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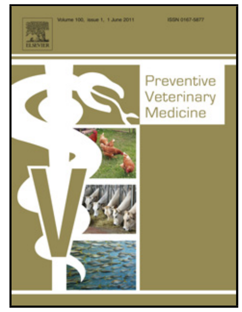

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Early life indicators predict mortality, illness, reduced welfare and carcass characteristics in finisher pigs

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ABSTRACT. The objective of this study was to investigate associations between early life indicators, lactation management factors and subsequent mortality, health, welfare and carcass traits of offspring. A total of 1,016 pigs from a batch born during one week were used. During lactation, number of liveborn piglets, stillborn and mummies, sow parity, number of times cross-fostered, weaning age, birth and weaning body weight (BW) were collected. Mortality was recorded throughout the offspring production cycle. Prior to slaughter, pigs were scored for lameness (1 = non-lame to 3 = severely lame). At slaughter, tail lesions were scored (0 = no lesion to 4 = severe lesion) and cold carcass weight (CCW), lean meat %, presence of pericarditis and heart condemnations were recorded. Additionally, lungs were scored for pleurisy (0 = no lesions to 4 = severely extended lesions) and enzootic pneumonia (EP) like lesions. There was an increased risk of lameness prior to slaughter for pigs born to first parity sows ($P < 0.05$) compared with pigs born to older sows. Sow parity was a source of variation for cold carcass weight ($P < 0.05$) and lean meat % ($P < 0.05$). Pigs born in litters with more liveborn pigs were at greater risk of death and to be lame prior to slaughter ($P < 0.05$). Pigs that were cross-fostered once were 11.69 times, and those that were cross-fostered ≥ 2 times were 7.28, times more likely to die compared with pigs that were not cross-fostered ($P < 0.05$). Further, pigs that were cross-fostered once were at greater risk of pericarditis and heart condemnations compared with pigs that were not cross-fostered ($P < 0.05$). Pigs with a birth BW of < 0.95 kg were at higher mortality risk throughout the production cycle. There was an increased risk of lameness, pleurisy, pericarditis and heart condemnations ($P < 0.05$) for pigs with lower weaning weights. Additionally, heavier pigs at weaning also had higher carcass weights ($P < 0.05$). There was an increased risk of lameness for pigs weaned at a younger age ($P < 0.05$). Males were 2.27 times less likely to receive a score of zero for tail biting compared with female pigs. Results from this study highlight the complex relationship between management, performance and disease in pigs. They confirm that special attention should be given to lighter weight pigs and pigs born to first parity sows and that cross-fostering should be minimised.

Key words: lactation period, mortality, organ condemnations, performance, pigs, respiratory diseases

1. Introduction

Mortality, reduced performance and poor health are the main sources of economic loss in pig industries worldwide (Maes et al., 2003). Additionally, they may be indicators of animals experiencing compromised welfare (Martínez et al., 2007; KilBride et al., 2012). All three are clearly interrelated. Reduced performance and poor health are, in part, the result of inadequate nutrition, housing, stockmanship, environmental factors and susceptibility to pathogens (Zimmerman, 2010; Coelho, 2014). Several studies report associations between early life indicators (e.g. low birth and weaning weight), management practices (e.g. cross-fostering in lactation, lactation length) and subsequent low growth performance (Quiniou et al., 2002; Wolter et al., 2002; Main et al., 2004; Larriestra et al., 2006; Fix et al., 2010a; Cabrera et al., 2010; Douglas et al., 2013) and survival (Neal and Irvin, 1991;Tuchscherer et al., 2000; Deen and Bilkei, 2004; Maes et al., 2004; Koketsu et al., 2006). However, most studies focused either on herd level factors (Kritas and Morrison, 2004; Fraile et al., 2010; Kilbride et al., 2012) or on specific production stages (Deen and Bilkei, 2004; Koketsu et al., 2006; Larriestra et al., 2006). Nevertheless, there is limited information in the scientific literature regarding the effect of sow and pig characteristics and management practices during the lactation period and their association with of poor health and reduced welfare in grower-finishing pigs.

Therefore, the objective of this study was to investigate possible associations between early life indicators (i.e. sow parity, number of liveborn piglets, stillborn and mummies, birth and weaning weight, cross-fostering, weaning age and gender), and the risk of mortality from birth to slaughter, disease and welfare indicators at slaughter and carcass traits. By understanding such relationships, it is possible to characterise pigs at greater risk of mortality, disease and poor performance. This in turn could be used to design preventive strategies that are easy to implement on a pig farm to optimise performance and improve pig health and welfare.

2. Materials and Methods

2.1.Care and Use of Animals

The study received ethical approval from the Teagasc Animal Ethics Committee (TAEC 40/2013). It was conducted on a 1,500 Large White × Landrace sow farrow-to-finish commercial farm in Ireland that was positive for porcine circovirus type 2, *Mycoplasma hyopneumoniae* and swine influenza virus. The farm followed a batch farrowing system with approximately 80 sows farrowing per week. All piglets (n = 1,016) born from the same batch of 18 gilts and 66 sows (average parity 3.3 ± 1.50; parity range 1 to 6), hereafter referred as sows, were followed from birth to slaughter. At birth, piglets were individually tagged, and the parity of its sow was recorded. The number of liveborn piglets, stillborn and mummies was counted for each litter. Cross-fostering was done within 24h after birth based on live weight to create sows with piglets of low weight and to equalize the numbers off pigs in different litters. Then, along lactation pigs were cross-fostered whenever sows showed problems with milk production. The number of times each piglet was cross-fostered between different sows was recorded as well as weaning age for each pig. Gender was recorded at weaning. Animals were managed as per usual practice on the farm. This farm declared that it followed an all-in/all-out (AIAO; Owsley et al., 2013) policy whereby pigs should spend 8 weeks in the nursery stages (4 weeks in nursery stage 1 and nursery stage 2) after weaning, 4 weeks in the growing stage and 8 weeks in the finisher stage.

At total of 901 pigs were weaned (106 pigs died during lactation) on the same day at approximately 28 days of age and they were individually weighed. Entire litters were moved together into the nursery stage 1 where they remained for 4 weeks housed in groups of 55 pigs with a minimum 0.30 m^2 per pig. Groups were split and mixed by size/BW and housed for the next 8 weeks (4 weeks in the nursery stage 2 and 4 weeks grower stage) in groups of 36 pigs with a minimum 0.55 m^2 per pig. Finally, pigs were transferred to the finishing unit for 8 weeks and housed in groups of 35 with a minimum 0.65 m^2 per pig being mixed. It is important to note that group composition changed between each stage according to regular farm management practices. Pigs were re-graded according to size/BW on transfer to each of the production stages. Smaller (i.e. slow growing) pigs from each pen were removed and re-grouped. No pigs were added to the pens with the heavier pigs. Some pigs were delayed from moving to the next stage on timely manner and were mixed with younger pigs from the next batch. Other pigs became sick and on return from the hospital pens were mixed with younger pigs. Nonetheless, all pigs were slaughter within a week at approximately 24 weeks of age.

All houses for each one of the stages had the same design and environmental control. Nursery and growing facilities had an automatic temperature control system with fans in the ceiling and finisher facilities had natural over pressure ventilation. In all stages, animals were housed on fully slatted floors, plastic for nursery and concrete for growers and finishers stages. Pigs were wet- fed common nursery diet with 18.3% CP and 10.5 MJ/DE per kg of feed; grower diet with 18.1% CP and 10.0 MJ/DE per kg of feed, and finisher diets with 16.9% CP and 9.9 MJ/DE per kg of feed. Pigs had ad libitum access to water via at least one nipple drinker in each pen.

2.2. Measurements

2.2.1. Lameness.

All pigs were individually scored while they walked approximately 10 m on solid concrete flooring on the alley-way of the loading room separate where they were moved before transportation on the day prior to slaughter. Pigs were visually scored for walking lameness by one trained observer on a 3-point scale adapted from the lameness scoring developed by Main et al. (2000) for finisher pigs where 1 = pig is bright, alert and responsive, sow stands squarely on all four legs and has even strides; 2 = pig is bright but less responsive (may remain lying or dog sitting before eventually rising), pig is limping and has shortened stride; and 3 = pig is unwilling to leave familiar environment, and it may not bear weight on affected limb and has shortened stride.

2.2.2. Tail lesions. At slaughter, tail lesions were scored by one trained observer after scalding and dehairing as per Harley et al., (2012) on a 5-point scale where 0 = no evidence of tail biting; 1 = healed or mild lesions; 2 = evidence of chewing or puncture wounds, but no evidence of swelling; 3 = evidence of chewing with swelling and signs of possible infection; and 4 = evidence of chewing with severe swelling/infection or an open wound where the tail used to be.

2.2.3. Carcass characteristics. Cold carcass weight, fat thickness, muscle content and percentage of lean meat were recorded by the slaughterhouse personnel. Fat thickness and muscle content were measured using a Fat-O-Meat'er (Carometec Food Technology, Carometec A/S, Hasselunden 9, Smørum, Denmark). Percentage of lean meat was calculated according to the formula established by the European Communities Pig Carcass Grading Amendment Regulations (Department of Agriculture, Fisheries and Food, 2001):

$$\%\,\text{lean meat} = 60.30 - (0.847 \times \text{fat thickness}) + (0.147 \times \text{muscle})$$

2.2.4. Health conditions. Pleurisy was scored using the Slaughterhouse Pleurisy Evaluation System (SPES; Dottori et al., 2007) by one trained observer on a 5-point scale where 0 = no lesions; 1 = cranio-ventral lesion: pleural adhesions between lobes or at ventral border of diaphragmatic lobes, 2 = dorso-caudal monolateral focal lesion, 3 = bilateral type 2 lesion or extended monolateral lesion (at least 1/3 of a diaphragmatic lobe) and 4 = severely extended bilateral lesion (at least 1/3 of both diaphragmatic lobes).

Enzootic pneumonia (EP) like lesions were scored according to the British Pig Executive (BPEX) Pig Health Scheme (2016) by one trained observer. Each pair of lungs was divided into 7 lobes; the cranial lobes, cardiac lobes, diaphragmatic lobes and a single accessory lobe. Cranial and cardiac lobes received a score from 0 to 10 and the cranial areas of the diaphragmatic lobes and the accessory lobe received a score from 0 to 5, depending on the level of disease observed. The total EP score varied from a minimum of 0 to a maximum of 55. Additionally, presence or absence of pericarditis and all instances of condemnations of heart, liver and lungs were recorded as per the decision of the acting veterinary inspector.

Mortality. Records of the numbers of animals that died and the date of death were maintained throughout the offspring production cycle. Information on causes of death were not available from farm records.

2.3.Statistical Analysis.

Each pig was considered as the experimental unit. As 26 females were selected as replacement gilts they did not have slaughter records, and were only used for the mortality analysis. Number of piglets per litter stillborn was classified as zero, one, two and ≥ 3 and number of mummies was re-classified as zero and ≥ 1 due to low numbers in the upper ranges. Number of times pigs were cross-fostered was classified as zero, one and ≥ 2. As only one pig was scored as severely lame prior to slaughter, lameness was classified as non-lame and lame. Similarly, as there were only four observations for tail lesion scores ≥ 3; tail lesions were re-classified as absent (i.e. score = 0), mild (i.e. score = 1) and moderate (i.e. scores ≥ 2). Pleurisy was re-classified as no lesions, mild lesions (i.e. scores 1 and 2) and severe lesions (i.e. scores 3 and 4). Only 15 pigs had their liver condemned and 12 pigs had their lungs totally condemned, therefore, liver and lung condemnations were not analysed. Descriptive statistics for predictor variables and carcass traits are presented in Table 1. Frequencies for mortality, welfare and health variables are presented in Table 2.

All data were analysed in SAS v9.3 (SAS Inst. Inc., Cary, NC). Either Mann-Whitney tests (PROC NPAR1WAY) or Spearman and Pearson correlations (PROC CORR) were calculated between predictor variables, to identify collinearity among predictor variables (Table 3). All data were analysed in PROC GLIMMIX. First univariable models were used to investigate the relationship between predicted and predictor variables (Table 4). Predictor variables with a $P \leq 0.10$ at the univariable level were selected for the multivariable models. If variables were highly correlated (r = ≥ 0.50), then the only variable that had the greatest effect in the univariable model was retained. A manual stepwise selection for fixed effects was used and only fixed effects with a $P < 0.05$ remained in the final model. Lameness, pericarditis, heart condemnations and mortality were analysed using binomial logistic regression; whereas tail lesion and pleurisy scores were analysed using multinomial logistic regression. Results are presented as odds ratios with the associated 95% confidence interval. In multinomial logistic regression, the odds ratios refer to the likelihood of receiving the lowest scores.

Cold carcass weight, lean meat percentage and EP score were evaluated for normality using the Shapiro-Wilk test and examining the normal plot. As EP score was not normally distributed, data were transformed to the log 10 scale and results were back transformed to the original scale. Data were analysed using linear model equations. Multiple means comparison were adjusted using Tukey–Kramer correction. Results for fixed effects are reported as least square means ± standard error (SE). For all analyses, results for continuous variables are reported as the regression coefficient ± SE.

The effect of birth BW on risk of mortality throughout the production cycle was further studied and the break point for birth BW was estimated using a segmented (i.e. broken line) regression model in the *Segmented* (Muggeo, 2008) package of *R* (R Core Team, 2015).

3. Results

One-hundred-and-ninety-four (19%) pigs died during the study. A total of 106 pigs (54.6%) died during the lactation period, 24 pigs died during nursery (12.4%), 3 pigs died during growing (1.5%) and 14 pigs (7.2%) died during the finishing stages and 47 pigs (24.2%) were euthanised for a study investigating respiratory pathologies. These animals were selected for euthanasia on the basis of showing external lesions and/or pathologies such as hernias, severe tail biting (i.e. complete tail loss), severe lameness, external abscesses, emaciation etc. Euthanized pigs were not included in the statistical analysis. Details on reasons for euthanasia and results for the study regarding respiratory pathologies will be presented in a separate manuscript.

3.1.Sow parity.

Sow parity was associated with number of liveborn piglets, number of stillborn and mummies, number of times cross-fostered, birth and weaning BW and weaning age ($P < 0.05$; Table 3). There was an increase in the risk of lameness prior to slaughter for pigs born to first parity sows ($P < 0.05$; Table 5) compared with pigs born to older parity sows. Sow parity was a source of variation for cold carcass weight ($P < 0.05$) and lean meat % ($P < 0.05$; Table 6); however, no defined pattern was observed. There was no association ($P > 0.05$) between sow parity and the rest of outcome variables.

3.2.Number of liveborn piglets.

Number of liveborn piglets was associated with sow parity, number of stillborn piglets, number of times cross-fostered, birth and weaning BW and weaning age ($P < 0.05$; Table 3). A moderate negative correlation was observed between number of liveborn piglets and birth BW (Table 3); therefore, as number of liveborn piglets increased, birth BW decreased. Pigs born in litters with more liveborn pigs were at greater risk of death and to be lame prior to slaughter ($P <$ 0.05; Table 5). There was no association ($P > 0.05$) between number of liveborn piglets and the rest of outcome variables.

3.3.Number of stillborn piglets.

Number of stillborn piglets was associated with mummies, times cross-fostered, weaning age and weaning BW ($P < 0.05$; Table 3). Carcasses of pigs born in litters with no stillborn piglets were approximately 3 kg lighter when compared with carcasses from pigs born in litters with one and ≥ 3 stillborn piglets, respectively ($P < 0.05$; Table 6). Additionally, pigs born in litters with ≥ 3 stillborn piglets received higher EP scores compared with pigs born in litters with one or two stillborn piglets ($P < 0.05$; Table 6).

3.4.Number of times cross-fostered.

Number of times cross-fostered was associated with sow parity, number of liveborn piglets, number of stillborn, birth and weaning BW and weaning age ($P < 0.05$; Table 3). Pigs that were cross-fostered once were 11.69 times, and those that were cross-fostered ≥ 2 times were 7.28, times more likely to die compared with pigs that were not cross-fostered ($P < 0.05$; Table 5). Further, pigs that were cross-fostered once were at greater risk of pericarditis and heart condemnations compared with pigs that were not cross-fostered ($P < 0.05$; Table 6).

3.5.Birth BW.

Birth BW was associated with sow parity, number of liveborn piglets, mummies, number of times cross-fostered and weaning BW ($P < 0.05$; Table 3). A strong positive correlation was observed between birth BW and weaning BW (Table 3). There was a reduced risk of lameness prior to slaughter associated with an increased on birth BW ($P < 0.05$; Table 5). Lighter pigs at birth were at greater risk of death ($P < 0.05$; Table 5). Using the segmented regression model, it was estimated that pigs with a birth BW of < 0.95 kg were at higher mortality risk throughout the production cycle (Figure 1). Average survival chances for pigs with a birth BW < 0.95 kg were estimated at 28.4% whereas survival chances for pigs with birth BW ≥ 0.95 kg were estimated at 87.1% (Figure 1)

3.6. Weaning BW.

Weaning BW was associated with sow parity, number of liveborn piglets, number of stillborn, number of times cross-fostered, birth BW and weaning age ($P < 0.05$; Table 3). There was an increased risk of lameness, pleurisy, pericarditis and heart condemnations ($P < 0.05$; Table 5) for pigs with lower weaning weights. Additionally, heavier pigs at weaning also had higher carcass weights ($P < 0.05$; Table 6).

3.7.Weaning age.

Weaning age was associated with sow parity, number of stillborn and mummies, number of times cross-fostered and weaning ($P < 0.05$; Table 3). There was an increased risk of lameness for pigs weaned at a younger age ($P < 0.05$; Table 5). There was no association ($P > 0.05$) between weaning age and the rest of outcome variables.

3.8.Gender

Gender was not associated with any of the other predictor variables ($P > 0.05$; Table 3). Males were 2.27 times (95% CI = 0.33 to 0.57; $P < 0.05$) less likely to receive a score of zero for tail biting compared with female pigs. Carcasses from males pigs were 2.57 kg heavier but they had 1.15% less of lean meat than carcasses from females ($P > 0.05$; Table 6). Males received lower scores for EP compared with females ($P > 0.05$; Table 6).

4. Discussion

The objective of this study was to identify early life indicators that could predict mortality, health and performance in finisher pigs. However, to discern which indicators could be useful at farm level could be tricky. All the predictor variables were correlated although correlations were weak to moderate except for birth and weaning weight where a strong positive correlation was observed. On the other hand, results were corrected for multiple comparisons based on the predictor variables but not on the outcome variables. The authors preferred to not use such severe approach; however, this might have resulted in a higher type I error (i.e. more false positives).

Sow parity was associated with the risk of lameness. Although lameness may be episodic (Rowles, 2001), early life indicators may be related to lameness occurrence later in life. For instance, Zoric (2008) studied lameness in piglets up to nine weeks of age and observed a greater percentage of lame piglets born from gilts compared to sows parity ≥ 4. In piglets, lameness is usually associated with infectious arthritis (Christensen, 1996) and it has been reported that litters from first parity sows are often more severely affected (Done et al., 2010). This suggest that immunity is important in the susceptibility to arthritis inducing factors (Zoric et al., 2003) since sows are more resistant to microorganisms than gilts (Loula, 2000; Wrathall et al., 2003). Additionally, first parity sows and have poorer colostrum quality (Quesnel, 2011) and milk production (Larriestra et al., 2006) than older sow parities. These factors combined mean that piglets born to gilts have lower intakes of poorer quality colostrum/milk leading to poorer immune development (Quiniou et al., 2002). Having gilts in the herd is unavoidable as there is always a need to replace cull sows. However, efforts can be made to improve sow longevity in order to reduce sow replacement rates and thus, the proportion of gilts in the herd. In practice, recommended proportion of gilts is 20% (Pinilla and Lecznieski, 2014); however, in the literature it ranges between 17% and 30% (Straw, 1984; Parson et al., 1990; Muirhead and Alexander, 1997; Carroll, 1999; Morrison et al., 2002). Having a higher proportion of gilts in the herd is associated with higher on farm prevalence of *Streptococcus suis, Actinobacillus suis, Haemophilus parasuis, Mycoplasma hyopneumoniae, Staphylococcus hyicus* and *Pasteurella* organisms (Sanz et al., 2002). Therefore, it should be ensured that the optimal proportion of gilt is maintained as high proportion of gilts in the herd also results in a lower mean litter size and (Hughes and Varley, 2003), consequently, less pigs weaned and less kg of dead weight produced per sow per year.

Greater number of liveborn piglets in the litter was associated with an increased risk of mortality. Piglets born in larger litters face greater competition for available functional teats leading to reduced colostrum and milk intake (Neal and Irvin, 1991; Le Dividich, 1999). In our study, pigs born in litters with a greater number of piglets born alive were also at greater risk of lameness prior to slaughter. This is probably related to the fact that larger litters were more likely to be cross-fostered. Cross-fostered pigs engage in a higher number of aggressive encounters (Robert and Martineau, 2001; Wattanaphansak et al., 2002) and aggression is a risk factor for leg problems (Spoolder et al., 2009).

Stillborn piglets are usually observed in larger litters (Segura-Correa and Solorio-Rivera, 2013). It has been reported that they are lighter than liveborn piglets (Leenhouwers et al., 1999) and have lower levels of α_2-macroglobulins (Svendsen et al., 1986). We are unable to provide an explanation for the relationship found between stillborn piglets and greater cold carcass weight. Nevertheless, it is possibly related to a sow parity effect. Most of stillborn piglets were observed litters from sows parity three and four and these produced pigs with lower cold carcass weight. The relationship between large litters and high number of stillborn piglets could also explain the higher EP scores received by pigs born in litters with ≥ 3 stillborn piglets as piglets from large litters are more likely to be cross-fostered and cross-fostering could have a negative impact on immunity development and long term health (Rooke et al., 2003).

Pigs that were cross-fostered were at greater risk of mortality, pericarditis and heart condemnations. Although cross-fostering is recommended to improve survivability of low birth weight piglets in large litters (Neal and Irvin, 1991; Straw et al., 1998) it can be stressful for piglets and disturb their behaviour (Heim et al., 2012). It also increases the likelihood of death through continuous exposure to pathogens (McCaw et al., 1996) against which they may not be fully protected (Wills et al., 1997). Cross-fostered piglets might have not spend enough time with their dams to consume an adequate amount of colostrum to acquire immunity for the protection against diseases (Cabrera et al., 2010). Additionally, as teat order is established very early in the piglets' life (McBride, 1963), adopted pigs engage in more aggressive encounters when accessing teats (Wattanaphansak et al., 2002) resulting in insufficient milk intake mostly due to irregular suckling (Robert and Martineau, 2001). Cross-fostering policy is the main management practice during lactation that can be easily controlled by farmers which could lead to improved performance. It is recommended that, if cross-fostering cannot be avoided, it is done only when it is needed and only between 12 to 24 h after farrowing before the teat order has been established (Heim et al., 2012). This is done to maximise colostrum intake and absorption of its immunoglobulins (Robert and Martineau, 2001). Additionally, continuous cross-fostering should be avoided to minimise stress and its negative effects on pig survival, performance and health (Neal and Irvin, 1991; Robert and Martineau, 2001).

In pigs, lighter birth weight is associated with lower immune development (Quiniou et al., 2002) and an increased risk of pre- and post-weaning mortality (Tuchscherer et al., 2000; Caceres et al., 2001; Fix et al., 2010a; Jourquin et al., 2016). In this study, < 0.95 kg of BW at birth was identified as a threshold for increased mortality throughout the production cycle. This result is similar to the results reported by Feldpausch et al. (2016) of 1.11 kg of birth BW and to those reported by Gadner et al. (1989) of a 32% survival rate for pigs < 0.80 kg of birth BW. Light weight pigs at birth have lower energy reserves (Elliot and Lodge, 1977), have lower vitality (Herpin et al., 1996) and they are more likely to delay their first suckle (Le Dividich, 1999). According to Neal and Irvin (1991) pig with lower birth weight are at disadvantage at the time of feeding leading to insufficient colostrum and milk consumption. In fact, it has been reported that besides crushing, inadequate colostrum intake is the main reason for pre-weaning mortality (Le Dividich et al., 2005). Le Dividich (1999) reported that heavier pigs had a greater ability to access the best teats and to stimulate them to induce greater milk flow. Indeed, as the pig immune system is not fully developed at birth (Tuchscherer et al., 2000), milk intake is vital for pig survival (Fix et al., 2010b). Besides meeting the piglets' nutritional requirements (Sørensen et al., 1998), milk provides the piglets with antimicrobials that promote the immune system development (Hosea Blewett et al., 2008). Therefore, identifying piglets below 0.95 kg BW at birth and providing them with extra attention could help to improve production survivability. For example, split suckling (Baxter et al., 2013) to ensure they are consuming sufficient colostrum or administering energy supplements (King'Ori, 2012) could be implemented.

Lower weaning weight was associated with an increased risk of lameness, pleurisy, pericarditis and heart condemnations. It is possible that lighter pigs at weaning were able to catch up by the time of slaughter and fast growth rates are associated with an increased risk of lameness (Grondalen and Vangen, 1974). This is supported by the fact that pigs born from first parity sows also had the lightest weaning weights (data not shown) and they were also at greater risk of lameness. On the contrary, Pagot et al. (2007) observed reduced growth on animals affected by pleurisy and since pigs weaned at lighter weight were the affected ones, we could hypothesise that the greater risk of pleurisy in lighter piglets is related to their lower immunological status (Quiniou et al., 2002) making them more susceptible to infectious agents such as *Actinobacillus* sp., and *Mycoplasma hyopneumoniae* causing pleurisy (VanAlstine, 2010). It is suggested that weaning weight may be a better indicator for growth performance than birth weight in pigs (Wolter and Ellis, 2001). However, results of previous studies on the effect of weaning weight in pig performance are inconsistent. For instance, Cabrera et al. (2010) reported that heavier pigs at weaning had a higher growth rate and a similar result was also reported by Douglas et al. (2013). On the contrary, Mahan et al. (1998) and Wolter and Ellis (2001) reported such relationship during the nursery phase not during the finishing period. Weighing individual pigs is not a common practice in commercial pig farms; nonetheless, as farmers usually sort piglets by size/BW, in practice, group weaning weight could be used as an early indicator for subsequent health and performance.

In this study, shorter lactation length was associated with an increased risk of lameness, and as for piglet mortality, this may be related to longer exposure to milk antibodies (Losinger et al., 1998). Gender was associated with tail lesions with males being at greater risk of mild and severe tail lesion than females. This is in agreement with other studies reporting that the prevalence of tail lesions is lower in females (Wallgren and Lindahl, 1996; van Staaveren et al., 2016) . However, the reason for a greater prevalence of tail lesions in males is still unclear. Nonetheless, in spite of tail biting being a multifactorial problem, our results suggest that early life indicators do not seem to influence the likelihood of being a tail biting victim and/or the present of tail lesions. Gender was also associated with carcass characteristics with males having heavier carcass weight with lower lean meat %. Rehfeldt et al. (2008) and Conte et al. (2011) reported that females had a greater lean meat percentage than entire males and Beattie et al. (1999) reported an increase in lean meat percentage with a decrease in carcass weight which is in agreement with our results.

5. Conclusion

Our results suggest that the importance of early life indicators should not be underestimated. They could enable the design of easily-adopted strategies to prevent disease in the young animal and improve performance throughout the production cycle. Special attention should be given to lighter piglets (i.e. < 0.95 kg) at farrowing in order to achieve heavier weaning weights and to optimise performance and health. Additionally, special attention should be given to pigs born to first parity sows as they were at greater risk of mortality and diseases. Cross-fostering increases the risk of mortality, pericarditis and heart condemnations and should be minimized. However, as it is highly related with other factors such as birth weight and number of liveborn piglets, randomised studies are necessary to further elucidate the impact of cross-fostering on mortality, performance and health.

Conflict of interest

None to declare.

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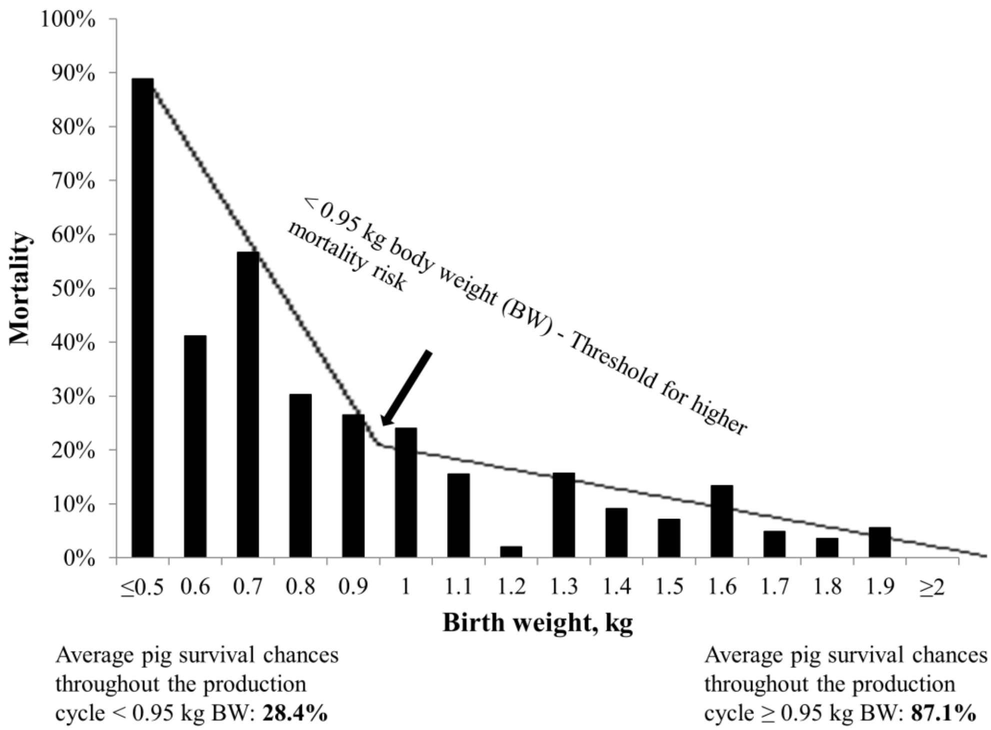

Figure 1. Relationship between birth weight (BW) and risk of mortality (%) from birth to slaughter in a study including 1,016 pigs on one commercial farm. The break point for birth weight was estimated using a segmented regression model in the *Segmented* (Muggeo, 2008) package of *R* (R Core Team, 2015).

Table 1. Descriptive statistics for the predictor variables used to identify early life indicators associated with pig mortality, performance and health traits in 1,016 pigs on one commercial farm

Predictor variables	Mean	SD	Minimum	Maximum
Sow parity	3.3	1.50	1	6
Number of liveborn piglets	13.2	2.51	4	19
Number of stillborn piglets	0.9	1.05	0	4
Number of mummies	0.2	0.42	0	2
Number of times cross-fostered	0.4	0.66	0	3
Birth weight, kg	1.3	0.32	0.45	2.42
Weaning weight, kg	7.1	1.68	1.53	11.75
Weaning age, days	25.6	1.51	21	30

Table 2. Frequency and percentage of pig mortality from birth to slaughter, pigs lame prior to slaughter and pigs with presence of tail lesions, pleurisy, enzootic pneumonia, pericarditis and heart condemnations at slaughter by five different early life indicators in a study involving 1,016 pigs on one commercial farm.

	Mortality (N=997)		Lameness[1] (N=806)		Tail lesions[2] (N=796)		Pleurisy[3] (N=774)		Enzootic pneumonia[4] (N=778)		Pericarditis[5] (N=777)		Heart condemnations[5] (N=778)	
	n	%	n	%	n	%	n	%	n	%	n	%	n	%
Parity														
1	37/187	19.8	39/128	30.5	76/127	59.8	33/122	27.0	64/123	52.0	20/122	16.4	19/123	15.4
2	11/119	9.2	13/102	12.7	60/100	60.0	26/95	27.4	46/96	47.9	6/96	7.9	8/96	8.3
3	29/208	14.0	25/174	14.4	100/171	58.5	35/166	21.1	65/167	38.9	14/167	8.4	14/167	8.4
4	30/262	11.6	31/227	13.7	153/225	68.0	50/220	22.7	96/220	43.6	18/220	8.2	16/220	7.3
5	29/160	18.2	20/125	16.0	81/124	65.3	26/122	21.3	58/123	47.2	10/123	8.1	11/123	8.9
6	8/61	13.1	5/50	10.0	31/49	63.3	14/49	28.6	22/49	44.9	8/49	16.3	8/49	16.3
	144/997	**14.4**	**133/806**	**16.5**	**501/796**	**62.9**	**184/774**	**23.8**	**351/778**	**45.1**	**76/777**	**9.8**	**76/778**	**9.8**
Born dead														
0	80/448	17.6	60/340	19.7	208/337	61.7	85/323	26.3	156/325	48.0	33/324	10.2	36/325	11.1
1	33/274	12.6	38/231	16.5	146/227	64.3	46/220	20.9	102/222	45.9	29/222	13.1	25/222	11.3
2	20/171	11.7	26/147	17.7	89/145	61.4	31/145	21.4	58/145	40.0	11/145	7.6	13/145	9.0
3+	11/104	10.6	9/88	10.2	58/87	66.7	22/86	25.6	35/86	40.7	3/86	3.5	2/86	2.3
	144/997	**14.4**	**133/806**	**16.5**	**501/796**	**62.9**	**184/774**	**23.8**	**351/778**	**45.1**	**76/777**	**9.8**	**76/778**	**9.8**
Mummified														
0	117/861	13.6	112/708	15.8	442/698	63.3	154/667	23.1	306/681	44.9	67/680	9.9	66/681	9.7

1	27/136	20.8	21/98	21.4	59/98	60.2	30/97	30.9	45/97	46.4	9/97	9.3	10/97	10.3
	144/997	**14.4**	**133/806**	**16.5**	**501/796**	**62.9**	**184/774**	**23.8**	**351/778**	**45.1**	**76/777**	**9.8**	**76/778**	**9.8**
Cross-fostering times														
0	27/647	4.5	86/599	14.0	367/607	62.1	129/572	21.9	246/575	42.2	44/575	7.6	44/575	7.9
1	93/257	35.6	37/147	24.5	95/152	65.1	40/145	26.8	73/145	50.3	28/145	18.8	26/145	17.4
2+	24/93	25.5	10/60	16.4	39/59	66.1	18/57	31.0	32/58	54.2	4/57	6.9	5/58	8.5
	144/997	**14.4**	**133/806**	**16.5**	**501/796**	**62.9**	**184/774**	**23.8**	**351/778**	**45.1**	**76/777**	**9.8**	**76/778**	**9.8**
Gender[6]														
Female	21/432	4.9	54/379	14.0	201/377	53.6	79/368	21.0	157/369	41.9	33/369	8.7	33/369	8.9
Male	23/476	4.8	79/423	18.1	297/415	71.4	103/402	25.6	191/405	47.0	43/404	10.7	43/405	10.7
	44/908	**4.8**	**133/802**	**16.6**	**498/792**	**62.9**	**182/770**	**23.6**	**348/774**	**45.0**	**76/773**	**9.8**	**76/774**	**9.8**

[1]Scored prior to slaughter on a 3-point scale were 1 = non lame; 2 = mildly lame and 3 = severely lame.

[2] Scored after scalding and dehairing by one trained observed as per Harley et al., 2012 from 0 = No evidence of tail biting to 4 = Evidence of chewing with severe swelling/infection or open, gaping wound where tail used to be.

[3] Scored using the Slaughterhouse Pleurisy Evaluation System (SPES; Dottori et al., 2007) from 0 = no lesions to 4 = severely extended lesions (at least 1/3 of both diaphragmatic lobes) and/ or acute (exudation and abundant granulation tissue).

[4] Scored according to the British Pig Executive, British Pig Health Scheme (2016).

[5] Recorded as present or absent

[6] Recorded at weaning. A total 147 pigs died during the production cycle. The figures presented in the table represent the 41 pigs that died after weaning.

Table 3. Associations[1] (correlation coefficients and/or *P* values) between predictor variables used to identify early life indicators associated with pig mortality, performance and health traits in 1,016 pigs on a commercial farm

	Sow parity	Number of liveborn piglets	Number of stillborn piglets	Number of mummies	Number of times cross-fostered	Birth weight	Weaning weight	Weaning age	Gender
Sow parity	1	- <0.001	- <0.001	- 0.0002	- <0.001	- 0.0004	- <0.001	- <0.001	- 0.481
Number of liveborn piglets		1	- 0.0002	- 0.315	- <0.001	**-0.341** <0.001	**-0.096** 0.004	**0.081** 0.011	- 0.621
Number of stillborn piglets			1	- 0.001	- <0.001	- 0.241	- 0.014	- <0.001	- 0.919
Number of mummies				1	- 0.363	- <0.001	- 0.366	- <0.001	- 0.224
Number of times cross-fostered					1	- <0.001	- <0.001	- <0.001	- 0.694
Birth weight						1	**0.531** <0.001	**-0.021** 0.509	- 0.366
Weaning weight							1	**0.193** <0.001	- 0.619
Weaning age								1	- 0.656
Gender									1

[1]Association between class variables (parity, cross-fostering, stillborn, mummies and gender) and liveborn piglets, days to weaning, birth and weaning weight were analysed using a Mann-Whitney test. Associations between liveborn piglets, birth and weaning weight were analysed using Pearson correlations. Associations between weaning age and liveborn piglets, birth and weaning weight were analysed using Spearman correlations.

Correlation coefficients are presented in bold numbers.

Table 4. Significance (*P* values) of different predictor variables used in univariable models to identify early life indicators associated with pig mortality, performance and health traits in 1,016 pigs on a commercial farm

Predictor variables	Mortality	Lameness[1]	Tail lesions[2]	Cold carcass weight	Lean meat %[3]	Pleurisy[4]	Enzootic pneumonia[5]	Pericarditis[6]	Heart condemnations[6]
Sow parity	0.025	0.001	0.219	0.032	0.011	0.560	0.136	0.059	0.119
Number of liveborn piglets	0.093	0.018	0.798	0.125	0.751	0.325	0.695	0.981	0.493
Number of stillborn piglets	0.035	0.406	0.284	0.001	0.548	0.373	0.007	0.078	0.137
Number of mummies	0.033	0.163	0.558	0.080	0.169	0.075	0.970	0.859	0.848
Number of times cross-fostered	<0.001	0.009	0.775	0.015	0.758	0.218	0.045	0.0003	0.003
Birth weight, kg	<0.001	0.233	0.106	<0.001	0.170	0.032	0.280	0.013	0.381
Weaning weight, kg	0.045	0.001	0.073	<0.001	0.361	0.031	0.203	<0.001	0.001
Weaning age, days	0.068	0.016	0.136	0.073	0.677	0.921	0.680	0.044	0.101
Gender	0.972	0.097	<0.001	<0.001	<0.001	0.182	0.053	0.339	0.349

[1]Scored prior to slaughter on a 3-point scale were 1 = non lame; 2 = mildly lame and 3 = severely lame.

[2] Scored after scalding and dehairing by one trained observed as per Harley et al., 2012 from 0 = No evidence of tail biting to 4 = Evidence of chewing with severe swelling/infection or open, gaping wound where tail used to be.

[3]Calculated according to the formula established by the European Communities Pig Carcass Grading Amendment Regulations (Department of Agriculture, Fisheries and Food, 2001) as $\%\text{ lean meat } = 60.30 - (0.847 \times \text{fat thickness}) + (0.147 \times \text{muscle})$

[4]Pleurisy was scored using the Slaughterhouse Pleurisy Evaluation System (SPES; Dottori et al., 2007) from 0 = no lesions to 4 = severely extended lesions (at least 1/3 of both diaphragmatic lobes) and/ or acute (exudation and abundant granulation tissue).

[5]Enzootic pneumonia like lesions were scored according to the British Pig Executive, British Pig Health Scheme (2016).

[6] Recorded as present or absent

Table 5. Early life indicators associated with the risk of mortality, lameness prior to slaughter, pleurisy, pericarditis and heart condemnations in a study including 1,016 pigs followed from birth to slaughter on one commercial farm.

Predictor variables	Mortality			Lameness[1,2]			Pleurisy[3]			Pericarditis[1,4]			Heart condemnations[1,4]		
		95% CI			95% CI			95% CI			95% CI			95% CI	
	OR	Lower	Upper	OR	Lower	Upper	OR	Lower	Upper	OR	Lower	Upper	OR	Lower	Upper
Sow parity															
Ref. category = 1															
2				0.36[a]	0.18	0.75									
3				0.30[a]	0.16	0.56									
4	NI[5]			0.25[a]	0.14	0.45	NI			NI			NI		
5				0.24[a]	0.12	0.48									
6				0.25[a]	0.09	0.69									
Number of times cross-fostered															
Ref. category = 0															
1	11.69[a]	7.19	19.00	NI			NI			1.83[a]	1.05	3.21	1.97[a]	1.13	3.43
2+	7.28[a]	3.86	13.76							0.53	0.18	1.62	1.02	0.41	2.60
Number of liveborn piglets[6]	-0.10 ± 0.044*			0.17± 0.046*			NI						NI		
Birth weight[6]	-2.15 ± 0.347*			NI			NI			NI			NI		
Weaning weight[6]	NI			-0.13 ± 0.063*			0.11 ± 0.052*			-0.38 ± 0.085*			-0.20 ± 0.078*		
Weaning age[6]	NI			-0.20 ± 0.075*			NI			NI			NI		

[1]Variables analysed using binomial logistic regression

[2]Scored prior to slaughter on a 3-point scale were 1 = non lame; 2 = mildly lame and 3 = severely lame.

[3]Scored using the Slaughterhouse Pleurisy Evaluation System (SPES; Dottori et al., 2007) from 0 = no lesions to 4 = severely extended lesions (at least 1/3 of both diaphragmatic lobes) and/ or acute (exudation and abundant granulation tissue). It was analysed using multinomial logistic regression

[4]Recorded as present or absent

[5] NI = not included in the final model; $P > 0.05$

[6]Results for continuous variables are reported as the regression coefficient ± SE

[a]Significantly different from reference category, $P < 0.05$

[*]$P < 0.05$

Table 6. Early life indicators associated with cold carcass weight, lean meat percentage and the risk of enzootic pneumonia in a study including 1,016 pigs followed from birth to slaughter on one commercial farm.

Predictor variables	Cold Carcass Weight, kg		Lean meat %[1]		Enzootic pneumonia[2]	
	LS mean	SE	LS mean	SE	LS mean	SE
Sow parity						
1	91.66[a]	0.87	56.37[b]	0.20		
2	89.03[a,b]	0.92	56.80[a,b]	0.22		
3	87.77[b]	0.77	57.33[a]	0.17	NI[3]	
4	87.61[b]	0.61	56.73[a,b]	0.15		
5	90.27[a,b]	0.82	56.67[a,b]	0.20		
6	87.79[a,b]	1.27	56.56[a,b]	0.31		
Number of stillborn piglets						
0	86.89[b]	0.55			0.37[a,b]	0.03
1	90.31[a]	0.65	NI		0.34[b]	0.03
2	88.70[a,b]	0.75			0.28[b]	0.05
3+	90.19[a]	0.99			0.53[a]	0.06
Gender						
Females	87.74[b]	0.50	57.32[a]	0.12	0.34[b]	0.03
Males	90.31[a]	0.49	56.17[b]	0.12	0.42[a]	0.03
Weaning weight[4]	2.84 ± 0.204[*]		NI		NI	

[1]Calculated according to the formula established by the European Communities Pig Carcass Grading Amendment Regulations (Department of Agriculture, Fisheries and Food, 2001) as $\%\,\text{lean meat} = 60.30 - (0.847 \times \text{fat thickness}) + (0.147 \times \text{muscle})$

[2]Enzootic pneumonia like lesions were scored according to the British Pig Executive, British Pig Health Scheme (2016).

[3]NI = = not included in the final model; $P > 0.05$

[4]Results for continuous variables are reported as the regression coefficient ± SE

[a,b] Within columns, significant differences between levels of each predictor variable; $P < 0.05$

[a b] Within columns, a is significantly different from b between levels of each predictor variable; $P < 0.05$

[*]$P < 0.05$