2008). The North-American genotype has been suggested to cause more severe respiratory disease than the European genotype (Martínez-Lobo *et al.*, 2011).

The transmission of the virus is horizontal (i.e. nose-to-nose, semen or airborne) and vertical (intra-uterine infection; Cho and Dee, 2006; Kristensen *et al.*, 2004; Pileri and Mateu, 2016; Zimmerman *et al.*, 2012). The virus enters via oronasal in nursery and finisher pigs and replicates in the regional lymphoid organs (retropharyngeal and alveoli macrophages). Systemic dissemination and replication follows the local replication, causing interstitial pneumonia in the acute form or intense interstitial pneumonia and coupled with bacterial infections in the chronic form (Brockmeier *et al.*, 2002). According to Brockmeier *et al.* (2002) and Thacker (2001), PRRSv infection of the macrophages, especially those of the alveoli and intravascular structures, has a great impact on the respiratory immune system of the pig, underlining PRRSv role in PRDC.

The symptoms differ between herds and whether the infection is acute or chronic. In the acute infection there are mainly reproductive problems, with low fertility, abortion, embryonic mortality, dyspnoea and concomitant bacterial infections, mainly in the farrowing house and nursery (Zimmerman *et al.*, 2012). In chronic infections the nursery and finishing units are the most affected ones, with poor growth, concurrent bacterial infections and variable mortality (Brockmeier *et al.*, 2002). No macro or microscopic lesions of PRRSv are described. In general, interstitial pneumonia and enlarged lymph nodes may be observed while the most common finding at histological level is interstitial pneumonia (Zimmerman *et al.*, 2012).

The diagnosis is based on the clinical symptoms and in PRRSv circulation during the disease. Laboratorial diagnosis can be achieved by several means including virus isolation, PCR detection in affected tissues (i.e. lung and spleen) and serology (Zimmerman *et al.*, 2012). Good management practices such as all-in/all-out, partial or total depopulation of the affected stages and the adequate acclimation of gilts are among the main control measures recommended (Cho and Dee, 2006). The vaccination of sows and gilts with either modified live vaccines (most predominantly) or inactivated vaccines is also an option (Pileri and Mateu, 2016), to stabilize PRRSv circulation and infection on farm, while piglet's vaccination is not a common practice.

3.3.2.3. *Mycoplasma hyopneumoniae* (MHyo)

Mycoplasma hyopneumoniae (MHyo) infections are paramount for respiratory health due to their role in enzootic pneumonia and PRDC (Maes, 2010). According to Maes *et al.* (2008), MHyo infections are highly prevalent in almost all pig producing countries, causing significant economic losses due to increased medication use and poor pig performance (Thacker and Minion, 2012).

The transmission is mainly done by direct contact between pigs or by sharing the same air space (Maes, 2010). Air disseminations of up to 3 km have been reported (Goodwin, 1985). Transmission also depends on the virulence of the strain and on the immune-competency of naïve animals (Maes, 2010). The disease is often complicated with co-infections by other infectious agents (Brockmeier *et al.*, 2002; Thacker, 2001; Thacker and Minion, 2012). MHyo colonizes the nasal airways of the host and lymph nodes, then the trachea, bronchi and bronchioles at the epithelium surface (Brockmeier *et al.*, 2002). It causes the stasis of the cilia and its destruction, predisposing pigs to other infections (Maes, 2010). The development of the infection leads to bronchiole-interstitial pneumonia, and the concurrent bacterial infections explain catarrhal-purulent pneumonias, as associated with enzootic pneumonia (Brockmeier *et al.*, 2002).

The sub-acute and chronic pneumonia are characterized by chronic dry cough (non-productive), sneezes, ocular and nasal discharges, fever, dyspnoea, tachypnoea, low body condition score, delay in growth, ear cyanosis, high morbidity and low mortality (Brockmeier *et al.*, 2002). The lesions include consolidation of the apical lobes, cardiac and intermediate and the cranio-ventral portions of the diaphragmatic lobes (Brockmeier *et al.*, 2002; Garcia-Morante *et al.*, 2016; Maes *et al.*, 2017; Thacker and Minion, 2012). In the histopathology, there are accumulations of lymphocytes and neutrophils in the lumina, thickening of the septae, and peri-vascular and peri-bronchial lymphoid hyperplasia (Brockmeier *et al.*, 2002; Thacker and Minion, 2012).

The diagnosis is done based on the anamnesis, clinical signs, demonstration of lung compatible lesions and detection of MHyo in the lungs by PCR or seroconversion in the absence of vaccination (Pieters *et al.*, 2017). Microbiological isolation is very difficult and slow (Brockmeier *et al.*, 2002; Thacker and Minion, 2012). Once MHyo elimination is difficult to achieve and maintain, most efforts are put towards the control of the disease (Maes, 2010; Maes *et al.*, 2017). The control and prophylaxis measures include the minimization of the mixing of piglets, all-in/all-out management, ventilation and temperature control, air quality and low stress (Thacker and Minion, 2012). When other infections are present (PRDC), clinical symptoms may occur at later stages, from 14 to 20 weeks of age, as suggested by Dee (1996). In farms where the infection is endemic, vaccination protocols are recommended. Once the onset of outbreaks happen mostly in the post-weaning period, piglets at weaning are the main target for vaccination, especially in farrow-to-finish farms (Pieters and Sibila, 2017; Sibila *et al.*, 2004).

3.3.2.4. *Actinobacillus pleuropneumoniae* (APP)

Actinobacillus pleuropneumoniae (APP) is the etiologic agent commonly associated with pleuropneumonia in pigs. It is one of the most important bacterial pulmonary pathogen in pigs and it can be found worldwide (Gottschalk, 2012; Thacker, 2001). The serotypes involved in the outbreaks reported in different countries varies and so does their virulence (Brockmeier *et al.*, 2002). According to Gottschalk (2012) most herds are infected with one or more serotypes of APP, but often these strains are of low virulence. VanAlstine (2012), reviewing the literature, suggested that low virulence strains are widely distributed, resulting in high seroprevalence, but not necessarily causing symptoms. Virulent strains, on the contrary, cause comparatively lower seroprevalence, showing only in diseased pigs (Gottschalk, 2012).

The highest risk of transmission is the introduction of infected gilts to naïve herds. Aerosol transmission at short distances is also possible (Brockmeier *et al.*, 2002). The incubation period can be quite variable. APP colonizes cells of the respiratory tract where the organism adheres to the alveolar epithelium through fimbria, as described by Thacker (2001). After reaching the lower respiratory tract, APP adheres to pneumocytes that line the alveoli (Bossé *et al.*, 2002; Overbeke *et al.*, 2002).

The clinical presentation of the disease can take several forms. In the peracute form, pigs become suddenly very sick and death can prevail in as little as 3h (Gottschalk, 2012). In an acute form, clinical signs include fever, lethargy, dyspnoea, reddened skin cyanosis, and recumbency. In the chronic form, there is intermittent cough, slow growth, and exercise intolerance (Bossé *et al.*, 2002; Brockmeier *et al.*, 2002; Gottschalk, 2012). Gross lesions are mostly seen in the lungs and depend on the stage affected. They consist of firm fibrinohemorrhagic pleuropneumonia, which could be dark-red, friable, and necrotic, affecting usually the diaphragmatic lobe. In chronic cases, pleural adhesions are commonly observed. According to Brockmeier *et al.* (2002), these lesions form “abscess-like nodules as the disease becomes more chronic and the fibrinous pleuritis progresses into fibrous adhesions”. At histological examination, fibrinosuppurative and necrohemorrhagic pleuropneumonia can be observed (Brockmeier *et al.*, 2002).

If typical clinical signs and gross lesions are observed, a diagnosis of APP should be suggested. Laboratorial confirmation is achieved by culture, PCR identification, and serotyping (Gottschalk, 2012). Serology is used to confirm herd status, especially for subclinical infections. However, serology tests do not differentiate between serotypes, which means they do not serve as diagnostic tools for high virulence serotypes (Gottschalk, 2012). Biosecurity as management protocols are of the utmost importance to maintain the APP-free status of herds or to alleviate the symptoms of those infected (Chiers *et al.*, 2002). In farms with clinical problems, an ideal vaccination protocol includes sow vaccination with killed organisms (bacterins) and grower/finisher vaccination with toxin-based vaccines, inhibiting disease development (Gottschalk, 2012, 2014).

3.3.3. Slaughterhouse checks

Slaughterhouse checks are useful because they allow the collection of data and health information from many different farms, minimizing resources. Plus, slaughter checks are a good indicator of animal health (Andreasen *et al.*, 2001) and welfare (Harley *et al.*, 2012), and at the same time, can be used to assure food safety. Collection of data and the methods employed depends on the objective to which they are being collected (Nielsen *et al.*, 2015).

From the farmers point of view, the data collected at slaughter is an easy, inexpensive and stress-free way of assessing pig health, especially in the later finisher stages (Andreasen *et al.*, 2001; Hurnik *et al.*, 1993). For the competent authorities, the collection of data at slaughter allows the monitorization of disease while assuring food quality and safety (Nielsen *et al.*, 2015).

3.3.3.1. Lung lesions and other recordings

Lung lesions have been used to infer about the farm's health status. The main lesions evaluated are pleurisy (or pleuritis) and pneumonia. In the literature, the terminology pleurisy and pleuritis is used indiscriminately to refer to inflammation of the pleural membranes, resulting in fibrinous adhesions between the lungs and the pleura (Jager *et al.*, 2012). Chronic pleurisy corresponds to the fibrous adhesions between the lung and thoracic walls and it is the outcome of fibrinous pleurisy (VanAlstine, 2012). The recent sub-division of pleurisy into dorsocaudal and cranial pleurisy is meant to distinguish lesions commonly attributed to different pathogens. Dorsocaudal pleurisy refers to pleurisy in the diaphragmatic lobe and has generally been attributed to APP (Merialdi *et al.*, 2012). Cranioventral pleurisy (or simply cranial pleurisy) refers to adhesions between the lobes and to the heart (Dottori *et al.*, 2007; Merialdi *et al.*, 2012). Some authors suggested it may be attributed to MHyo infections (Andreasen *et al.*, 2001). One of the main setbacks of studying pluck lesions, especially lung lesions, is its poor ability to predict pig health in the early stages (Sitjar *et al.*, 1996). Most of lung lesions in pigs in the early stages of production resolve before slaughter age and do not necessarily leave scars (VanAlstine, 2012). Therefore, finding healthy lungs at slaughter can only be related to good finisher health.

Lung abscesses, scars and other lesions compatible with certain pathogens (such as APP-like lesions) may also reveal important information. Other slaughter checks (pluck lesions) include pericarditis, commonly attributed to *Haemophilus parasuis* but multifactorial, and milk spots on the liver. The latter has been attributed to the migration of *Ascaris suum* larvae (Bernardo *et al.*, 1990b; Sanchez-Vazquez *et al.*, 2010b), and it can also impair lung health due to the subsequent migration of the larvae to those organs. Both pericarditis and milk spots on the liver are easy to check at the slaughter line and they reflect herd health and management on farm (Nielsen *et al.*, 2015). The recording of these lesions has been standardized into several protocols, many of which are available nowadays (Thacker and Minion, 2012; VanAlstine, 2012). For example, Sibila *et al.* (2014), in the scope of APP infections, compared four pleurisy scoring protocols for slaughterhouse use, pointing their main advantages and disadvantages. In another review, Garcia-Morante *et al.* (2016) compared pneumonia scoring systems described in the literature. Many pharmaceutical companies make use of them to assess the impact of their vaccinations on lung health.

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In the literature review, we revised the definitions and ideas behind biosecurity principles, selected feeding practices, and the importance and brief description of four key respiratory pathogens. The review also underlines their importance in pig production. All factors were stated to affect and be related to performance. However, one common factor was that their relative importance may shift with the type of production and the context (i.e. the industry development or disease status and production costs), region or country.

Naturally, most of the research focuses on production in countries with a developed pig industry, meaning their conclusions may not be applicable in countries with smaller pig industries and lots of variability in production styles. In the following chapters (4, 5 and 6), the same methodology and statistical approaches were used to study the effect of these factors in productive performance of Irish farrow-to-finish pig farms.

Chapter 4. Using the Biocheck.UGent™ scoring tool in Irish farrow-to-finish pig farms: assessing biosecurity and its relation to productive performance

4.1. Introduction

Pig production is the third biggest agricultural activity in Ireland (Department of Agriculture Food and the Marine, 2016), with a self-sufficiency of 219% (Central Statistics Office, 2017a). In 2016, there were approximately 149,900 breeding sows, producing an estimate of 4,000,000 pigs per year (Central Statistics Office, 2017a). The industry identified animal health and management as key inputs for productivity, and highlighted that the biggest challenges in the Irish setting are the control of endemic diseases, the prevention of introduction of exotic diseases, and the reduction of the use of antimicrobials, among others (Department of Agriculture Food and the Marine, 2016). In the last few years, biosecurity practices have been widely discussed.

On-farm biosecurity protects farms from disease by preventing pathogenic agents to enter (external biosecurity) or spreading once inside the farm (internal biosecurity, which can also overlap with management). Good biosecurity practices were related to improved performance, better financial return for farmers (Postma *et al.*, 2016b; Rojo-Gimeno *et al.*, 2016), and to a low use of antimicrobials (Laanen *et al.*, 2013; Postma *et al.*, 2017). Moreover, few studies provide quantitative data effectively linking production performance to biosecurity (Amass and Clark, 1999; Laanen *et al.*, 2013; Pinto and Urcelay, 2003). The Biocheck.UGent™ scoring system developed by Gent University (http://www.biocheck.ugent.be/) assesses biosecurity using a risk assessment approach and it has been successfully applied in several EU countries (Filippitzi *et al.*, 2017; Kruse *et al.*, 2018; Postma *et al.*, 2016b). Postma *et al.* (2016b) showed that biosecurity has moderate correlations to production performance in four European countries (Belgium, France, Germany, Sweden) and concluded that biosecurity practices vary with the country. This indicates that industry characterization and contextualization are important to understand the connection between biosecurity and performance in each national setting (Kruse *et al.*, 2018). For research purposes, this contextualization is difficult when the methods used across countries are not the same. For industry purposes, record keeping, and benchmarking are necessary tools in efficient and competitive sectors. In this study, we aim to describe biosecurity status in Irish pig farms, to investigate which biosecurity aspects are more relevant by using the Biocheck.UGent™ scoring system, and to study the impact of such aspects on farm performance.

4.2. Material and methods

Fifty-Eight Irish pig farms were scored between February and May 2016 using the biosecurity scoring system Biocheck.UGent^{TM}. Performance data for 2016 for these farms were retrieved from Teagasc e-Profit Monitor (ePM) – a national herd monitoring system – and the effect of the biosecurity practices on selected productive performance indicators was estimated.

4.2.1. Farm selection

The Teagasc ePM is a herd monitoring system available on a voluntary basis to all the farmers in the Republic of Ireland. In 2016, it included 129 pig herds representing over 96,000 sows (65% of the national commercial sow herd). All the farmers providing data to the ePM were offered the biosecurity assessment of their farrow-to-finish farms using Biocheck.UGent^{TM} and 58 farmers participated voluntarily. Farms were recruited through the Teagasc advisory service and represent approximately 29% of the national commercial sow herd.

4.2.2. Biosecurity assessment

Four researchers visited farms and interviewed farmers to complete the Biocheck.UGent^{TM} questionnaire. All interviewers were trained to conduct the questionnaire. A detailed description of the questionnaire and its scores was explained by Backhans *et al.* (2015) and Laanen *et al.* (2013). Briefly, the questionnaire has 109 questions grouped in 12 categories corresponding to either external (six categories) or internal biosecurity (six categories). Each category assesses several practices and its score is given in a rank from 0 (worst scenario) to 100 (best scenario). External and internal biosecurity scores are computed as a weighted average of the scores achieved in the corresponding categories. Overall biosecurity is computed as the average of external and internal biosecurity scores. A paper copy of the questionnaire was completed at the farm and the results were transcribed to the website and Microsoft Office Excel format. The final scores for each biosecurity category were obtained for each farm and were used for the analysis.

4.2.3. Productive performance data

Performance data for the year 2016 were retrieved from the Teagasc ePM database for all 58 farms included in the study. ePM data is collected on farms every trimester with the support of Teagasc advisors and collated into a single database. This information is used to produce the yearly National Pig Herd Performance Report (Teagasc, 2017), and for different international comparisons like the InterPIG report (AHDB, 2017). The productive performance indicators selected for analysis in the present study were piglet (pre-weaning) and finisher mortality (%), number of pigs produced per sow per year, average daily gain (ADG, g/day) corresponding to the period from weaning to slaughter, and feed conversion ratio (FCR), corresponding to the same period.

4.2.4. Statistical analysis

All statistical procedures were performed in R version 3.4.4 (Vienna, Austria, https://www.R-project.org/). Alpha level for significance and tendency were 0.05 and 0.10, respectively. Differences in productive performance between the study sample and the Teagasc ePM population were tested by means of independent samples *t* test (means) and F-tests (variance). The effect of biosecurity on productive performance was estimated through multivariable linear models. Productive performance indicators were used as dependent variables and basic farm characteristics (number of sows, years of experience of farm managers, number of workers, age of the oldest building in which pigs were kept, and age of the youngest building in which pigs were kept), and biosecurity scores were used as independent variables or predictors. First, Spearman Rank correlations were calculated between all the independent variables to detect collinearity. Then, for each performance indicator, a multivariable linear model was fitted with predictors selected from the farm characteristics, and the biosecurity categories' scores. When fitting the model for piglet mortality, biosecurity scores related to the nursery and finishing unit management were left out. A forward regression approach was used to improve the models fitted (ols_step_forward function from the olsrr package in R (Hebbali, 2017)), using a cut-off value of 0.15 for predictor retention in the model. Predictors collinearity was further checked using Variance Inflation Criterion (VIF) from the R package rms (Harrel Jr, 2018). Finally, for each model, residuals' normality was visually assessed. A simple linear model fitting internal biosecurity scores from external scores was also done.

To identify the most relevant biosecurity aspects in Irish pig farms, a Principal Component Analysis (PCA) was also performed on the biosecurity categories. After this, Hierarchical Clustering Analysis was used to group farms according to their similarities regarding their biosecurity practices and, finally, ANOVA followed by

Tukey's correction was used to test differences in productive performance indicators across those clusters.

4.3. Results

4.3.1. Farm characteristics

Table 4.1 summarizes the characteristics of the 58 pig farms included in this study. The farms employed farm managers with an average of 26.8 (± 10.14) years of experience. The number of sows (hereinafter, average herd size) was strongly correlated to the number of workers on farm (r_s = 0.92, $P < 0.001$) with a ratio of one worker per 154 sows. Although the oldest farm buildings in which pigs were kept were on average 35.3 (± 25.46) years old, this figure includes a farm which was 210 years old. The second oldest farm was 60 years old. The youngest buildings were on average 3.9 (± 5.14) years old with some farms reporting to be building new accommodation at the time. In this study, 34.5% of the farms reported keeping other animals for commercial purposes on the farm grounds.

4.3.2. Farm productive performance

The average herd size of the farms assessed was 754 sows with a range from 113 to 2479 sows. Piglet and finisher mortality showed great variability across farms with a coefficient of variation (CV) of 28.7 and 44.7%, respectively. On the other hand, the number of pigs produced per sow per year, ADG, and FCR showed less than 10% variability across farms (CV = 8.7, 8.8, and 5.9%, respectively). Between the study sample and the ePM population, differences were found only in the variance of finisher mortality and ADG ($P < 0.001$ and $P = 0.037$, respectively), but not in their means. No other differences regarding means or variance were found ($P > 0.05$) across average herd size, piglet mortality, number of pigs per sow per year, or FCR.

4.3.3. Biosecurity scores

The results of the biosecurity assessment are presented in Table 4.2. The overall biosecurity score of Irish pig farms was 68.3 ± 9.52. Total external biosecurity scored higher than internal biosecurity ($P < 0.001$) and its practices were applied consistently across Irish pig farms (CV = 9.8 %). The highest score in this category (external biosecurity) was achieved in the category purchase of animals and semen (98.8 ± 5.05, range = 70 - 100). The lowest score in this category was in the feed, water, and equipment supply (54.5 ± 14.57). Regarding internal biosecurity, disease management scored the highest with 82.4 ± 21.55, and cleaning and disinfection obtained the lowest score (42.0 ± 27.25) with 12.1% of the farms not applying any of these practices (score 0).

Table 4.1. Description of the sample of 58 Irish farrow-to-finish pig farms used in the 2016 biosecurity assessment and comparison to the Teagasc database (ePM) population (n = 129).

	ePM (n = 129)	**Study sample (n = 58)**[1]				**P-value**[2]
Farm characteristics	**Mean ± SD**	**Mean ± SD**	**Median**	**Min**	**Max**	
No. of sows	726 ± 610.8	754 ± 554.9	639	113	2479	0.764
Experience of farm manager, years	-	26.8 ± 10.14	28.0	5.0	50.0	-
Number of workers	-	4.9 ± 3.65	4.0	1.0	16.0	-
Age of the oldest building, years	-	35.3 ± 25.46	32.5	5.0	210.0	-
Age of the youngest building, years	-	3.9 ± 5.14	3.0	0	25.0	-
Herd productive performance						
No. of pigs produced per sow per year	25.7 ± 2.30	26.0 ± 2.27	25.8	18.0	31.2	0.521
Piglet mortality, %	10.5 ± 2.80	10.3 ± 2.70	9.8	5.1	16.3	0.623
Finisher mortality, %	2.4 ± 1.47	2.2 ± 0.97	2.0	0.8	5.1	0.332
ADG, g/day	703 ± 79.8	704 ± 62.0	699	554	856	0.842
FCR	2.41 ± 0.171	2.38 ± 0.144	2.36	2.01	2.78	0.210

Legend: [1]Farm characteristics retrieved from the Biocheck.UGent™ scoring tool which was applied to 58 Irish farrow-to-finish pig farms from February to May 2016. The correspondent herd productive performance was retrieved from the Teagasc ePM for the year 2016. [2] T test for comparison of means. ADG – average daily gain; FCR – feed conversion ratio.

4.3.4. Effect of biosecurity scores and farm characteristics on productive performance

The number of workers was left out of the predictors due to collinearity with average herd size (r_s = 0.92, P < 0.001). Among the biosecurity categories, the purchase of animals and semen was also left out of the predictors due to its low variability (CV = 5.1%). Table 4.3 summarizes the models selected.

The model selected for piglet mortality (%) explained 8% of the variability. There was an increase in mortality with age of the youngest building in which pigs were kept (*P* < 0.001), and a tendency for mortality to decrease in farms with better score in the biosecurity category referring to feed, water, and equipment supply (*P* = 0.079).

Table 4.2. Biosecurity scores (Biocheck.UGent™) for the different categories of internal and external biosecurity in 58 farrow-to-finish Irish pig farms.

	Mean	SD	Median	Min	Max
External biosecurity score	78.7	7.75	79.0	62.0	94.0
Purchase of animals and semen	98.8	5.05	100.0	70.0	100.0
Transport of animals, removal of manure and dead animals	80.1	11.26	83.0	43.0	96.0
Feed, water, and equipment supply	54.5	14.57	53.0	10.0	80.0
Personnel and visitors	73.9	18.61	76.0	24.0	100.0
Vermin and bird control	68.3	19.84	70.0	30.0	100.0
Environment and region	79.5	23.35	80.0	20.0	100.0
Internal biosecurity score	57.4	14.16	60.0	29.0	80.0
Disease management	82.4	21.55	80.0	20.0	100.0
Farrowing and suckling period management	53.6	18.75	57.0	7.0	86.0
Nursery unit management	63.5	16.11	64.0	36.0	100.0
Fattening unit management	72.7	22.12	79.0	21.0	93.0
Measures between compartments and use of equipment	50.0	16.16	50.0	21.0	86.0
Cleaning and disinfection	42.0	27.25	40.5	0	95.0
Overall biosecurity score	68.3	9.52	70.0	47.0	87.0

Legend: biosecurity scores are computed from the practices assessed in each category. Category scores are given in a rank from 0 (worst scenario) to 100 (best scenario). External and internal biosecurity scores correspond to the average of the scores obtained in the corresponding categories. The overall biosecurity corresponds to the average between the external biosecurity score and the internal biosecurity score.

The model for finisher mortality (%) explained 23% of the variability. Mortality increased with the average herd size (*P* < 0.001) and decreased with good disease management scores (*P* = 0.028). High scores in the categories environment and region and in nursery unit management were related to higher mortalities (*P* = 0.059 and *P* = 0.050, respectively). Good measures between compartments and use of equipment seemed to decrease finisher mortality although this was not statistically significant (*P* = 0.126).

The model for ADG (g/day) explained 16% of the variability. It decreased in large farms (No. of sows, *P* = 0.043) and with the experience of the farm manager (*P* = 0.029). Good practices in disease management improved ADG (*P* = 0.039).

Table 4.3. Multivariable linear regression modelling of herd productive performance.

Outcome	Predictor	Estimate	SE	*P*-value
Piglet mortality %	Intercept	12.04	1.334	<0.001
Adjusted R^2 = 0.08	Age of the youngest building, years	0.13	0.066	0.067
P = 0.039	Score for feed, water, and equipment supply	-0.04	0.023	0.079
Finisher mortality %	Intercept	1.50	0.683	0.032
Adjusted R^2 = 0.23	No. of sows [per 100 sows]	0.8	0.21	<0.001
P = 0.002	Score for disease management	-0.01	0.006	0.028
	Score for environment and region	0.01	0.005	0.059
	Score for nursery unit management	0.02	0.008	0.050
	Score for measures between compartments and use of equipment	-0.01	0.008	0.126
ADG (g/day)	Intercept	706.27	37.734	<0.001
Adjusted R^2 = 0.16	No. of sows	-0.03	0.0133	0.043
P = 0.006	Experience of farm manager, years	-1.65	0.734	0.029
	Score for disease management	0.73	0.343	0.039

Legend: Each productive performance indicator (piglet mortality (%), finisher mortality (%), number of pigs per sow per year, ADG (g/day), and FCR) was modelled from herd characteristics and biosecurity scores (categories), presented in Table 4.1 and 4.2, respectively. The table presents the final models after a forward regression approach with a cut-off value of 0.15 for predictor retention. The models fitting the number of pigs per sow per year and FCR were not significant (overall F-test with *P* = 0.067 and *P* = 0.075, respectively).

The models for number of pigs per sow per year and for FCR were not significant (overall F-test with *P* = 0.067 and *P* = 0.075, respectively).

4.3.5. Relationship between internal biosecurity and external biosecurity

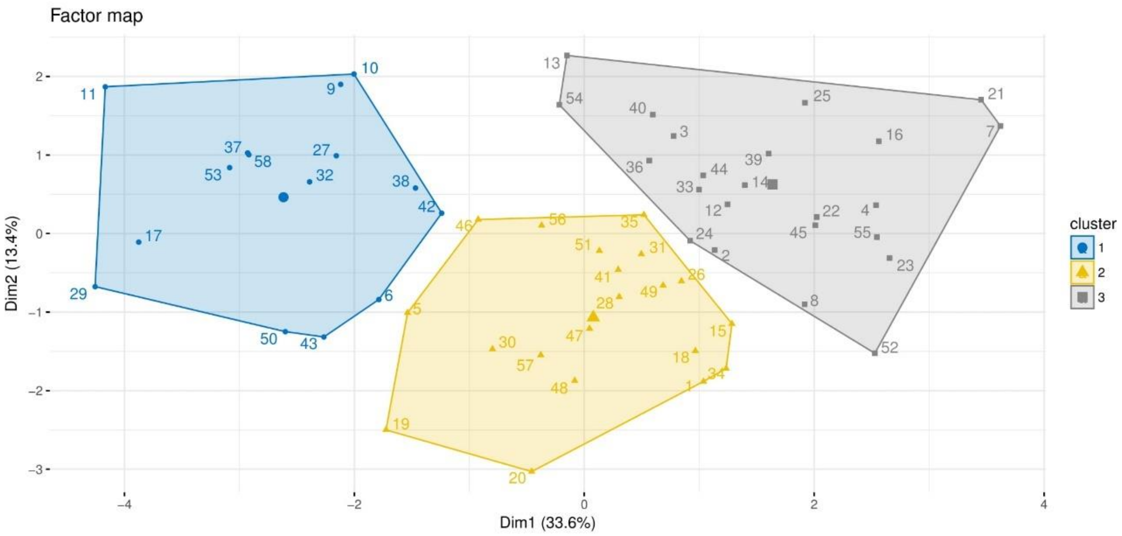
Around 20% of the variability in internal biosecurity (adjusted R^2 = 0.20, *P* < 0.001) could be explained by the scores obtained in external biosecurity:

$$Internal\ biosecurity = -8.434 + 0.836 * External\ biosecurity$$

4.3.6. Farm clusters based on biosecurity practices

The first two dimensions of the PCA of the farms depending on their biosecurity practices accounted for 47% of variability. Dimension 1 accounted for 33.6% of variability and was mainly explained (66.1%) by internal biosecurity practices. Dimension 2 accounted for 13.4% of variability and was mainly linked to external biosecurity (68.4%). Three clusters of farms were identified based on their similarities in biosecurity practices (Figure 4.1).

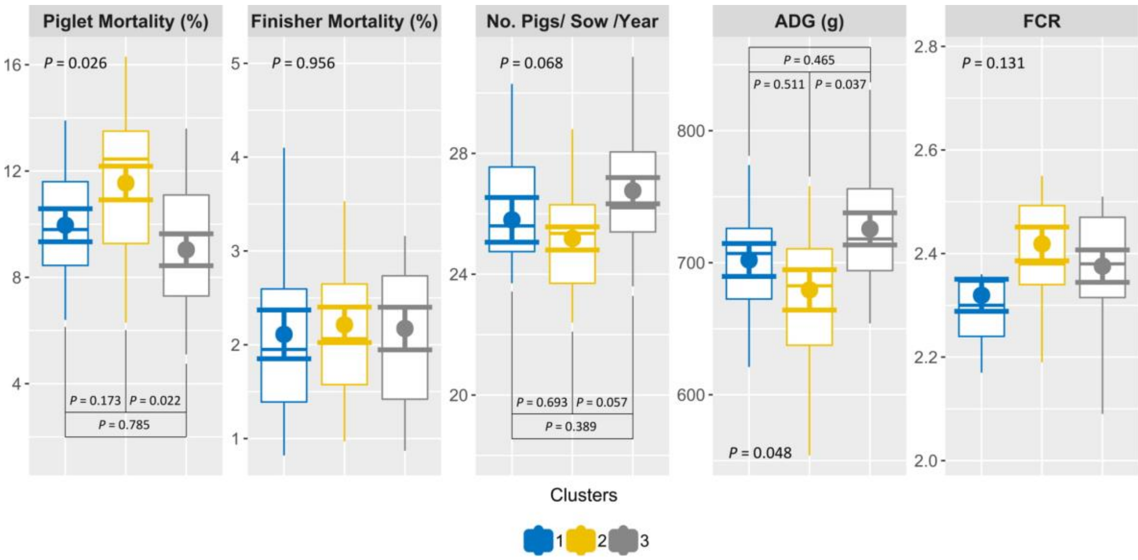
Figure 4.1. Clusters of farms grouped according to their biosecurity scores in external and internal biosecurity categories



Legend: Dim1 – Dimension 1; Dim2 – Dimension 2. A Principal Components Analysis followed by Hierarchical Clustering Analysis grouped farms according to their scores in external and internal biosecurity practices. Dimension 1 was mainly related with internal biosecurity and dimension 2 was mainly related with external biosecurity. The three clusters identified group farms with low internal biosecurity and high external biosecurity (cluster 1), average internal and external biosecurity (cluster 2), and high internal and external biosecurity (cluster 3).

In Figure 4.1, the clusters grouped farms with low internal biosecurity and high external biosecurity (cluster 1), average internal and external biosecurity (cluster 2), and high internal and external biosecurity (cluster 3). Cluster 1 was lower than the other two clusters regarding internal biosecurity ($P < 0.001$). Cluster 3 was better in external biosecurity when compared to the other two clusters ($P < 0.001$). No other differences were found between clusters. The productive performance indicators for each cluster of farms are presented in Figure 4.2. Cluster 2 was the worst performing cluster and it was different when compared to the best performing cluster (cluster 3) in piglet mortality (9.4 ± 2.39% vs 11.6 ± 2.84%, *P* = 0.022), in ADG (726 ± 58.3 g vs 679 ± 68.2 g/day, *P* = 0.037) and it tended to be different also in the of number pigs per sow per year (26.8 ± 2.08 vs 25.2 ± 1.71, *P* = 0.057). Finisher mortality and FCR did not differ between clusters (*P* = 0.956 and *P* = 0.131, respectively).

Figure 4.2. Boxplots of productive performance indicators (with mean ±SD) across farm clusters of farms grouped according to their biosecurity scores in external and internal biosecurity categories.



Legend: ADG (g/day) – Average daily gain, FCR – Feed conversion ratio. The clusters represent farms with similar biosecurity scores in external and internal categories. Cluster 1 groups farms with low internal biosecurity and high external biosecurity, cluster 2 groups farms with average external and internal biosecurity, and cluster 3 groups farms with high external and internal biosecurity scores. The productive performance of the farms in each cluster is presented above. ANOVA tests followed by Tukey's correction were used to test differences in productive performance across those clusters.

4.4. Discussion

The aim of this study was to describe biosecurity practices among Irish farrow-to-finish pig farms and to relate biosecurity to productive performance. The overall biosecurity scores agreed to what has been described in five European countries so far (Belgium, France, Germany, Sweden, and Denmark; Kruse *et al.*, 2018; Postma *et al.*, 2016b). External biosecurity was higher in Ireland than in any of those countries, except for Denmark whose industry's structure is focused on high health status farms supported by strict biosecurity practices, according to Kruse *et al.* (2018). This result is related to the characteristics of the Irish pig industry which includes mostly closed herds, resulting in less animal movements. Likewise, 94.5% of the farms reported to be buying only semen from genetic companies and did not purchase gilts. In other European pig industries, gilts are purchased and quarantined on farm before introducing them to the breeding herd (Boklund *et al.*, 2004; Casal *et al.*, 2007; Postma *et al.*, 2016b). This is indeed a big risk for external biosecurity but breeding your own replacement gilts in the farms is often seen as a risk for decreased genetic progress. This seems not to be the case in the Irish farms which keep productive performance similar to other countries (AHDB, 2017). On the other hand, internal biosecurity scores showed a lack of compliance with cleaning protocols and compartmentalization within the farm. Again, this result is in line with what other countries reported, with internal biosecurity showing greater variability than external biosecurity (Kruse *et al.*, 2018; Postma *et al.*, 2016b). It is likely that farmers do not value the pertinence of internal biosecurity. Casal *et al.* (2007), in a study describing the perceptions of Spanish pig farmers towards biosecurity, states that farmers are likely to implement biosecurity measures they perceive as important. Adding to this, the awareness towards biosecurity has traditionally been focused on external biosecurity once the major threats perceived by farmers are those of diseases not endemic to their farms. In recent years, debate on the usefulness of internal practices resurged and gained new strength with the development of the Biocheck.UGent™ scoring system. In this study, similar to other countries where this tool was employed (Backhans *et al.*, 2015; Filippitzi *et al.*, 2017; Kruse *et al.*, 2018; Postma *et al.*, 2016b), internal biosecurity was positively correlated to external biosecurity. This result conveys the robustness of this study, establishing a parallel between Irish pig production and other European pig industries.

The multivariable model for pig mortality explained only 8% of the variability. The connection between piglet mortality and the age of the youngest building is not straightforward. The age of the buildings where pigs were kept revealed the evolution Irish pig farms have endured over the past decade: 79% of the farms had built new housing for pigs within the previous 5 years. Farms which had their latest renovation 10 or 15 years ago suggest that their investment in efficient management and technology is lacking. The other factor related to piglet mortality was the feed, water, and equipment supply. This relationship is straightforward to understand. Farms paying less attention to the feed, water, and equipment supply increase the risk of introduction of new diseases, which can be linked to higher mortality rates. Surprisingly, the farrowing unit management was not retained in the final model for piglet mortality. This management, as measured by the Biocheck.UGent™, focuses on cross-fostering practices, cleaning and disinfection of materials between litters, and on castration protocols. None of the farms in current study were castrating piglets, as per normal practice in Irish pig farms. Regarding cross fostering, in a 2016 review on non-infectious causes for pre-weaning mortality, Muns *et al.* (2016) concluded that further research is necessary to validate cross-fostering practices in different settings. We speculate that other management factors such as sow management, farrowing supervision, colostrum intake, split suckling, and training of staff (Kirkden *et al.*, 2013; Muns *et al.*, 2016) are more likely to have a greater impact on piglet mortality than the litter management practices captured in the category of the questionnaire for farrowing unit management.

The model for finisher mortality was the best one, explaining 23% of the variability. Bigger farms had higher finisher mortality. We suspect that bigger farms may have a greater ratio of pigs per worker, in which case less attention may be paid to individual finisher pigs, as suggested by Agostini *et al.* (2014). However, in the data studied there was only a weak to moderate correlation between the ratio of pigs per worker and the average herd size ($r_s = 0.36$, $P = 0.006$). Gardner, Willeberg and Mousing (2002) described the duality faced by bigger farms which, on one hand face higher risks of infection due to frequent animal movements and high pressure of infection, and, on the other hand, they usually have higher biosecurity standards to minimize those risks. As expected, better disease management, including herd health protocols and veterinary expertise, were linked to decreased mortality in finisher pigs. Conversely, the correlations between finisher mortality, and areas with lower pig density and management of the nursery unit seem contradictory. We could not explain this result and no confounding effects were found.

As for the ADG model, it explained 16% of the variability. Average herd size and experience of farm managers had a negative impact on ADG, and a better disease management was positively correlated to ADG. The negative impact of average herd size in growth rate could be somewhat related to the connection found between herd size and finisher mortality. In herds with higher disease pressure, growth rates are decreased (Cornelison *et al.*, 2018). It is likely that other factors such as herd health and/or vaccination protocols played a role in the connections reported here with average herd size. The negative impact of experience could be related to several factors. Laanen *et al.* (2013), in a study relating biosecurity to productive performance and antimicrobial treatment in pig herds in Belgium, found that older farmers were associated with older infrastructures and poor internal biosecurity, suggesting that experience in such circumstances could mean a lesser ability to deal with changes, and therefore to address production challenges.

The associations found between biosecurity categories and productive performance suggest that, in general, farms with good biosecurity had better performance. Laanen *et al.* (2013) identified such associations with ADG and FCR, but not with finisher mortality. Further similarities between that study and ours are the low R^2, meaning only a small proportion of the variability of the productive performance indicators modelled was explained by biosecurity practices. Indeed, the biosecurity assessment as carried by the Biocheck.UGent™ poses as a risk assessment tool whose linkage to productive performance alone lacks the baseline factors impacting on performance such as herd health, genetics, vaccination protocols, use of antimicrobials, and, the most important factor in Irish pig farms, the feeding system and nutrition (Laanen *et al.*, 2013). Other authors suggested that there was a lack of scientific validation to support biosecurity practices (Amass and Clark, 1999) and, consequently, of their effect on productive performance. Many biosecurity assessment tools were designed by expert panels using experience and logical reasoning to establish risks associated with different biosecurity practices (Laanen *et al.*, 2013). Finally, some of these tools were designed to address certain pathogens (i.e. PRRSv), not necessarily providing a risk assessment liable to account for other potentially harmful pathogens (Iowa State University, n.d.). Given the limitations stated above, we used a different approach by grouping the farms according to their biosecurity practices and then comparing their productive performance.

In a multivariate approach to the data, farms were separated in three clear clusters based on their biosecurity practices. The main categories contributing to the clustering of the farms were: cleaning and disinfection, compartmentalization, transport of animals and removal of manure and dead animals, and management of the different stages in dimension 1 (mainly internal biosecurity categories); and the environment and region, feed, water, and equipment, management of the different stages, and personnel and visitors in the dimension 2 (mainly external biosecurity categories). The three clusters of farms grouped farms with 1) good external biosecurity but low internal biosecurity, 2) average external and internal biosecurity and 3) high external and internal biosecurity scores. The highest production performance was found in farms with high external and internal biosecurity compared to farms with average biosecurity. The latter may have a lower level of care of biosecurity in general and change may be difficult to achieve.

However, in the case of farms with high external but low internal biosecurity, it may be related to the traditional focus on external biosecurity and not necessarily to worse practice. In this cases change may be easier to achieve.

4.4.1. Limitations of the study

All the farms recruited were enrolled in the Teagasc advisory service and the present sample is representative of the Teagasc ePM pig population, as presented in the results. Although this study accounts for almost 30% of all the breeding sows in Ireland, these herds were likely to represent a better end of the Irish pig farms, as suggested by Staaveren *et al.* (2017). Also, the biosecurity data was collected in a cross-sectional study in in-office interviews which may have led to bias towards answers stating measures believed to be applied on farm rather than stating measures applied (Casal *et al.*, 2007). Contributing to this bias was also the different interviewees with farm owners being less likely to be aware of the daily management practices and actual cleaning routines in their farms when compared to farm managers and other workers. Finally, as this was an observational study, causal relationships should not be inferred from the results presented.

Chapter 5. Feeding practices on Irish farrow-to-finish pig farms and its effects on productive performance

5.1. Introduction

Feed is one of the main factors affecting pig production efficiency as it represents over 70% of the production costs (Patience *et al.*, 2015). Over the years, researchers have studied diverse feeding practices and nutritional factors to maximise growth performance and feed efficiency (Kerr *et al.*, 1995; I'Anson *et al.*, 2012; Lebret, 2008; Ulens *et al.*, 2015) while reducing feed cost (Pomar *et al.*, 2014; Saddoris-Clemons *et al.*, 2011), and lately also to optimize gut health, and to reduce the use of antimicrobials and environmental impact (Allaart *et al.*, 2017; Cheng *et al.*, 2014; Liu *et al.*, 2018; Missotten *et al.*, 2010). This research has been largely based on randomized controlled trials comparing feeding practices such as feed delivery methods (dry vs. wet feeding), or feed form (meal vs. pelleted feed; Chae, 2000; Chae and Han, 1998; Flis *et al.*, 2014; Patience *et al.*, 2015). These type of trials are free of bias and confounding but might not be fully representative of the complex reality of pig farms (Nyachoti *et al.*, 2004).

Concomitantly, the evolution of pig farming in top producing countries over the last two decades has resulted in newer and bigger farms that are often part of larger structures, like cooperatives or vertical integrations (Davies, 2012). This change has led to a homogenization of the feeding practices employed within and between countries (DeRouchey and Richert, 2010) which, to some extent, reduces flexibility in the use of ingredients and the adoption of new technologies. For example, in a recent study assessing the main production factors in 216 finishing farms in Brazil, Silva *et al.* (2017) reported that 99.6% of the farms were feeding pellets. In another study by Agostini *et al.* (2014), including more than 200 finisher farms in Spain only nine different diets were used, all of them pellets. On the other hand, there is still some countries where feeding practices are more diverse but information on the advantages and disadvantages of each practice is missing.

Although the total pig production in Ireland is relatively small compared to other countries (around 150,000 sows (Department of Agriculture Food and the Marine, 2017)), the pig industry represents the third most relevant agricultural sector after dairy and beef (Central Statistics Office, 2017b) and the average herd size is one of the biggest in the EU (Eurostat, 2014), with an average herd size of 775 sows (Teagasc, 2017). It is accepted that there is a wide variety of feeding practices across Irish pig farms (Teagasc, 2015), however, this variety has not yet been characterized. At the same time feed cost in Ireland is one of the highest among the twenty countries belonging to the InterPIG network (AHDB, 2017). Although in 2016 the Irish pig industry was self-sufficient by 219% (Central Statistics Office, 2017a), the current price fluctuations mean that farmers must control their production costs to remain in the market, with feed cost being the first to be addressed. The need to reduce costs, coupled with the variety of feeding practices existent, casts an opportunity to study, at country level, the impact of different feeding strategies on productive performance.

This study aims to describe the feeding strategies of sows (gestating and lactating), gilts and pigs from weaning to slaughter in Irish farrow-to-finish farms, and to study the effects of such feeding practices on productive performance and feed cost.

5.2. Material and methods

Data on feeding practices was obtained by survey in 56 Irish farrow-to-finish pig farms between February and May of 2016. Similar to the procedure followed in Chapter 4, Performance data for 2016 for these farms were retrieved from Teagasc e-Profit monitor (ePM). A descriptive analysis of the information gathered was carried out, followed by the study of the effects of selected feeding strategies in each stage (gestating sows, lactating sows, gilts and pigs from weaning to slaughter) on productive performance.

5.2.1. Farm selection

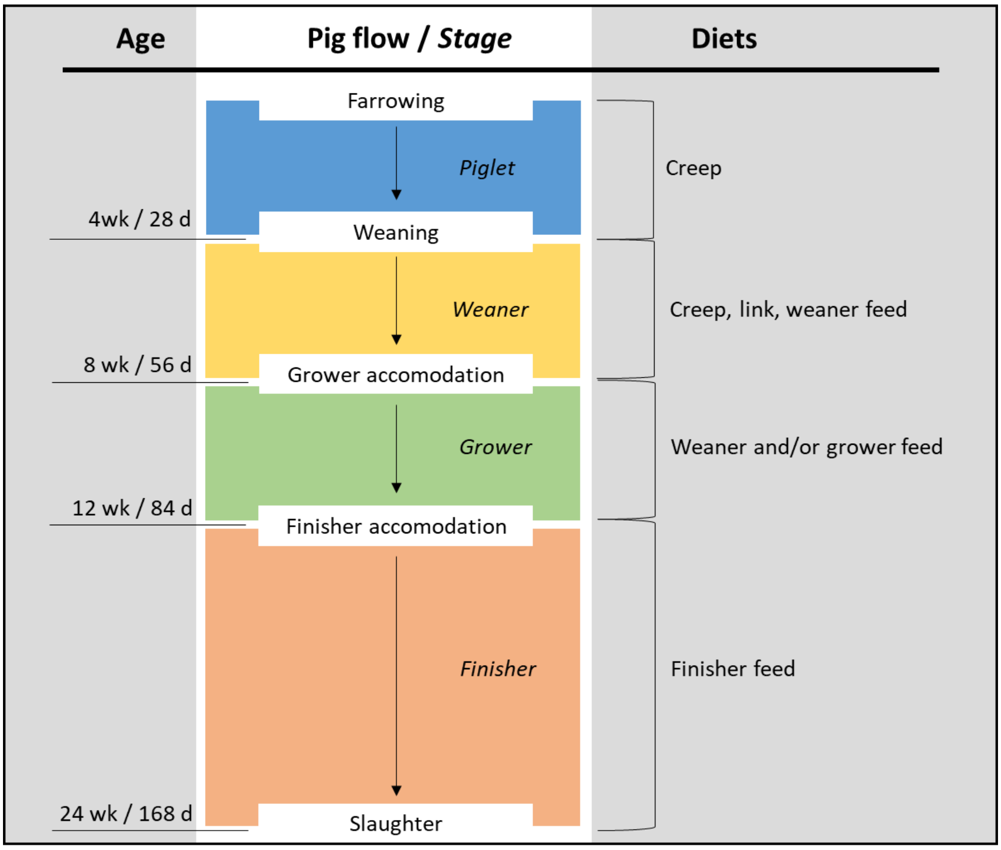
The farm selection followed the same procedures as described in Chapter 4. The feeding strategies survey was offered to all the farrow-to-finish pig farmers providing data to the ePM, and 56 farmers participated voluntarily. Farms were recruited through the Teagasc advisory service and represent approximately 27.5% of the national commercial sow herd.

5.2.2. General management in Irish pig farms

In 2015, 90% of the herds enrolled in the Teagasc advisory system (which accounted for 67% of the national breeding herd in that year) were farrow-to-finish farms, with breeders, nursery (hereinafter, weaner) and finisher pigs in one location (Gerard McCutcheon, personal communication, 31st August 2018). Replacement gilts are typically raised on farm with the finisher pigs up to slaughter weight (100 to 110 kg) and then selected and kept separated up to breeding age. From selection to breeding gilts are fed a gestation, lactation or a specific gilt diet. After service, gilt and sow management does not differ from other countries; they are kept in the service unit until gestation is confirmed, then moved to gestation accommodation and moved into farrowing facilities three to seven days before their expected due date. A gestation and lactation diets are used, respectively.

Management of piglets after farrowing is summarized in figure 1. Piglets are weaned at around 28 d of age and they are typically offered creep feed (milk replacer of pre-starter diet) during lactation. Weaners spend 4 to 5 weeks in the nursery until 20-25 kg live weight (weaner stage) where they are typically offered a pre-starter and/or starter diets followed by a link (i.e. a transition diet between starter and weaner diet) up to the second week post-weaning and then a weaner diet. Pigs spend 4 to 5 weeks in the grower stage where they are on a weaner or grower diet; and then they are moved to the finisher accommodation (at 35 to 50 kg of live weight). There pigs spend approximately 12 weeks until slaughter (finisher stage) and are fed finisher diets. In general, subsequent diets are provided when pigs are moved to a different building.

Figure 5.1. Typical pig flow and feeding scheme from birth to slaughter in a farrow-to-finish Irish pig farm.



5.2.3. Feeding Strategies survey

Four researchers interviewed farmers to complete the feeding practices survey. The survey consisted of closed questions covering the feeding practices in the different stages of pig production, including gestating and lactating sows, gilts, piglets, weaners, growers, and finishers. The practices surveyed were feed origin, feed delivery, feed form, and feeding frequency. All interviewers were trained to conduct the questionnaire in a test interview. Sow and gilt information is presented in Table 5.1. Although most Irish farms breed their own replacement gilts, the feeding practices surveyed focused on the period from selection to breeding. The variables used to study the effect of feeding practices on productive performance of sows and gilts were feed origin (purchasing vs. home-milling), feed form (pellets vs. meal), feed delivery (dry vs. wet), and feeding frequency. Feed form and feed delivery were combined into feed group, resulting in only three groups: dry-meal, dry-pellets, and wet-meal. Feeding frequency was categorized depending on the stage (lactating sow, gestating sow and gilts), as shown in Table 5.1. Gilts' diet type from selection to breeding was also included in the survey as gilt specific vs. non-specific diet.

Table 5.1. Description of variables recorded on-farm regarding feeding practices in sows of 56 farrow-to-finish Irish pig farms.

Variable	**Categories (% of batches in each class)**
Gestating Sows	
Feed origin	Home-Milling (42.9%), purchasing (57.1%)
Feed group	Dry-meal (8.9%), dry-pellets (23.2%), wet-meal (67.9%)
Feeding frequency[1]	Once per day (42.9%), more than once per day (57.1%)
Lactating Sows	
Feed origin	Home-milling (42.9%), purchasing (57.1%)
Feed group	Dry-meal (10.7%), dry-pellets (23.2%), wet-meal (66.1%)
Feeding frequency[1]	Twice per day (48.2%), more than twice per day (51.8%)
Gilts	
Diet	Gestating sow (60.7%), gestating/lactating diets (16.1%), gilts' diet (23.2%)
Feed origin	Home-milling (41.1%), purchasing (58.9%)
Feed group	Dry-meal (12.5%), dry-pellets (26.8%), wet-meal (60.7%)
Feeding frequency[1]	Once per day (16.1%), 2 or 3 times per day (57.1%), *ad libitum* (26.8%)

The variables describing the feeding practices for pigs from weaning to slaughter (Table 5.2) were the number of diets from birth to slaughter (total number of diets), number of diets from weaning to slaughter, number of finisher diets, feed origin (purchasing vs. home-milling; it was considered home-milling if it included all diets from weaning to slaughter), feed delivery (dry, wet, or both; same delivery across all diets from weaning to slaughter, or feeding diets with both delivery types in different stages), and feed form (pellets, meal, or both; keeping the same form across all diets from weaning to slaughter, or feeding diets with both forms in different stages). These variables, together with the number of peri-weaning diets (diets provided before or immediately after weaning including milk replacer, pre-starter and starter), and provision of link were used to study the effect of feeding practices from weaning to slaughter on productive performance.

Table 5.2. Description of variables recorded on-farm regarding feeding practices in pigs from weaning to slaughter of 56 farrow-to-finish Irish pig farms

Variable	**Categories (% of batches in each class)**
Pigs from weaning to slaughter	
Total number of diets	Four (48.2%), five (26.8%), more than five (25.0%)
Number of peri-weaning diets[1]	One (71.4%), two or three (28.6%)
Number of diets weaning to finishing	Two (57.1%), three (25.0%), more than three (17.9%)
Number of finishing diets	One (78.6%), two or three (21.4%)
Feed origin	Home-milling (28.6%), Purchasing (71.4%),
Feed form	Pellets (26.8%), meal (58.9%), both (14.3%)
Feed delivery	Dry (48.2%), wet (37.5%), both (14.3%)

Legend:[1]Diets provided to the piglet before weaning or immediately after weaning including milk replacer, pre-starter and starter diets.

5.2.4. Performance data and herd characteristics

Performance data from the year 2016 were retrieved from the Teagasc ePM. Data is collected on farms every trimester with the support of Teagasc advisors and collated into a single database. A cost-benefit analysis is also carried out with the economic data of the farms as part of the ePM including feed cost of the feed as delivered to the pig. Table 5.3 presents the herd characteristics, performance parameters for sows and finishers and feed cost used for the statistical analysis.

Table 5.3. Description of herd characteristics, productive performance, and feed cost of 56 Irish farrow-to-finish pig farms for the year 2016.

	Mean	**± SD**	**Median**	**Min**	**Max**
Herd characteristics					
Average herd size[1]	761	563.2	650	113	2479
Average live weight at slaughter (kg)	107	5.2	107	94	121
Sow performance					
Sow culling (%)	48.0	11.35	49.0	18.8	80.1
Sow mortality (%)	4.4	1.95	4.1	1.4	11.2
Litters per sow per year	2.3	0.10	2.3	1.9	2.5
No. born alive per litter	13.2	0.69	13.2	11.6	14.8
Piglet mortality (%)	10.3	2.68	9.8	5.1	16.3
No. weaned per litter	11.8	0.65	11.8	10.4	13.4
Weaning to slaughter performance					
Average daily feed intake (g/day)	1680	139.7	1684	1396	2026
Average daily gain (g/day)	706	59.7	699	575	856
Feed conversion ratio (kg/kg)	2.38	0.150	2.36	2.01	2.78
Age at sale (d)	172.0	12.41	170.0	146.0	205.0
Weaner Mortality	2.7	1.45	2.5	0.7	9.4
Finisher mortality (%)	2.2	0.97	2.0	0.8	5.1
No. pigs produced/sow-year	26.0	2.30	25.9	18.0	31.2
Feed cost kg dead (cents, €)	99.5	7.15	100.2	82.4	114.8

Legend: [1]No. of sows. Data retrieved from the Teagasc e-ProfitMonitor.

5.2.5. Statistical analysis

All statistical procedures were performed in R version 3.4.4 (Vienna, Austria, https://www.R-project.org/). Alpha level for significance and tendency were 0.05 and 0.10. Associations between feeding practices (categorical variables) in each stage were tested by means of Fisher tests. Correlations between farm productive performance indicators and herd characteristics were tested using Spearman rank correlations. The effect of feeding practices on productive performance was estimated through multivariable linear models. Sow productive performance indicators (dependent variables, Table 5.3) were modelled from the feeding practices of sows (gestating and lactating; Table 5.1), and gilts (predictors, or independent variables; Table 5.1) and the average herd size was also used as a predictor. Productive performance indicators from weaning to slaughter (dependent variables, Table 5.3) were modelled from herd characteristics (Table 5.3) and feeding practices from weaning to slaughter (Table 5.2). A forward regression approach was used to improve the models fitted (ols_step_forward_p function from the olsrr package in R (Hebbali, 2017)) using a cut-off value of 0.15 for predictor retention in the model. Predictors collinearity was further checked using Variance Inflation Criterion (VIF) from the R package rms (Harrel Jr, 2018). Collinear variables were removed manually. Finally, residuals' normality was visually assessed. A log transformation of the sow mortality data was used to fit with the normality assumptions of linear regression. The model is presented in log form but the estimates were back transformed for discussion using R package emmeans (Lenth, 2018). Only models explaining more than 15% of variability are described in the results.

5.3. Results

A total of 56 farrow-to-finish farms were included in this study. The average herd size of the farms was 761 ± 563.2, with a range from 113 to 2479 sows. The average live weight at which pigs were sent to slaughter in these farms was 107 ± 5.2 kg, as per the sale target defined by each farmer. Tables 5.1 and 5.2 show the frequencies for the different categories of the variables recorded on-farm regarding feeding practices in sows and growing pigs respectively. Table 5.3 summarises the herd characteristics, and performance of sows and growing pigs. In this sample, pigs were weaned at 29.2 ± 3.70 d of age.

5.3.1. Feeding practices in sows and gilts

The feeding practices captured for sows are summarised in Table 5.1. For gestating sows, most farms were purchasing the diet (57.1%), feeding wet-meal (67.9%) and feeding them more than once per day (57.1%). For lactating sows, most farms were purchasing diet (57.1%), feeding wet-meal (66.1%) and feeding them more than twice per day (51.8%). In 60.7% of the farms, gilts were fed with gestating sows' diet, while in 16.1% gilts were fed with gestating sows' diet followed by lactating sows' diet in the weeks before breeding. Twenty-three percent of the farms fed their gilts' development diet. For gilts, 58.9% of the farms were purchasing feed, 60.7% were feeding them wet-meal and 57.1% were feeding them two or three times per day.

Average herd size was correlated with home-milling in gestating and lactating sows and in gilts (*P* = 0.002, *P* = 0.002, and *P* = 0.005, respectively), and with wet-meal feeds (*P* < 0.001 for all stages). A bigger herd size also tended to be associated with feeding lactating sows more frequently (*P* = 0.061). Feed origin was always associated with feed group (*P* < 0.001) with home millers only producing meal. Feed origin was also associated with feeding frequency in lactating sows (*P* = 0.013, farms home-milling fed more frequently) but not in gilts or gestating sows (*P* = 0.225 and *P* = 0.274, respectively). Feed group was associated with feeding frequency (*P* = 0.016, *P* = 0.027 and *P* < 0.001 for gestating sows, lactating sows and gilts respectively) with farms feeding wet-meal feeding more frequently.

5.3.2. Effect of feeding practices in sows and gilts, and average herd size on productive performance

The effect of feeding practices in sows (gestating and lactating) and in gilts, and average herd size on sow productive performance is presented in Table 5.4. The model for sow culling explained 19% of the variability. Farms feeding dry-pellets to lactating sows had lower cull rates (%) than farms feeding dry-meal (*P* = 0.015), and farms feeding gilts *ad libitum* had higher cull rates (%) than farms feeding gilts once per day (*P* = 0.018).

The model for sow mortality explained 22% of the variability. Farms feeding wet-meal to their gestating sows tended to have higher sow mortality than farms feeding dry-meal (*P* = 0.066). Also, farms feeding gestating sows more than once per day had lower mortality when compared to farms feeding gestating sows once per day (*P* < 0.001). Farms feeding lactating sows more than twice per day tended to have higher sow mortality when compared to farms feeding lactating sows twice per day (*P* = 0.092). Finally, feeding gilts specific diets tended to decrease sow mortality, when compared to farms feeding gestating/lactating sow's diets (*P* = 0.088).

The models for the number born alive per litter, and piglet mortality were significant but explained less than 15% of variability. The models for the number of litters per sow per year and number of piglets weaned per litter were not significant (*P* = 0.124 and *P* = 0.283, respectively).

Table 5.4. Multivariable linear regression modelling of sow productive performance indicators from feeding practices from sows (gestating and lactating), and gilts.

Model	Predictors	Estimate	SE	P-value
Sow culling (%)				
Adj. R^2= 0.19	Intercept	47.71	5.241	<0.001
P-value[1] = 0.010	LS feed group: dry-meal [Ref]	-	-	-
	LS feed group: dry-pellets	-13.43	5.541	0.015
	LS feed group: wet-meal	-2.10	5.463	0.586
	Gilts freq.: once [Ref]	-	-	-
	Gilts freq.: 2 or 3 times	5.06	4.254	0.241
	Gilts freq.: *ad libitum*	10.82	4.396	0.018
Log Sow mortality (%)				
Adj. R^2= 0.22	Intercept	1.29	0.190	<0.001
P-value[1] = 0.011	GS feed group: dry-meal [Ref.]	-	-	-
	GS feed group: dry-pellets	0.09	0.213	0.669
	GS feed group: wet-meal	0.36	0.192	0.066
	GS freq.: once	-	-	-
	GS freq.: more than once	-0.48	0.125	<0.001
	LS freq.: twice	-	-	-
	LS freq.: more than twice	0.21	0.121	0.092
	Gilts diet: GS [Ref.]	-	-	-
	Gilts diet: DS>LS | LS	-0.11	0.154	0.464
	Gilts diet: Gilts	-0.24	0.136	0.088

Legend:[1] *P*-value for the F-test for overall significance. GS – gestating sows; LS – lactating sows; feeding freq. – feeding frequency per day. Ref. – reference category.

5.3.3. Feeding practices from weaning to slaughter

The feeding practices from weaning to slaughter are summarised in Table 5.2. Only one farm did not provide creep feed and the number of peri-weaning diets provided ranged from one to three, with 71.4% of the farms providing only one type. Most farms were purchasing creep (87.3%) and 92.7% were feeding it dry. These diets were mostly fed as pellets (78.2%), or as meal (16.4%). A small proportion of farms (5.4%) reported feeding a mix between pellets and meal. A total of 92.8% of the farms also provided link feed in the weaner stage. Of these, a total of 78.8% of the farms were purchasing link, and it was fed dry in 86.5% of the farms. Link was provided as meal in 23.1% of the farms, as pellets in 71.1%, and 5.8% reported that their link was a mix between meal and pellets. Farms provided an average of 6.2 ± 3.05 kg of link per piglet.

Forty-eight percent of the farms provided 4 diets from birth to slaughter, while 26.8% provided 5 diets, and 25.0% provided more than 5 diets. From weaning to slaughter (excluding peri-weaning and link diets), 57.1% of the farms provided 2 diets, 25.0% of the farms provided 3 diets, and 17.9% provided more than 3 diets. In the finisher stage, only 21.4% of the farms provided more than one diet. From weaning to slaughter, 71,4% of the farms were purchasing their feed. While most of the farms were feeding these diets as meal (58.9%) or pellets (26.8%), 14.3% of the farms fed both meal and pellets. Similarly, there was 14.3% of farms feeding both wet and dry diets, while most farms fed either only dry (48.2%) or only wet (37.5) diets. All diets from weaning to slaughter were fed *ad libitum*.

Feed origin was not related to the number of diets from birth to slaughter, from weaning to slaughter or in the finisher stage ($P > 0.458$). Feed origin was associated with feed form ($P < 0.001$) but not with feed delivery ($P = 0.414$). Feed form and feed delivery were associated with each other ($P < 0.001$). Pellets were always associated with dry and purchased feed.

5.3.4. Effect of feeding practices in pigs from weaning to slaughter on productive performance

The effect of feeding practices from weaning to slaughter and average herd size on productive performance and feed cost is presented in Table 5.5. The model for average daily gain (ADG) explained 29% of the variability. The ADG impacted positively on the average live weight at slaughter ($P = 0.002$). On the other hand, ADG tended to decrease in bigger farms ($P = 0.098$). Although not significant, the number of peri-weaning feeds and the use of link were retained in the model having a positive effect on ADG ($P = 0.114$ and $P = 0.137$, respectively).

Table 5.5 Multivariable linear regression modelling of productive performance indicators from feeding practices from weaning to slaughter and herd characteristics.

Model	Predictors	Estimate	SE	P-value
ADG (g/day)				
Adj. R^2 = 0.29	Intercept	178.3	153.76	0.252
P-value[1]< 0.001	Average live weight at slaughter (kg)	4.77	1.422	0.002
	Average herd size	-0.02	0.014	0.098
	No. of peri-weaning diets[2]: 1 [Ref]	-	-	-
	No. of peri-weaning diets[2]: 2 or 3	27.71	17.168	0.114
	Link feed per weaner (kg)	4.54	2.993	0.137
Finisher mortality (%)				
Adj. R^2 = 0.27	Intercept	0.75	0.379	0.054
P-value[1]= 0.002	Average herd size [per 100 sows]	0.08	0.027	0.003
	Feed origin: Home-milling [Ref]	-	-	-
	Feed origin: Purchasing	0.82	0.301	0.010
	No. finishing diets: 1 [Ref]	-	-	-
	No. finishing diets: 2 or 3	0.64	0.288	0.033
	No. of peri-weaning diets[2]: 1 [Ref]	-	-	-
	No. of peri-weaning diets[2]: 2 or 3	0.43	0.282	0.135
Feed cost per kg dead (cents, €)				
Adj. R^2 = 0.39	Intercept	91.4	2.84	<0.001
P-value[1]< 0.001	Feed origin: Home-milling [Ref]	-	-	-
	Feed origin: Purchasing	7.78	1.811	<0.001
	No. diets from weaning to finishing: 2 [Ref]	-	-	-
	No. diets from weaning to finishing: 3	-0.95	2.354	0.688
	No. diets from weaning to finishing: >3	6.61	2.688	0.018
	Feed delivery: dry [Ref]	-	-	-
	Feed delivery: wet	-5.25	2.368	0.033
	Feed delivery: both	2.31	2.509	0.363
	Link feed per weaner (kg)	0.60	0.373	0.115

Legend:[1] *P*-value for the F-test for overall significance. ADG – average daily gain (g/day), Adj. R^2 – adjusted R^2; Ref. – reference category. [2]Diets provided to the piglet before weaning or immediately after weaning including milk replacer, pre-starter and starter diets.

The model for finisher mortality explained 27% of the variability. Finisher mortality was higher in bigger farms (P = 0.003), and farms purchasing their weaning to slaughter diets had higher finisher mortality when compared to farms home-milling (P = 0.010). Farms with two or three finisher feeds also had higher mortality in finishers, when compared to farms with one finisher feed (P = 0.033). Although not significant the use of more peri-weaning feeds was retained in the model (P = 0.135).

The model for feed cost explained 39% of the variability. Farms purchasing their weaning to slaughter diets paid more for their feed when compared to farms home-milling them (P < 0.001). Farms with more than three diets had higher feed cost when compared to farms with two diets (P = 0.018). Farms feeding exclusively wet diets from weaning to slaughter had lower feed cost than farms providing dry feed (P = 0.033).

The models for pigs produced per sow per year, ADFI and age at sale were significant but explained less than 15% of variability. The models for weaner mortality and FCR were not significant (P = 0.052 and P = 0.097, respectively).

5.4. Discussion

The objectives of this study were to describe the current feeding practices employed in Irish farrow-to-finish pig farms and to study the impact of such practices on productive performance, including mortality, and feed cost.

Our description of the feeding practices in Irish pig farms reveal, as hypothesised, a wide variety of practices. In this sample, 42.9% of the farms were home-milling at least one diet, and 51.8% of the farms were feeding wet diets in at least one of the production stages from weaning to slaughter. Phase-feeding does not appear to be implemented in many Irish farms, with 78.6% of the farms providing only one finisher diet. However, this finding may be related with the late transfer of growers to finisher accommodation, which also coincides with the change to finisher diets. This may explain part of the higher feed cost reported by Irish farms in the annual InterPIG reports (AHDB, 2017).

Although several variables related to sow productivity were included in the multivariable analysis, only sow culling and mortality had models with feeding practices explaining more than 15% of the variability by the feeding practices described. Feeding dry-pellets to lactating sows was related to lower sow culling, when compared to farms feeding dry-meal. This result is difficult to explain. Feed pelleting has actually been associated with the development of gastric ulcers and keratinization (De Jong *et al.*, 2016; Mößeler *et al.*, 2012), which would produce the opposite effect. On the other hand, pellet was associated with feed purchased from big commercial mills which in general have more quality controls in place, resulting in less contaminated feedstuffs being used. The main reasons for sow culling are lameness and infertility (Stalder *et al.*, 2004), thus a possible explanation for the lower culling with pellets could be a lower presence of mycotoxins which often induce reproductive problems (Kanora and Maes, 2009). However, feed origin was not significant in this model. Culling rates were also higher for farms feeding gilts *ad libitum* compared to farms feeding gilts once per day. In a review on sow longevity, Stalder *et al.* (2004) point that over-feeding may lead to excessive weight gain and increased culling rate as a consequence of lameness in sows. Fabà *et al.* (2018) found similar results. According to Stalder *et al.* (2004), several studies reported that limiting energy intake during rearing impacted sow longevity positively.

Sow mortality was related to the use of wet-meal feeding in gestating sows compared to dry-meal. Again, this association is difficult to explain. In gestation, wet systems are related to troughs while dry systems are related to both troughs and (often) electronic feeding stations that allow individual feeding. Farms feeding their gestating sows more often had lower sow mortalities. Abiven *et al*. (1998) studied risk factors for high sow mortality in French herds and found similar associations. In their study, lower feeding frequency and feeding in groups were related to higher sow mortality. However, these authors also found that 67% of the farms feeding dry-meal to gestating sows had high sow mortality, and only 32% of the farms feeding wet-meal had such a problem which is in conflict with these results. The results also showed that farms feeding lactating sows twice per day had lower sow mortality than those farms feeding lactating sows more than twice per day. Abiven *et al*. (1998) also reported a higher risk of mortality for farms feeding lactating sows *ad libitum* and showed a tendency in which higher amounts of feed seemed to lead to an increased likelihood of higher sow mortality. Finally, feeding gilts a specific diet also decreased sow mortality, when compared to farms feeding gilts with gestating sows' diets. Likewise, farmers feeding gilts with specifically formulated diets suggest that their gilt rearing and management is satisfying the requirements for the gilts proper development and this is commonly associated with sow longevity (Solà-Oriol and Gasa, 2017; Stalder *et al.*, 2004; Stalder *et al.*, 2000).

Regarding the general productive performance indicators in growing pigs, only the models for ADG and finisher mortality explained more than 15% of variability. The average live weight at slaughter was positively associated with ADG. It was also associated with ADFI but not to FCR (models not shown). This association makes sense in the range of slaughter weights of Irish pigs because they fall in the linear section of the growth curve. The average herd size also tended to be associated with ADG although, having a negative impact. In a study analysing production parameters and production cost over time (2010-2014) in Spain, Rocadembosch *et al.* (2016) concluded that herd size affected negatively most performance indicators, including ADG in nursery and finishing stages. The authors suggested that smaller farms, with fewer employees, may have better compliance with standard operating procedures on-farm. The scale to which farms were classified as big or small was however much different when comparing that study to the present study: Spanish farms were considered small if the number of sows was less than 5000, and the biggest herd in study had approximately 2500 sows. Nevertheless, the explanation may be similar. Agostini *et al.* (2013) described the factors affecting performance in 452 growing-finishing pig farms in Spain and found the same association, with herd size affecting negatively ADG, the total duration of the finishing period, and grower-finisher mortality rate. The number of peri-weaning diets and the amount of link diet provided were also retained in the model although they were not statistically significant. Still, it is interesting to notice that the direction of their correlation is positive for farms providing several diets as a method to adapt the piglet to a solid plant-based diet. This observation would support the importance of the use of creep and link diets for a good growth during the whole growing period.

The model for finisher mortality suggests that larger farms have also higher mortality. This was also reported by Agostini *et al.* (2014; 2013) when assessing management factors affecting finisher mortality in Spanish farms. The authors suggested pigs in larger herds may have received less supervision from farm workers. Conversely, Rocadembosch *et al.* (2016) did not find any correlation between finisher mortality and average herd size. One possible explanation could be the higher risk of infection due to frequent animal movements in bigger farms, as described by Gardner *et al.* (2002). Farms purchasing feed from weaning to slaughter also had higher finisher mortality when compared to farms home-milling. One possibility is that purchased feed, normally in pellet form, have higher amounts of fine particles, leading to ulcers. This could also be an explanation to the association between farms using two or three finisher diets, instead of only one, and higher finisher mortality. Those farms home milling are limited to one or maximum two diets for finisher pigs and farms doing phase feeding are normally purchasing pelleted feed from commercial mills.

Finally, the feed cost's variability was explained by 39% with the model fitted. Three factors were impacting on feed cost: feed origin, the number of diets from weaning to slaughter, and feed delivery. As expected, farms purchasing the feed had higher feed cost than those home-milling. Farms with more than 3 diets from weaning to slaughter also had higher feed cost when compared to farms with 2 diets in that period. This result is not in accordance with published research indicating that phase-feeding results in a more economical feeding program (Han *et al.*, 2000). However, Brossard *et al.* (2009), when modelling the variation in performance of a population of growing pigs affected by lysine supply and phase-feeding, concluded that the knowledge of nutrient requirements becomes more critical when a greater number of diets are used. Thus, it is possible that the provision of more than 3 diets was not being correctly evaluated on farm before its implementation.

Overall, these results corroborate the importance of feed in pig production. Apart from diet formulation and quality, and the use of feed additives, feeding practices also explain a significant part of the variability of the productive performance indicators here discussed. This research also shows the complex relationships between different feeding practices due to practical limitations. The data captured revealed great variability in feeding practices across Irish pig farms. This variability is important to compare different feeding practices, but it also makes the categorisation of farms difficult. In addition, many feed related factors known to impact productive performance were not considered in this study. A few relevant examples are the diet quality and nutritional composition, feeder type or in-feed antimicrobials and zinc oxide. Finally, although we found significant associations between feeding practices and productive performance indicators, the observational nature of this study precludes the inference of causation. Instead, these associations represent possible areas where attention by pig farmers or further research could be beneficial.

Chapter 6. Effect of respiratory disease on productive performance in pig farms

6.1. Introduction

Respiratory disease is known to be one of the most important factors impacting on pig production worldwide. The increase of herd size and stocking densities over the years coupled with keeping pigs indoors translates into higher pressure of infection and higher potential to cause losses (VanAlstine, 2012). However, the literature describes conflicting information regarding the effects of respiratory disease on performance (Pagot *et al.*, 2007; Straw *et al.*, 1990; Wilson *et al.*, 1986). Many experimental studies have described the influence of specific diseases, such as Porcine Reproductive and Respiratory Syndrome virus (PRRSv), *Actinobacillus pleuropneumoniae* (APP) and *Mycoplasma hyopneumoniae* (MHyo) infections on farm productive performance (Byrt *et al.*, 1985; Nathues *et al.*, 2017; Neumann *et al.*, 2005; Straw *et al.*, 1990), although most highlight the multitude of confounding factors complicating the clear attribution of growth impairment to respiratory disease (Pagot *et al.*, 2007; Straw *et al.*, 1990). The extrapolation of these effects to a wider population has not been thoroughly researched yet. In recent cross-sectional studies, the aim has been to correlate lung lesion patterns with serology or with risk factors for the development of respiratory infections on farm (Alawneh *et al.*, 2018; Fablet *et al.*, 2012a; Fablet *et al.*, 2012b; Meyns *et al.*, 2011; Wellenberg *et al.*, 2010).

Veterinary practitioners carry out regular diagnostics to monitor the health status of pig farms and the efficacy of disease control measures, like vaccination (Ramirez and Karriker, 2012). Slaughterhouse checks, including lung scoring and the recording of other lesions like pericarditis and milk spots on the liver (caused by *Ascaris suum*) are cheap monitoring tools, allowing the collection of data from several farms at one point in space and time (Correia-Gomes *et al.*, 2016). Serology of finisher pigs at slaughter also allows to screen for several pathogens and to draw the prevalence of infection or the efficacy of vaccination on farm (Elbers *et al.*, 1990; Regula *et al.*, 2000). Combining slaughterhouse checks and serology with information on the vaccination protocols is useful to infer about the farms' health status towards respiratory disease.

In Ireland, there is no available information on the prevalence of key pathogens implicated in pig production. Likewise, the future implementation of control and eradication plans demand the characterization of the national herd health status (Greiser-Wilke *et al.*, 2003). This national characterization is also important at farm level given its susceptibility to new outbreaks when the regional disease prevalence is high, or neighbour farms are infected.

Thus, this study aimed 1) to describe seroprevalence for four main pathogens related to respiratory disease: Swine Influenza Virus (SIV), PRRSv, MHyo and APP in Irish farrow-to-finish pig farms, 2) to describe the prevalence of pleurisy, pneumonia, pericarditis and milk spots in finisher pigs of those farms, and 3) to estimate the impact respiratory disease on productive performance.

6.2. Material and methods

Data on lung lesions, presence of pericarditis and milk spots on the liver, and blood samples were obtained through visits to eight slaughterhouses (seven in the Republic of Ireland and one in Northern Ireland, UK) from November 2017 to April 2018, targeting 56 Irish farrow-to-finish pig farms. One batch per farm was assessed. A batch was defined as all the finisher pigs from a given farm killed in a slaughterhouse in the same day. Performance data for 2017 for each farm were retrieved from Teagasc e-Profit monitor (ePM). Vaccination data were obtained through phone calls to farmers and corresponding private veterinary practitioners (PVPs) during the same period. First, a descriptive analysis of the information gathered is presented. Second, we present the effects of vaccination and seroprevalence to SIV, PRRSv, MHyo and APP on productive performance and its connections with lung lesions.

6.2.1. Farm selection and productive performance indicators and farm characteristics

In 2017, the Teagasc ePM included 107 pig herds representing over 77,000 sows or 52% of the national commercial sow herd (Teagasc, 2018). As stated before, the farms surveyed in Chapters 4 and 5 were enrolled in the Teagasc advisory system and provided data to the Teagasc ePM. The surveyed herds were targeted and followed at slaughter. These farms represented 29.2% of the national commercial sow herd. Performance data from the year 2017 were retrieved from the Teagasc ePM.

The productive performance indicators used were percentage of weaner and finisher mortality, number of pigs produced per sow per year, average daily feed intake from weaning to slaughter (ADFI), average daily gain from weaning to slaughter (ADG), feed conversion ratio from weaning to slaughter (FCR) and age at sale.

6.2.2. Blood sampling and pluck examinations at slaughter

In the slaughterhouse, blood was collected from a total of 32 randomly selected pigs per farm at sticking. Samples were transported for analysis to the Blood Testing Lab of the Department of Agriculture Food and the Marine (Cork, Ireland). Blood was allowed to clot at room temperature, serum was separated into aliquots and frozen at -80ºC until testing. For analysis, 16 samples per farm for PRRSv and MHyo, and 32 samples per farm for SIV and APP were used. The number of samples to be analysed for each disease was decided based on preliminary prevalence data obtained on a pilot study.

Pluck examinations were all carried out by the same veterinarian. For each pig, lung lobes were scored for pneumonia lesions according to the method described by Madec and Kobisch (1982) with the overall surface affected averaged accounting for lobe weights (Christensen *et al.*, 1999). The variables prevalence of pneumonia (%) and average surface affected out of pneumonic lungs (%), hereinafter called (lung) surface with pneumonia (%), were used for statistical analysis. Pleurisy was scored in the dorsocaudal lobes using a modified version of the Slaughterhouse Pleurisy Evaluation System (SPES) developed by Dottori *et al.* (2007) and described by Merialdi *et al.* (2012). The scores were 0 (no pleurisy), 2 (focal lesions in one lobe), 3 (bilateral adhesions or monolateral lesions affecting more than 1/3 of the diaphragmatic lobe), and 4 (extensive lesions affecting more than 1/3 of both diaphragmatic lobes). The prevalence of pleurisy (lesions with SPES ≥ 2) and the prevalence of scores 3 and 4 (prevalence of moderate or severe dorsocaudal pleurisy) were used for statistical analysis. Cranial pleurisy (adhesions between lobes, in the surface of the apical and cardiac lobe, and/or adhesions between the lung and the heart), which would correspond to score 1 of the original SPES, and scars (healing indicative of pneumonic lesions which developed earlier in the pig's life) were recorded as absent or present and used in the analysis. Thus, all pleurisy-related variables were: pleurisy, moderate and severe pleurisy and cranial pleurisy, while pneumonia-related variables were: pneumonia, lung surface with pneumonia and scars. Lung abscesses (presence of one or more abscesses in the lung) were also recorded. Other recordings included pericarditis (defined as an adhesion between the heart and the pericardium (Welfare Quality®, 2009)), milk spots (presence of white spots in the liver indicative of transhepatic migration of the larvae of *Ascaris suum* (Welfare Quality®, 2009) on the liver.

6.2.3. Serology

Seroprevalence of antibodies against SIV, PRRSv, MHyo and APP Apx IV were determined using the following IDEXX ELISA kits (Westbrook, Maine, USA) respectively: Influenza A Ab Test (80-93% sensitivity, 100% specificity), PRRSv X3 Ab

Test (98.8% sensitivity, 99.9% specificity), HerdChek *Mycoplasma hyopneumoniae* Antibody Test (100% sensitivity, 99.7% specificity), and APP-ApxIV Ab Test (82.9% sensitivity, 99.6% specificity). Following the manufacturers' recommendations each pig was considered positive to: SIV if their S/N-value (sample to negative[1]) was less than 0.6, PRRSv if their S/P value (sample to positive[2]) was greater or equal to 0.4, MHyo if their S/P values were greater than 0.4, and to APP if their S/P values were greater or equal to 0.5. ELISA results were transcribed into three variables per infectious pathogen: farm positivity (farms were considered positive if at least one animal tested positive in the ELISA test), on-farm prevalence (number of pigs positive divided by the total number of pigs tested per farm), and average S/P value or S/N value (in the case of SIV) on farm.

6.2.4. Vaccination

The main vaccination protocols on farm were recorded, with special focus on vaccination for SIV, PRRSv, MHyo and APP in sows and in piglets, as present or absent. The variables retained for further analysis were vaccination for SIV and PRRSv in sows, and vaccination for MHyo and APP in piglets.

6.2.5. Statistical analysis

All statistical procedures were performed in R version 3.4.4 (Vienna, Austria, https://www.R-project.org/). Alpha level for significance and tendency were 0.05 and 0.10, respectively. Productive performance indicators were used as dependent variables. Vaccination, serology, pluck lesions, average herd size and average live weight at slaughter were used as predictors or independent variables. First, a univariable analysis was carried out to study the associations between productive performance indicators and each one of the predictors. Associations between categorical variables (vaccination and serology positivity) and productive performance indicators were tested using Kruskal Wallis test. Correlations between serology, pluck lesions and farm productive performance indicators were tested using Spearman rank correlations. Then the effect of vaccination, serology and pluck lesions on productive performance indicators was estimated through multivariable linear models. A forward regression approach was used to improve the models fitted (ols_step_forward_p function from the olsrr package in R (Hebbali, 2017) using a cut-off value of 0.10 for

[1] Corresponds to the ratio of the optical density (O.D.) of the sample (spectrophotometry) divided by the mean O.D. of the negative control.
[2] Corresponds to the ratio of O.D. of the sample divided by the mean O.D. of the positive control.

predictor retention in the model. Two-way interactions were also investigated and retained when relevant. Collinearity among predictors was initially assessed by Spearman rank correlations and those showing r_s > 0.70 were considered collinear. Further checks of collinearity were carried out using Variance Inflation Criterion (VIF) from the R package rms (Harrel Jr, 2018). Colinear variables were removed manually from the multivariable model retaining the one with the highest association to the dependent variable (largest coefficient for numerical variables or lowest p-value for categorical variables). Normality of the residuals was visually assessed for all the models.

6.3. Results

6.3.1. Farm performance and herd characteristics

A summary of the farm performance and herd characteristics is shown in Table 6.1. A total of 56 farrow-to-finish farms were included in this study. The average herd size of the farms was 789 ± 564.1, with a range from 109 to 2498 sows. The average live weight at which pigs were sent to slaughter in these farms was 111 ± 4.9 kg, as per the sale target defined by each farmer. In this sample, pigs were weaned at 29.8 ± 4.27 d of age.

Table 6.1. Description of productive performance indicators in 56 Irish farrow-to-finish pig farms for the year 2017.

Productive performance indicators	Mean	± SD	Median	Min	Max	N
Herd characteristics						
Average herd size [a]	789	564.1	659	109	2498	56
Average live weight at slaughter (kg)	111	4.9	110	102	121	55
Productive performance indicators						
Weaner mortality (%)	2.8	1.61	2.7	0.5	8.9	55
Finisher mortality (%)	2.0	0.76	1.8	0.9	4.1	55
No. pigs /sow-year	26.7	2.23	26.5	21.8	32.0	56
ADFI (g/day)	1740	121.3	1755	1495	2044	54
ADG (g/day)	726	62.6	725	538	903	55
FCR	2.38	0.110	2.38	2.21	2.68	56
Age at sale (d)	174	11.8	172	148	208	55

Legend: [a] No. of sows. Legend: Data retrieved from the Teagasc e-ProfitMonitor; ADFI – Average daily feed intake; ADG – Average daily gain; FCR – Feed conversion ratio; No. pigs /sow-year – Number of pigs produced(/sold) per sow per year.

6.3.2. Vaccination for SIV, PRRSv, MHyo and APP and farm serology results

A total of 39.3 and 42.9% of the farms were vaccinating sows for SIV and PRRSv, respectively. Additionally, one farm reported also vaccinating piglets for SIV, and five farms were also vaccinating piglets for PRRSv. A total of 76.8% of the farms were vaccinating for MHyo, although only 73.2% were covering piglets. Among the farms vaccinating piglets, 39% referred giving a double shot. APP vaccination was only used in five farms (8.9%), all of them vaccinating weaner pigs and one farm was also vaccinating sows for APP. Approximately 94.6% of the farms were vaccinating for PCV2 (Porcine circovirus type 2), 80.4% were vaccinating for E. Coli, 17.9% were vaccinating for Clostridium spp., and 7.1% reported vaccinating for atrophic rhinitis. All farms were vaccinating their sows for Porcine Parvovirus and *Erysipelothrix rhusiopathiae,* and none was vaccinating for *Haemophilus parasuis*.

Serology positivity at farm level was 78.6% for SIV, 58.9% for PRRSv, 78.6% for MHyo, and 98.2% for APP. The prevalence for the different diseases was (all values are mean ± SD; parenthesis shows mean ± SD only for positive farms) 39.5 ± 32.95% (50.3 ± 28.88%) for SIV, 49.5 ± 48.43% (83.9 ± 32.34%) for PRRSv, 67.2 ± 42.38% (85.6 ± 32.45%) for MHyo, and 74.7 ± 29.69% (76.0 ± 28.15%) for APP. The average S/N values for SIV were 0.7 ± 0.26 (0.6 ± 0.24), and the average S/P-values for PRRSv, MHyo and APP were: 0.7 ± 0.74 (1.2 ± 0.57), 1.0 ± 0.67 (1.2 ± 0.52), and 1.0 ± 0.50 (1.0 ± 0.49), respectively.

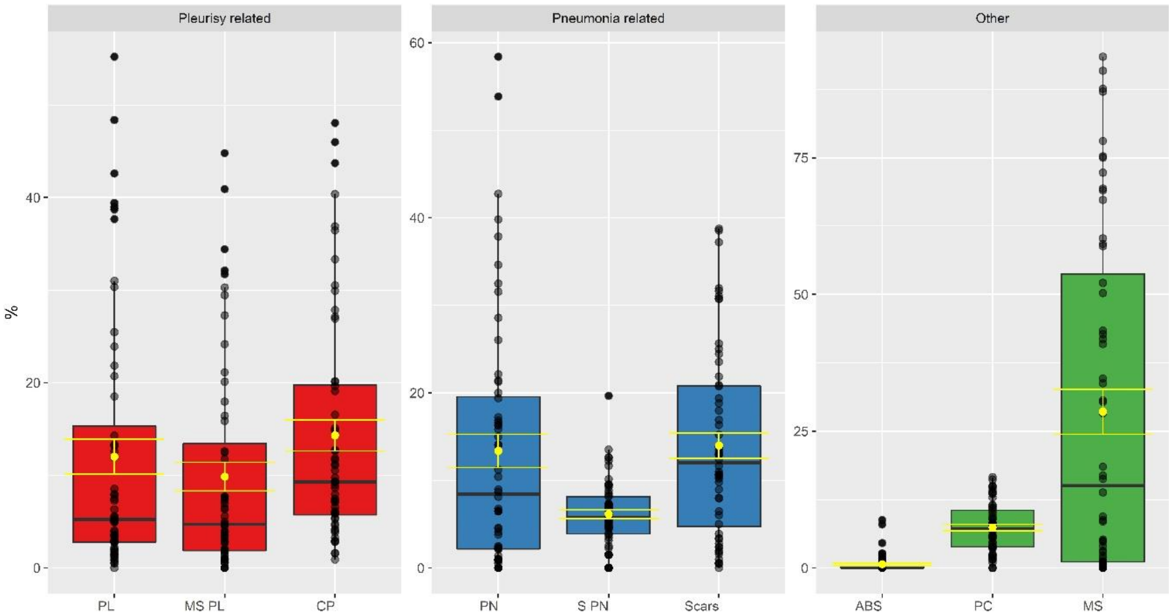
Positivity, vaccination, prevalence and S/P values were highly correlated ($r_s > 0.72$) for PRRSv and MHyo. For SIV and APP only prevalence and S/P or S/N showed high correlation values ($r_s > 0.88$). The prevalence of MHyo was correlated with the prevalence of SIV and PRRSv on farm ($r_s = 0.53$ and $r_S = 0.46$, $P < 0.001$). The prevalence of PRRSv on farm was weakly correlated with the prevalence of SIV, or the prevalence of APP ($r_s = 0.30$, $P = 0.024$ and $P = 0.022$, respectively).

6.3.3. Pluck lesions

The prevalence of the lung lesions, pericarditis and milk spots recorded at slaughter is presented in Figure 6.1. A total of 9254 plucks were assessed at slaughter. On average, each farm had 162 ± 52 plucks assessed (range 55 - 308). The prevalence (mean ± SD) of pleurisy at farm level was 12.0 ± 14.15%, mostly moderate or severe

(9.9 ± 11.59%), and 14.3 ± 12.58% of lungs showed cranial pleurisy. The prevalence of pleurisy was highly correlated to moderate and severe pleurisy (r_s = 0.99) and cranial pleurisy (r_s = 0.88). The prevalence of pneumonia was 13.4 ± 14.21%, the surface with pneumonia was 6.2 ± 3.88% and 14.0 ± 10.80% of the lungs had scars. The prevalence of abscesses, pericarditis and milk spots were 0.7 ± 1.73%, 7.4 ± 4.52%, and 28.6 ± 30.94%, respectively.

Figure 6.1. Prevalence (%) of lung lesions, pericarditis and milk spots on the liver of finisher pigs of 56 Irish farrow-to-finish pig farms for the year 2017 (mean ± SE in yellow).



[a] Average lung surface affected out of bronchopneumonic lungs. Each dot represents a farm.
Legend: PL – Pleurisy; MS PL – Moderate and severe pleurisy; CP – Cranial Pleurisy; PN – Pneumonia; S PN – Surface with pneumonia; ABS – Lungs with abscesses; PC – Pericarditis; MS – Milk spots on the liver.

6.3.4. Estimating productive performance indicators from the vaccination and serology for SIV, PRRSv, MHyo and APP and pluck lesions

The univariable analyses of the vaccination, serology and slaughterhouse checks variables with the productive performance are presented in Tables 6.2 to 6.5. In table 6.2, productive performance indicators were worse (P < 0.05) in all cases except for FCR for those farms vaccinating for PRRSv than for those not vaccinating. Farms vaccinating for MHyo also showed higher weaner and finisher mortality (P < 0.01), less pigs per sow per year (P = 0.016) and tended to have higher ADFI (P = 0.089) and age at sale (*P* = 0.052) than those not vaccinating. Vaccination for APP did not affect any of the performance indicators and those farms vaccinating for SIV had higher weight at sale (*P* = 0.014) than those not vaccinating.

Table 6.2. Differences in performance according to vaccination for SIV, PRRSv, Mhyo and APP.

	SIV sows	PRRSv sows	MHyo piglets	APP piglets
No. Farms vaccinating (%)	22 (39.3)	24 (42.9)	43 (76.8)	5 (8.9)
Weaner mortality (%)	Yes: 2.9 ± 1.43 No: 2.7 ± 1.73 *P* = 0.257	Yes: 3.3 ± 1.15 No: 2.3 ± 1.79 *P* < 0.001	Yes: 3.1 ± 1.68 No: 1.9 ± 0.94 *P* = 0.003	Yes: 2.7 ± 1.44 No: 2.8 ± 1.64 *P* = 1.000
Finisher mortality (%)	Yes: 2.1 ± 0.80 No: 1.9 ± 0.74 *P* = 0.414	Yes: 2.2 ± 0.82 No: 1.8 ± 0.67 *P* = 0.047	Yes: 2.1 ± 0.75 No: 1.6 ± 0.66 *P* = 0.008	Yes: 2.0 ± 0.68 No: 2.0 ± 0.78 *P* = 0.907
No. pigs /sow-year	Yes: 26.6 ± 2.00 No: 26.8 ± 2.40 *P* = 0.557	Yes: 26.1 ± 2.02 No: 27.2 ± 2.30 *P* = 0.048	Yes: 26.3 ± 2.23 No: 27.8 ± 1.84 *P* = 0.016	Yes: 27.4 ± 1.65 No: 26.6 ± 2.28 *P* = 0.464
ADFI (g/day)	Yes: 1716 ± 124.1 No: 1755 ± 119.0 *P* = 0.316	Yes: 1698 ± 112.4 No: 1771 ± 119.9 *P* = 0.046	Yes: 1720 ± 111.7 No: 1790 ± 134.7 *P* = 0.089	Yes: 1708 ± 174.0 No: 1743 ± 116.7 *P* = 0.687
ADG (g/day)	Yes: 708 ± 74.9 No: 739 ± 50.3 *P* = 0.149	Yes: 706 ± 66.8 No: 743 ± 55.0 *P* = 0.042	Yes: 716 ± 59.9 No: 753 ± 63.8 *P* = 0.126	Yes: 729 ± 55.0 No: 726 ± 63.8 *P* = 0.953
FCR	Yes: 2.40 ± 0.104 No: 2.37 ± 0.107 *P* = 0.486	Yes: 2.38 ± 0.113 No: 2.39 ± 0.101 *P* = 0.417	Yes: 2.39 ± 0.108 No: 2.37 ± 0.099 *P* = 0.617	Yes: 2.30 ± 0.007 No: 2.40 ± 0.110 *P* = 0.294
Age at sale (d)	Yes: 179 ± 12.2 No: 170 ± 10.3 *P* = 0.014	Yes: 178 ± 12.8 No: 171 ± 10.0 *P* = 0.014	Yes: 176 ± 12.0 No: 169 ± 10.0 *P* = 0.052	Yes: 172 ± 7.05 No: 174 ± 12.2 *P* = 0.884

Legend: [a] Differences were estimated using Kruskal Wallis tests; ADFI – Average daily feed intake; ADG – Average daily gain; FCR – Feed conversion ratio; No. pigs /sow-year – Number of pigs produced(/sold) per sow per year. SIV sows – farms vaccinating sows for SIV; PRRSv sows – farms vaccinating sows for PRRSv, MHyo piglets – farms vaccinating piglets for MHyo; APP piglets – farms vaccinating piglets/growers for APP.

In Table 6.3 and 6.4, positivity and higher prevalence of SIV were only associated with higher age at sale (*P* < 0.05). Positivity, higher prevalence and higher S/P values for PRRSv were associated with higher weaner mortality (*P* < 0.01) and age at sale (*P* < 0.01), and lower ADG and ADFI (*P* < 0.05). Positivity to MHyo was associated with lower ADFI (*P* = 0.040), higher age at sale (*P* = 0.046), and tended to be associated with higher weaner mortality (*P* = 0.097). A higher S/P value for APP was associated with lower ADG (*P* = 0.025) and higher age at sale (*P* = 0.009).

Table 6.3. Differences in performance according to serology positivity on farm.

	SIV	**PRRSv**	**MHyo**
Weaner mortality (%)	Pos.: 2.8 ± 1.39 Neg.: 2.6 ± 2.3 *P* = 0.166	Pos.: 3.2 ± 1.39 Neg.: 2.2 ± 1.77 *P* = 0.002	Pos.: 2.9 ± 1.71 Neg.: 2.1 ± 0.97 *P* = 0.097
Finisher mortality (%)	Pos.: 2.1 ± 0.78 Neg.: 1.8 ± 0.69 *P* = 0.421	Pos.:2.1 ± 0.80 Neg.: 1.9 ± 0.70 *P* = 0.384	Pos.: 2.1 ± 0.76 Neg.: 1.7 ± 0.71 *P* = 0.103
No. pigs /sow-year	Pos.: 26.7 ± 2.21 Neg.: 26.6 ± 2.39 *P* = 0.897	Pos.: 26.5 ± 2.03 Neg.: 27.0 ± 2.50 *P* = 0.355	Pos.: 26.5 ± 2.33 Neg.: 27.5 ± 1.63 *P* = 0.106
ADFI (g/day)	Pos.: 1725 ± 109.6 Neg.: 1793 ± 148.8 *P* = 0.173	Pos.: 1703 ± 111.1 Neg.: 1789 ± 119.3 *P* = 0.015	Pos.: 1720 ± 110.2 Neg.: 1810 ± 136.5 *P* = 0.040
ADG (g/day)	Pos.:716 ± 60.9 Neg.: 763 ± 57.0 *P* = 0.032	Pos.: 710 ± 64.2 Neg.: 750 ± 53.3 *P* = 0.025	Pos.:717 ± 59.8 Neg.: 759 ± 64.4 *P* = 0.117
FCR	Pos.: 2.39 ± 0.105 Neg.: 2.35 ± 0.105 *P* = 0.201	Pos.: 2.38 ± 0.113 Neg.: 2.38 ± 0.096 *P* = 0.758	Pos.: 2.38 ± 0.107 Neg.: 2.38 ± 0.103 *P* = 0.913
Age at sale (d)	Pos.: 176 ± 11.6 Neg.: 166 ± 9.8 *P* = 0.025	Pos.:178 ± 12.4 Neg.: 168 ± 8.3 *P* = 0.002	Pos.: 175 ± 11.8 Neg.: 168 ± 9.9 *P* = 0.046

Legend: [a] Differences were estimated using Kruskal Wallis tests. [b] Results for APP are not presented as there was only one farm negative to APP. Legend: ADFI – Average daily feed intake; ADG – Average daily gain; FCR – Feed conversion ratio; No. pigs /sow-year – Number of pigs produced(/sold) per sow per year; Pos.: positive – farms positive (at least one animal positive in the ELISA test) to the respective infectious agent; Neg.: negative – farms negative (all animals negative in the ELISA test) to the respective infectious pathogen.

Table 6.4. Correlations between productive performance and serology: prevalence and average S/N or S/P values per farm.

	SIV prev. (%)	PRRSv prev. (%)	Mhyo prev. (%)	APP prev. (%)	SIV SN	PRRSv SP	Mhyo SP	APP SP
Weaner mortality (%)	0.10	0.36 **	0.30	0.04	-0.10	0.36 **	0.21	0.14
Finisher mortality (%)	0.16	0.24	0.19	0.12	-0.16	0.25	0.19	0.11
No. pigs /sow-year	0.11	-0.21	-0.27	-0.07	-0.08	-0.21	-0.23	-0.03
ADFI (g/day)	-0.23	-0.41 **	-0.23	-0.14	0.23	-0.42 **	-0.16	-0.14
ADG (g/day)	-0.22	-0.36 **	-0.21	-0.24	0.19	-0.37 **	-0.11	-0.30 *
FCR	0.10	0.00	0.10	0.15	-0.03	-0.01	0.07	0.21
Age at sale (d)	0.33 *	0.45 ***	0.25	0.28	-0.28	0.46 ***	0.16	0.35 **

Legend: [a] All the correlations were estimated using Spearman rank correlations. Legend: ADFI – Average daily feed intake; ADG – Average daily gain; FCR – Feed conversion ratio; No. pigs /sow-year – Number of pigs produced(/sold) per sow per year; SIV prev. – Average prevalence of pigs positive to SIV on farm; PRRSv prev. – average prevalence of pigs positive to PRRSv on farm; MHyo prev. – Average prevalence of pigs positive to MHyo on farm; APP prev. – average prevalence of pigs positive to APP on farm; SIV SN – Average S/N values for SIV on farm; PRRSv SP – average S/P values for PRRSv on farm; MHyo SP – average S/P values for MHyo on farm; APP SP – average S/P values for APP on farm. Significance levels: *** $P < 0.001$, ** $P < 0.01$, * $P < 0.05$.

Regarding the pluck lesions (Table 6.5), higher levels of pleurisy were associated to lower ADG and higher age at sale ($P = 0.001$). Higher levels of cranial pleurisy were associated with higher weaner mortality ($P = 0.002$), FCR ($P = 0.020$) and age at sale ($P < 0.001$), and lower ADFI ($P = 0.012$) and ADG ($P < 0.001$). A higher surface of the lungs affected by pneumonia was associated with lower ADFI and ADG ($P = 0.011$ and $P = 0.018$, respectively), while higher levels of scars and pericarditis were associated with higher weaner mortality ($P = 0.001$ and $P = 0.006$, respectively). A higher scar level was also associated with less pigs per sow per year ($P = 0.015$).

Table 6.5. Correlations between productive performance and pluck lesions.

	PL (%)	MS PL (%)	CP (%)	PN (%)	S PN (%)	Scars (%)	ABS (%)	PC (%)	MS (%)
Weaner mortality (%)	0.3	0.28	0.41 **	-0.02	0.17	0.43 **	-0.03	0.37 **	-0.02
Finisher mortality (%)	0.17	0.16	0.27	0.07	0.05	0.26	0.27	0.04	-0.25
No. pigs /sow-year	-0.04	-0.04	-0.09	0.12	-0.07	-0.32 *	0	-0.07	-0.07
ADFI (g/day)	-0.23	-0.24	-0.34 *	-0.11	-0.34 *	-0.16	0.11	0.1	-0.2
ADG (g/day)	-0.39 **	-0.39 **	-0.49 ***	-0.17	-0.32 *	-0.23	0.02	-0.01	-0.14
FCR	0.23	0.2	0.31 *	0.15	0.14	0.24	0.17	0.13	-0.01
Age at sale (d)	0.44 ***	0.41 **	0.52 ***	0.1	0.29	0.11	0.05	0.11	0.08

Legend: [a] All the correlations were estimated using Spearman rank correlations. Legend: ADFI – Average daily feed intake; ADG – Average daily gain; FCR – Feed conversion ratio; No. pigs /sow-year – Number of pigs produced(/sold) per sow per year; PL – Pleurisy; MS PL – Moderate and severe pleurisy; CP – Cranial Pleurisy; PN – Pneumonia; S PN – Surface with pneumonia; ABS – Lungs with abscesses; PC – Pericarditis; MS – Milk spots on the liver. Significance levels: *** $P < 0.001$, ** $P < 0.01$, * $P < 0.05$.

The multivariable linear models fitted for each productive performance indicators are presented in Table 6.6 and were able to explain 8.2 to 47% of variability. Only those models explaining more than 15% of the variability are shown in the table.

The model for weaner mortality explained 26% of the variability. Weaner mortality was positively associated with the prevalence of scars at slaughter (P = 0.019), and it tended to be higher in farms with higher prevalence of cranial pleurisy (P = 0.099) and higher prevalence of pericarditis (P = 0.085). The model for finisher mortality explained 20% of the variability. Finisher mortality was higher in bigger farms (P = 0.028) and in farms vaccinating piglets for MHyo (P = 0.046) when compared to farms not vaccinating for MHyo, while it tended to be positively associated with higher prevalence of lung abscesses (P = 0.065).

Table 6.6. Multivariable linear regression modelling of productive performance indicators from herd characteristics and vaccination protocols, and serology results and pluck lesions from finisher pigs of 56 farrow-to-finish Irish pig farms.

Models	**Predictors**	**Estimate**	**SE**	**P-value**
Weaner mortality (%)	Intercept	1.16	0.404	0.006
Adjusted R^2 = 26%	Cranial pleurisy (%)	2.81	1.670	0.099
P-value < 0.001	Scars (%)	4.52	1.871	0.019
	Pericarditis (%)	7.83	4.458	0.085
Finisher mortality (%)	Intercept	1.30	0.204	<0.001
Adjusted R^2 = 20%	Avg. herd size [per 100 sows]	0.04	0.017	0.028
P-value = 0.002	MHyo piglet vaccination: yes	0.43	0.211	0.046
	Lung abscesses (%)	10.09	5.350	0.065
ADFI (g/day)	Intercept	614.53	280.306	0.033
Adjusted R^2 = 47%	Avg. live weight at slaughter (kg)	11.53	2.542	<0.001
P-value < 0.001	MHyo: positive	-86.36	32.183	0.010
	PRRSv SP value	-45.10	17.66	0.014
	Cranial pleurisy (%)	-183.02	100.755	0.076
	Milk spots (%)	-108.03	40.539	0.010
ADG (g/day)	Intercept	231.72	151.229	0.132
Adjusted R^2 = 40%	Avg. live weight at slaughter (kg)	4.89	1.358	<0.001
P-value < 0.001	PRRSv: positive	-31.41	13.642	0.025
	Cranial pleurisy (%)	-200.63	53.744	<0.001
Age at sale (d)	Intercept	161.00	2.491	<0.001
Adjusted R^2 = 41%	Avg. herd size [per 100 sows]	0.48	0.230	0.041
P-value < 0.001	PRRSv SP value	4.52	1.775	0.014
	Cranial pleurisy (%)	39.21	10.150	<0.001

Legend: ADFI – Average daily feed intake; ADG – Average daily gain. Avg. herd size – Average herd size (No. of sows); MHyo piglet vaccination – On-farm vaccination for MHyo in piglets; MHyo: positive – Farms seropositive to MHyo based on ELISA tests in finisher pigs; PRRSv SP value – average on farm S/P values for PRRSv as the output given in the ELISA tests; PRRSv: positive – Farms seropositive to PRRSv based on ELISA tests in finisher pigs.

The model for ADFI explained 47% of its variability. Farms slaughtering pigs at higher live weights and negative for MHyo at slaughter had higher ADFI (*P* < 0.001). The S/P values for PRRSv, the prevalence of cranial pleurisy and the prevalence of milk spots were negatively correlated with ADFI (*P* = 0.014, *P* = 0.076, and *P* = 0.010, respectively). The model for ADG explained 40% of its variability. Farms slaughtering pigs at heavier weights had higher ADG ($P < 0.001$). The prevalence of cranial pleurisy and positivity to PRRSv also impacted negatively on ADG ($P < 0.001$, and $P = 0.025$, respectively). The model for age at sale explained 41% of the variability. The age at sale was increased in bigger farms ($P = 0.041$), in farms with higher S/P values for PRRSv ($P = 0.014$) and with higher prevalence of cranial pleurisy ($P < 0.001$). Finally, the models for number of piglets per sow per year and FCR only explained 8.2 and 14% of the variability, respectively.

6.4. Discussion

The first objective of this study was to describe the seroprevalence of four main pathogens: SIV, PRRSv, MHyo and APP in Irish farrow-to-finish pig farms. In this sample, 59% of the farms were positive to PRRSv, while 79% were positive to SIV and MHyo, and 98% were positive to APP. The within herd prevalence for each disease was highly variable. These results are comparable to those of four cross-sectional studies on respiratory disease in Spain, Belgium and France (Fablet *et al.*, 2012b; Fraile *et al.*, 2010; Martínez *et al.*, 2009; Meyns *et al.*, 2011). The prevalence of SIV in Irish farms is not high considering that the ELISA kit used does not distinguish subtypes, drawing the overall prevalence of pigs exposed to Influenza A. Fraile *et al.* (2010) and Meyns *et al.* (2011) tested for antibodies against SIV H1N1, H1N2, and H3N2, concluding that over 90% of the herds were positive to those subtypes in Spain and Belgium. Fablet *et al.* (2012b) reported a prevalence of 60 and 57.6% for subtypes H1N1 and H1N2 in French herds. Regarding PRRSv, the prevalence was similar to that reported by the French study (Fablet *et al.*, 2012b), while studies in Spain (89%; Fraile *et al.*, 2010; and 100%; Martínez *et al.*, 2009), and Belgium (88%; Meyns *et al.*, 2011) reported a higher prevalence. The prevalence of MHyo was similar to the prevalence reported by Fraile *et al.* (2010), although lower when compared to the studies from Belgium and France (Fablet *et al.*, 2012b; Meyns *et al.*, 2004). The APP prevalence is similar to those described in other studies for apxIV detection by ELISA (Fraile *et al.*, 2010; Merialdi *et al.*, 2012; Meyns *et al.*, 2011), and by PCR in 50 herds from Ontario, Canada (MacInnes *et al.*, 2008). Although the results indicate that virtually all farms are positive to APP, the test does not differentiate infection with highly virulent serotypes from infection with mild serotypes. Chiers *et al.* (2002) stress that this serological assay cannot be used to detect subclinical infections. Thus, the clinical presentation on farm and its relationship with pleurisy lesions at slaughter are necessary to recognize a problem (Marsteller and Fenwick, 1999). Serological examinations of herds have some limitations, especially in vaccinated herds. These herds will be positive by serology whether the vaccine is working, and the disease is under control or not. In this study, herds not vaccinating for a pathogen tended to be negative in the serology test. The interpretation of the serological results of herds vaccinated should incorporate pathogen detection by PCR, for example.

The second objective was to describe the prevalence of pleurisy, pneumonia, lung abscesses, pericarditis and milk spots on liver in finisher pigs of those farms. The prevalence of pleurisy is difficult to compare between countries due to the characterization of this lesion, which is poorly described in some studies (Andreasen *et al.*, 2001). In Spain, Fraile *et al.* (2010) presented an overall prevalence of 26.8% (cranial and dorsocaudal pleurisy), and 14.2% of dorsocaudal pleurisy, which is comparable to the 12% reported in this study. In Belgium, Meyns *et al.* (2011) also used the SPES and reported an average pleurisy of 20.8% but for scores > 1. The prevalence of pneumonia was much lower than those reported by other countries (Eze *et al.*, 2015; Fraile *et al.*, 2010; Martínez *et al.*, 2009; Meyns *et al.*, 2011; Pagot *et al.*, 2007) but similar to the prevalence reported in Northern Ireland, UK (Eze *et al.*, 2015). Although we report an average prevalence of 13.4% of pneumonia on farm, the average surface affected was low (6.2%). However, considering that the prevalence of scars was approximately 14%, the results suggest that up to almost 30% of the pigs had pneumonia or had evidence of having had pneumonia (scars) over the course of their lifetime. Still, this figure is likely to be an underestimate once most respiratory infections are thought to heal before slaughter age, not necessarily leaving scars (Pagot *et al.*, 2007; Straw *et al.*, 1990; VanAlstine, 2012). Therefore, other methods that assess the impact of respiratory disease throughout the life of the pig may be necessary to complement slaughter checks. Such methods may include monitoring clinical signs (cough monitors, activity monitors), and monitoring the presence of common respiratory pathogens over time. The prevalence of abscesses is similar to that reported in the UK (Eze *et al.*, 2015). The prevalence of pericarditis is much higher to that reported in Austria (Schleicher *et al.*, 2013) and in Denmark (Nielsen *et al.*, 2015). However, these authors sustain that the method of inspection, which avoids heart incisions, probably contributed to a lower rate of detection of this lesion. Finally, the prevalence of milk spots was unexpectedly high, contrasting to the much lower prevalence stated in other countries (Fausto *et al.*, 2015; Ondrejková *et al.*, 2012; Sanchez-Vazquez *et al.*, 2010a). The prevalence of pleurisy and pneumonia in this study is consistent with those figures described by Teixeira *et al*. (2016) in Irish pig farms, although the prevalence of pericarditis and milk spots are much higher in this study.

The third and last objective of this study was to estimate the impact of respiratory disease on productive performance indicators. It is accepted that both slaughter checks and serology are mostly related to the health status of the pig by the end of the finisher stage. However, some of the lesions found in slaughterhouse were related to mortality in weaner stage. The prevalence of scars was related to higher weaner mortality, which is compatible with the nature of these lesions. Scars are healed pneumonia lesions, most probably occurring in weaner or early finisher stages. The tendencies found for cranial pleurisy and pericarditis were also biologically logical as higher cranial pleurisy and pericarditis reveal on-farm health issues such as bacterial polyserositis, driving mortality up, especially in weaners. The time distance between the appearance of pericarditis and pleurisy and its finding in the abattoir is not well defined in the literature and needs to be investigated in future research to confirm their relationship to weaner mortality.

Vaccination for MHyo was related to higher finisher mortalities. This association is likely to be explained by the higher health status of farms free from MHyo which, therefore, were not vaccinating for that pathogen. In general, vaccination for MHyo and PRRSv were related to worse productive performance indicators in the univariable analysis, showing that vaccines are in place when there are issues that affect performance. The number of farms affected by these pathogens but not vaccinating was low which makes it difficult to estimate the effect of vaccination in positive farms. MHyo infections are also relevant due to the aggravation of the lung lesions with secondary infections, which are commonly linked to lung abscesses (Blackall *et al.*, 2000; Maes *et al.*, 1996). Finisher mortality was also related to the size of the herd. Agostini *et al.* (2014) found similar results and suggested that in bigger farms less attention may be paid to individual finisher pigs.

Farms slaughtering pigs at higher live weights had increased ADFI. This finding makes complete sense as it is well known that the ADFI of pigs increases as they grow. Positivity to MHyo and the level of antibodies for PRRSv were both related to a decrease in ADFI. Both diseases are known to be among the main ones affecting performance in pig herds (Byrt *et al.*, 1985; Maes *et al.*, 1996; Neumann *et al.*, 2005). Of the studied lesions, the prevalence of cranial pleurisy and milk spots on the liver decreased ADFI. Pleurisy is known to cause respiratory distress to pig and as an inflammatory process should be expected to reduce intake. The milk spots are highly suggestive of infection by *Ascaris suum* (Bernardo *et al.*, 1990b; Sanchez-Vazquez *et al.*, 2010b), which is also related to decreased ADFI and ADG (Bernardo *et al.*, 1990a; Kipper *et al.*, 2011; Vlaminck *et al.*, 2015).

The models for ADG and age at sale were very similar. Positivity for PRRSv and the prevalence of cranial pleurisy were both related to lower ADG and higher age at sale. PRRSv is the main disease affecting growth of pigs with (post-outbreak) estimated costs of 17.7$ USD per pig in farrow-to-finish farms (Anonymous, 2013). The findings confirm the relevance of PRRSv as an important factor affecting performance also in Irish conditions. Pleurisy is also known to be related to important production losses. In the UK, a pleurisy prevalence of 10% at batch level was estimated to cost approximately 226p (£, GBP) per slaughter pig (British Pig Executive, 2009). In all the models described in this study, cranial pleurisy showed better predictive values than total pleurisy or moderate to severe lesions. However, the three of them were highly correlated and could all be used interchangeably in the models. Although cranial pleurisy may not necessarily be linked to a particular disease, dorsocaudal pleurisy is in general related to APP (Merialdi *et al.*, 2012) which is very prevalent in Irish pig farms as shown in this study. Taking into account the low use of vaccination for APP in Ireland, the situation could be improved with a wider use of vaccination (Goethe *et al.*, 2000; Prideaux *et al.*, 1999; Wilson *et al.*, 1986), which in turn, would result in a reduction of the use of antibiotics. The only difference for the models for ADG and age at sale was that ADG increased as weight at slaughter was higher but age at sale was more affected by herd size. It is well known that ADG increases as the pig increases in size, thus it makes sense that selling bigger pigs improves ADG. On the other hand, a worsening in performance as the size of the herd increases has been reported previously. In a study analysing production parameters and production cost over time (2010-2014) in Spain, Rocadembosch *et al.* (2016) concluded that herd size affected negatively most performance indicators, including ADG in nursery and finishing stages, as also found in this other study (Cornelison *et al.*, 2018).

The models fitted explained a significant percentage of the variability for weaner mortality, finisher mortality, ADFI, ADG, and age at sale. It is interesting to notice that the models were able to explain almost the double of the variability in ADFI, ADG, and age at sale when compared to the variability of weaner and finisher mortality. The understanding of the morbidity and mortality of disease, especially in the absence of secondary infections, could explain the impact on performance without necessarily causing increased mortality. However, pigs per sow per year and FCR did not produce good models. The pigs produced per sow per year were included as an indicator of sow productivity to study the effects of respiratory disease in the performance of sows. However, in this study no significant effects were found. On the other hand, FCR was only affected negatively by herd size and cranial pleurisy, but these effects only accounted for 14% of the variability. This result suggests that disease affects the growth rate and feed intake of pigs but does not necessarily makes production less efficient in terms of feed use.

Chapter 7. General Discussion

“*Use your little grey cells, mon ami.*”

Hercule Poirot in “The Mysterious Affair at Styles”

(Agatha Christie)

The main goal of this thesis was to study the main factors affecting pig production in Ireland. The three areas studied were biosecurity and management, feeding practices, and respiratory disease. These represent limiting factors affecting productive performance in pig production worldwide, but their relative importance shifts notably within the context of each pig industry. The methodologies used in these studies procured to characterize those factors and to analyse their impact in productive performance.

7.1. Relative importance and connections of the main factors affecting productive performance

Our results suggest that respiratory disease is the most important factor affecting productive performance in Irish pig farms among the factors studied. The direct comparison of the linear models fitted in each chapter is shown in Table 7.1.

Table 7.1 Comparison of the (adjusted) R^2 obtained in the multivariable models of reported in Chapters 4 to 6.

	Chapter 4	**Chapter 5**	**Chapter 6**
ADFI (g/day)	NM	13%	47%
ADG (g/day)	16%	29%	40%
FCR	NS	NS	14%
Finisher mortality (%)	23%	27%	20%
No. pigs per sow per year	NS	7%	8%
Age at sale (d)	NM	12%	41%

Legend: ADFI – Average Daily Feed Intake; ADG – Average Daily Gain; FCR – Feed Conversion Ratio; NM – not modelled; NS – not significant (overall F-test with P > 0.05).

Slaughter checks, serology and vaccination explain the largest portion of variability in ADFI, ADG and age at sale, while FCR was poorly explained in all chapters. One of the reasons for this result probably lies on the limitations stated in Chapters 4 and 5. In brief, the biosecurity assessment as conveyed by the Biocheck.UGent™ represents a risk assessment tool developed by a panel of experts. The variables used in the analysis correspond to the scores given by that tool, which might mask the importance of each practice. However, the value of Biocheck.UGent™ lies in the ability to compare farms in an intuitive way through the benchmark report issued at the end of each assessment (Annex 1 provides an example of that report). The feedback given to farmers is important and it raises awareness for the farm's weaknesses and strengths.

The feeding practices, on the other hand, explained higher proportions of the ADG but presented some conflicting results with the literature. An unexpected result was the poor explanation of FCR across all the Chapters. This productive performance indicator is affected by many factors and it is naturally related to feeding practices, as reviewed in the literature (Chapter 3). Therefore, one of the reasons for this result are, once again, the possible confounding factors not surveyed. Another possibility is that Irish farmers pay close attention to this indicator, regardless of their facilities and feeding system. At the same time, the best model in Chapter 5 (feeding practices) was the finisher mortality. This sounds conflicting once the indicators expected to be related to feed are ADFI, ADG and FCR, not mortality. While these feed efficiency indicators are closely monitored and related to feed practices, the connection between feed and mortality is not expected, and therefore it is difficult to address.

One possible hypothesis for higher relevance of respiratory disease compared to biosecurity and feeding strategies is that, when assessing pluck lesions at slaughter, we are also assessing the environmental conditions and the management on farm. High concentrations of dust and ammonia contribute to poor lung health and can exacerbate the effect of some diseases or open the door to other infections. These are often the reflection of poor ventilation and of manure management. Small particle sizes are associated with high dust levels. Further, milk spots on the liver are commonly attributed to infections by *Ascaris suum* but can easily be avoided with deworming protocols, while the pressure of infection can be substantially decreased with adequate cleaning and disinfection of the facilities, and the correct disposal of manure. Thus, the data captured at slaughter is likely to reflect, to some extent, the management protocols employed. Another factor to consider is the level of control that the farmers have over the three factors studied. Respiratory disease stands aside to the other two due to its unpredictability. Biosecurity, management and feeding practices are more easily managed and controlled by farmers. This may also contribute to the lesser impact the latter two had on productive performance, comparatively to respiratory disease.

7.2. Main outcomes

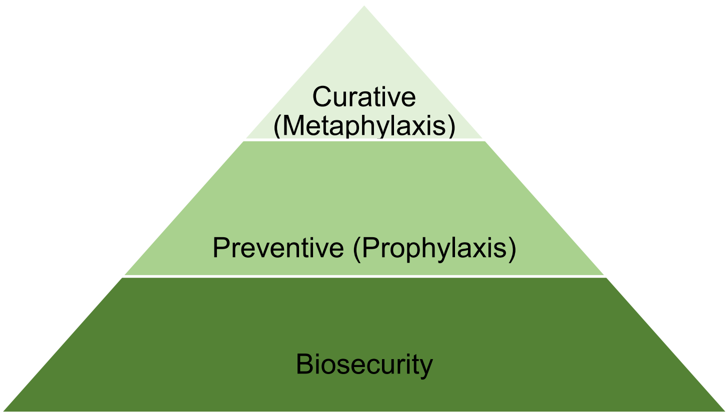
As stated in the introduction, the objectives fulfilled in this thesis targeted three outputs 1) the research or peer-reviewed publications, 2) the provision of feedback to farmers, and 3) the establishment of national and international collaborations with Teagasc. In this section we discuss each Chapter according to these outputs.

7.2.1. Research methodology

7.2.1.1. Biosecurity practices

In Chapter 4, we assessed the impact of the biosecurity practices in Irish pig farms on production performance. The PCA and clustering techniques suited the nature of the biosecurity tools used, which corresponds to a combination of measures that can have unknown relationships and synergistic effects. From a practical point of view, the interpretation of results given by the cluster comparing the performance of groups of farms is better understood by farmers. While the importance and potential of biosecurity (Figure 7.1) is re-affirmed repetitively (Dewulf and Van Immerseel, 2018; Laanen *et al.*, 2013; Postma *et al.*, 2016a; Postma *et al.*, 2016b), its application depends on many factors and is frequently matter of debate. Recently, Hernandez-Jover (2018) appointed key social and institutional factors influencing the engagement of farmers with biosecurity and stressed the need to understand them for the effectiveness of any on-farm, regional or national biosecurity programs. To address these issues, a closer collaboration between social and veterinary sciences should be envisaged.

Figure 7.1. Biosecurity as the foundation of all disease prevention programmes according to Dewulf & Immerseel (2018).



7.2.1.2. Feeding practices

In Chapter 5, the nature and the complexity of the associations found requires further research. The feeding practices studied explained approximately 20% of the variability in sow culling and sow mortality and 30% of ADG and finisher mortality in slaughter pigs. As stated before, contributing to the results is the lack of information on confounding factors like particle size and feeder design. The variability found in Irish farms, which may have different feeders in different accommodation for the same stage, meant that the inclusion of these practices in the study was not feasible. An interesting result was the retention of the gilts' feeding practices on the models for sow culling and mortality. Although the benefits of an adequate rearing of the gilts are well established, gilts only represent a small proportion of the breeding pigs on farm and their feeding practices are usually restricted to the period between selection and breeding. It shows the importance of what may seem to the farmer a small detail compared to the gestation and lactation periods. Here too, alternative statistical approaches could help to explain the correlations between the variables studied and their implications to production, providing simpler tools for farmers. However, in this chapter, the biggest need may be to identify new relevant variables and to eliminate confounders.

7.2.1.3. Respiratory disease

Chapter 6 described for the first time the prevalence of SIV, PRRSv, MHyo and APP in Irish pig farms. The comparison of its prevalence with that of other countries helps contextualizing the results obtained. Although the results describe some of the health challenges in Irish farms, the interpretation of the results should be careful. For instance, we would expect that, due to the protective effect of the vaccines, farms vaccinating had better performance compared to farms not vaccinating but also positive to a certain pathogen. However, in the present dataset, farms not vaccinating were, in general, free from disease as inferred by the serology results and the prevalence of slaughter lesions. Other diagnostic techniques must be used to clarify the epidemiology of those infections in the setting of the Irish industry. For example, according to Gottschalk (2012) most farms are seropositive to APP. To understand the clinical relevance of the findings, it is necessary to gather further information from the farm and typing the APP isolates collected from lung lesions or other samples. In the cross-sectional study described in Chapter 6, lung lesions were also sampled, and the study will continue with the laboratorial analysis of these. The lung samples were processed for the bacteriological analysis (culture and isolation), histopathology and PCR techniques, and the main findings will be related to farm data. Further information on PRRSv infection will follow with the PCR testing and sequencing of the finisher blood samples collected at slaughter. There is also interest in mapping PRRSv infection by merging the serology and PCR results with the geolocation of the farms and slaughterhouses surveyed.

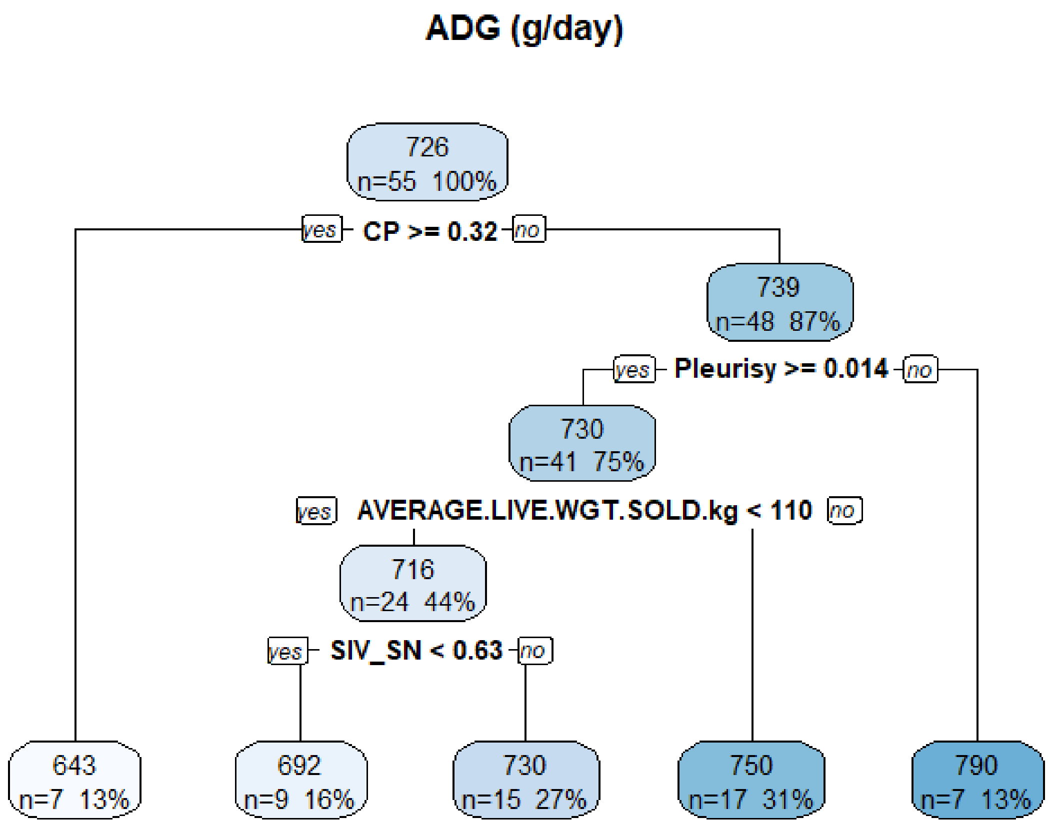
7.2.1.4. Overall research outcome

One big asset of this thesis is the use of a standardized approach in all studies. In other words, the impact of the main factors affecting Irish pig production was done using the same methods and data sources. Biosecurity and feeding practices were assessed using farmers' interviews, while respiratory disease information was gathered through phone-calls to farmers and veterinarians and slaughterhouse visits. The performance data for all studies was retrieved from the Teagasc e-ProfitMonitor, meaning all performance indicators were calculated using the same formulas and farmers had access to advisory expertise on how to collect on-farm data. This confers an opportunity to compare, from the same standpoint, the effects of each factor on performance, as discussed above. The author wanted all the data to be from the same year but the intensity of the work prevented this from happening.

We can also conclude that the statistical methods employed for research may not be useful to apply the knowledge gained into pig production. Other approaches, such as decision trees could serve the purpose of advancing research – i.e. improving the understanding of factors affecting an outcome, such as ADG or FCR - and, at the same time, be used to give meaningful advice to farmers. As a result of this work, the Chapter on biosecurity practices was submitted to the Porcine Health Management Journal and is currently under review. Chapters 5 and 6 are currently in preparation for submission, with focus on the use of alternative statistical methods, in complement of the multivariable linear models. Figure 7.2 shows a decision tree modelling ADG from the predictors of respiratory disease summarised in Chapter 6: vaccination, serology and pluck lesions.

A decision tree is a predictive model built using a machine learning algorithm. In brief, the algorithm partitions the data into subsets using if/then rules. The partitioning process starts with a binary split and continues using different variables to split the data, until no further splits can be made. Different rules can be applied, and the tree can be pruned to simplify the results. The models produced are easy to interpret, can handle different types of data, and don't require normality assumptions of the data. In the decision tree (Figure 7.2), cranial pleurisy is confirmed as the main detrimental predictor for ADG, as seen in the correspondent linear model in Chapter 6. Farms with more than 32% of cranial pleurisy have the lowest ADG with a mean of 643 g/day.

Figure 7.2. Decision tree model of ADG (g/day) using vaccination, serology and pluck lesions as predictors.

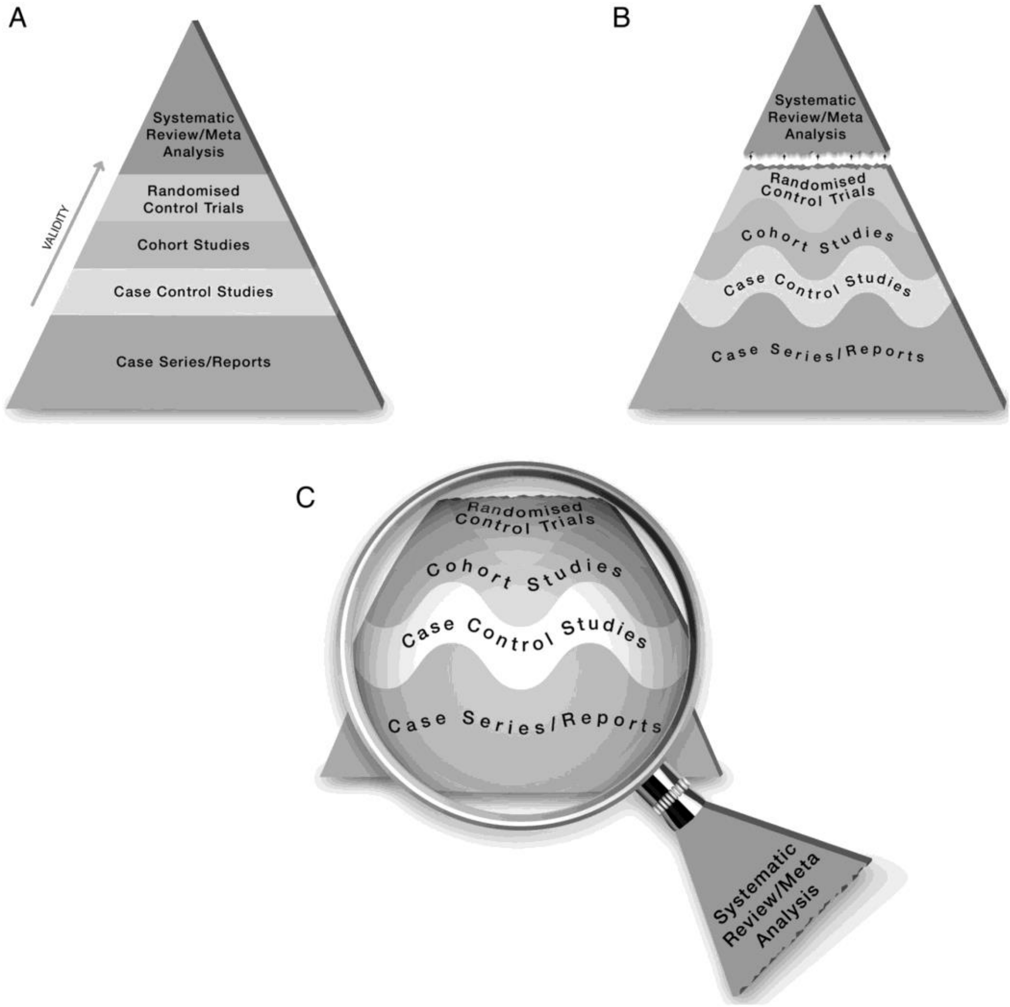


Legend: ADG – Average Daily Gain, CP – Cranial Pleurisy, SIV_SN – Average S/N values for SIV on farm.

Seven farms fitted this description. On the other hand, farms with less than 32% of cranial pleurisy and with less than 1.4% of pleurisy have the highest ADG with an average of 790 g/day. Naturally, the average live weight sold conditions positively ADG, like discussed in Chapter 6. Finally, within farms with high cranial pleurisy (>= 32%), higher pleurisy (>=1.4), and with smaller live weights at slaughter, farms less exposed to SIV (SIV_SN > 0.63) have a higher ADG when compared to farms in the same circumstances but more exposed to SIV. Interestingly, the SIV S/N value to split the tree is very close to the threshold value for positiveness in the ELISA kit used, which was set at 0.6. Thus, this kind of analysis guides the understanding of the results in a more comprehensive way.

Finally, all experimental Chapters were based on observational cross-sectional studies. As stated repeatedly, their nature implies the classification of the results as associations and precludes the inference of causation. In the pyramid of evidence-based medicine (Figure 7.3, A), these studies are positioned intermediately, meaning their strength of evidence may be lacking when compared to other studies, like randomized control trials (RCT). The latter are designed to minimize bias and to eliminate confounding factors. RCT are useful when the factors to study are already characterized and the objective is to study their impact in other variables. According to Vandeweerd *et al.* (2012), observational studies are prevalent in the literature and their usefulness is mainly connected with economic and logistic reasons. The authors state that these studies are favoured if the study subjects "are not easy to control for practical and ethical reasons". Recently, Murad *et al.* (2016) proposed two modifications to the pyramid of evidence (Figure 7.3, B and C). In the second figure (Figure 7.3 B), the authors argue that the quality of the evidence cannot be solely based on study design because other factors like imprecision and inconsistency may also affect the results. On the other hand, the quality of evidence provided by some observational studies should be graded up, provided that their results are robust. In the second change (Figure 7.3 C), the authors sustain that some systematic reviews and meta-analyses are based in other studies which may contain flaws and inconsistencies. Therefore, their relevance should be carefully analysed, which leads to the suggestion of using them as "a lens through which other types of studies should be seen". Other authors criticize the poor representativeness of the results obtained by RCTs. For example, Nyachoti *et al.* (2004), in a review on voluntary feed intake, stated that most of the data available on the subject derived from RCT studies, which were designed to evaluate one single factor at a time and involving small groups or individually housed pigs. The authors argue that these data do not indicate how various factors affect feed intake in pigs, and therefore the results are "often difficult to extend to commercial production systems". The objectives of this thesis were to characterize the factors affecting Irish pig production and to draw the prevalence of key respiratory pathogens. Likewise, this approach was the most suitable to meet that purpose.

Figure 7.3. New pyramid of evidence (Source: Murad *et al.* (2016)).



7.2.2. Feedback to farmers

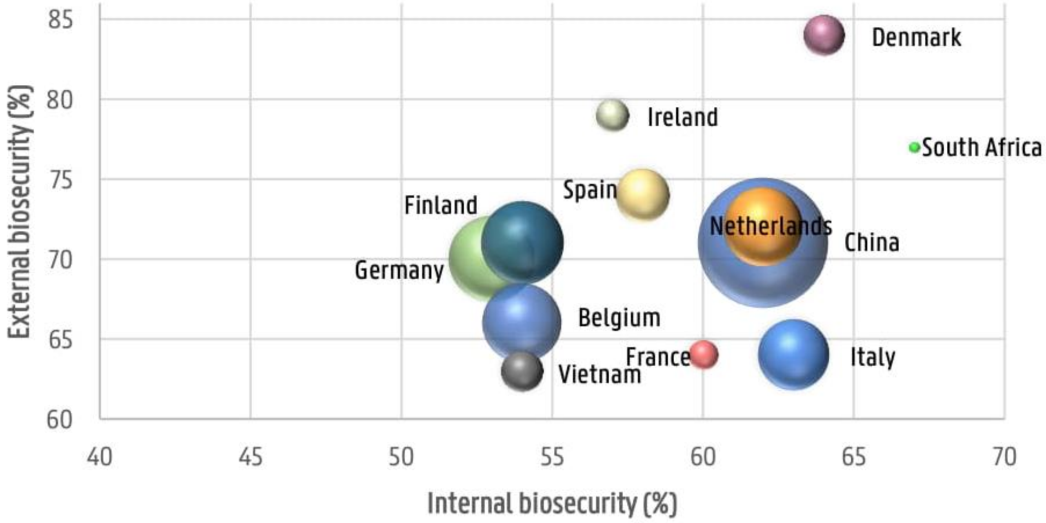
From the Irish farmers point of view, these practical purposes were to raise awareness for the biggest issues impairing efficiency in their farms. In another Teagasc project (AMURAP), the antimicrobial's usage on farm (in-feed medication) was collected by farmers' interview. This information was collated with the results of the studies on biosecurity and respiratory disease (slaughter checks), and their productive performance. Then, these data were compiled into individual benchmarking reports. An example of those benchmarking reports can be found in Annex 2. The detailed reports of the farm's results on biosecurity, antimicrobial's usage and slaughter checks was also delivered (examples in Annexes 1, 3 and 4). The result of this benchmarking exercise was a better understanding of the individual and national constraints to production efficiency. Biosecurity practices and respiratory disease status were linked to the performance achieved and the antimicrobial's usage in each farm. All the data fed back to farmers helped to understand its potential uses. The gathering and the use of data fuels the development of the industry, providing sound support for decision-making, both at an individual farm level and at regional or national level (Figure 7.4). In the context of the European community, the discussion and drafting of new legal rules also requires evidence and scientific validation. Therefore, it is important to use national data as means to sustain positions.

Ultimately, during the farm visits, it became evident the existence of multiple actors providing guidance, advisory and veterinary services to farmers. The team responsible for each farm frequently involves farmers, employees, advisors, nutritionists, veterinarians and others. The results obtained indicate there is room for improvement in coordinating the efforts of all parties, striving for a common goal: improved animal health and welfare, performance and consequent economic return.

7.2.3. National and International collaborations

Finally, the collaborations established to develop this work are very relevant to the Irish industry. At an internal level, the research and farm outputs of the work developed enhanced the communication between the advisory and research teams of the Teagasc Pig Development Department. At an external and international level, the use of the Biocheck.UGent™ protocol connected Ireland to the research developed on biosecurity in several European countries. For Irish farmers, the comparisons to top performing countries such as Denmark and the Netherlands were very important, and with the Biocheck.UGent™, they were able to identify their weaknesses and strengths having top performing pig producing countries as references. The Irish results were uploaded to the Biocheck.UGent™ website, ensuring both parties took advantage of the connection established (Dewulf, 2018). Figure 7.4 illustrates the Irish external and internal biosecurity scores compared to other countries. Following this successful application of the Belgian biosecurity methodologies in Irish pig farms, Animal Health Ireland (AHI) – an Irish institution with the aim to improve animal health – revealed interest in applying the survey in all Irish pig farms. This partnership sponsors biosecurity assessments undertaken by trained PVPs and shares the data with the Biocheck.UGent™ database and AHI database, while providing support and advisory to farmers when analysing the farm report.

Figure 7.4. Average external and internal biosecurity scores given by the Biocheck.UGent™ in each country. (Source: Dewulf (2018))



Legend: bubble size represents the number of times de Biocheck.UGent™ was filled in each country. Data collected since the beginning of 2017.

The use of Biocheck.UGent™ was also linked to the collaboration with PROHEALTH project (http://www.fp7-prohealth.eu/). This collaboration helped in the development of the Teagasc pig economic model and suggested the use of Precision Livestock Farming (PLF), which will be further investigated in future projects.

Another international collaboration was initiated with the Veterinary Diagnostic Laboratory (VDL) of the University of Minnesota. This was necessary to overcome the lack of diagnostic resources and expertise in Ireland. The collaboration was established to design the sampling and data collection at the slaughterhouse and it resulted in a two-month overseas traineeship for the analysis of the results. This contact has led to a joint USDA grant application for a project on respiratory disease between the VDL, Teagasc and the Agri-Food and Biosciences Institute (AFBI), which is currently under review.

7.3. Future research

This thesis characterizes Irish pig production and identifies the biggest challenges impairing efficiency. The proposals for improvement, such as changes in biosecurity practices, should be validated on farm, filling the gap of research identified in this area. At the same time, more research is needed on the motivational drivers to implement those changes. The variety of feeding practices could be further explored by trialling feeding practices such as alternating wet and dry diets, as proposed in the literature and suggested by the findings in Chapter 5. It would be also interesting to investigate some of the associations identified, such as the increased mortality and the phase-feeding in finisher pigs. Finally, the results on respiratory disease described are only but the tip of the iceberg to understand and characterize the Irish herd health status. Research is needed to draw the prevalence of other relevant diseases and understand what is being done at farm level to address the identified health challenges. All of these are necessary prior the design of national control and monitorization disease programs (Greiser-Wilke *et al.*, 2003). In a broader One Health context, these research/production approaches, based on sound data, are the means for the reduction of the use of antimicrobials and the improvement of animal health and welfare, ultimately safe-guarding food security, food safety and public health (Mardones *et al.*, 2017).

Chapter 8. Conclusions

The results of the studies described in Chapter 4, 5 and 6 and their general discussion and interpretation (Chapter 7) led to the following conclusions:

- The level of biosecurity in Irish pig farms is similar to that of other European countries. The external biosecurity score, as per the Biocheck.UGent™, was higher than most countries and the internal biosecurity score was similar to those, although it has great variability among farms. Practices related to the environment and region, feed, water, and equipment supply and the management of the different stages, need to be particularly addressed in poor performing farms to improve productivity.

- There is a wide variety of feeding practices in Irish pig farms with 42.9% of the farms home-milling at least one diet and 51.8% of the farms feeding wet diets at some stage from weaning to slaughter. Only 21.4% of the farms are phase-feeding. Sow culling and mortality is associated with sow and gilt feeding practices. Feeding practices from weaning to slaughter explain 29 and 27% of the variability in ADG (g/day) and finisher mortality (%), and 39% of feed cost variability.
- The prevalence of SIV, PRRSv, MHyo and APP in Ireland is similar or lower to those in other European countries. The prevalence of lung lesions at slaughter was variable, with the national average prevalence for pleurisy and pneumonia figuring as one of the lowest compared to those reported in peer-reviewed publications. The prevalence of milk spots in the liver is higher than in other countries.

- Productive performance was more affected by respiratory disease when compared to the impacts of biosecurity and feeding practices. The studied biosecurity and feeding strategies are directly manageable by farmers, while respiratory disease is not.

- There needs to be more coordination in the team responsible for each farm (farmer, employees, veterinarians, nutritionists and advisors). The data collection at farm and at slaughter is useful at many levels and should integrate larger databases, providing meaningful advice and feedback to farmers.

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Chapter 10. Annexes

Annex 1– Example of a biosecurity report as issued by the Biocheck.UGent™.

GHENT UNIVERSITY

BIOCHECK.UGENT

ID: 29661/984122/v/2_0/R
Entry date: 2016-11-29 12:12:22
Identification: BQ72Teagasc

PIG

Nr	Description	Score	Country average	Global average
	External biosecurity			
A	Purchase of animals and semen	100 %	99 %	89 %
B	Transport of animals, removal of manure and dead animals	96 %	81 %	71 %
C	Feed, water and equipment supply	80 %	55 %	50 %
D	Personnel and visitors	100 %	74 %	70 %
E	Vermin and bird control	100 %	71 %	67 %
F	Environment and region	80 %	85 %	62 %
	Subtotal External biosecurity:	***94 %***	***79 %***	***71 %***
	Internal biosecurity			
A	Disease management	100 %	80 %	67 %
B	Farrowing and suckling period	36 %	54 %	56 %
C	Nursery unit	64 %	64 %	66 %
D	Fattening unit	93 %	73 %	67 %
E	Measures between compartments and the use of equipment	86 %	49 %	49 %
F	Cleaning and disinfection	78 %	45 %	57 %
	Subtotal Internal biosecurity:	***77 %***	***57 %***	***58 %***
N/A = Not applicable	**Total:**	**86 %**	**68 %**	**65 %**

You can compare your total score and your scores for each subcategory (A - F) with the average scores. Since the Biocheck was filled in more than 40 times in your country, you achieve your country average to compare with. It should be noted that the maximum scores (100 %) should really be your ultimate goal, not the average scores.

If you wish to know why a certain score is obtained or what the ideal measures are for a certain category, you can **click on the different titles in the table** after which you will be redirected to a webpage with a lot of information concerning this part of the biosecurity.

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www.biocheck.ugent.be

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(Annex 1 – continuation)

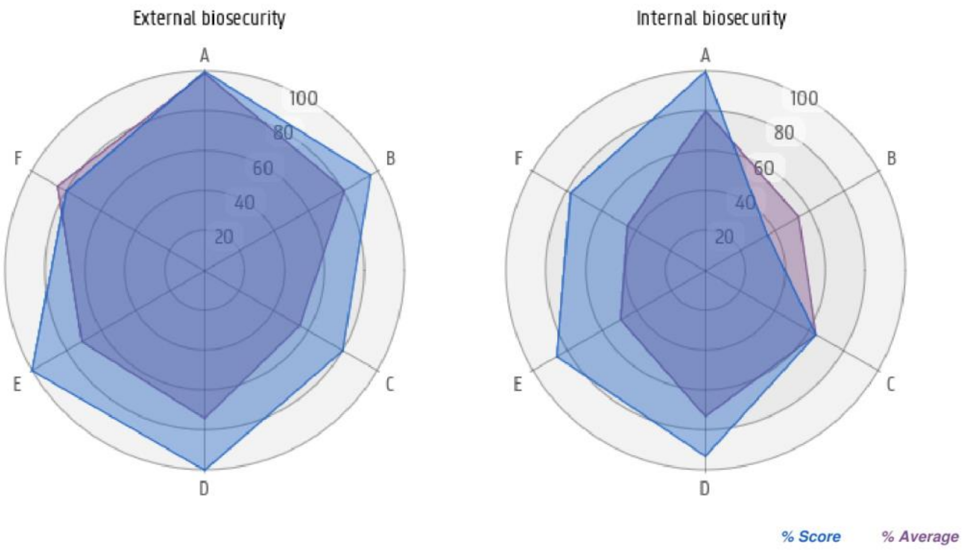
GHENT UNIVERSITY

BIOCHECK.UGENT

ID: 29661/984122/v/2_0/R
Entry date: 2016-11-29 12:12:22
Identification: BQ72Teagasc

PIG

These figures show **your results** graphically compared to the **average scores**. The bigger the blue area, the better your result. The letters of the axes correspond to the numbering in the report above.



For more information about biosecurity on a pig farm and how to improve this, you can always look at the extensive information available on the **Biocheck.UGent website** in the sections "about biocheck" and "downloads and links". You can also contact your veterinarian for advice on biosecurity measures on your farm.

FACULTY OF VETERINARY MEDICINE accredited by EAEVE

www.biocheck.ugent.be

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Annex 2 – Example of a benchmarking report for Irish pig farmers.

#BENCHMARKYOURFARM

Teagasc Pig Development Department

teagasc

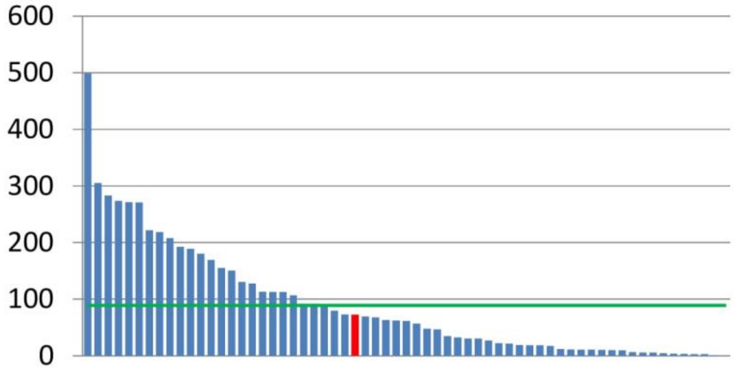
AGRICULTURE AND FOOD DEVELOPMENT AUTHORITY

THE GRAPH INCLUDES ALL THE FARMS THAT TOOK THE SURVEY
YOUR FARM IS INDICATED AS THE RED BAR
THE GRAPH INCLUDES THE MEAN VALUE IN GREEN
THE VALUE FOR EACH VARIABLE IN YOUR FARM IS BELOW THE GRAPH
THE POSITION OF YOUR FARM IN THE LIST IS BELOW THE GRAPH

This report is intended for farmers. Veterinary practitioners and advisors can get more detailed information by contacting Teagasc (Edgar.GarciaManzanilla@teagasc.ie). Written authorization from the farmer will be required before any data can be shared.

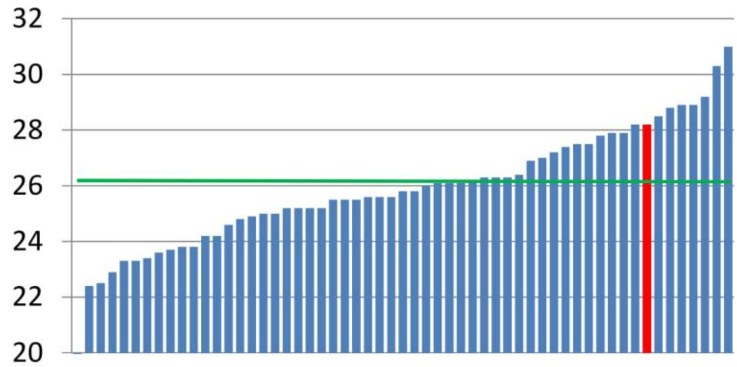
(Annex 2 - continuation)

TOTAL ANTIBIOTIC USE IN mg/kg



VALUE: 72.5
BENCHMARK: 37th

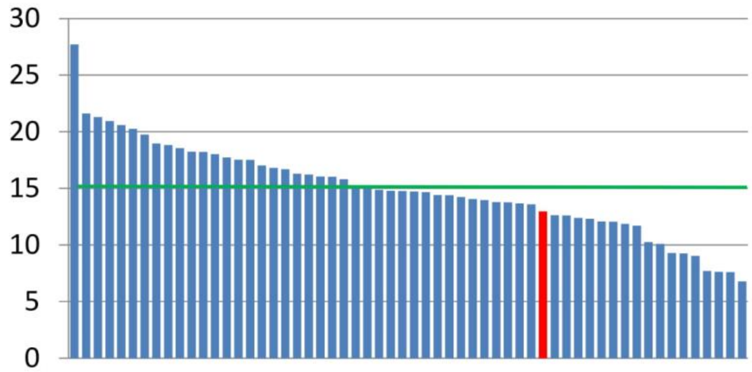
PIGS PER SOW PER YEAR



VALUE: 28.2
BENCHMARK: 8th

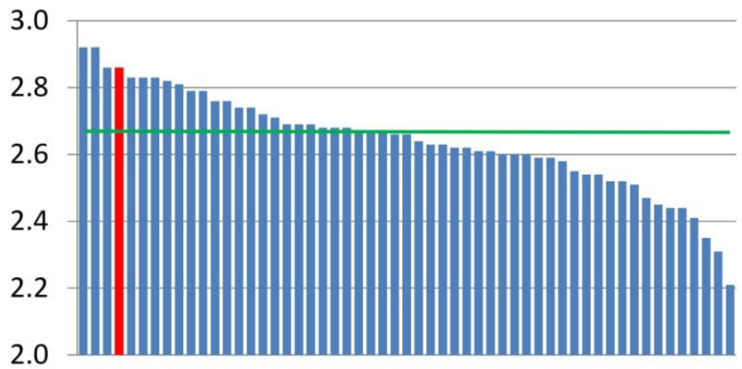
(Annex 2 - continuation)

TOTAL MORTALITY, %



VALUE: 13.0%
BENCHMARK: 18th

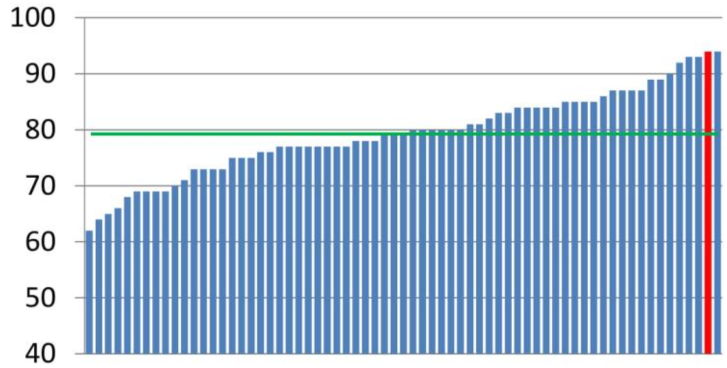
HERD FEED CONVERSION RATIO



VALUE: 2.86
BENCHMARK: 52nd

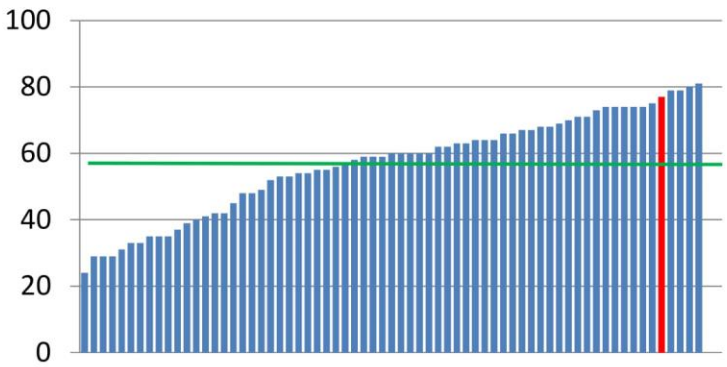
(Annex 2 - continuation)

EXTERNAL BIOSECURITY



VALUE: 94
BENCHMARK: 2nd

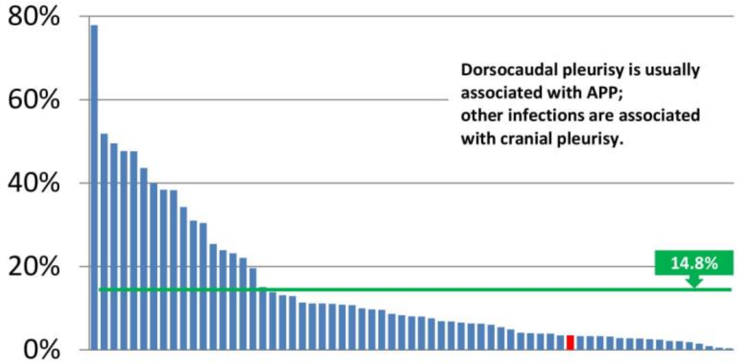
INTERNAL BIOSECURITY



VALUE: 77
BENCHMARK: 5th

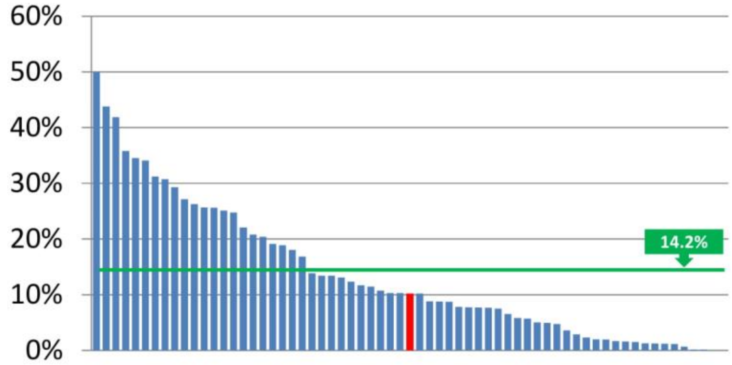
(Annex 2 - continuation)

PERCENTAGE OF DORSOCAUDAL PLEURISY



VALUE: 3.4%
BENCHMARK: 17th

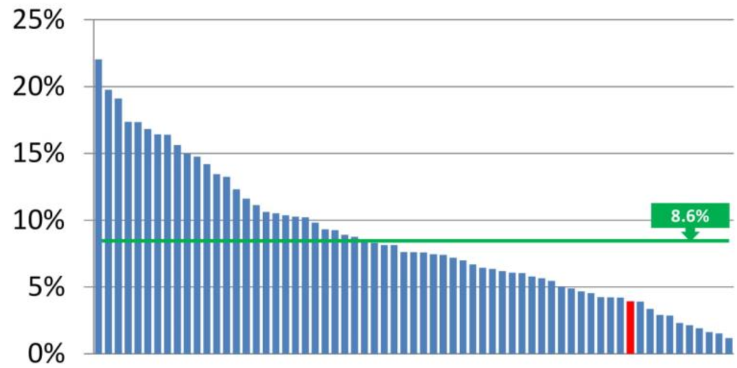
PERCENTAGE OF PNEUMONIA



VALUE: 10.3%
BENCHMARK: 33rd

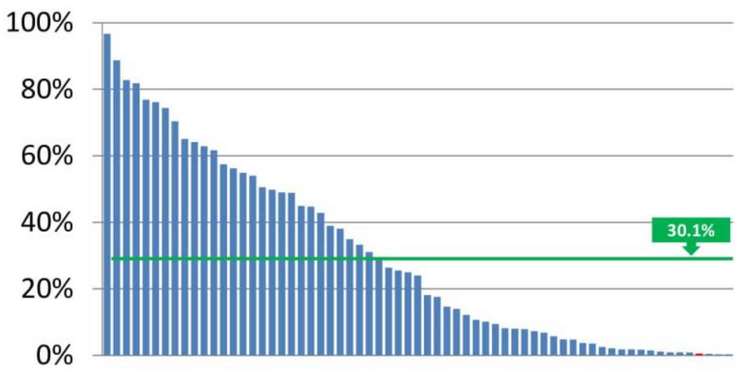
(Annex 2 - continuation)

PERCENTAGE OF PERICARDITIS



VALUE: 3.9%
BENCHMARK: 11th

PERCENTAGE OF MILK SPOTS



VALUE: 0.5%
BENCHMARK: 4th

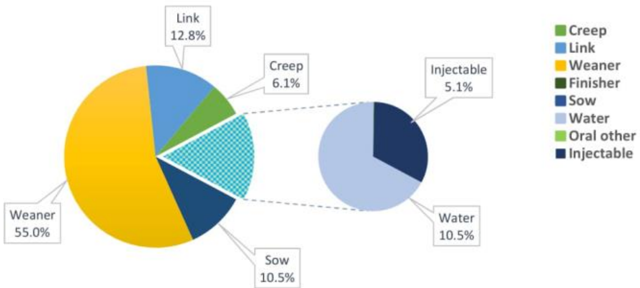
Annex 3 – Example of an antimicrobial usage report for Irish pig farmers.

Agriculture and Food Development Authority

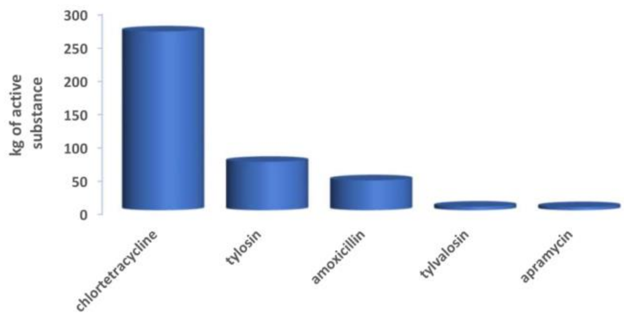
Antimicrobial Usage Report	01/06/2018
Farmer	[redacted]
Slap	

Period:	01/01/2016 to 31/12/2016	
Summary		
Route of administration	Total used	**mg/kg liveweight sold**
Medicated feed	337.2kg	**61.2**
Water	41.8kg	**7.6**
Other oral remedy	0.1kg	**0.0**
Injectable	20.2kg	**3.7**
Total	399.4kg	**72.5**

Routes of administration



Which Antimicrobials are used on my farm?

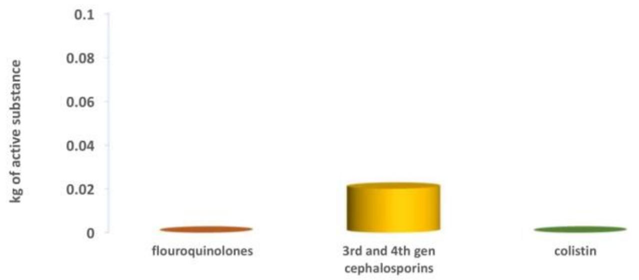


(Annex 3 – continuation)

Critically Important Antimicrobials

Critically Important Antimicrobials are those considered most important for use in human medicine. Under the classification system used by the European Medicine Agency (EMA), Class 1 antimicrobials are **not** permitted for use in animals. The use of Class 2 antimicrobials is permitted but may be subject to monitoring or restrictions in the future.

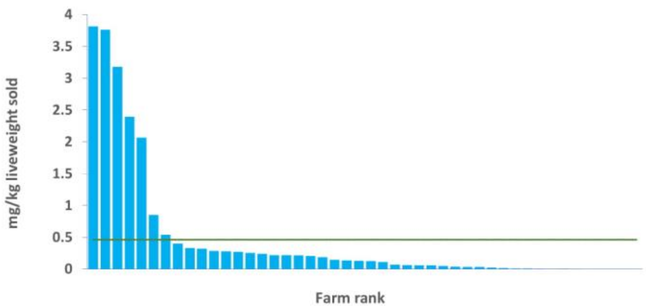
Critically Important Antimicrobials (Class 2): use on my farm



Total: 0.02kg

How does my farm compare?

Consumption of Class 2 Critically Important antimicrobials (mg/kg)



VALUE: 0.0
BENCHMARK: 7th

Which drugs are Critically Important Antimicrobials?

	drug name	examples of brands
Fluoroquinolones:	enrofloxacin	Baytril, Enrocare, Fenoflox
	marbofloxacin	Marbocyl, Boflox, Forcyl
3rd and 4th Generation Cephalosporins:	ceftiofur	Naxcel, Excenel
Polymixins:	colistin*	Coliscour*

*withdrawn in 2017

Annex 4 – Example of a slaughter checks' report for Irish pig farmers.

Teagasc
Agriculture and Food Development Authority

Farmer [redacted]
Factory Report

SLAP/Date	No Lungs scored	Pleurisy % Dorso-Caudal Pleurisy	Average score Dorso-Caudal Pleurisy	% Cranial Pleurisy
[redacted]	1154		[scores 0,2,3 and 4]	
06/12/2017	229	2.2%	2.60	6.1%
13/12/2017	330	2.1%	3.00	6.1%
22/01/2018	208	5.8%	3.25	9.6%
29/01/2018	201	5.0%	3.10	9.0%
01/02//2018	186	2.2%	2.50	7.5%
Average	**231**	**3.4%**	**2.89**	**7.7%**

SLAP/Date	No Lungs scored	EP-like lesions % Bronchopneumonic Lungs	% Average Surface Affected Out of Pneumonic Lungs	% Scar
[redacted]	1154			
06/12/2017	229	16.6%	5.7%	24.5%
13/12/2017	330	18.8%	7.8%	15.5%
22/01/2018	208	6.3%	7.6%	22.1%
29/01/2018	201	7.0%	3.3%	15.9%
01/02//2018	186	2.7%	4.7%	19.9%
Average	**231**	**10.3%**	**5.8%**	**19.6%**

SLAP/Date	No Lungs scored	Heart % Pericarditis	Liver % Milk Spots
[redacted]	1154		
06/12/2017	229	2.2%	1.7%
13/12/2017	330	2.4%	0.0%
22/01/2018	208	9.6%	0.5%
29/01/2018	201	5.5%	0.5%
01/02//2018	186	0.0%	0.0%
Average	**231**	**3.9%**	**0.5%**

Comments

Dorso-caudal pleurisy: pleurisy in the diaphragmatic lobes

Cranial pleurisy: pleurisy on the surface of the lobes (apical and cardiac) or between them or the heart.

Bronchopneumonic lungs: any lungs with signs of pneumonia, whichever the severity.

More info on the scores used: https://www.ceva.co.uk/Swine/Ceva-Lung-Program/Ceva-Lung-Program