A systematic review and meta-analysis on the influence of farrowing pens on piglet traits

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By

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Executive Summary

There are conflicting reports on the influence of farrowing house accommodation on sow performance with regards to piglet mortality and the number of pigs weaned despite a strong research focus that spans almost 40 years. Two comparisons are usually tested; the performance of a farrowing crate versus that of a farrowing pen. The farrowing crate restricts sow's movement in order to protect piglets from sow overlay. There is evidence that this housing type results in compromised sow welfare during farrowing and throughout lactation. To improve sow welfare, farrowing pens reduce the level of sow confinement, allowing the sow to perform a more diverse behavioural repertoire. To date, no publication exists that objectively reviews the outcomes from all publications comparing the performance of crates and pens with regards to piglet survival. The aim of this investigation was to use a systematic review process in order to summarise the results of such publications, and then to perform a meta-analysis of these results to determine the effects of lactation housing on farrowing house performance across publications.

The literature searches were conducted during February 2018 in four databases; Scopus, BIOSIS Previews, Cab Abstracts and Web of Science. A search protocol was designed to obtain any articles that provided data on sow farrowing performance and the design of farrowing accommodation. The specific terms that were used varied based on the database in question, but all methods included the terms 'farrow' AND 'sow' AND 'design' OR 'housing' OR 'system'. A total of 6695 articles were identified by searching the four databases. After the removal of duplicates, and screening using the inclusion and exclusion criteria, 23 publications were retained for the systematic review qualitative assessment and meta-analyses. Random effects meta-analyses were performed on the compiled database, using the metaphor package R statistical software to examine whether pooled effect sizes for crate versus pen sow farrowing housing altered number born alive, number of stillborn, pre-weaning mortality and number of pigs weaned. Additionally, the modifiers of level of confinement (no confinement or partial confinement), enrichment (no enrichment or enrichment provided), and pen size (small, medium or large) were examined to test whether such variables influenced the piglet traits of interest.

The overall quality of all the publications was high with half of publications obtaining a score greater than 70% (range = 25-31) and 95% of publications obtaining a score greater than 50% (range = 19-31). Over 59% of articles reported a decrease in the number of stillborn piglets found within farrowing pens while 37% of published work indicated the contradictory result, an increase in stillborns in pens. There was no overall effect of pen versus crate on the incidence of piglets born dead, however when the modifier of enrichment was included, it was identified that no difference in this trait existed between enriched pens and crates, but stillbirths were reduced in non-enriched pens ($P = 0.01$). Seventeen of 30 articles indicated an increase in pre-weaning mortality in farrowing pens, while 40% of published data indicated that farrowing crates had more piglet mortality. The average pre-weaning mortality for farrowing crates was 101.66 piglets/trial (range = 7-506) which was lower than 123 piglets/trial (range = 9-590) in farrowing pens. There was a 16% increase in the odds of piglet mortality in farrowing pens when they were compared with crates ($P = 0.0015$). None of the modifiers examined affected this result. The number weaned was 9.81 piglets/litter in farrowing pens (range = 7.54-12.3) and 9.73 piglets/litter in farrowing crates (range = 7.1-12). One third of articles indicated a decrease in the number of piglets weaned/litter in farrowing pens, 46% measured an increase while 20% recorded no difference between housing types. There was no overall influence of housing type on number of pigs weaned.

This has been the first systematic review and met-analyses performed on the performance of farrowing crates versus pens and the results are clear. Farrowing pens do compromise post-natal piglet survival. Future efforts should focus on improving sow comfort in the farrowing crate to maximize both piglet and sow welfare.

Table of Contents

1. Introduction

The farrowing crate has been instrumental in the reduction of piglet mortality, primarily from sow overlay. However, this has come at a cost to sow welfare as confinement results in an increased stress response at certain times during farrowing and lactation. There are numerous examples of farrowing pen design, but a common goal across all is the reduction of sow confinement. Perhaps of largest concern to producers, which has led to the failure of large scale commercial pen adoption, is that the reduced confinement of sows in farrowing pens leads to an increase in exactly what farrowing crates were designed to minimise: piglet mortality. Whilst some investigations report exactly this (Blackshaw et al., 1994, Marchant et al., 2000) results from others suggest that farrowing pen design results in little influence on piglet mortality (Cronin et al., 2000). The reason as to why some pen investigations achieve similar results to crates is unclear but is most likely explained by a range of influences that would include design, management, sow factors and environment. There are many published reviews on lactation housing (Barnett et al., 2001, Edwards, 2002, Wechsler and Weber, 2007, Baxter et al., 2011) and in addition to this, Australian Pork Limited and the Pork CRC have recently published the Lactation Housing Index (Anon, 2016). This document compared four alternate farrowing pens to traditional crates by placing a weighting on several key variables including animal welfare, production and capital cost. Whilst valuable, these previous publications and reports provide subjective assessments of pen design features and performance. Perhaps a more objective comparison is required.

A systematic review involves the selection of previously published studies that meet a defined criterion. In this project, we performed a systematic review of farrowing pens that reported the key outcomes of piglets born dead, post-natal mortality and number of pigs weaned. A meta-analysis is the next logical step to follow on from this systematic review. A meta-analysis is a statistical tool that combines the results from multiple scientific studies and allows for the determination of important factors that affect key variables across experiments. To determine the relative importance of pen design features in grower pig housing, Averós et al. (2010) applied a meta-analysis to 45 experiments reported in 42 publications. From this, these authors determined the impact of factors such as space allowance, enrichment and group size on behaviour, growth and efficiency of pigs. A similar methodology has been applied to gestation housing in sows (McGlone et al., 2004), which was able to evaluate physiology, behaviour and production outcomes from multiple publications where groups and stall housing were compared. To date, there is no published evidence of such an analysis on lactation sow housing. Thus, we aimed to conduct a systematic review into the effects of farrowing pen housing on piglet traits, and then perform a meta-analysis on included publications, to determine key factors that aid in the success within farrowing pens.

2. Methodology

Guidelines for conducting a systematic review were obtained from Chinner & Hazel (2016). The literature searches were conducted in four databases; Scopus, BIOSIS Previews, Cab Abstracts and Web of Science and occurred on the 21st of February 2018. A search protocol was designed to obtain any articles that provided data on sow farrowing performance and the design of farrowing accommodation. The search terms that were used were identified as relevant by the authors and were designed broadly to ensure that all publications that were conducted in farrowing pens were included. The specific terms that were used varied based on the database in question, but all methods included the terms 'farrow' AND 'sow' AND 'design' OR 'housing' OR 'system'. The actual search frames that were used for each database are provided below.

A total of 6695 articles were identified by searching the four databases. All articles collected from the online searches were downloaded to Endnote (X7.7.1). Hard copy conference proceedings from the 2011-2017 Australasian Pig Science Association (APSA) and final reports available online from research supported by the Pork CRC were imported into the database and screened accordingly. Reference lists of included studies were scanned for potential new inclusions using the study eligibility form.

A range of libraries were established within Endnote to enable screening. All publications were sorted by the first author. The title and abstract of the articles were screened to remove duplicates. A species scan was conducted to remove articles that did not focus on porcine animals. An inclusion/exclusion checklist was developed to identify papers that were conducted in a research area relevant to the topic (Table 1). Studies with relevant titles were further examined by reading the abstract and then the full paper. If there was uncertainty on whether an individual publication complied with the inclusion and exclusion criteria, a decision was made by discussion with all authors.

Table 1: Inclusion and exclusion criteria used to screen and identify publications relevant to the topic

Inclusion criteria	Exclusion criteria
Did the publication have farrowing pens included in this study?	Did the publication include group housing accommodation during farrowing?
Did the publication compare non-confinement farrowing accommodation with a traditional farrowing crate?	Did the publication include outdoor housing accommodation during farrowing?
Did the publication include the required outcomes of piglet mortality rate, number of stillborn piglets and number of piglets weaned?	Was the publication written in a language other than English?
Did the publication include information on farrowing crate design?	Was the publication released before 1990?

A publication was selected if the experimental design included a comparison of a non-confinement farrowing environment with a traditional farrowing crate. In addition, the methodology was required to include detail on the design of the farrowing area and to measure piglet performance (number of stillborn piglets, mortality rate, and number of

weaned piglets). Any study that involved outdoor, free range or group housing during parturition and lactation was excluded. Publications that were written in a language other than English were excluded if a translatable version was not accessible. Similarly, articles published prior to 1990 were excluded if there were no accessible copies. Each publication was reviewed, and data required for the systematic review was extracted using a specifically-designed data sheet (Table 2). The data obtained was used to complete a new dataset to enable a meta-analysis to be conducted. Data was extracted for each article and collated in Microsoft Excel (v. 2016).

Table 2: List of data that was collected from each publication for inclusion in the systematic review and meta-analysis

	Data extracted from each publication
1	Paper title
2	Authors
3	Journal
4	Publication year
5	Country
6	Source of publication – Scopus, BIOSIS Previews, Web of Science, CAB Abstracts
7	Publication type – Journal article, conference proceedings, final report
8	Primary aim
9	Secondary aim
10	Number of farrowing accommodations compared
11	Parity structure of herd
12	Sample size for each experimental group
13	Inclusion of experimental controls
14	Randomisation
15	Standardisation – were experiments conducted in same room/shed or separate site
16	Statistical tests
17	Significance level
18	Length of pre-farrow confinement
19	Length of confinement – pre-farrow, post-farrow, total
20	Fostering procedures
21	Mortality recording procedures
22	Supervision procedure
23	Assistance procedure
24	Area of farrowing space available to sow
25	Area of farrowing space allocated to creep
26	Total area of farrowing space
27	Creep area features – flooring, heating, shape, materials, lid, enrichment
28	General pen features – flooring, lighting, ventilation, materials, enrichment
29	Piglet protection designs – farrowing rails, sloped walls
30	Farrowing details – TB, BA, SB, M
31	Mortality records
32	Weaning details

A quality assessment form was adapted from Wylie et al. (2011) to enable the analysis of the quality of each publication through a weighted comparison of separate studies (Table 3). The rating system provided two individual scores; the first score measured the quality of generic experimental design and the second score quantified the specific details of the farrowing environment. These two scores were combined, and each article was assigned a rating out of 36, with a higher score indicating that the experiment was robust and relevant to the topic of this review. One reviewer conducted the quality scoring on all publications that were included in the systematic review and meta-analysis.

Table 3: Quality assessment scoring system that was used to assess the quality of experimental design

Quality assessment questions		Score 0	Score 1	Score 2
A1	How was the study ***reported***?	Letter/poster presentation, unpublished, non-peer reviewed	Abstract, conference proceeding	Full paper
A2	Was the ***study population*** representative of a general population (e.g. range of parity)?	No	Yes, the population was described or only consisted of one parity group	Yes, population described and includes range of parities
A3	Was the ***sample size*** sufficient?	<20 sows per treatment	20-60 sows per treatment	>60 sows per treatment
A4	Was the ***control*** group appropriate?	No, not present	Partially, not well selected	Yes
A5	Were appropriate ***statistical tests*** conducted?	No	Simple inferential statistics or incorrect methods used	Yes, multivariable analysis
A6	Were conclusions made based on statistical ***significance*** (P<0.05 or less)?	No	Yes	
A7	Was the experimental design ***randomised***?	No	Yes	
B1	Did this ***study aim*** to compare the effect of accommodation on farrowing performance?	No	Yes, secondary aim	Yes, primary aim
B2	How many suitable ***accommodation types*** were compared?	-	Two	Three
B3	Were the ***dimensions/area*** of the accommodation provided?	No	Yes, total area provided	Yes, creep and sow areas defined separately
B4	Are ***lighting*** conditions described?	No	Yes	
B5	Are ***heating*** conditions described?	No	Yes	
B6	Are ***flooring/mat*** conditions described?	No	Yes	
B7	Are ***ventilation*** conditions described?	No	Yes	
B8	Are ***piglet protection/sow restraint*** measures described?	No	Yes	Described in detail or pictures provided
B9	Are ***enrichment*** conditions described?	No	Yes	
B10	Are ***pre-farrow confinement*** periods provided?	No	Yes	
B11	Are ***lactation lengths/confinement periods*** provided?	No	Yes	
B12	Are ***fostering*** protocols described?	No	Yes	

B13	Are ***mortality*** definitions described?	No	Yes, limited definitions and values provided	Yes, detailed definitions and values provided
B14	Are comprehensive ***farrowing details*** (TB, BA, BD, M) provided?	One detail provided	Two details provided	>Three details provided
B15	Are ***weaning details*** (number, weight, average weight) provided?	-	One detail provided	>Two details provided
B16	Are farrowing designs located in different physical ***locations/rooms/sheds***?	Different sheds	Same sheds, different room	Same shed, same room

The extracted data was analysed in individual meta-analysis models using four data subgroups; number of piglets born alive (n=28), number of stillborn piglets (n=27), total piglet mortality from parturition to weaning (n=30) and number of piglets weaned (n=15). The sample size varied for each analysis, based on the data that was published in each article. The data was represented as the total number present in each litter, rather than as a percentage of total born or born alive piglets, with sow being an experimental unit. Any articles that reported these values as a percentage of total born or born alive were transformed using these litter sizes to a value that represented a total number per litter. Each data-point included in the meta-analysis demonstrated a comparison between a farrowing crate and one type of pen. If there was more than one pen-type included in an article, they were included as separate data-point.

Random effects meta-analyses were performed on the database, using the metaphor package R statistical software (version 3.2.5) to examine whether pooled effect sizes for crate versus pen sow farrowing housing altered number born alive, number of stillborn, pre-weaning mortality and number of pigs weaned (Viechtbauer, 2010). A pooled estimate of the mean log-odds of these traits and corresponding 95% confidence interval were calculated by random effects logistic regression model (binomial-normal model) to allow for heterogeneity in the analysis. Estimates of the traits and their associated confidence interval were calculated by transforming the mean log-odds and its confidence interval back into the probability scale. The Q-test was used to assess statistical heterogeneity between studies and the I^2 was calculated to describe the amount of inconsistency of findings across studies. To evaluate potential moderators to explain heterogeneity, post hoc exploratory meta-regression analyses were performed which included enrichment (provided or not provided), confinement (full or partial), and pen area (small, medium and large). A p-value of less than 0.05 was considered significant.

3. Outcomes

The database search identified 6,693 articles from four databases and two articles from external sources. After duplicates were removed, there were 4,483 articles remaining. Of these publications, 380 were deemed relevant when the inclusion and exclusion criteria were applied to the title and abstract. Twenty-two of these articles were examined in detail to enable extraction of information for the systematic review and meta-analysis while the other 4,462 articles were not included.

A total of 21 articles were included in the systematic review and meta-analysis, including 32 individual comparisons between a farrowing crate and a farrowing pen. Data was extracted from 4385 litters, with data provided from 2182 and 2203 sows farrowing in crates and pens, respectively. The articles were conducted in a range of countries including Australia, Canada, China, Czech Republic, Denmark, Finland, Germany, New Zealand, United Kingdom and USA and was published from 1987 to 2016. Only 14% of articles were abstracts, conference proceedings or final reports while 86% of publications were peer-reviewed, full journal articles.

The average sample size for included studies was 68 (range = 6-394). Sample size was often restricted in these publications with 40% involving less than 20 sows per treatment while 22% of studies were conducted with more than 60 animals per treatment. Pen brand was not assessed as the sample size for each type was too small for analysis. Studies using full confinement from loading to weaning and studies with partial confinement during parturition and early lactation were included in the review. The presence or absence of straw as a source of enrichment for sows within farrowing accommodation was recorded. Each pen environment was classified as small, medium or large with ranges of 2.8-4.9m^2, 5-7.5m^2 and greater than 7.5m^2 respectively.

A quality assessment score was provided for each publication. The scores associated with each publication for the twenty-two quality assessment criteria are presented below (Table 4). The overall quality of all the publications was high with half of publications obtaining a score greater than 70% (range = 25-31) and 95% of publications obtaining a score greater than 50% (range = 19-31). Only one publication was assigned a score of less than 50%.

Table 4: Percentage of publications that were assigned scores for the quality assessment of 22 criteria, separated for all studies according to the highest rating. Refer to Table 3 for the questions associated with each criterion.

	All studies		
Criterion	**Score 0 (%)**	**Score 1 (%)**	**Score 2 (%)**
A1	4.5	9.1	86.4
A2	18.2	31.8	50
A3	40.9	36.4	22.7
A4	0	9.1	90.9
A5	0	45.5	54.5
A6	4.5	95.5	
B1	0	27.3	72.7
B2	0	81.8	18.2
B3	0	13.6	86.4
B4	95.5	4.5	
B5	4.5	95.5	
B6	0	100	
B7	72.7	27.3	
B8	9.1	54.5	36.4
B9	31.8	68.2	

B10	9.1	90.9	
B11	31.8	68.2	
B12	50	50	
B13	4.5	68.2	27.3
B14	22.7	27.3	50
B15	36.4	36.4	27.3
B16	22.7	18.2	59.1

The systematic review identified 28 articles reporting the number of piglets born alive in each litter. The average number of piglets born alive was found to be 12.54 in both farrowing crates (range = 8.4-17.1) and farrowing pens (range = 8.8 – 17.1). The results in 50% of articles indicated a decrease in born alive in farrowing pens, 32% indicated an increase in born alive and the remaining articles found no change between farrowing housing types.

Twenty-seven articles recorded the number of stillborn piglets for farrowing pens and crates. Stillborn piglets were recorded as a total number of stillborns in all litters for each farrowing accommodation type. Crates resulted in 77.81 stillborns (range = 5-416) across all litters while 81.37 (range = 8-440) stillborns were found in farrowing pens. Over 59% of articles reported a decrease in the number of stillborns found within farrowing pens while 37% of published work indicated the contradictory result, an increase in stillborns in pens.

Pre-weaning mortality, the total number of piglet deaths from farrowing until weaning, was available in 30 articles. This was recorded as a total number of piglet deaths in each farrowing accommodation across all litters. Seventeen of these articles indicated an increase in pre-weaning mortality in farrowing pens, while 40% of published data indicated that farrowing crates had more piglet mortality. The average pre-weaning mortality for farrowing crates was 101.66 piglets/trial (range = 7-506) which was lower than 123 piglets/trial (range = 9-590) in farrowing pens.

The number of piglets weaned per litter was published in 15 articles. The number weaned was 9.81 piglets/litter in farrowing pens (range = 7.54-12.3) and 9.73 piglets/litter in farrowing crates (range = 7.1-12). One third of articles indicated a decrease in the number of piglets weaned/litter in farrowing pens, 46% measured an increase while 20% recorded no difference between housing types.

Meta-analysis

Each measure of piglet vitality was examined in separate meta-analyses to compare the effect of farrowing environment (pen or crate) by considering individual inter-publication variation. The measure of heterogeneity (I2) indicated the variation between studies. Total piglet mortality and number of stillborns was analysed using relative risk. Risk, as opposed to odds, is calculated as the number of piglets in the group who died divided by the total number of piglets in the group. Risk ratio or relative risk is a ratio of two “risks”. A relative risk greater than 1 indicates increased likelihood of the stated outcome being achieved in the treatment group. If the relative risk is less than 1, there is a decreased likelihood in the treatment group. A ratio of 1 indicates no difference, that is the outcome is just as likely to occur in the treatment group as it is in the control group. Born alive and weaned number are continuous variables and so were analysed using standardized mean difference (SMD).

Total piglet mortality had a moderate amount of heterogeneity (I2=69.81%, P=0.002). The relative risk of piglet mortality in a farrowing pen was 16% higher than a farrowing crate (Figure 1). Several external factors were examined as moderators. There was no effect of confinement type; whether sows were confined for the entire lactation period or partial confinement (P=0.853), sow enrichment with straw (P=0.801) or relative pen size (P=0.206) on pre-weaning mortality in penned sows.

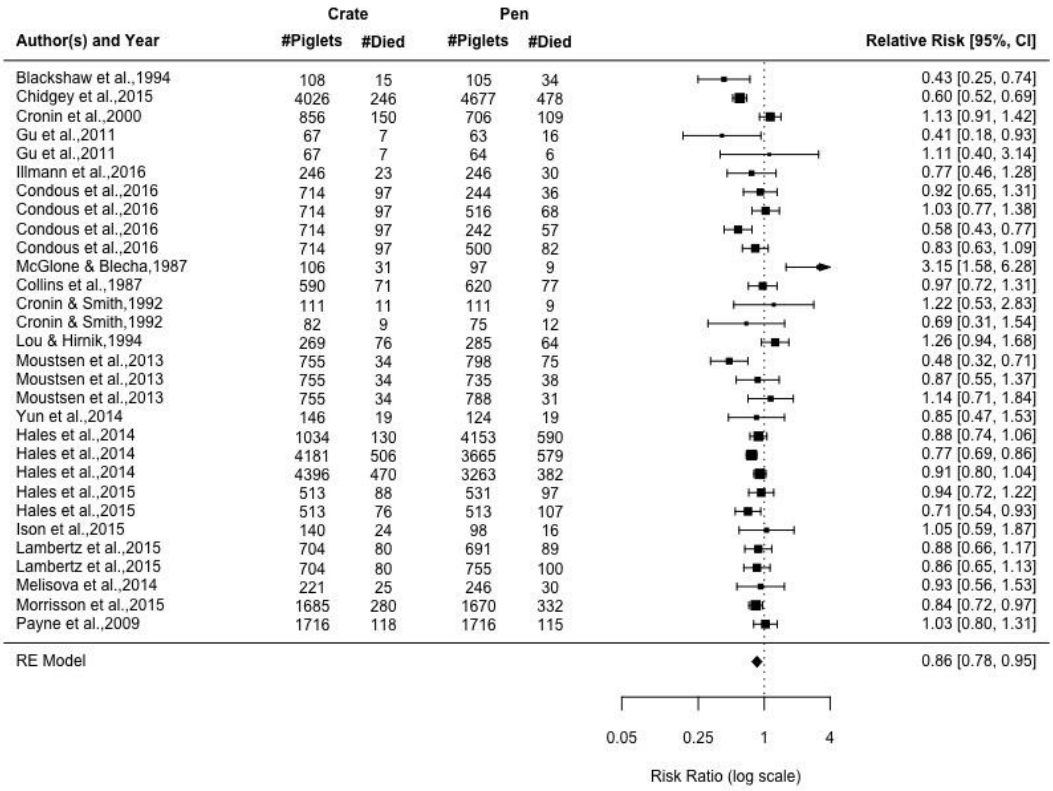

Figure 1: Sample size and total number of pre-weaning deaths recorded within all litters for farrowing crates and farrowing pens. Relative risk for all articles are presented with 95% confidence interval. Each line represents an article or individual comparison between a farrowing crate and a farrowing pen alternative. A relative risk greater than 1 indicates increased likelihood of the piglet mortality being achieved in farrowing pens when compared to farrowing crates.

The number of stillborn piglets recorded in each litter had a moderate amount of heterogeneity (I2 = 57.93%, P=0.001). The relative risk of stillborn piglets were comparable in farrowing pen and farrowing crates (Figure 2). There was no effect when comparing confinement type (P=0.706), or pen size (P=0.089) within farrowing pens. However, when including enrichment as a moderator there was a significant difference between crates and pens. There was no difference in the relative risk of stillborn piglets in crates and pens when enrichment was provided but when there was no enrichment of the farrowing pen, still born piglets in crates was 22% higher than in pens (P=0.01).

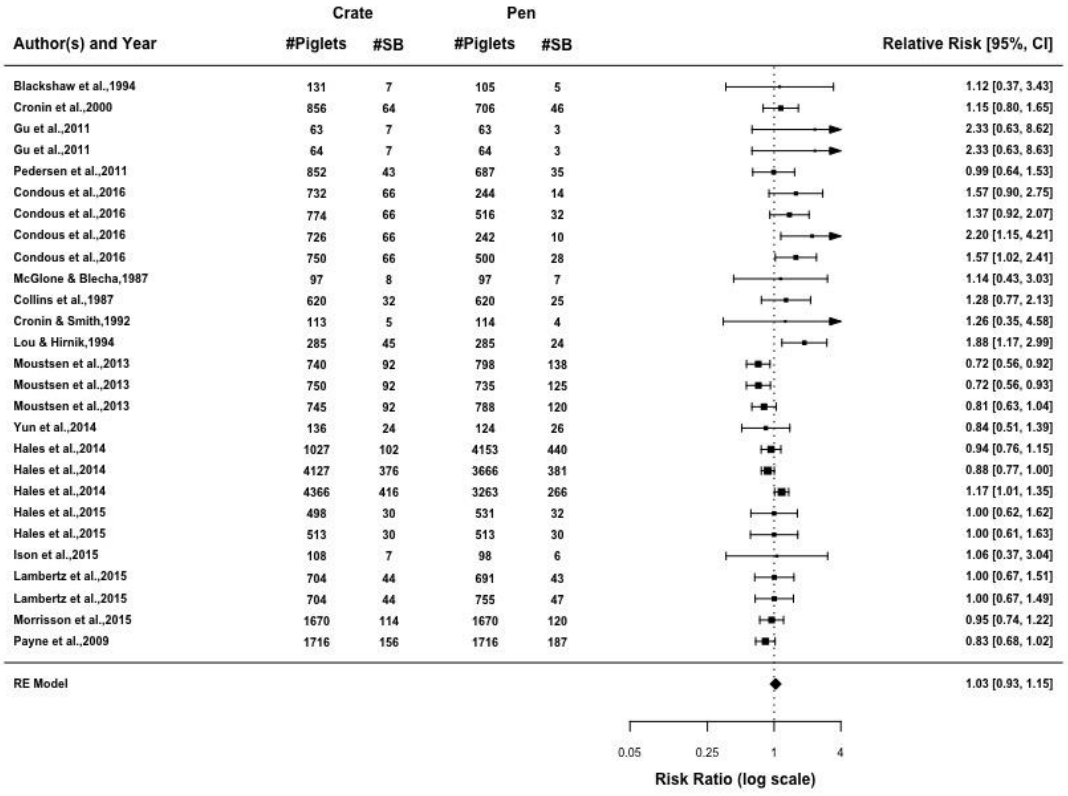

Figure 2: Sample size and total number of stillborn piglets recorded within all litters for farrowing crates and farrowing pens. Relative risk for all articles are presented with 95% confidence interval. Each line represents an article or individual comparison between a farrowing crate and a farrowing pen alternative. A relative risk greater than 1 indicates increased likelihood of stillborn piglets being achieved in farrowing pens when compared to farrowing crates.

The number of piglets born alive in each litter had a high amount of heterogeneity (I2=0%, P=0.303). Farrowing crates and pens had no difference in piglets born alive and, within farrowing pens there was no effect of confinement type (P=0.786), sow enrichment (P=0.597) or pen size (P=0.659).

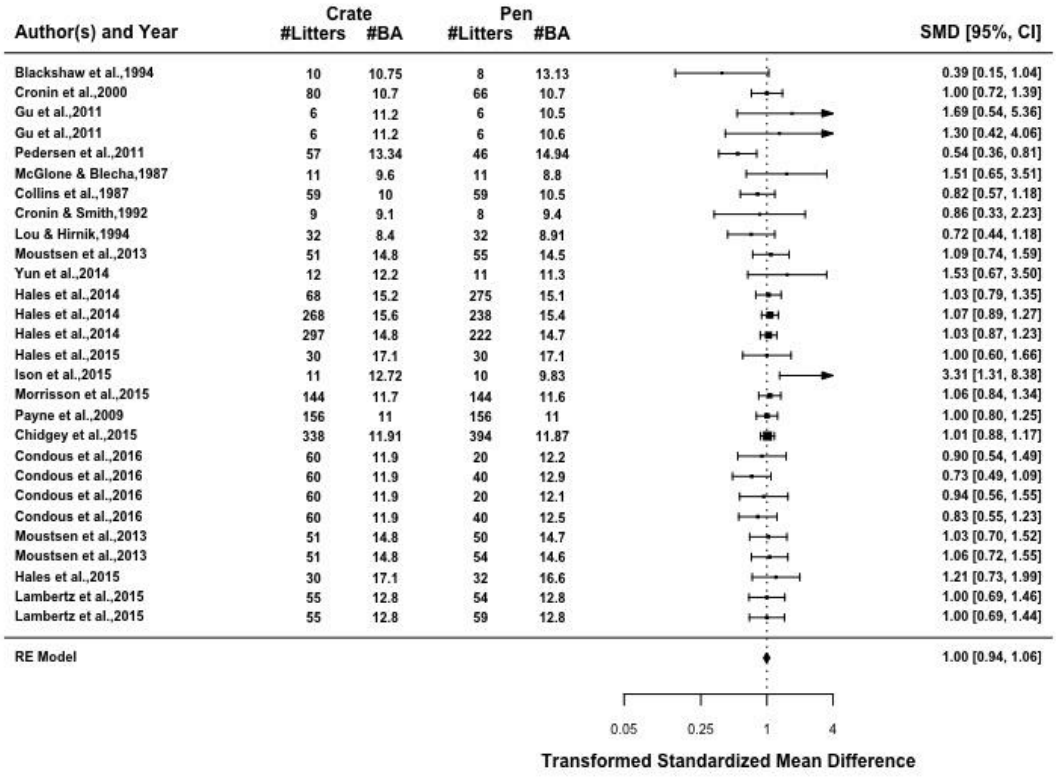

Figure 3: Sample size and total number of piglets born alive per litter for farrowing crates and farrowing pens. Standardised mean difference (SMD) for all articles are presented with 95% confidence interval. Each line represents an article or individual comparison between a farrowing crate and a farrowing pen alternative. A SMD greater than 1 indicates increased likelihood of stillborn piglets being achieved in farrowing pens when compared to farrowing crates.

The number of pigs weaned from each litter had a low amount of heterogeneity (I2=43.96%, P=0.021). There was no difference in the number of pigs weaned between crates and pens, and there was no effect when comparing confinement type (P=0.567), sow enrichment (P=0.765) or pen size (P=0.333) within pens.

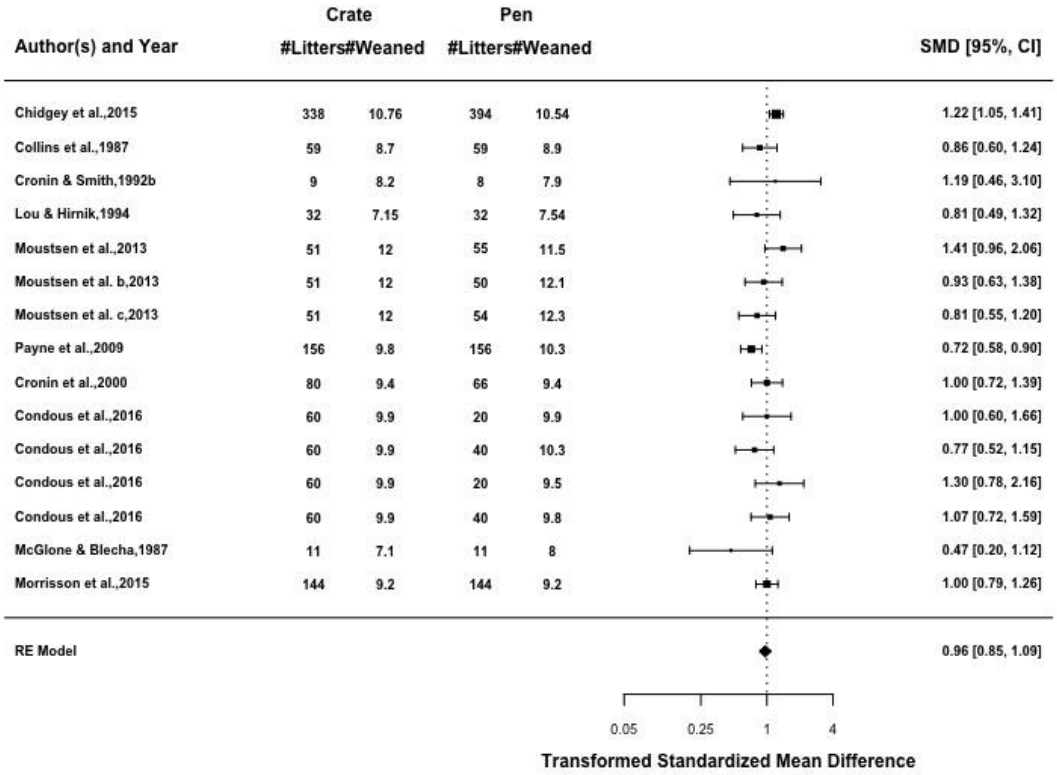

Figure 4: Sample size and total number of piglets weaned per litter for farrowing crates and farrowing pens. Standardised mean difference (SMD) for all articles are presented with 95% confidence interval. Each line represents an article or individual comparison between a farrowing crate and a farrowing pen alternative. A SMD greater than 1 indicates increased likelihood of wean number being achieved in farrowing pens when compared to farrowing crates.

4. Application of Research

Traditionally, farrowing crates have been the preferred housing type to enhance piglet survivability. This is particularly relevant around farrowing as the sow undergoes hormonal changes that lead to restlessness and erratic posture changes (Alonso-Spilsbury et al. 2007). The restrictive nature of a farrowing crate prevents sow movement leading to a reduction in the number of piglets that are crushed by the sow; the primary cause of piglet death (Spicer et al. 1986). It does this successfully in two ways; firstly, by reducing the incidence of posture changes, and secondly by slowing these changes down enabling the piglets to vacate the area under the sow. Subsequently, pre-weaning piglet mortality can be maintained at 10% for litters housed within farrowing crates. In addition, farrowing crates usually have a smaller surface area. A crate with a smaller area has fewer spaces that can cause piglet deaths associated with exposure to cold temperatures. Most farrowing crates have a separate heated creep area to accommodate for the different temperature requirements for piglets and sows. Ultimately, the farrowing crate was designed to ensure piglet comfort and survival.

The farrowing crate has been designed to enhance comfort, survival and hygiene of the piglet and the safety of stock-people, but this comes with a compromise in sow welfare and comfort (Barnett et al. 2001). The minimal space available leads to a reduction in activity levels from parturition to weaning. This is a major source of discomfort and often results in changes to normal behaviour. In the lead up to farrowing, the sow has an inherent drive to build a nest, and restriction within a crate limits such behaviours resulting in distress (Jarvis *et al*. 2006). As lactation progresses, confinement can result in unwillingness to move which leads to the development of lesions and sores, and acts to reduce feed intake and so impact on sow body condition (Baxter 1982). Under the confinement of farrowing crates, piglets are kept in constant contact with the sow and therefore a milk supply, which results in improvements in lactation growth rates. This continual contact with piglets has been suggested to elicit a stress response later in lactation for sows housed in farrowing crates as under 'natural' conditions, the sow gradually spends less time with her litter as lactation progresses (Cronin *et al*. 1991). So, taken collectively, there is evidence that the restriction of crated sows can impact on welfare leading up to farrowing, and throughout lactation. Because of this, many investigations into the housing of sows in lactation pens rather than farrowing crates has been undertaken.

The main benefit of a farrowing pen is an increase in the freedom of movement, ensuring that sows can conduct a normal range of behaviour, particularly during farrowing (Oliviero et al. 2008). However, this increased range of movement within a pen is expected to be associated with an increase in piglet death due to sow overlay (Li et al. 2010). The current finding that total piglet mortality is 16% more likely in a pen than in a crate supports this notion. Farrowing crates were designed to reduce movement of the sow that could cause overlaying or squashing of piglets. By removing the restrictive structures sows can perform more posture changes, and do these changes at a greater speed which heightens the risk of overlays. However, there are other factors outside of this that may lead in increases in piglet deaths. Farrowing pens are often larger in size than crates, and so specifically designed areas (creeps), which meet thermal needs of newborn piglets become harder to locate. If a piglet fails to locate the creep, death from exposure is more likely. Novel projects (see CRC Final Report 1A-116) that increase the likelihood of piglets locating the creep area within a

pen may act to limit piglet chilling. Whilst pen size was shown to exert little influence on piglet deaths in our analyses, the numbers of animals used in most investigations were likely too few to examine such impacts on exact causes of piglet mortality. The last way in which piglet mortality may be increased under pen conditions is the willingness of the stockperson to interact with the sow and her litter when confinement is reduced. Farrowing crates provide a safer environment for stockpeople to work in, especially during the period immediately following farrowing when hormonal changes in the sow often result in high levels of aggression. Under pen conditions, the reduced confinement and high levels of sow aggression can make stockperson interventions aimed at improving piglet survival more difficult. Hales *et al*. (2014) cited significant farm differences in mortality comparisons between crates and pens. Whilst there would have been animal, environmental and nutritional differences between farms, personal communication with the authors indicated that the farm with pen performance comparable to crates employed stockpeople with exceptional neonatal piglet care skills. Obviously, no detail on the level of stockperson skill was included in any of the publications included in this review and meta-analysis, and so we could not examine this variable objectively.

Confinement during the peri-parturient period has been linked to an increased incidence of stillbirth rates (Baxter and Petherick 1980). The phenomenon is now commonly referred to as 'the confinement-stillbirth hypothesis'. Investigations into the physiological underpinnings have identified that confined sows exhibit an increased level of cortisol prior to farrowing (Lawrence et al. 1994), a decrease in post-expulsion oxytocin pulse (Oliviero et al. 2008), as well an extended farrowing duration and inter-piglet birth intervals (Oliviero et al. 2008; Oliviero et al. 2010). However, since its inception, some have refuted the link between sow confinement and incidence of intra-partum piglet mortality (Fraser et al. 1997). The results from the current meta-analysis would suggest that there is no overall improvement in the incidence of stillbirths in pens compared with crates. However, when no enrichment was included, the relative risk of stillborn piglets was 22% lower in farrowing pens. This cements the idea that simply allowing the sow a greater freedom of movement leading up to and during farrowing reduces the risk of intra-partum piglet death.

The observed pre-weaning mortality was significantly higher in farrowing pens, and so logically this would then impact on the number of pigs weaned. However, lactation housing bore no impact on how many piglets were weaned. The majority of piglet deaths occur within the first 36 hours post-farrowing (Spicer et al. 1986). A common husbandry technique adopted within farrowing houses in cross-fostering, which involves the movement of piglets from one sow to another (Alexopoulos et al. 2018). Given that this process generally occurs at 24h after farrowing, any piglets that die prior to this fostering process can be replaced. With this reasoning, pre-weaning mortality can be higher in pens (when it occurs prior to fostering) with number of pigs weaned remaining constant. The systematic review found that 50% of published literature failed to describe the fostering protocol used and only one article indicated that fostering occurred within treatment. While some publications did describe the protocol implemented, there was a lack of consistency in reporting which introduced variation in the data presented, making a meta-analysis unfeasible. However, individual piglet viability is variable, and recent findings within our group have identified differences in piglet vitality between pen and crate litters (see Pork CRC Report 1C-114). Additionally, fostered piglets that are moved from one litter to another may experience greater stress in the crucial peri-natal period. Future studies should identify if there are

differences in growth potential between fostered and non-fostered piglets in different birth and rearing environments.

5. Conclusion

This was the first systematic review and meta-analyses conducted into the influence of farrowing pen housing on the piglet traits important for farrowing house performance. The relative risk of pre-weaning mortality were 16% higher in farrowing pens compared with crates. The number of piglets born dead was comparable between crates and pens with enrichment, but the relative of stillbirth was reduced by 22% in pens without enrichment. Number of pigs weaned was unaffected by lactation housing design, but this result could reflect flawed experimental design and data inclusion in publications.

6. Limitations/Risks

We had planned to examine more moderators such as creep design, parity profiles, piglet protection modifications and other factors that may have impacted on pre-weaning survival in pen housing. However, few studies contained enough detail for inclusion in the analyses. Thus, there may be other moderators that explain differences in pen performance, but they could not be tested within this project.

7. Recommendations

As a result of the outcomes in this study the following recommendations have been made:

1. The data from studies included in this study would suggest that pre-weaning piglet mortality is increased in farrowing pens when compared with farrowing crates.
2. Stillborn piglets are less likely in farrowing pens that are not enriched when compared with crates
3. Thus, piglet survival and welfare is compromised under farrowing pen conditions.

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Appendices

Appendix 1: Published articles included in systematic review

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