



Managing respiratory disease in finisher pigs: Combining quantitative assessments of clinical signs and the prevalence of lung lesions at slaughter

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ABSTRACT

This study aimed to assess the relationship between quantitative assessments of clinical signs of respiratory disease (recorded manually and automatically) and the prevalence of lung lesions at slaughter to validate the use of both in the management of respiratory disease on farm. This was an observational study where pigs ($n = 1573$) were monitored from 25 ± 5.3 kg (week 12) to slaughter at 114 ± 15.4 kg (week 24). Pigs were housed in eight rooms divided into six pens on a wean-to-finish farm. A manual pen-based coughing (CF) and sneezing (SF) frequency was recorded weekly, for ten consecutive weeks, and a SOMO box (SoundTalks®) was installed in each room, issuing a daily respiratory distress index (RDI) for 13 weeks. Lungs were individually scored for pneumonia, scarring and dorsocaudal (DC) and cranial (CP) pleurisy lesions at slaughter. Relationship between prevalence of lung lesions and weekly RDI and CF and SF was assessed using Spearman's rank correlations and multivariable linear and logit-normal models.

Both coughing and lung lesions were largely pen-specific, which fit the disease presentation of *Mycoplasma hyopneumoniae*. Results showed agreement between RDI and CF ($r_s = 0.5$, $P < 0.001$), measuring higher levels of coughing at the beginning (weeks 13–14) and end (weeks 21–24, and weeks 21–22, respectively) of the finisher period. Positive associations were found between the prevalence of pneumonia and CF on week 21 and 22 ($P < 0.001$ and $P = 0.011$, respectively) and RDI on week 21–24 ($r_s > 0.70$; $P < 0.050$); the prevalence of DC and CP, and CF on week 22 ($P < 0.001$); and prevalence of scar lesions and CF on week 17 and 21 ($P = 0.013$ and $P = 0.004$, respectively), and RDI on week 21–24 ($r_s > 0.70$; $P < 0.050$).

In the earlier weeks of the finisher stage, coughing was recorded but was not reflected in a higher prevalence of lung lesions at slaughter. These findings highlight the benefit of including measurements of coughing frequency to complement *post mortem* findings, to improve the management of respiratory disease on farm.

1. Introduction

The pig industry suffers substantial economic losses due to respiratory disease worldwide (Haden et al., 2012; Maes et al., 1999; Nathues et al., 2017). These losses are due to increased mortality, medication use, and condemnations at slaughter as well as reduced performance (Calderon Diaz et al., 2020). Furthermore, respiratory disease is also the main reason for antimicrobial use in growing and finishing pigs in Ireland (Pereira do Vale, unpublished data), and it is likely to have a significant negative impact on pig welfare although such an effect is rarely considered in the literature.

The porcine respiratory disease complex is characterized by a combination of environmental risk factors and primary infectious agents, such as the Reproductive and Respiratory Syndrome virus (PRRSv), Influenza A Virus (IAV), *Mycoplasma hyopneumoniae* (Mhyo), and *Actinobacillus pleuropneumoniae* (APP), which may lead to opportunistic infectious agents (Brockmeier et al., 2002; Sibila et al., 2009).

Diagnosis and severity estimation of respiratory disease in pig herds is achieved through clinical examination and *post mortem* examinations of dead or euthanized animals during farm visits, and routine slaughter checks (VanAlstine, 2012). Customarily, a combination of these and direct identification of the pathogen in affected tissue are used to reach

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an etiological diagnosis. This approach is costly and, being time consuming and retrospective, delays the implementation of intervention strategies crucial to minimise negative impacts on pig performance and welfare. Therefore, alternative ways to detect and monitor respiratory disease are needed.

Coughing is the most common and easily assessed clinical sign of respiratory disease in pigs. Indeed, [Luehrs et al. \(2017\)](#) and [Nathues et al. \(2012\)](#) reported that a single quantitative assessment of coughing in finisher pigs close to slaughter weight can be used to diagnose Enzootic Pneumonia associated with Mhyo. Furthermore, quantitative coughing assessments can be used in the detection of IAV ([Ryt-Hansen et al., 2019](#)).

Sneezing is another common clinical sign of respiratory disease in pigs. Although highly non-specific regarding aetiology ([VanAlstine, 2012](#)), sneezing is also commonly assessed during clinical examinations on farm. Indeed, quantitative assessments of both sneezing and coughing are included in the Welfare Quality® on-farm monitoring scheme ([Czycholl et al., 2016](#); [Temple et al., 2011](#)). However, intensification of the pig industry is such that there are often thousands of pigs on large farms which when combined with labour constraints makes the likelihood of widespread adoption of manual assessments of coughing and sneezing unlikely.

Precision technologies play an increasingly important role in the early diagnosis of disease in intensive production systems ([Norton and Berckmans, 2018](#)). Focusing on increased efficiency, Precision Livestock Farming (PLF) technologies collect animal- and environment-based outcome data to support decision making at farm level. In the case of respiratory disease, the Pig Respiratory Distress Package by SoundTalks® (SOMO) performs continuous and automated measurements of coughing by analyzing the sound collected within a pig house using a microphone ([Hemeryck et al., 2015](#)). This tool was developed to give farmers an objective measure of coughing frequency in finisher pigs (>25 kg) and studies show its potential for early detection of episodes of respiratory disease when compared to detection by farm personnel ([Berckmans et al., 2015](#); [Polson et al., 2019](#)).

Detailed inspections of lung lesions at slaughter have potential to provide a comprehensive picture of a farm's respiratory health status ([Fablet et al., 2012](#); [Meyns et al., 2011](#); [Rodrigues da Costa, 2018](#)). However, due to their ability to heal with no scarring, lung lesions are a poor indicator of pig health in the early production stages ([Pagot et al., 2007](#)). However, combining lung inspections with on farm quantitative manual and automatic coughing measurements could fill significant knowledge gaps regarding the onset of respiratory disease at different stages of the production cycle. The objective of this study was to assess the relationship between manual and automatic quantitative assessments of coughing and the prevalence of lung lesions at slaughter to validate the use of both in the management of respiratory disease on farm.

2. Material and methods

This study took place on a commercial wean-to-finish pig farm from July to November 2018. The farm was positive for Mhyo, PRRSv, IAV and APP and vaccinated for Mhyo, PRRSv and IAV. Productive performance figures for the first six months of 2018 included average daily gain (885 g/day), feed conversion ratio (FCR; 2.52) and finisher mortality (3.9 %; as per data submitted to the Teagasc e-Profit Monitor). The equivalent figures for the Irish finisher herd were 885 g/day, 2.72 and 2.4 %, respectively (Teagasc, 2019).

Pigs were housed in rooms with fully slatted concrete floors, fed three times per day (Hydromix wet feeding system, Big Dutchman, IDS, Portlaoise, Co. Laois, Ireland) and water was provided *ad libitum*. For pigs aged 12–18 weeks, environmental conditions were controlled with an automatic temperature-based control system using roof-mounted exhaust fans (Big Dutchman®). Thereafter, rooms were naturally ventilated. The rooms were artificially illuminated from 0800 till 1700

h.

Over a six-week period, four batches of pigs (1573 in total) of approximately 12 weeks of age and weighing 25 ± 5.3 kg were housed in eight rooms each divided into six pens (mean number of pigs: 197 ± 5 per room and 33 ± 2 per pen) on arrival at the farm. All pigs were individually identified with ear-tags such that they could be monitored individually for 13 weeks, until reaching the targeted slaughter weight of 110 kg (114 ± 15.4 kg live-weight). Following routine farm practices, all pigs removed from the study (either dead or removed to hospital pens) were registered daily.

2.1. Manual coughing and sneezing frequency assessments

For each of the 48 pens, the number of coughs and sneezes were counted over a 5-minute period once per week, for ten consecutive weeks starting when the animals were aged 13 weeks until 22 weeks of age, hereafter referred to as week 13–22. All assessments were performed by the first author following the Welfare Quality Protocol® guidelines. The average coughing frequency (CF) was estimated as:

$$CF = \frac{\sum \text{Number of coughs in a Pen}}{\text{number of examined pigs (n)} * \text{total time of observation (min.)}}$$

Sneezing frequency (SF) was estimated using the same formula.

2.2. Automatic coughing frequency assessments

The SOMO (SoundTalks NV, Ambachtenlaan 1, 3001 Leuven, Belgium) performs continuous and automated measurements of cough sounds, issuing a Respiratory Distress Index (RDI), which corresponds to the average number of coughs per pig per twenty-four hours. It also generates an automated warning which is calculated with a patented Statistical Process Control algorithm using the history and the variation of the RDI from a specific room.

One SOMO box was installed in each room, following the manufacturer's guidelines. All data collected during the 13 weeks of the trial were stored and accessed using the SOMO associated pig respiratory distress monitoring (RDM) software.

2.3. Slaughterhouse checks

Pigs went to the slaughterhouse in eight batches, corresponding to the eight rooms monitored with the SOMO boxes. Pigs were individually identified by a unique slap number, which was linked to each ear-tag number, in order to attribute lungs to the corresponding pen/room. The first author carried out all lung examinations.

For each pig, individual lung lobes were examined for pneumonia lesions using a scoring method based on [Madec and Derrien \(1981\)](#). The scores were 0 (no pneumonia), 1 (1–25% of the lung lobe affected), 2 (26–50%), 3 (51–75%) and 4 (76–100%). The overall surface affected was also estimated and it accounted for lobe weights, as per [Christensen et al. \(1999\)](#). Lung scars, defined as healed pneumonia lesions, were recorded as absent (0) or present (1).

Pleurisy was scored on the dorsocaudal (DC) lobes using a modified version of the Slaughterhouse Pleurisy Evaluation System (SPES) ([Dottori et al., 2007](#)). The scores were 0 (no pleurisy), 2 (focal lesions in one lobe), 3 (bilateral adhesions or monolateral adhesions affecting more than 1/3 of the diaphragmatic lobe), and 4 (extensive lesions affecting more than 1/3 of both diaphragmatic lobes). Cranial pleurisy (CP; adhesions between the surface of the apical and cardiac lobe, and/or adhesions between the lung and the heart) was recorded as absent (0) or present (1).

2.4. Statistical analysis

R version 3.5.1 was used for the statistical analyses (R Core Team,

2018).

2.4.1. Lung lesions and CF and SF assessments

The dependent variables used for statistical analysis were the prevalence of dorsocaudal pleurisy ($SPES \geq 2$), cranial pleurisy, pneumonia (scores ≥ 1), and scar lesions. Independent variables corresponded to the average coughing and sneezing frequency for every week ($n = 10$) in which the trial pigs were assessed. Pen was the experimental unit.

Independent variables were initially investigated using Spearman's rank correlations and carried forward for multivariable regression analysis when $r_s > 0.2$. Independent variables were also assessed for collinearity ($r_s > 0.7$).

Prevalence of DC, CP and scar lesions were modelled using multivariable linear regression and prevalence of pneumonia was modelled using logit-normal regression. Mixed models were used to test the effect of pen within room. This effect was not significant therefore fixed effects models were used.

We constructed the models using a backward stepwise elimination and variables with a significance probability $P < 0.05$ were retained in the model. Alpha level for significance and tendency were 0.01 and 0.05, respectively. Residuals' normality was assessed visually and using Shapiro Wilk normality test for all models.

2.4.2. CF and SOMO measurements

All CF assessments per room were matched with the specific dates of the daily SOMO measurements (80 days in total) and Spearman's rank correlation was performed to examine their association.

2.4.3. Lung lesions and SOMO measurements

Spearman's rank correlations were performed to examine the associations between the SOMO measurements (independent variables; median RDI values corresponding to each week ($n = 12$) in which the pigs were on trial) with lung lesions (same dependent variables as in 2.4.1), using room as the experimental unit. Alpha level for significance and tendency were 0.05 and 0.1, respectively.

3. Results

Average daily gain (ADG) from week 12 to slaughter was 917 ± 45.2 g/day and the percentage of pigs removed from the study was 6.8 ± 5.18 %. The percentage of removals was highest on weeks 13 (1.0 ± 1.56 %) and 14 (1.0 ± 1.70 %), and lowest on week 16 (0.1 ± 0.56 %).

3.1. CF, SF and SOMO measurements

In general, the CF was high in all pens in week 13, with 0.015 ± 0.0159 coughs/pig/min, the frequency of coughing decreased in the following weeks but another increase in the CF was recorded on week 22 (0.017 ± 0.0293 coughs/pig/min) (Fig. 1). Overall, there were outliers every week indicating that although most pens presented low CF, others consistently exhibited higher values. The SF was highest in week 13 and reduced thereafter (Fig. 1).

The SOMO captured cough sounds for a period of 13 weeks such that coughing was recorded from 12 to 24 weeks of age (Fig. 2). In general, RDIs were higher during weeks 12 and 13, decreasing thereafter and remaining somewhat constant until the last three weeks (22–24), when RDIs reached the highest levels in 3 of the 8 rooms.

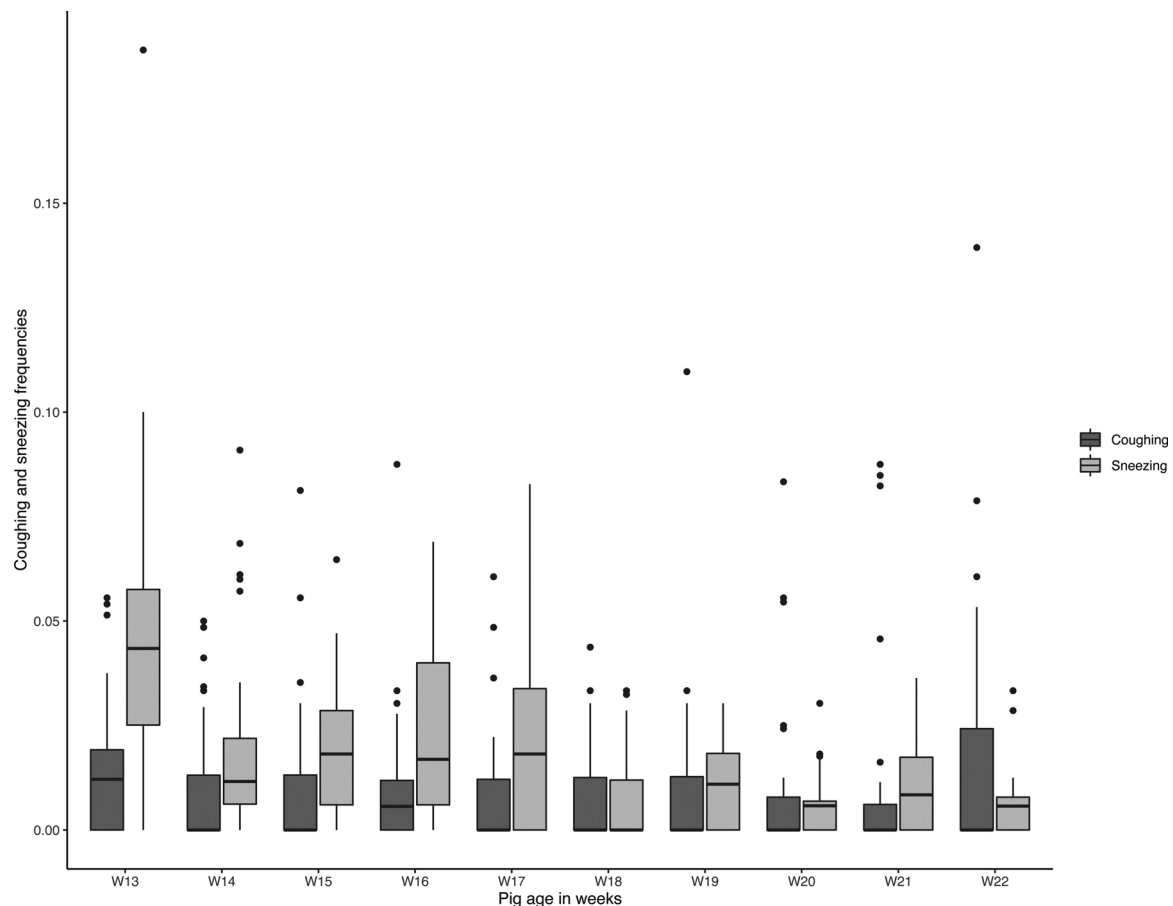


Fig. 1. Coughing and sneezing frequencies (average number of coughs/sneezes per pig per minute) measured in 48 pens of pigs aged 13 weeks ($n = 33 \pm 2$ pigs/pen) for ten consecutive weeks, on an Irish finisher pig farm in 2018 (box: median and interquartile range (IQR); whiskers: $1.5 \times$ IQR).

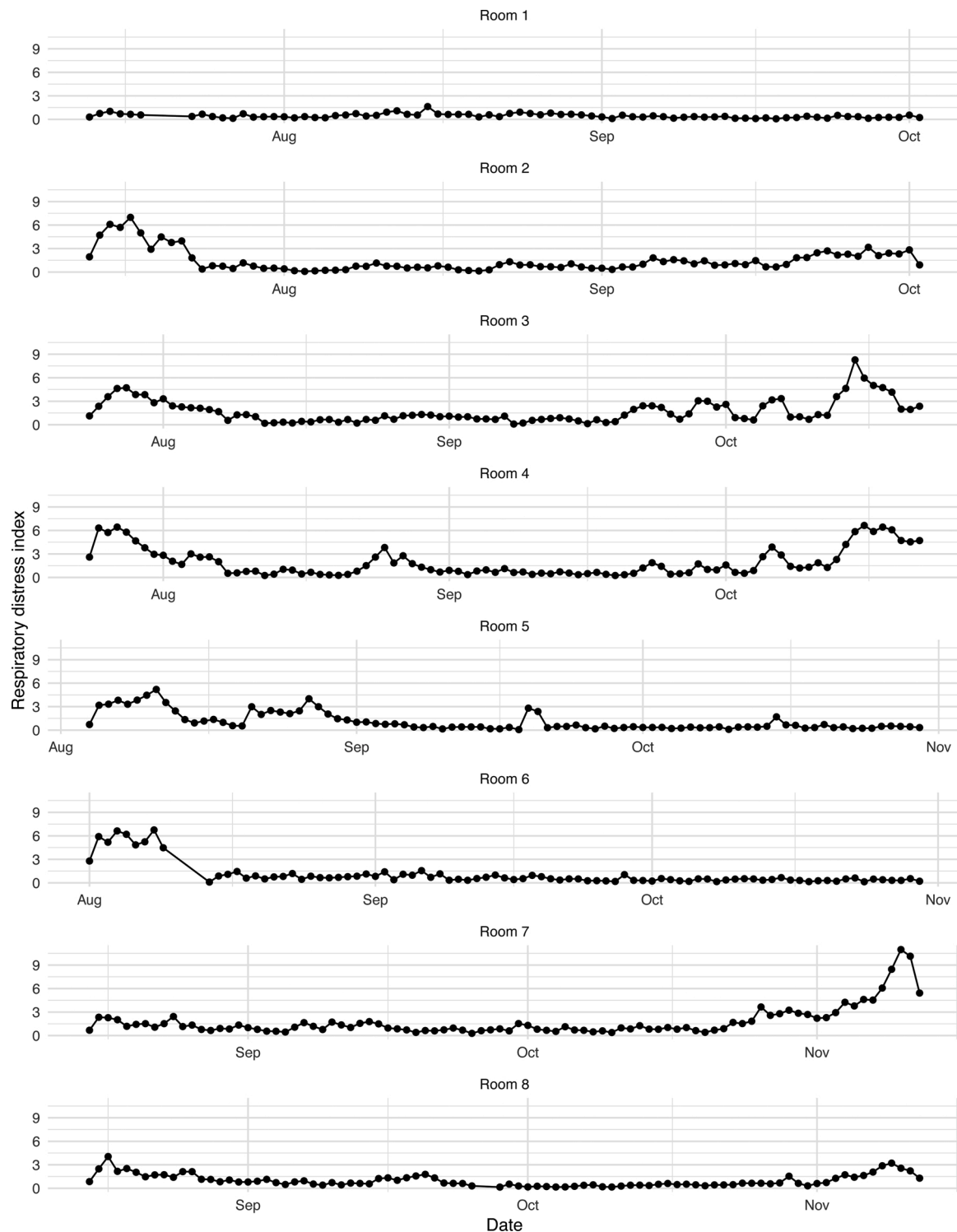


Fig. 2. Respiratory distress index (RDI; average number of coughs per pig per twenty-four hours) measured continuously in 8 rooms of pigs aged 12 weeks ($n = 197 \pm 5$ pigs/room) until 24 weeks of age, on an Irish finisher pig farm in 2018.

3.2. Lung lesion scores at slaughter

A total of 1540 pairs of lungs were assessed at slaughter. On average each room had 193 ± 5 lungs assessed (range 185–199) and each pen had 32 ± 2 lungs (range 27–35). The prevalence of dorsocaudal and cranial pleurisy, scars and pneumonia is presented in Table 1. The average score for dorsocaudal pleurisy was 3.19, with 83.0 % of lungs with a SPES of 3 or 4 and the average affected pulmonary area with

pneumonia was 10.9 % (range 1.3 %–42.3 %).

3.3. Associations between CF and SF recorded weekly and lung lesions recorded at slaughter

The multivariable models fitted for the prevalence of DC, CP, pneumonia, and for scar lesions are presented in Table 2 and were able to explain 39–55% of variability. The prevalence of dorsocaudal pleurisy

Table 1

Prevalence (%) of pigs per room (n = 193 ± 5 pigs) and pen (n = 32 ± 2 pigs) on an Irish finisher farm affected by lung lesions assessed at the slaughterhouse in 2018.

Lung lesion	Mean (%)	Median (%)	SE (%)	Min (%)	Max (%)
Dorsocaudal pleurisy					
Room	11.9	10.6	1.90	3.2	18.4
Pen	11.9	9.8	1.33	0.0	41.9
Cranial pleurisy					
Room	16.0	17.1	2.11	7.6	23.8
Pen	16.0	15.6	1.35	0.0	45.2
Scars					
Room	17.0	17.1	2.4	8.9	23.8
Pen	17.0	15.9	1.31	0.0	42.4
Pneumonia					
Room	21.5	15.1	6.00	6.1	42.6
Pen	21.5	15.0	2.61	3.0	64.7

Table 2

Multivariable regression models of lung lesions at slaughter from coughing (CF) and sneezing (SF) frequencies (average number of coughs/sneezes per pig per minute) measured in 48 pens of pigs aged 13 weeks (n = 33 ± 2 pigs/pen) for ten consecutive weeks, on an Irish finisher pig farm in 2018.

Models	Predictors	Estimate (SE)	P-value
Dorsocaudal pleurisy (%) Adj. R ² = 39%	Intercept	0.05 (0.021)	0.027
	SF week 16	1.85 (0.592)	0.004
	CF week 22	1.83 (0.459)	< 0.001
Cranial pleurisy (%) Adj. R ² = 55%	Intercept	0.21 (0.018)	< 0.001
	CF week 13	-3.35 (0.761)	< 0.001
	CF week 15	-2.70 (0.700)	< 0.001
	CF week 22	2.27 (0.400)	< 0.001
Pneumonia (%) ^a	Intercept	-1.75 (0.219)	< 0.001
	CF week 21	19.31 (4.691)	< 0.001
	CF week 22	11.31 (4.178)	0.011
Scar lesions (%) Adj. R ² = 45%	Intercept	0.12 (0.018)	< 0.001
	CF week 17	2.23 (0.845)	0.013
	SF week 17	1.14 (0.531)	0.040
	CF week 19	-1.86 (0.619)	0.005
	CF week 21	1.55 (0.504)	0.004

^a A logit-normal regression model was used for pneumonia.

was higher in pens where higher SF occurred on week 16 (P = 0.004) and when higher CF occurred on week 22 (P < 0.001). A higher prevalence of cranial pleurisy was associated with lower CF on weeks 13 and 15 (P < 0.001) and higher CF on week 22 (P < 0.001). Prevalence of scar lesions was positively associated with the CF on weeks 17 and 21 (P = 0.013 and P = 0.004, respectively) and negatively associated with CF on week 19 (P = 0.005). Prevalence of pneumonia lesions was positively associated with CF on weeks 21 and 22 (P < 0.001 and P = 0.011, respectively).

3.4. Associations between SOMO measurements, CF and lung lesions recorded at slaughter

Daily RDI and CF assessments showed good correlation (rs = 0.5, P < 0.001; Fig. 3).

The univariable analysis of the median RDI for each week of finisher stage and the four lung lesions is presented in Fig. 4.

There were no correlations between lung lesions and RDI values in weeks 12 and 13 (P > 0.05), even though high values of RDI were recorded. Dorsocaudal pleurisy was negatively correlated with RDI values on week 15 and positively correlated with RDI values recorded on week 17 (P = 0.016 and P = 0.027, respectively). Only one association was found between cranial pleurisy and the RDI, also occurring on week 15 (P = 0.019).

Correlations were found between pneumonia lesions and RDI values

on weeks 17 (P = 0.041), 19 (P = 0.037) and 21–24 (P = 0.043, P = 0.012, P = 0.008 and P = 0.011, respectively). There were also associations between scar lesions and RDI values on week 19 (P = 0.037) and 21–24 (P = 0.023, P = 0.045, P = 0.003, P = 0.019).

4. Discussion

In the current study, we aimed to investigate the relationship between on-farm manual and automatic (SOMO) records of coughing frequency throughout the finisher stage and lung lesions at slaughter. We hypothesized that quantitative semi- and continuous monitoring of clinical signs could complement *post mortem* findings by providing information in the earlier stages of production, when lung lesions are known to be uninformative.

We selected the farm to ensure the presence of clinical signs of respiratory disease during the study. However, this in turn meant that finisher mortality (3.9 %) was higher than the Irish pig herd average of 2.4 % (Teagasc, 2019). Nevertheless, ADG was comparable to, and the FCR was better, than the national average (Teagasc, 2019). Regarding lung lesions, the prevalence of pneumonia (21.5 %) and its severity (10.9 % of lung surface affected) was higher compared to findings of an Irish cross sectional study involving 30 % of the Irish pig herd (11 % prevalence and 5.8 % of lung surface affected) (Rodrigues da Costa et al., 2020). The prevalence of scars was 17.0 %, which suggests that, conservatively, around 38.5 % of pigs had pneumonia at one point in their lifetime. This high prevalence of pneumonia-related lesions is consistent with the presence of clinical signs of respiratory disease on farm. Findings for the other lung lesions were in line with previous figures for Irish herds (Rodrigues da Costa et al., 2020).

The role of coughing as a diagnostic tool has been investigated in several studies (Baraldi et al., 2019; Luehrs et al., 2017; Nathues et al., 2012; Ryt-Hansen et al., 2019). All used the ‘coughing index’ (Bahnsen, 1993), which defines a coughing episode as either a single cough or a set of continuous coughs by a single animal. The method used represents the average percentage of pigs coughing within one minute, but information on the number of actual coughing episodes is not attainable. In this study we considered a coughing episode as any cough a pig suffered during the time of observation, thus allowing us to compare our manual assessments to those performed by the SOMO. Manually assessing coughing on-farm overtime has logical disadvantages. In this study, it took over 40 h to assess CF for 10 weeks in 48 pens (containing approximately 1600 pigs). The possibility that much less frequent direct assessments of coughing frequency could also yield useful information requires further investigation. However, it would be difficult to surpass the effectiveness of the SOMO in terms of time-effectiveness/labour saving.

The SOMO measurements showed similar trends as the manual quantitative coughing assessments, measuring higher levels of coughing at the beginning (weeks 13–14) and end (weeks 21–24 and weeks 21 and 22, respectively) of the finisher period. This agreement shows that both assessments are useful to quantitatively measure coughing frequency on farm.

Positive associations were found between lung lesions and RDI from week 21 through to week 24, and lung lesions and CF from week 21 through to week 22. This is consistent with the findings of Pagot et al. (2007), who reported an association between age and increased pneumonia lesions at slaughter. Interestingly, scar lesions were associated with CF on week 17. As these lesions indicate that infection occurred at an earlier stage, associations with higher coughing levels at that time are coherent. However, no associations were found between pneumonia-related variables at slaughter and either the RDI or the CF in the early weeks of the finisher period (i.e. weeks 13–14). These findings are consistent with the fact that lung lesions associated with respiratory disease in younger animals heal and may leave no scar tissue (Pagot et al., 2007; Straw et al., 1990; VanAlstine, 2012).

Our findings strongly suggest that pneumonia lesions at slaughter have no value for assessing respiratory health in younger pigs, and that

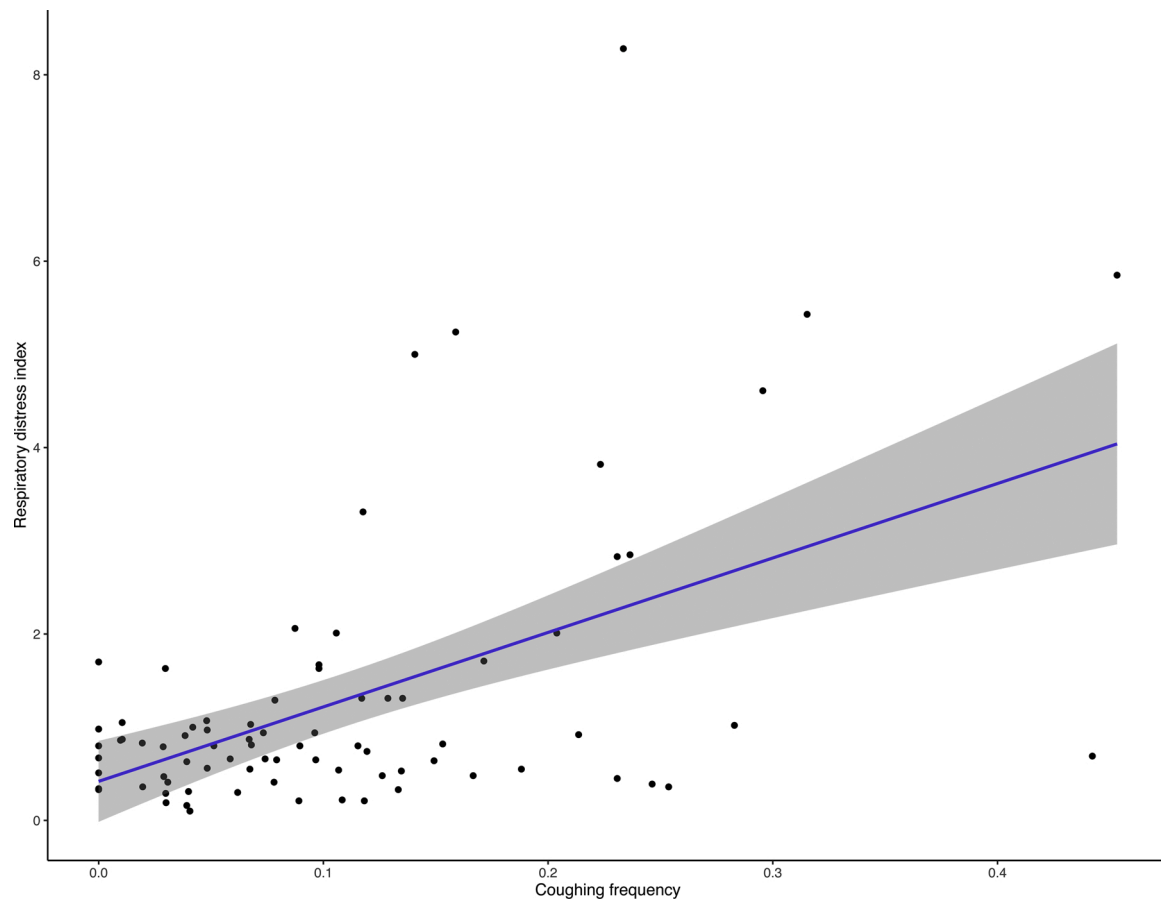


Fig. 3. Correlation between the respiratory distress index (RDI; average number of coughs per pig per twenty-four hours) and coughing frequency (average number of coughs/sneezes per pig per minute) measured at room level ($n = 197 \pm 5$ pigs/room) on the same day (80 measurements in total), on an Irish finisher pig farm in 2018 ($r_s = 0.5$, $P < 0.001$; trend line and confidence interval correspond to blue line and grey area, respectively) (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article).

measuring coughing frequency should be employed for that purpose.

Furthermore, a negative association was found between CF on week 13 and cranial pleurisy. This means that in spite of recording high levels of coughing at this time there was no corresponding higher prevalence of cranial pleurisy at slaughter, in fact the opposite was true. The fact that the percentage of removed pigs was highest on weeks 13 and 14 may explain this negative association. Indeed, the removal of pigs showing clinical signs of respiratory disease likely explains why coughing frequency declined in the subsequent weeks. Moreover, we found negative associations between CF and RDI on week 15, and cranial pleurisy. In this study, data on antibiotic treatments received by the pigs during the finishing period were not available. However, the timing and quality of these treatments could be an important factor influencing both the reduction in the frequency of coughing over time and the healing of lung lesions at the time of slaughter. Indeed, in a study where manual quantitative assessments of coughing overtime were performed in veal calves (Leruste et al., 2012), the authors discuss the same limitation, highlighting the importance of integrating farm records of antibiotic treatments with on-farm clinical examination and slaughterhouse information. Further research is needed to understand variations of coughing frequency, mortality, and antimicrobial use.

Our findings call into question the validity of RDI values above 10 indicating the presence of respiratory disease on-farm (Berckmans et al., 2015). Despite the high prevalence of lesions recorded at slaughter and given the higher than the Irish prevalence and the severity of lesions associated with pneumonia, an RDI greater than 10 was only recorded once in the current study. Indeed, Hemeryck et al. (2015) reported a 48 % prevalence of pneumonia lesions and a 12 % prevalence of pleurisy

with a corresponding RDI of ≈ 10 on just two occasions when monitoring one batch of finisher pigs. Another study reports RDI values of 10–23 and positive results for IAv (Polson et al., 2018). Moreover, the SOMO's automated warning only activated twice during this study. This warning is based on a threshold calculated with a patented Statistical Process Control algorithm that uses the history and the variation of the RDI from a specific room. The exact RDI value to indicate the presence of respiratory disease is likely to be farm-dependant (Cui et al., 2019). However, further studies are needed to clarify differences in levels of coughing: throughout production stages, in different environmental conditions (e.g. high concentrations of ammonia and particulate matter), and to verify the baseline coughing frequency in healthy pigs, to better calibrate the SOMO's warning system.

Furthermore, it is not yet possible to acquire pen-specific information with the SOMO, as it records coughing sounds at room level. Our data from the manual coughing assessments indicate that coughing was largely pen-specific, as were the corresponding lung lesions. These findings fit the disease presentation of Mhyo, as transmission of this pathogen between pen-mates is slow (Maes et al., 2017).

Overall, quantitative measurements of coughing frequency can be useful to detect and manage respiratory disease. By providing farmers and their veterinarians with objective information, adjustments to vaccination and treatment protocols can be made, and ultimately the effect of those changes can be assessed. Further, efforts to characterize coughing patterns according to primary aetiology are being made (Polson et al., 2019). These data could be useful for surveillance of specific pathogens, particularly for IAv due to its zoonotic potential.

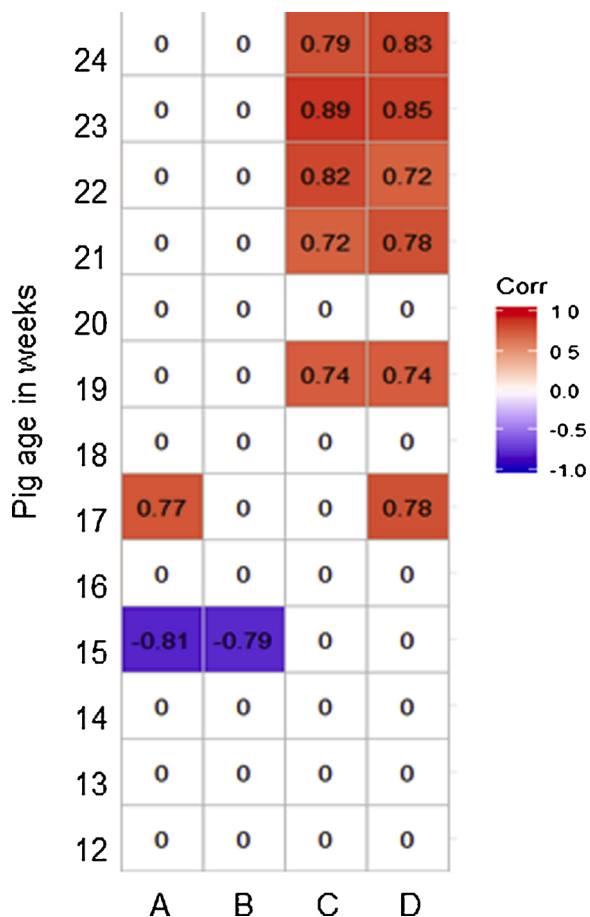


Fig. 4. Spearman rank correlations between prevalence of dorsocaudal (A) and cranial (B) pleurisy, scar lesions (C) and pneumonia (D), and the respiratory distress index (RDI; average number of coughs per pig per twenty-four hours) at room level (n = 197 ± 5 pigs/room) in function of pigs age in weeks, on an Irish finisher pig farm in 2018. Cells with zeros correspond to non-significant results (P > 0.05).

5. Conclusion

Under the conditions of this study, there was good association between the prevalence of lung lesions recorded at slaughter and coughs recorded on farm by the SOMO and by manual quantitative assessments at the end of the finisher stage. In contrast, though coughing was recorded in the earlier weeks of the finisher stage, it was not reflected in a higher prevalence of lung lesions at slaughter. This indicates that respiratory health of pigs in the earlier production stages is not reflected in lung lesions recorded at slaughter. This highlights the benefit of including either manual or automatic measures of coughing frequency to complement *post mortem* findings, in order to improve the management of respiratory disease on farm.

In addition, our findings provide new evidence which can be used to refine the SOMO’s threshold for detecting episodes of respiratory disease on farm.

Further studies are needed to clarify differences in levels of coughing throughout the production stages, to classify patterns of coughing according to their primary aetiology and to environmental risk factors, and to verify the baseline coughing frequency in healthy pigs.

Declaration of Competing Interest

None to declare.

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:<https://doi.org/10.1016/j.prevetmed.2020.105208>.

References

Bahnsen, P.B., 1993. The application of a clinical index of coughNo title. In: 24th Annual Meeting of the American Association of Swine Practitioners. Kansas City, pp. 701–705.

Baraldi, T.G., Cruz, N.R.N., Pereira, D.A., Galdeano, J.V.B., Gatto, I.R.H., Silva, A.F.D., Panzardi, A., Linhares, D.C.L., Mathias, L.A., de Oliveira, L.G., 2019. Antibodies against *Actinobacillus pleuropneumoniae*, *Mycoplasma hyopneumoniae* and influenza virus and their relationships with risk factors, clinical signs and lung lesions in pig farms with one-site production systems in Brazil. *Prev. Vet. Med.* 171, 104748 <https://doi.org/10.1016/J.PREVETMED.2019.104748>.

Berckmans, Dries, Hemeryck, Martijn., Berckmans, Daniel, Vranken, Erik, van Waterschoot, Toon, 2015. Animal sound... talks! Real-time sound analysis for health monitoring in livestock. In: International Symposium on Animal Environment & Welfare. Chongqing, pp. 215–222.

Brockmeier, S., Halburg, P.G., Thacker, E.L., 2002. Porcine respiratory disease complex. In: Brogden, K., Guthmiller, J. (Eds.), *Polymicrobial Diseases*. ASM Press, Washington DC.

Calderon Diaz, J., Fitzgerald, R., Shalloo, L., Rodrigues da Costa, M., Niemi, J., Leonard, F., Kyriazakis, I., Garcia Manzanilla, E., 2020. Financial analysis of herd status and vaccination practices for porcine reproductive and respiratory syndrome virus, swine influenza virus and *Mycoplasma hyopneumoniae* in farrow-to-finish pig farms using a bio-economic simulation model. *Front. Vet. Epidemiol. Econ.* <https://doi.org/10.3389/fvets.2020.556674>.

Christensen, G., Soerensen, V., Mousing, J., 1999. Diseases of the respiratory system. In: Straw, B., D’Allaire, S.M.W., Taylor, D.J. (Eds.), *Diseases of Swine*. Iowa University Press, Ames, pp. 913–940.

Cui, Z.Y., Buyens, D., Berckmans, D., de Volder, I., Degezelle, I., Vranken, E., 2019. Technological tools for infection detection: case studies with the SOMO respiratory distress monitor in Belgian pig farms. In: European Conference on Precision Livestock Farming. Cork, Ireland, pp. 292–297.

Czycholl, I., Kniese, C., Büttner, K., Beilage, E.G., Schrader, L., Krieter, J., 2016. Test-retest reliability of the Welfare Quality® animal welfare assessment protocol for growing pigs. *Anim. Welf.* 25, 447–459.

Dotoli, M., Nigrelli, A.D., Merialdi, G., Gozio, S., Bonilauri, P., Cominotti, F., 2007. Proposta di un nuovo sistema di punteggiatura delle pleuriti suine in sede di macellazione. *La griglia S.P.E.S. (Slaughterhouse Pleuritis Evaluation System)*. *Large Anim. Rev.* 13, 161–165.

Fablet, C., Marois-Créhan, C., Simon, G., Grasland, B., Jestin, A., Kobisch, M., Madec, F., Rose, N., 2012. Infectious agents associated with respiratory diseases in 125 farrow-to-finish pig herds: a cross-sectional study. *Vet. Microbiol.* 157, 152–163. <https://doi.org/10.1016/J.VETMIC.2011.12.015>.

Haden, C., Painter, T., Fangman, T., Holtkamp, D., 2012. Assessing production parameters and economic impact of swine influenza, PRRS and mycoplasma hyopneumoniae on finishing pigs in a large production system. American Association of Swine Veterinarians Annual Meeting 75–76.

Hemeryck, M., Berckmans, D., Vranken, E., Tullo, E., Fontana, I., Guarino, M., van Waterschoot, T., 2015. The pig cough monitor in the EU-PLF project results and multimodal data analysis in two case studies. In: 7th European Conference on Precision Livestock Farming (EC-PLF). Milan, pp. 147–155.

Leruste, H., Brcsic, M., Heutinck, L.F.M., Visser, E.K., Wolthuis-Fillerup, M., Bokkers, E. A.M., Stockhofe-Zurwieden, N., Cozzi, G., Gottardo, F., Lensink, B.J., van Reenen, C. G., 2012. The relationship between clinical signs of respiratory system disorders and lung lesions at slaughter in veal calves. *Prev. Vet. Med.* 105, 93–100. <https://doi.org/10.1016/j.prevetmed.2012.01.015>.

Luehrs, A., Siegenthaler, S., Grütznert, N., grosse Beilage, E., Kuhnert, P., Nathues, H., 2017. Occurrence of *Mycoplasma hyorhinis* infections in fattening pigs and association with clinical signs and pathological lesions of Enzootic Pneumonia. *Vet. Microbiol.* 203, 1–5. <https://doi.org/10.1016/j.vetmic.2017.02.001>.

Madec, F., Derrien, M., 1981. Fréquence, intensité et localisation des lésions pulmonaires chez le porc charcutier: Résultats d’une première série d’observations en abattoir. *Journées de La Recherche Porcine En France*, pp. 231–236.

Maes, D., Deluyker, H., Verdonck, M., Castryck, F., Miry, C., Vrijens, B., Verbeke, W., Viaene, J., de Kruijff, A., 1999. Effect of vaccination against *Mycoplasma*

- hyopneumoniae in pig herds with an all-in/all-out production system. *Vaccine* 17, 1024–1034. [https://doi.org/10.1016/S0264-410X\(98\)00254-0](https://doi.org/10.1016/S0264-410X(98)00254-0).
- Maes, D., Sibila, M., Kuhnert, P., Segalés, J., Haesebrouck, F., Pieters, M., 2017. Update on *Mycoplasma hyopneumoniae* infections in pigs: knowledge gaps for improved disease control. *Transbound. Emerg. Dis.* 65, 110–124. <https://doi.org/10.1111/tbed.12677>.
- Meyns, T., Van Steelant, J., Rolly, E., Dewulf, J., Haesebrouck, F., Maes, D., 2011. A cross-sectional study of risk factors associated with pulmonary lesions in pigs at slaughter. *Vet. J.* 187, 388–392. <https://doi.org/10.1016/J.TVJL.2009.12.027>.
- Nathues, H., Sperser, J., Rosengarten, R., Kreienbrock, L., Grosse Beilage, E., 2012. Value of the clinical examination in diagnosing enzootic pneumonia in fattening pigs. *Vet. J.* 193, 443–447. <https://doi.org/10.1016/j.tvjl.2012.01.013>.
- Nathues, H., Alarcon, P., Rushton, J., Jolie, R., Fiebig, K., Jimenez, M., Geurts, V., Nathues, C., 2017. Cost of porcine reproductive and respiratory syndrome virus at individual farm level – an economic disease model. *Prev. Vet. Med.* 142, 16–29. <https://doi.org/10.1016/j.prevetmed.2017.04.006>.
- Norton, T., Berckmans, D., 2018. Precision livestock farming: the future of livestock welfare monitoring and management? In: Butterworth, A. (Ed.), *Animal Welfare in a Changing World*. CABI, p. 130.
- Pagot, E., Pommier, P., Keïta, A., 2007. Relationship between growth during the fattening period and lung lesions at slaughter in swine. *Rev. Med. Vet. (Toulouse)* 158 (5), 253–259.
- Polson, D.D., Playter, S., Berckmans, D., Stoffel, A., Quinn, B., 2018. Classification of cough patterns in growing pigs using continuous sound monitoring and an algorithm-based respiratory distress index. *European Symposium of Porcine Health Management*.
- Polson, D., Playter, S., Berckmans, D., Cui, Z., Quinn, B., 2019. Evaluation of an audio-based sensor platform to classify patterns of clinical respiratory episodes in large growing pig populations. In: *European Conference on Precision Livestock Farming*. Cork, Ireland, pp. 553–558.
- Rodrigues da Costa, M., 2018. *Evaluation of Current Feeding and Management Practices in Irish Pig Production and Future Strategies for Improvement*. Universitat Autònoma de Barcelona.
- Rodrigues da Costa, Maria, Fitzgerald, Rose Mary, Garcia Manzanilla, Edgar, O'Shea, Helen, Moriarty, John, McElroy, Maire C., Leonard, Finola Catherine, 2020. A cross-sectional survey on respiratory disease in a cohort of Irish pig farms. *Ir. Vet. J.* 73 (24) <https://doi.org/10.1186/s13620-020-00176-w>.
- Ryt-Hansen, P., Larsen, I., Kristensen, C.S., Krog, J.S., Wacheck, S., Larsen, L.E., 2019. Longitudinal field studies reveal early infection and persistence of influenza A virus in piglets despite the presence of maternally derived antibodies. *Vet. Res.* 50 <https://doi.org/10.1186/s13567-019-0655-x>.
- Sibila, M., Pieters, M., Molitor, T., Maes, D., Haesebrouck, F., Segalés, J., 2009. Current perspectives on the diagnosis and epidemiology of *Mycoplasma hyopneumoniae* infection. *Vet. J.* 181, 221–231. <https://doi.org/10.1016/J.TVJL.2008.02.020>.
- Straw, B.E., Shin, S.J., Yeager, A.E., 1990. Effect of pneumonia on growth rate and feed efficiency of minimal disease pigs exposed to *actinobacillus pleuropneumoniae* and *mycoplasma hyopneumoniae*. *Prev. Vet. Med.* 9 (4), 287–294.
- Temple, D., Dalmau, A., de la Torre, J.L.R., Manteca, X., Velarde, A., 2011. Application of the Welfare Quality® protocol to assess growing pigs kept under intensive conditions in Spain. *J. Vet. Behav.* 6, 138–149.
- VanAlstine, W.G., 2012. Respiratory system. In: Zimmerman, J.J., Karriker, L.A., Ramirez, A., Schwartz, K.J., Stevenson, G.W. (Eds.), *Diseases of Swine*. Wiley-Blackwell, Ames, pp. 348–363.