RESEARCH REPORT

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ANIMAL WELFARE

Title: Impact of duration of farrowing crate closure on sow welfare and piglet mortality – NPB #17-068

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INDUSTRY SUMMARY:

Individual crates have been the predominant farrowing environment in the last 50 years in the United States as well as globally. Unfortunately farrowing crates limit the sow's ability to perform many natural behaviors during parturition and lactation. Concerns about the welfare of sows in farrowing crates continues to grow, given the physical and behavioral restriction on the sow, the compromise of natural maternal behaviors and physical comfort, creating a need for an alternative farrowing and lactation housing. A wide variety of alternative farrowing systems have been developed, trying to address sow's needs, including temporary crates. However, alternatives can be problematic because of reports of increased pre-weaning mortality, which is one of the major economic and welfare concerns related to piglets in all farrowing and lactation systems. Here, we performed two studies using temporary or hinged farrowing crates, which is a hybrid between a crated and a pen based farrowing system. In this study, we evaluated its effect on sow welfare and piglet mortality, by opening them in two time points, at 4 and 7 days post-farrowing. In the first study, 36 sows and their litters were examined for behavioral, physiological and physical indicators of animal welfare. We found after opening the crates at 4 or 7 days post-farrowing, sows utilize the additional space provided to them, and spent more time active and performing motivated maternal behaviors (such as interacting with their piglets and exploring the environment). In the opened crates, sow salivary cortisol decreased post farrowing and sows had less teats lesions compared with the closed crates sows. A second study focused on piglet mortality during lactation and examined 630 sows and their litters. The total piglet mortality following crate opening was not different from

the crated control. Laid on and low viability were the two most common reasons for piglet death with each

comprising about 1/3 of the total mortality. There was no difference in the risk of being laid during the period 1-3 days post farrowing when all crates were closed. However, this risk increased whenever the crate was opened. Perhaps unexpectedly the risk associated with several other causes of mortality also increased when the crates were opened at day 4 but not at day 7. No association was found between treatment and physical measures of welfare (body condition scoring, lameness and shoulder sores), but there was a higher risk for teat lesions in crated sows at weaning. In summary, both behavioral and physical measures of welfare employed in this study indicate that the opening of a hinged farrowing crate contributes to improving the welfare of lactating sows. However, the piglet mortality data suggest that only opening the crate after 7 days post-farrowing, and thus avoiding the period when piglets are most vulnerable to crushing and other causes of death in the absences of a crate, has the potential to maintain total risk of mortality at levels similar to crated sows while still providing welfare improvements to the sow.

KEY FINDINGS:

1 – Sows utilize additional space available to them when farrowing crate is converted to a farrowing pen as well as perform more motivated maternal behaviors

2 – Risk of piglet mortality due to crushing increases when the crate is opened.

3 – Piglet mortality due to crushing represents about 1/3 of total pre-weaning morality

4 – Risk of other causes of mortality also increases when crates are opened at 4 days post-farrowing, but not at 7 days.

PROJECT CONCLUSIONS:

Both behavioral and physical measures of welfare employed in this study indicate that the opening of a hinged farrowing crate contributes to improving the welfare of lactating sows. However, the piglet mortality data suggest that only opening the crate after 7 days post-farrowing, and thus avoiding the period when piglets are most vulnerable to crushing and other causes of death in the absences of a crate, has the potential to maintain total risk of mortality at levels similar to crated sows while still providing welfare improvements to the sow.

SCIENTIFIC ABSTRACT: Concerns about the welfare of lactating sows housed in farrowing crates have emerged because crates physically restrict the sows and possibly compromise their behavior and comfort. The aim of the first experiment was to identify how the opening of a hinged farrowing crate on different days (4 or 7) post-farrowing impacts sow welfare. A total of 36 sows were studied. The sows were randomly allocated to 1 of 3 treatment groups: PC- crate remained closed until weaning (n = 13), T4- crate was opened on day 4 post-farrowing (n = 12), and T7- crate opened on day 7 post-farrowing (n = 11). Three different types of welfare indicators were used: behavioral (activity, posture and location-direction inside the pen), physical (udder and body lesions, lameness and body condition score) and physiological (salivary cortisol concentration). On days 3–8 post-farrowing, salivary samples were collected at 8:00 h and sow behavior captured by continuous video recording of each individual sow daily from 6:00 h to 18:00 h. Sow behavior was observed using instantaneous recording (with a 2-minute fixed sampling interval) and focal animal as the sampling route. Lameness and body condition score (BCS) were evaluated when the sows were moved to farrowing pens and again when they were weaned, while skin lesions were evaluated on those days as well as on days 4 and 7 post-farrowing. After opening the crates (either at 4 or 7 days post-farrowing), we observed that sows utilized the additional space provided to them. Sows exhibited a ~5 fold average increase in the number of different orientations and positions that they occupied in the pen after the crate was opened. Furthermore, sows also spent more time active and performing motivated behaviors such as interacting with their piglets and exploring the environment. Sows kept in pens with open crates also had less teats lesions on day 21 post farrowing compared to sows remaining in closed crates. Salivary cortisol concentration differed only on day 5 as the mean concentration for T4 was greater than T7, but neither differed from PC. The aim of the second experiment was to identify the effect of opening a hinged farrowing crate on piglet mortality and physical indicators of sow welfare. A total of 696 sows were studied. The sows were randomly allocated to the same treatment groups Experiment 1. Piglet mortality and four physical indicators of sow welfare were examined: body condition score (BCS), lameness, shoulder lesion and teat lesions, measured on loading day and the day before weaning. The total percentage of piglet mortality was higher for T4 litters than T7, but neither treatment differed from the control group. Laid on and low viability were the two most common reasons for piglet death with each comprising about 1/3 of the total mortality. The risk of piglets being laid on varied by treatment at different times during lactation. While no difference in the risk of being laid on was found in the period 1-3 days post farrowing when all crates were closed, this risk increased whenever the crate was opened. Perhaps unexpectedly the risk associated with several other causes of mortality also increased when the crates were opened at day 4 but not at day 7. We found no association between treatment and three of the sow physical welfare indicators evaluated in the study: BCS, lameness and shoulder sores, but we found a higher risk for teat lesions in PC sows at weaning. In summary, both behavioral and physical measures of welfare employed in this study indicate that the opening of a hinged farrowing crate contributes to improving the welfare of lactating sows. However, the piglet mortality data suggest that only opening the crate after 7 days post-farrowing, and thus avoiding the period when piglets are most vulnerable to crushing and other causes of death in the absences of a crate, has the potential to maintain total risk of mortality at levels similar to crated sows while still providing welfare improvements to the sow.

INTRODUCTION

In modern swine husbandry, the ability of a sow to raise large litters and to meet the piglets' needs for warmth and milk provision is essential. To reduce piglet losses and to facilitate human intervention, farrowing crates have been developed to limit the sow's movements during parturition and lactation (Robertson et al., 1966; Edwards and Fraser, 1997). Most piglets die early in life (Hellbrügge et al., 2008) by getting trapped under the sow (Marchant-Forde et al., 2000; Edwards, 2002; Kilbride et al., 2012). As trapping can result in injuries and suffocation, pre-weaning mortality is both a production and welfare challenge. Farrowing crates are an attempt to balance the welfare of the piglets with temporary restraint of the sow.

To date, however, three countries (Sweden, Switzerland and Norway) have banned farrowing crate use completely, with New Zealand and Australia implementing bans in 2015 (NAWAC, 2010) and 2017 (PISC, 2008). There is also voluntary industry uptake of loose-farrowing alternatives (e.g. UK, Denmark, and Austria), with a number of different systems being developed and tested (Arey, 1997; Edwards and Fraser, 1997; Johnson and Marchant-Forde, 2009; Baxter et al., 2012). However, the implementation of farrowing crate alternatives has been slow by the European commercial industry. The proportion of sows farrowing in crates is estimated to be at 70% in the United Kingdom (BPEX, 2004), and 95% in the EU overall (Johnson and Marchant-Forde, 2009). The slow uptake perhaps results from the lack of practical solutions for farmers to implement.

There are approximately nine different options for housing a lactating sow and her piglets; which range from the conventional crate, to the hinged crate, to the open pen and communal pen systems (Johnson and Marchant-Forde, 2009). There are advantages and disadvantages to each of these housing systems with respect to sow and piglet welfare during parturition and lactation (Johnson and Marchant-Forde, 2009). In a hinged crate system, the sow is initially crated, but when the piglets reach a designated age, the crate is opened providing the sow additional space. The hinged crate, though it does not provide the same benefits to the sow that a farrowing pen provides, fits in a similar footprint to a standard farrowing crate and protects the piglets for a designated period of time early in life when mortality is the greatest. The hinged crate therefore may be a practical solution for farmers. Several studies have reported that closed crate sows weaned more pigs than open crate sows (Verhovsek et al., 2007; Pedersen et al., 2011; Chidgey et al., 2015). However, in contrast, we recently reported (Mack et al., 2017) that hinged crates can yield similar pre-weaning mortality to a closed crate. Similar to our study, Moustsen et al. (2013) observed no differences in mortality or litter size at weaning. Pedersen et al. (2011) only fixed the sows in the crates during farrowing; Verhovsek et al. (2007) opened the crates when the pigs were 2 days of age; Chidgey et al. (2015) and Moustsen et al. (2013) opened the crates at 4 days of age; and we opened them at 14 days of age. These results suggests that 2 day closed is not sufficient for piglet protection and that although 4 day may be long enough, piglets in some systems may benefit from greater closure duration. As with most alternative lactation systems, research has been conducted in Europe (Verhovsek et al., 2007; Pedersen et al., 2011; Hales et al, 2014, Hales et al, 2016; Lambertz et al, 2015; Moutson et al, 2013), New Zealand (Chidgey et al, 2015; Chidgey et al, 2016), and Australia (Condous et al, 2016) but little is known about how North American management and genetics influence the success of hinged crates. Thus in order to extend the findings of previous work, the aim of this study is to examine the effect of opening a hinged farrowing crate after 4 or 7 days post-farrowing has on piglet mortality and sow behavior and welfare under North American conditions.

Objectives

Objective 1: To examine the effect of opening the hinged crate at different time points on sow welfare parameters.

The findings from this objective are summarized in Appendix I (page 8):

Ceballos, M.C., K.C.R. Góis, and T.D. Parsons. The opening of a hinged farrowing crate improves lactating sows' welfare. Applied Animal Behaviour Science. 230:105068-105077 (2020).

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Objective 2: To determine the effect of timing of the opening of a hinged farrowing crate on piglet mortality.

The findings from this objective are summarized in Appendix II (page 36) :

Ceballos, M.C., K.C.R. Góis, T.D. Parsons and M.K. Pierdon. Impact of duration of farrowing crate closure on physical indicators of sow welfare and piglet mortality. *Submitted and under review for publications*

Appendix III (page 65) contains an explanation of methodological differences between the original project proposal and implementation of project.

Appendix I

Findings from the study that examined the effect of opening the hinged crate at different time points on sow welfare parameters.

The opening of a hinged farrowing crate improves lactating sows' welfare

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Abstract

Concerns about the welfare of lactating sows housed in farrowing crates have emerged because crates physically restrict the sows and possibly compromise their behavior and comfort. The aim of this study was to identify how the opening of a hinged farrowing crate on different days (4 or 7) post-farrowing impacts sow welfare. A total of 36 sows were studied. The sows were randomly allocated to 1 of 3 treatment groups: PC- crate remained closed until weaning (n=13), T4- crate was opened on day 4 post-farrowing (n=12), and T7- crate opened on day 7 post-farrowing (n=11). Three different types of welfare indicators were used: behavioral (activity, posture and location-direction inside the pen), physical (udder and body lesions, lameness and body condition score) and physiological (salivary cortisol concentration). On days 3-8 post-farrowing, sow behavior was captured by continuous video recording of each individual sow daily from 6:00 h to 18:00 h. Sow behavior was observed using instantaneous recording (with a 2-minute fixed sampling interval) and focal animal as the sampling route. Salivary samples were also collected on these same days at 8:00 h. Lameness and body condition score (BCS) were evaluated when the sows were moved to farrowing pens and again when they were weaned, while skin lesions were evaluated on those days as well as on days 4 and 7 post-farrowing. After opening the crates (either at 4 or 7 days post-farrowing), we observed that sows utilized the additional space provided to them. Sows exhibited a ~5 fold average increase in the number of different orientations and positions that they occupied in the pen after the crate was opened. Furthermore, sows also spent more time active and performing motivated behaviors such as interacting with their piglets and exploring the environment. Sows kept in pens with open crates also had less teats lesions on day 21 post farrowing compared to sows remaining in closed crates. Salivary cortisol concentration differed only on day 5 as the mean concentration for T4 was greater than T7, but neither differed from PC. Taken together, both behavioral and physical measures of welfare employed in this study indicate that the opening of a hinged farrowing crate contributes to improving the welfare of lactating sows.

Keywords: behavior, physiology, welfare indicators, lactation, pig

1. Introduction

In modern swine husbandry, the ability of a sow to farrow and nurse large litters is essential. To limit piglet mortality and facilitate human intervention, farrowing crates were developed to restrict the sow's movements during parturition and lactation (Robertson et al., 1966; Baxter et al., 2018). Crated farrowing systems have emerged as the predominant farrowing environment during the last 50 years (Wackermannová et al., 2017). Nevertheless, welfare concerns relating to farrowing crates have been raised related to the physical and behavioral restriction of the sow, compromised natural maternal behaviors and physical discomfort (Baxter et al., 2018). These concerns have resulted in the increasing interest and pressure for the development of alternative farrowing and lactational housing systems (Singh et al., 2017; Wackermannová et al., 2017).

Three countries (Sweden, Switzerland and Norway) to date have banned farrowing crate use completely (Baxter et al., 2018). There is also voluntary industry uptake of loose-farrowing alternatives in countries such as United Kingdom and Denmark where a number of different systems are being developed and tested (Arey, 1997; Johnson and Marchant-Forde, 2009; Baxter et al., 2012, Chidgey et al., 2016, Hales et al., 2016; Singh et al., 2017; Baxter et al., 2018; King et al., 2019).

In a hinged crate system, the sow is initially crated, and when the piglets reach a designated age, the crate is opened providing the sow additional space. Most previous research on alternative farrowing systems has evaluated different aspects of sow welfare in hinged crates. The effect of opening crates at different times post-farrowing has been studied in European farm systems, specifically evaluating its effect on sow behavior and stress level when crates are opened at day three (Goumon et al., 2018) and four (Hales et al., 2016), or only on sow behavior, opening the crate at day four (Chidgey et al., 2016) and seven (morning or afternoon - King et al., 2019), and sow behavior and integument lesions, opening the crate at day fourteen post-farrowing (Lambertz et al., 2015). In general, these studies demonstrated better welfare for sows in open crates compared to closed crated because of the sow's ability to express more behaviors. However, to our knowledge, there are no studies that simultaneously employ behavioral, physical and physiological measures of welfare to assess sows in farrowing systems providing different durations of confinement post-farrowing (crate closed). Thus, in order to extend the findings of previous work, the aim of this study was to examine the effects of opening of a hinged farrowing crate 4 or 7 days post-farrowing on a variety of different sow welfare measures.

2. Animals, Material and Methods

All animal procedures in this research study were approved by the University of Pennsylvania's Institutional Animal Care and Use Committee (Protocol #804656).

2.1. Animals, housing and experimental design

The study was conducted at the University of Pennsylvania's Swine Teaching and Research Center, located in Kennett Square, Pennsylvania, United States of America, between June and September 2018. A total of 39 Line 241 sows (DNA Genetics, Columbus, NE) selected from four bi-weekly farrowing groups were initially included in the study and had an average parity of 3.5 ± 1.4 (range: 1 – 6). Three sows and their litters were removed because of illness. At approximately gestational day 110 (Loading day), study sows were moved into their farrowing room with their breeding cohort into one of four identical farrowing rooms (10.7 x 5.5 m) with 10 farrowing pens in each room, five on either side of a common aisle. The farrowing pen dimensions were 2.1 x 2.0 m and provided 4.2 m^2 in total area. Each farrowing pen was equipped with perforated plastic flooring (MIK, International, Ransbach-Baumbach, Germany), a heat pad (0.8 × 0.6 m) embedded in the flooring, and a farrowing crate with hinged sides having the dimensions of 0.64 × 1.73 m (Figure 1 a & b). The hinged crate could be opened to provide the sow additional space and freedom of movement including being able to turn around, with 3.03 m^2 available to her (Figure 1 c & d). The heat pad was maintained at approximately 32°C by a combination of radiant heat and hot water circulating through the heat plate. Solid-sided dividers were used between pens and no substrate was provided.

The farrowing crate remained in the open position until day 113 of gestation, at which point it was changed to the closed position. The sows were distributed into three treatments: *i.* sow permanently crated until weaning (PC, n= 13 sows and 16.7 average total pigs born per litter), *ii*. sows crated until the fourth day post-farrowing (2 ± 1.2 days confined from loading until farrowing), when the crate was opened and remained so until weaning (T4, n= 12 sows and 17.1 average total pigs born per litter) and, *iii.* sows crated until the seventh day post-farrowing (2 ± 1.5 days confined from loading until farrowing), when the crate was opened and remained so until weaning (T7, n= 11 sows and 16.6 average total pigs born per litter). All crate openings or closings occurred at 8 AM due to work flow and feeding schedules in the barn. Sows were equally distributed across the treatments (based on parity) and the parity ± SD per treatment was 3.5 ± 1.4; 3.4

± 1.3, and 3.5 ± 1.3 for PC, T4 and T7 respectively. Day of farrowing was considered as day 0 and the opening of the crates happened at 8:00 am. Upon entry to the farrowing rooms, sows were fed 2.7 kg of a lactational diet that met or exceeded the NRC guidelines (NRC, 2012) once daily. After farrowing, sows were challenge fed as needed to increase feed intake by increasing the number of times a day a sow received a 2.7 kg feeding as follows: from one (6:30), three (6:30, 11:00 and 15:00), four (6:30, 9:00, 11:00, 15:00) until five times per day (6:30, 9:00, 11:00, 15:00 and 23:57). Feed increases did not start before 3 days and were maximal for all sows by 12 days of lactation. The piglets received creep feed from day 14 post-farrowing. All sows and their litters had free access to water via a nipple drinker (one for the sow and one for the piglets). Cross fostering of piglets between the litters was applied during the first 48 hours post-farrowing if the number of piglets exceeded the number of functional teats the sow had. The handling of the sows and litters was always performed by the same people. No sows in this study were induced to farrow. Piglets were weaned between 28 and 35 days of age. Problem sows post-farrowing were treated with Vitamin B12 if the sow was inappetent and with the non-steroidal anti-inflammatory drug, flunixin meglumine (Banamine®, Merk Animal Health- USA), if the sow, in addition to inappetence, also had edematous mammary glands or other possible painful conditions. Room temperature was recorded daily (min = 22°C and max= 32°C average temperature).

2.2. Animal welfare indicators

Three different classes of indicators were used to evaluate sow welfare: behavioral (activity, posture and location-direction inside the pen), physical (udder and body lesions, lameness and body condition score) and physiological (salivary cortisol concentration).

2.2.1. Behavioral indicators

Individual sow behavior was continuously video recorded, from day 3 to 8 post-farrowing, using an overhead camera (IPX DDK-1700D Infrared IP Dome Camera, Farmingdale, New Jersey - USA) positioned 2 m above the farrowing crates and did not necessitate any changes to the standard husbandry practices in the farrowing rooms. Observer XT (Noldus, version 11.5, Wageningen, the Netherlands) was used to code the video recordings and quantify behavioral data. Three groups of behaviors were captured: activity, posture and position inside the pen. Behavior was observed daily for 12-hour periods (from 6:00 to 18:00) to focus our observations on when the sows were most active. Specific behaviors within each of the three classes (activity, posture, and position inside the pen) was assessed using instantaneous recording (with a 2-minute fixed sampling interval) and focal animal as the sampling route to obtain the frequency of each behavior. Ethograms for activity and posture behaviors are based on Chidgey et al. (2016) and summarized in Table 1. In addition, a new variable, called *posture changes,* was defined as the number of times the sow changed her posture. On day D4 and D7, post-opening behaviors were slightly under-estimated as the crate was not opened until 8 AM, two hours after the start of the daily observation period. The videos were coded by three trained observers. Inter-observer reliability was assessed by the scoring of a 6-hour video segment (180 instantaneous samples). Each observer scored three 2-hour segments across which all groups of behaviors were compared. This resulted in 9 pair-wise assessments of inter-observer reliability with Kappa coefficient values ranging from 0.72 to 0.96 and a media value of 0.83, or almost perfect according to Landis and Koch (1977).

The sow's position within the pen was characterized as one of thirty possibilities, with the sow's orientation scored with H when her head was facing the feeder, and scored with R when the sow's head was opposite the feeder (i.e. H1 to H15, and R1 to R15 - see supplemental material 1 A & B).

From the sow position data, frequency of each position as well as two more variables were derived: the *quantity of positions used*, defined as the number of unique positions the sow used during the observation time period; and *position changes,* defined as the number of times the sow changed her positions during the observation time period.

2.2.2. Physical indicators

The assessment of physical indicators such as body condition score (BCS) and lameness were conducted when sows were moved to farrowing (Loading day) and on the 21st day after farrowing (d21). BCS was assessed using a standard visual scale based on the quantity of backfat and prominence of hipbones and spine using the following scale: 1: emaciated; 2: thin; 3: ideal; 4: fat; and 5: overly fat (Coffey et al., 1999). No changes in BCS were observed between Loading day and d21 of lactation and thus no subsequent analysis was carried out using BCS. Lameness was scored as absence or presence of any sign of lameness, such as shifting the weight away from a limb and/or limping when walking. Only one sow in the study was lame upon entry to farrowing and no animals developed lameness during farrowing. Accordingly, no further analysis using lameness was pursued.

Other physical indicators of welfare including shoulder, body, teat, and udder lesions were collected on Loading day as well as on d4, d7 and d21 post-farrowing. Shoulder lesions were scored using the following scale: 1: absence of shoulder lesion, 2: developing shoulder lesion (when the skin was soft, almost near to develop a lesion, but not open), and 3: presence of shoulder lesion (an open lesion on the shoulder). Body lesions were scored by counting the number of superficial scratches and deep lesions on the neck, side and rear of the sow. Udder lesions were scored by counting the number of superficial scratches and deep lesions in the udder (adapted from Gallois et al., 2005) which were divided in small (≤ 5 cm) or large (≥ 5 cm), and the presence of lesions in the teats, divided in deep or superficial wounds on the teat.

2.2.3 Physiological indicator

Saliva samples were collected at 8:00 h (from day 3 to day 8 post-farrowing) by simultaneous insertion of two cotton swabs in the animal's mouth and allowing the sows to chew for 1-2 min until they were thoroughly moistened. The swabs were placed in a 10 ml syringe and kept on ice until centrifuged for 2 min at 1100 rpm to transfer the saliva to a 50 ml tube. Usually 1.5 - 3.0 ml of saliva was retrieved, which was stored in Eppendorf's at -80℃ until analyzed in the laboratory. Cortisol concentrations were measured for 34 sows (PC=12, T4=11, T7=11), with an enzyme-linked immunosorbent assay (ELISA) following the instructions provided by the High Sensitive SALIVARY CORTISOL Enzyme Immunoassay Kit (Salimetrics, State College, PA, USA). The inter-assay coefficient of variance (CV) for cortisol concentration was 7.2 % and the intra-assay CV was 6.1%.

2.3. Statistical analysis

2.3.1. Behavioral indicators

Sow behavior was analyzed to see if it systematically varied across lactation from day 3 to 8 post-farrowing and between treatments. For that, generalized linear mixed models for repeated measures were fitted using PROC GLIMMIX in SAS (SAS Institute Inc., Cary, NC, USA version 9.4). All models included treatment (PC, T4 or T7) nested with day of assessment (d3 to d8) and parity as fixed effects. Raw and standardized residuals were plotted for all dependent variables following either normal or lognormal link functions. Residual plots were examined and determined that the following dependent variables were normally distributed: quantity of directions used, nursing and lateral lying; whereas exploring environment, investigating piglet, nosing piglets, vacuum chewing, biting fixture, inactive behavior, direction changes, posture changes, sitting, and standing were lognormal. The random effect of sow was considered as a repeated measure within the assessment day. We tested individually the effect of the size of the litter and room temperature, which were categorized into three scores (low = 1, average = 2 and high = 3), by using the following criteria: low (< mean - 0.5 SD), average (= mean ± 0.5 SD) and high (> mean + 0.5 SD). We also tested whether there was an effect of treatment with vitamin B12, Banamine®-S (injectable fluxinin meglumine, Merck Animal Health, Madison, NJ, USA), and the effect of shoulder lesion development. Then, when significant, we included the factor in the model as a random effect for each behavioral variable. Means were compared using *post hoc* Tukey tests. A probability of $P < 0.05$ was chosen to define statistical significance. For the statistical analysis we used SAS (SAS Institute Inc., Cary, NC, USA version 9.4) and RStudio, an integrated development environment for R (version 3.42, R Core Development Team, Vienna, Austria).

2.3.2. Physical indicators

The Kruskal-Wallis test in combination with the Dunn *post hoc* test (R package FSA) was used to assess the effect of treatment on the presence of shoulder lesion as only 5 sows developed shoulder lesions with a score of 3, and only 4 sows scored a 2 when assessed on day 21 of lactation. Principal Component Analysis (PCA) was applied to the teat, body, and udder lesion scores. This method serves to reduce the number of variables by examining the matrix of correlation coefficients between all measurements and infers components, or factors, that may help to classify the data. Physical welfare measurements are defined by and clustered based on their loadings to specific principal components using a cutoff of 0.5 or greater. Daily observations on individual sows including the regional quantities of different udder, teats and body lesions were summed to create 10 variables: superficial teat lesions, deep teat lesions, small superficial udder scratches, large superficial udder scratches, small deep udder lesions, large deep udder lesions, small superficial body scratches, large superficial body scratches, small deep body lesions, and large deep body lesions. From these new variables, nine exhibited sufficient sampling adequacy having a Kaiser-Meyer-Olkin test (KMO) ≥ 0.6 and Bartlett's Test of Sphericity reaching statistical significance ($P < 0.001$). Deep body lesions did not meet these criteria and therefore were not included in the PCA. The PCA was performed with 36 subjects across nine variables, across each day of observation, and yielded three components with eigenvalues exceeding 1.0, being: superficial udder and body lesions, teat lesions, and large deep body lesions indexes, and explained 52.8% of the variance among the variables. Sows received scores for the three components determined from PCA by using the least squares regression approach. Regression factor scores predict the location of each individual on the component. This standardized method produces scores similar to a Z-score metric, where values of the indices range from approximately -3.0 to 3.0.

To analyze the variation of those indexes along the measured days (Loading day, d4, d7 and d21 post-farrowing), generalized linear mixed models for repeated measures were fitted using PROC GLIMMIX in SAS, version 9.4. All models included treatment (PC, T4 or T7) nested with day of assessment and parity as fixed effects. The random effect of sow was considered as a repeated measure within the evaluation day. The raw and standardized residuals distribution of the principal components were determined to be Poisson for the superficial udder and body lesion index, with log link function; normal for the teat lesion index; and lognormal for the large deep body lesion index, the last two with identity link function.

2.3.3 Physiological indicator

Cortisol concentration was analyzed using a generalized linear mixed model for repeated measures with PROC GLIMMIX. The model followed the same structure, fixed and random effects used for the analyses of behavior (see 2.3.1). After examining the raw and standardized residuals, the distribution was characterized as lognormal.

3. Results

3.1 Behavioral indicators

Sow behaviors exhibited a complex dependency on both treatment and assessment day. A similar effect of treatment nested with day was observed on days 4 and 7 post-farrowing for both positional and postural behaviors. This included the number of positions utilized by sows in different crate configurations ($F_{17,158} = 116.25$, $P < 0.0001$) as well as the frequency with which they changed those positions ($F_{17,158} = 26.81$, $P < 0.0001$) and the proportion of time standing ($F_{17,188} = 3.37$, $P < 0.001$). The opening of the hinged crate post-farrowing resulted in an increase in the number of positions utilized by the sow compared to control on day 4 (3 vs. 14.3 ± 3.9) and on day 7 (3 vs. 15.2 ± 2.3) for treatments T4 and T7, respectively (Figure 2A). Likewise, the number of daily position changes also increased compared to control when the crate was opened, from 22.9 ± 7.8 to 43.8 ± 15.6 on day 4 and from 26.5 ± 10.9 to 62.3 ± 17.9 on day 7, for treatments T4 and T7, respectively (Figure 2B). Both the number of positions and the frequency of position changes were maintained or increased on days subsequent to the crate opening. The percentage of time that sows spent standing also increased compared to control when the crate was opened on day 4 (from 6.8 ± 2.5 to 10.4 ± 6.6 %) and on day 7 (from 8.1 ± 3.8 to 11.5 ± 4.1%) (Figure 2C).

Several other posture related behaviors of sows also exhibited significant treatment nested by day effects (Table 2). This includes the frequency of posture changes ($F_{17,189} = 4.87$, $P < 0.0001$), sitting ($F_{17,145} = 2.47$, $P < 0.05$), ventral lying ($F_{17,189} = 1.92$, $P < 0.05$) and lateral lying ($F_{17,8} = 2.04$, $P < 0.05$). However, these treatments nested by day effects were complicated. Posture changes only differed between treatments on day 7, with the lowest frequency of changes for PC (45.9 ± 16), compared with T4 (56.6 ± 25) and T7 (72.6 ± 29) which did not differ between them. Sows in T7 spent a greater proportion of their time sitting on d6 (4.1 ± 2.6) and d7 (6.1 ± 4.0) compared with PC (2.6 ± 2.0; 2.9 ±1.3) and T4 (3.7 ± 6.0; 3.3 ± 2.9) respectively. Ventral lying decreased on days 4 and 5 for T4, and on day 8 for T7, compared to control. Lateral lying only decreased on day 8 in the sows that had their crates opened on day 4 compared to sows that had their crates opened on day 7, but not the control.

A treatment nested with day effect was also observed for many of the behaviors defined as activities (Table 3). This included inactive behavior ($F_{17,189} = 3.23$, $P < 0.05$), exploring environment ($F_{17,164} = 4.13$, $P < 0.05$), investigating piglets ($F_{17,85} = 2.26$, $P < 0.05$), vacuum chewing ($F_{17,118} = 1.92$, $P < 0.05$) and nursing ($F_{17,188} = 1.71$, $P < 0.05$). There was no significant effect on nosing piglets and biting fixtures ($P > 0.05$). There was a difference between treatments, especially after opening the crate (for both T4 and T7) having an increase in the proportion of time spent exploring the environment (175.4 and 227.9%) and interacting with the piglets (90.0 and 55.0%). Pairwise comparisons were limited to T4 and PC using means of d4 to d8, and between T7 and PC using means of d7 to d8. There was also a reduction in the proportion of time spent inactive for T4 and T7 (7.9 and 7.2%, respectively). For vacuum chewing, there was a difference between treatments on d3 with the least amount exhibited by PC compared to either T4 or T7, which were not different from each other. On d6, T7 displayed more vacuum chewing compared to PC or T4, which were now not different from each other. Nursing was higher only in T4 on day d4, compared with T7 and PC whose did not differ between them. In the other days, there was no difference in the proportion of time the sows spent nursing between treatments. Over time there was no difference among days for PC and T7, while for T4 there was an increase in the time the sows spent nursing their piglets.

3.2. Physical and physiological indicators

3.2.1. Shoulder lesion

No effect of treatment was found on shoulder lesion (P > 0.05, Ch-Sq = 1.8, T4: 3 sows, T7: 1 sow, PC: 1 sow).

3.2.2. Body, udder and teat lesion

The PCA performed for these indicators generated three principal components (PC) with eigenvalues exceeding 1.0. These PC explained a total of 52.8% of the variance among the lesion variables. In the first principal component (covering 21.3% of the variance), four variables (small superficial udder scratches, large superficial udder scratches, small superficial body scratches, and large superficial body scratches) had negative loadings above 0.5, and this factor was characterized as *the superficial udder and body lesion index*; the second component (explaining 17.2% of the variance), two variables (superficial and deep teats lesions) had negative loadings above 0.5, and that principal component was characterized as the *teat lesion index*; the third component (explaining 14.3% of the remaining variance) had one variable (large deep body lesion) had positive loadings above 0.5 (Table 4).

We observed an effect of treatment nested with day ($P < 0.001$), having a variation between treatments and along days in the teat lesion index ($F_{11,96} = 6.69$), but not for the superficial udder and body lesion index or the large deep body lesion index ($P > 0.05$). Teat lesions was greater on the 21st day for PC, compared with T4 and T7, which did not differ between them. For the other evaluation days there were no differences between treatments (Figure 3). Note that components derived from lesions measures with negative loadings would have increased in lesion quantity and severity as the component score became smaller. To more easily visualize the treatment by day effect on teat lesion, the original teat lesion index was mathematically transformed by multiplying the z-score by -1 and then adding 1.5 to obtain a new variable where increasing scores describe increasing lesion severity (Figure 3).

3.2.3. Salivary cortisol concentrations

There was an effect of treatment nested with day ($F_{17,179} = 2.07$, $P < 0.001$). The overall trend for cortisol concentration was to decrease post-farrowing as mean cortisol concentration was lower on day 8 than day 3 for all treatments (from 2.25 ± 1.08 to 1.45 ± 0.79; from 2.06 ± 0.88 to 1.97 ± 0.78 and from 2.34 ± 1.26 to 1.28 ± 0.41 ng/ml on days 3 and 8 for PC, T4 and T7, respectively). Cortisol concentrations only was different between treatments on day 5 where T4 was not different from PC but from T7, which did not differ from PC (2.22 ± 1.32, 2.59 ± 1.08 and 1.36 ± 0.48; means ng/ml ± SD for PC, T4 and T7 respectively).

4. Discussion

In this study, we employed multiple types of welfare indicators to better understand the impact on a sow of opening a hinged farrowing crate on different days of lactation (days 4 and 7 post-farrowing). We observed that many of the indicators used (behavioral and physical) suggest that releasing a sow from confinement after a few days of lactation improves sow welfare compared to her remaining crated for the duration of lactation.

4.1. Behavioral indicators

Our findings showed an immediate impact of opening the hinged farrowing crate on behavioral indicators. The sows increased both quantity of positions used and frequency of position changes when the crate was opened at either 4 or 7 days post-farrowing, compared with animals that remained confined in a closed crate. Similarly, the proportion of time spent in standing position, exploring the environment, interacting with their piglets increased mainly on the day of crate opening for both T4 and T7 treatments, compared with PC. These significant changes in post-opening behaviors on D4 and D7 are notable as their underestimation due to the 2-hour delay in opening the crates compared to the onset of observations would have biased these outcomes toward the null hypothesis. Also, as a consequence of increases in other behaviors, the proportion of time spent inactive decreased. We expected that, due to the increased availability of space for the sows, they would spend more time performing motivated behaviors (such as interacting with their piglets or exploring the environment) and accessing positions they could not while confined in the crates.

Boredom can develop in animals when exposed to spatially or temporally monotonous environments such as when continuously crated (Burn, 2017). Sow-piglet interaction commonly occurs when both are able to freely interact (Portele et al., 2019), and this contact is facilitated by the freedom of the sow inside the pen (Singh et al., 2017), as we found in our study when the crate was opened for sows in T4. Chidgey et al. (2016) also found that loose sows spent more time investigating and touching their piglets, compared with crated sows. Our results reflecting the activity of the sow are consistent with Goumon et al. (2018) who found an increase in the time spent being active in the first 24 h after opening the crate, on day 4 post-farrowing. On the other hand, our findings contrast those reported by Chidgey et al. (2016) who did not find a difference in activity (standing and rooting) following the opening of the crate on day 4 compared to crated sows. Lambertz et al. (2015), after opening the crate on days 7 and 14, respectively, also did not find differences between treatments on activity in the first week, compared with sows in closed crates. Those differences may be explained by the sampling method used to evaluate the behavior data in these different studies. Lambertz et al. (2015) sampled every 10 minutes, Chidgey et al. (2016) restricted their sampling to only 4 periods during the day, whereas we sampled every 2 minutes over the 12 hour time period that the animals were expected to be most active.

To our knowledge, this is the first study to examine how the sow uses the increased space afforded to her following the opening of a hinged farrowing crate. The sows performed more position changes after the opening of the crate (56.4 for T4 and 64.5 for T7) compared to PC, where the sows performed only 25.0 and 28.3 position changes per day, respectively. Additionally, the sows utilized approximately 5 times more positions within the pen after the crate was opened. Thus, sows clearly take advantage of the added freedom of movement afforded to them when their crates are opened. Previous studies have not focused on such a complete repertoire of position changes as in our work, but some did include rolling events (change of posture from sternal to lateral). These studies found an increase in these rolling events during the first few days post-farrowing for sows after crate opening compared to crated sows (Hales et al., 2016; Goumon et al., 2018).

It has been suggested that excessive posture changes of lactating sows could reflect attempts to reduce contact with the litters (Boyle et al., 2002; Lewis et al., 2005). However, although position changes were high in our study, postures changes for the most part did not differ between treatments, and no differences were found in lateral lying positions between treatments. The same trend was observed for nursing, while it increased on days 4 and 5 in T4, compared to sows crated throughout lactation, no decreases in nursing behavior were observed. Our results corroborate the findings of Illmann et al. (2019) who reported that udder access to the piglets was not altered after opening the crate, even with the sows having an increased activity (Goumon et al., 2018). Singh et al. (2017) also found this trend, comparing sows in lactation pen and farrowing crates from day 3 post-farrowing to weaning. Together these findings suggest that when given the opportunity, sows perform more position changes after opening the crate without reducing piglet contact or nursing behavior.

We also found that sows whose crates remained closed spent more time performing ventral lying posture compared with other treatments on days after crate opening. De Passillé and Robert (1989) described that posture as sows' attempts to reduce piglets contact with the udder. Lewis et al. (2005), for example, found that sows nursing teeth intact piglets, compared with resected or clipped teeth piglets, spend more time in this position, which they suggest is to avoid the contact from the piglets with their udders. However, the results of our study suggest avoiding piglet contact may not be the reason for preferring a ventral lying posture because, as discussed above, the time the sows spent nursing and in lateral lying posture did not differ between treatments. Lambertz et al. (2015) found that the proportion of time spent in this position by the sows increased from the first to the third week of lactation, but did not find differences between crated and non-crated sows. Ventral lying may be the most comfortable position for sows to maintain compared to either standing or lying laterally when constrained by the crate and as a result crated sows will spend more time inactive given the dearth of alternative activities.

In our study, we found differences in the proportion of time sows spent vacuum chewing but not biting fixtures. Both behaviors can be considered stereotypies (Broom and Fraser, 2015). It has been suggested that these behavioral disorders are indicative of compromised welfare when observed more than 10% of the time (Broom, 1991; Broom and Fraser, 2015). In our study, sows performed these behaviors, on average, less than 10% of the time; only 1% for biting fixtures, and less than 2% of vacuum chewing. These observations are consistent with the interpretation that the limited amount of fixture biting and vacuum chewing observed by sows in this study are not indicative of compromised welfare.

It is important to note that many of the changes in behavior we documented in sows after their crates were opened such as exploring environment, interacting with piglets, inactive or in standing position were quite small in terms of the animal's daily time budget. One of the challenges with studying sow behavior, especially in farrowing, is that these animals spend up to 70% of their time essentially inactive – resting or sleeping – even during the most active part of the day (note that if we included analysis from 6 PM to 6 AM the total time sleeping or resting would increase to close to 90%). Thus, while some of the absolute changes in how the animal allocates its time across the day may seem small (e.g. less than 10%), these may represent relatively large changes in the expression of those particular behaviors.

4.2. Physical indicators

We found no differences in the presence of shoulder lesions between treatments. Our results are consistent with the findings of Lambertz et al. (2015) who observed that these lesions increased during lactation, independent of the treatment, from less than 1% prevalence of shoulder lesions on day 7 to 14% on day 25 post-farrowing. We observed 0% on days 4 and 7, and 13.9% on day 21 post-farrowing. Some studies have shown that sows maintained in both closed crates and loose conditions develop shoulder lesions. In a review, Hersink et al. (2011) reports a prevalence of shoulder lesions in different European countries, with an incidence of 17% in sows maintained in conventional crates in Denmark, and the incidence of the same lesions ranging from 10% in UK and Norway to 34% in Sweden in loose sows. Those results, together with ours, indicate that the type of housing is not the only environmental risk factor that increases shoulder lesions (Baxter et al., 2018). Environmental factors such as flooring type, pen location, temperature, humidity and floor friction properties, as well as other animal-centric variables such parity, post-farrowing body condition, lameness, health status, previous history of shoulder lesion, litter weaning weight, lactation length, sow behavior, breed and genetics all contribute to the development of shoulder sores (Rioja-Lang et al., 2018).

We observed no differences in the udder and body lesions index between treatments along days (from loading to weaning). However, we found differences in teats lesion index, which revealed more lesions for the sows in PC on day 21 post-farrowing. Our results corroborate with Verhovsek et al. (2007) and Lohmeier et al. (2019), who found a higher incidence of teat lesions in crated sows compared with loose-housed sows at day 23 and four weeks post-farrowing, respectively. According to Verhovsek et al. (2007), the restriction of the sows, when getting up and lying down, inside the closed crates results in teats abrasions from the hind limbs of the sows. An additional contributor to teat lesions in crated sows, might be differences in the piglets' access to the sow's teats. A sow in late lactation in a closed crate might have less options to avoid unwanted nursing events compared to a sow in an open crate. Although Illmann et al. (2019) demonstrated that temporary crating is a safe alternative to permanent crating in terms of nursing and suckling behavior (observed on day 3 and 25 post-farrowing), future studies could include more observation days and sow welfare indicators in late lactation stage, with larger sample size, to understand if there are differences in postures and activities performed by the sows.

4.2. Physiological indicator

Saliva cortisol concentrations, in general, diminished from day 3 to day 8 for all treatments presumably reflecting the recovery from physiological stressors associated with parturition. Cortisol levels only significantly differed on one of 6 measurement days and for only one of three possible comparisons between treatment groups on that day. Thus, our results are more similar than different from other studies that did not see differences in cortisol levels between crated or loose sow (Cronin et al., 1991; Biensen et al., 1996; Goumon et al., 2018). All these findings diverge from Oliviero et al.

(2008), who reported lower salivary cortisol concentrations in loose sows, compared with crated sows, from days 2 to 5 post-farrowing. Thus, our findings taken together with the majority of the published work support Goumon et al.'s (2018) statement that research aiming to understand whether confinement is a chronic stressor in early lactation, measured by sows' cortisol concentrations, is inconclusive. Salivary cortisol is better suited for acute stressors, not for reflecting chronic stress, so future studies could use hair cortisol as a potential measure of chronic stress in sows. Other physiological measures such as leukocyte ratio (Davis et al., 2008) or heart rate variability (Kovács et al., 2015) might provide better physiological measures of the chronic stress response relevant to sows reared in different types of housing systems.

5. Conclusion

The results of our study support the idea that the ability to open a hinged farrowing crates provides the opportunity for better sow welfare compared to the confinement of a traditional farrowing crate. Our findings demonstrate an immediate effect on sow welfare once the crate is opened, the sow has the possibility to exercise more freedom of movement, interact more with her environment and piglets and perform more motivated behaviors. Sows also appear to be less prone to having teats injuries at 21 days post-farrowing and this reflects a more sustained benefit to the sow of the open crate. From the perspective of sow welfare, opening of the crate at day 4 post-farrowing would be recommended as she gains the advantages of an opened crate earlier in lactation. However, the benefits to the sow must be balanced against how the opening the farrowing crate impacts the productivity and welfare of her piglets, particularly pig mortality. More studies, particularly under commercial scale and conditions, are needed to better define the consequences of crate opening on the piglets.

Conflict of interest statement

The authors declare that there are no conflicts of interest associated with this publication.

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Table 1. Definition of the behavioral categories of the activity and posture groups.

Group of categories	Behavior category	Description
Activity	Eating	Lowering the head into the feeder and ingesting food.
	Drinking	Having the mouth in the nipple while ingesting water.
	Nursing	Sow is lying in lateral position, and the piglets are awake and suckling while the milk letdown. A nursing event begins when 50% of the piglets are suckling at the udder (teat in mouth while performing sucking movements), and finishes when sow terminates the event (sow roll onto the udder or stand up) or 50% of the piglets stop being active at the udder (leaving the udder or falling sleep).
	Vacuum Chewing	Repetitive chewing without food in the mouth.
	Inactive	Sow stays motionless, remaining in lying, sitting or standing posture with closed or open eyes.
	Investigate piglet	Sow turns toward and sniff a piglet.
	Nose piglet	Sow touches or moves a piglet with the snout.
	Biting fixture	Biting repetitively at any of the fixtures within the crate (e.g. bars, feeder). Sow could do head movements laterally while biting.
	Exploring environment	Sniffing and/or touching the floor, or the walls of the pen with the snout ("digging"), as well as accompanying head movements.
Posture	Standing	The sow maintaining an upright body position with 4 legs supporting body weight.
	Sitting	The sow is partly erect on front legs (leaning on the knees or forelegs) with the hindquarters in contact with the floor (without standing on hind legs).
	Lateral Lying	The sow is lying flat on one side with a shoulder on the floor and exposing udder.
	Ventral Lying	The sow is lying on sternum/belly, without a shoulder touching the floor, and partially or totally obscuring the udder.

Table 2. Real means ± SD of the proportion of time spent in ventral lying, lateral lying and sitting, and the ave
number of posture changes for each treatment (PC, sow permanently crated until weaning, T4, sows crated unt
fourth day post farrowing, and T7 sow permanently crated until weaning) along the assessment days (from day
8 post-farrowing) [1]

Behavior	Treatment	N	day3	day4	day5	day6	day7	
Ventral Lying	PC	13	21.7±9.0 ^{Ba}	24.2±9.9 ^{ABa}	27.1±10.5 ^{Aa}	23.0±7.9 ^{ABa}	21.4±8.2 ^{Ba}	
	T4	12	18.0±9.2 ^{Aa}	17.0±4.7 ^{Ab}	16.8±9.1 ^{Ab}	18.6±9.2 ^{Aa}	18.0±8.5 ^{Aa}	
	T7	11	15.2±6.1 ^{Ba}	21.2±8.5 ^{Aab}	19.8±8.9 ^{ABab}	17.5±7.3 ^{ABa}	17.9±6.4 ^{ABa}	
Lateral Lying	PC	13	70.2±9.3 ^{Aa}	64.5±10.2 ^{ABa}	61.2±9.8 ^{Ba}	64.7±7.8 ^{ABa}	66.0±9.2 ^{ABa}	(
	T4	12	72.3±9.1 ^{Aa}	68.4±5.7 ^{ABa}	68.5±12.6 ^{ABa}	65.0±19.0 ^{BCa}	65.2±8.5 ^{BCa}	
	T7	11	75.3±8.3 ^{Aa}	66.2±10.3 ^{Ba}	67.2±10.1 ^{Ba}	69.1±8.9 ^{ABa}	62.8±8.1 ^{Ba}	
Sitting	PC	13	2.0±1.8 ^{Bb}	3.0±2.8 ^{ABa}	2.8±2.2 ^{Ba}	2.6±2.0 ^{Bb}	2.9±1.3 ^{ABb}	
	T4	12	1.9±1.4 ^{Aab}	2.5±1.8 ^{Ab}	2.1±2.9 ^{Aa}	3.7±6.0 ^{Ab}	3.3±2.5 ^{Ab}	
	T7	11	2.9±2.8 ^{Aa}	3.8±2.9 ^{Aa}	3.4±2.6 ^{Aa}	4.1±2.6 ^{Aa}	6.1±4.0 ^{Aa}	
Posture changes	PC	13	33.5±9.28 ^{Ba}	40.6±14.5 ^{ABa}	44.5±10.6 ^{Aa}	42.8±12.1 ^{Aa}	45.9±15.7 ^{Ab}	
	T4	12	31.4±11.8 ^{Da}	44.3±17.0 ^{BCa}	40.3±19.2 ^{Ca}	45.9±22.3 ^{BCa}	56.6±24.8 ^{ABa}	
	T7	11	39.4±19.6 ^{Ca}	44.3±17.4 ^{Ca}	43.8±14.9 ^{Ca}	47.3±12.6 ^{BCa}	72.6±29.0 ^{Aa}	

[1] Means $^{a-b}$ followed by the same lower case letters in the same column are not statistically different ($P > 0.05$), by Tukey test. $^{A-D}$ Means followed by the same uppercase letters in the same row are not statistically different ($P > 0.05$), by Tukey test.

Table 3. Real means ± SD of the proportion of time spent resting/sleeping, exploring environment, investigati piglets and vacuum chewing, for each treatment (PC, sow permanently crated until weaning, T4, sows crated ur the fourth day post farrowing, and T7 sow permanently crated until weaning) along the assessment days (fr day 3 to 8 post-farrowing)[1]

Behavior	Treatment	N	day3	day4	day5	day6	day7
Resting/ Sleeping	PC	13	75.3±4.5 ^{Aa}	72.3±4.6 ^{Aba}	70.8±3.8 ^{Aa}	72.4±4.6 ^{Aa}	69.6±4.3 ^{Aa}
	T4	12	72.3±8.4 ^{Aa}	65.1±7.4 ^{Bb}	64.8±8.7 ^{Bb}	65.0±7.7 ^{Bb}	64.1±10.2 ^{Bb}
	T7	11	72.0±6.8 ^{Aa}	71.6±7.1 ^{Aa}	71.3±6.2 ^{Aa}	68.1±7.0 ^{ABab}	63.8±6.2 ^{Bb}
Exploring environment	PC	13	0.83±0.7 ^{Aa}	1.38±1.3 ^{Ab}	1.53±1.5 ^{Aab}	1.02±0.9 ^{Ab}	0.96±1.1 ^{Ab}
	T4	12	1.32±1.0 ^{Ba}	3.42±3.0 ^{Aa}	3.54±3.8 ^{Aa}	3.35±3.0 ^{ABa}	3.30±3.5 ^{Aa}
	T7	11	0.93±0.9 ^{Ba}	1.22±1.1 ^{BCb}	1.59±1.3 ^{Bb}	1.29±1.7 ^{Bb}	3.96±2.4 ^{Aa}
Investigate piglets	PC	13	0.36±0.5 ^{Aa}	0.47±0.5 ^{Ab}	0.56±0.5 ^{Aa}	0.40±0.4 ^{Aa}	0.41±0.7 ^{Aa}
	T4	12	0.43±0.7 ^{Ba}	1.36±1.3 ^{Aa}	0.99±1.1 ^{Aa}	0.92±1.2 ^{ABa}	0.45±0.5 ^{Ba}
	T7	11	0.23±0.3 ^{ABa}	0.29±0.3 ^{ABb}	0.23±0.2 ^{Bb}	0.20±0.3 ^{ABa}	0.69±0.4 ^{Aa}
Vacuum chewing	PC	13	0.75±0.78 ^{Ab}	0.80±0.89 ^{Aa}	1.00±1.34 ^{Aa}	0.68±0.77 ^{Ab}	0.92±1.16 ^{Aa}
	T4	12	2.78±3.73 ^{Aa}	1.80±2.10 ^{Aa}	1.76±2.74 ^{Aa}	2.24±4.45 ^{Aab}	1.73±3.22 ^{Aa}
	T7	11	2.97±3.77 ^{Aa}	1.88±1.96 ^{Aa}	1.50±1.83 ^{Aa}	2.38±2.43 ^{Aa}	1.45±1.91 ^{Aa}
Nursing	PC	13	15.64±0.05 ^{Aa}	15.53±0.04 ^{Ab}	16.38±0.03 ^{Aab}	15.96±0.05 ^{Aa}	17.55±0.05 ^{Aa}
	T4	12	15.21±0.04 ^{Ba}	19.68±0.06 ^{Aa}	20.15±0.05 ^{Aa}	18.67±0.07 ^{Aa}	18.71±0.06 ^{Aa}
	T7	11	15.05±0.03 ^{Aa}	14.95±0.04 ^{Ab}	15.20±0.04 ^{Ab}	17.55±0.04 ^{Aa}	16.59±0.04 ^{Aa}

[1] Means $^{a-b}$ followed by the same lower case letters in the same column are not statistically different (P > 0.05), by Tukey test. $^{A-C}$ Means followed by the same uppercase letters in the same row are not statistically different (P > 0.05), by Tukey test.

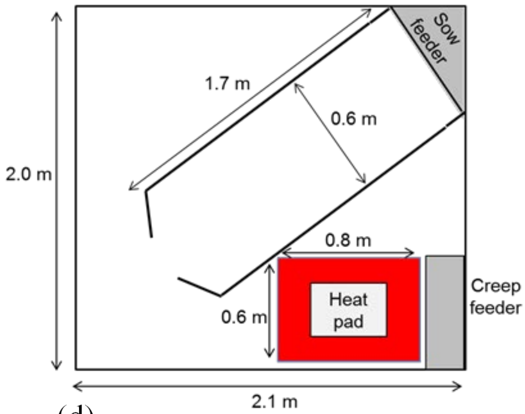
Table 4 – Principal component analysis of physical indicators. Variables with loadings greater than 0.5 (bolted) represents those with the most positive and negative contributions to the composition of the physical indicators indexes.

Lesion indicator	Body and udder lesion	Teats lesion	Large deep body lesion
Superficial teat lesions	-0.102745	**-0.672141**	-0.194493
Deep teat lesions	-0.041519	**-0.703413**	0.062771
Small superficial udder scratches	**-0.521630**	-0.445088	0.150952
Large superficial udder scratches	**-0.578171**	0.078156	0.495950
Small deep udder lesions	-0.274105	-0.407460	-0.361946
Large deep udder lesions	-0.493204	-0.019054	-0.331600
Small superficial body scratches	**-0.713528**	0.277317	-0.303086
Large superficial body scratches	**-0.619636**	0.377083	-0.160076
Large deep body lesions	-0.292994	-0.085991	**0.785335**
Eigenvalues	1.92	1.54	1.29
% Variance	21.3	17.2	14.3

Figure 1. Representative schematic of the pen with the hinged farrowing crate closed (a & b) or opened (c & d).

(a)

(b)



(c)

(d)

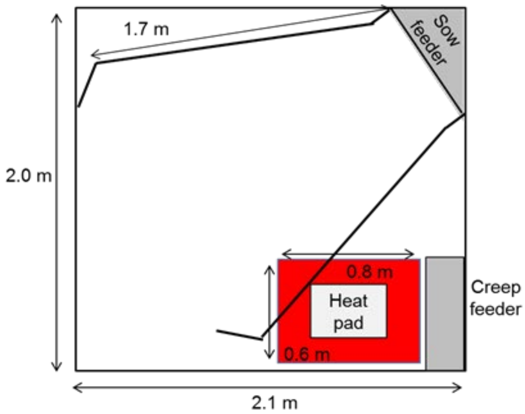
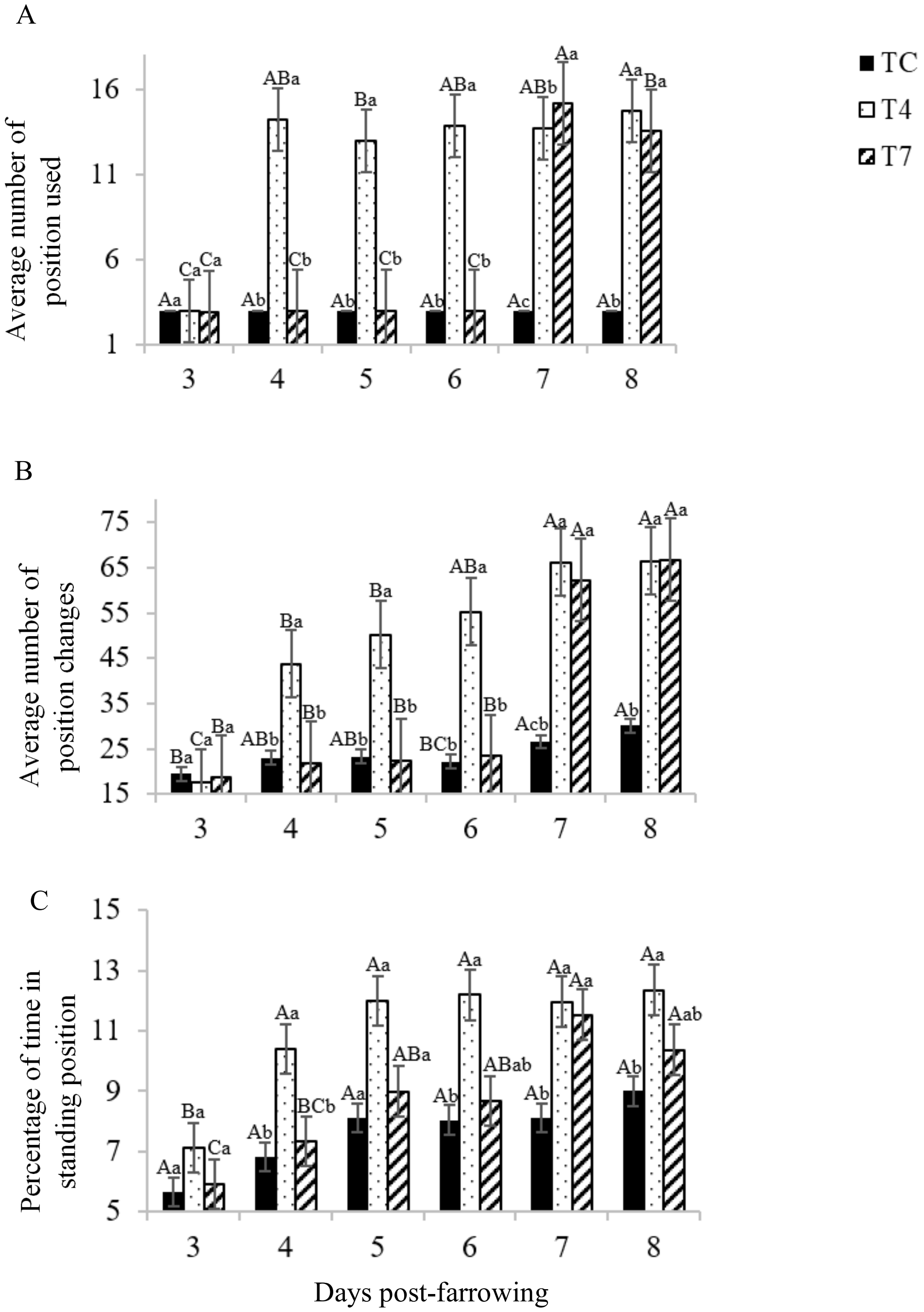
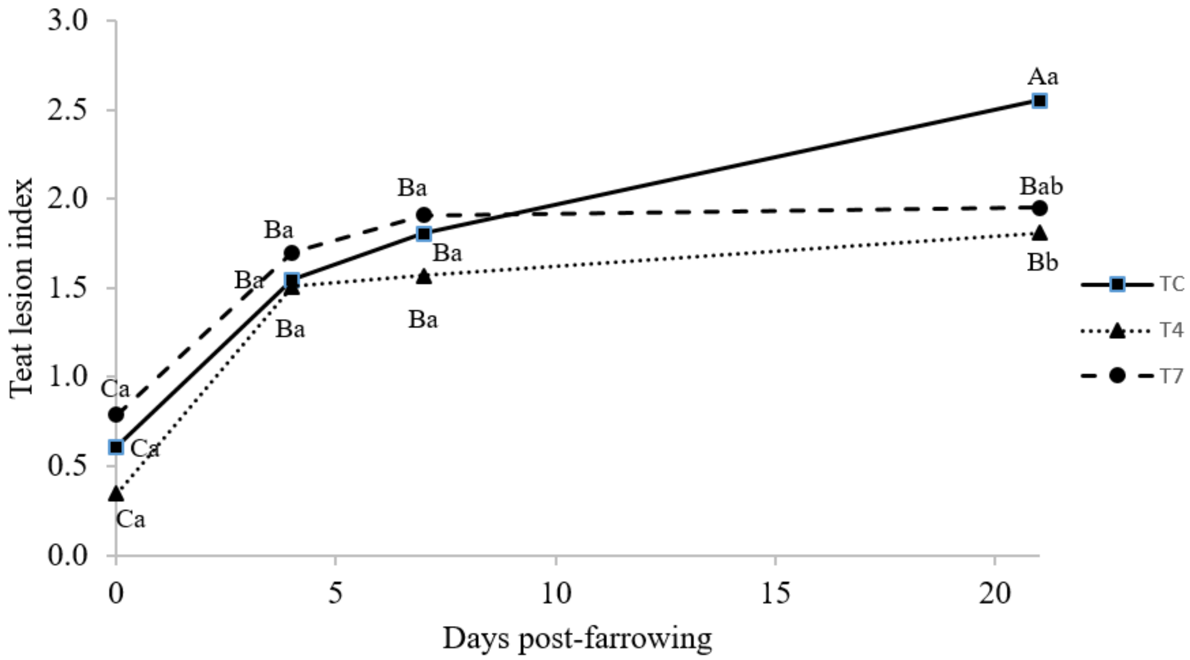


Figure 2. Real means ± SEM of 12 hours observation (from 6 AM to 6 PM) of: A. Average number of position used, B. Average number of position changes, and C. Percentage of time spent in standing position for each treatment (TC: sow permanently crated until weaning, T4: sows crated until the fourth day post farrowing, and T7: sow permanently crated until weaning), along the assessment days (from day 3 to 8 post-farrowing)[1].



[1] Means $^{a-c}$ followed by the same lower case letters in the same day are not statistically different (P > 0.05), by Tukey test. $^{A-D}$ Means followed by the same uppercase letters in the same treatment are not statistically different (P > 0.05), by Tukey test.

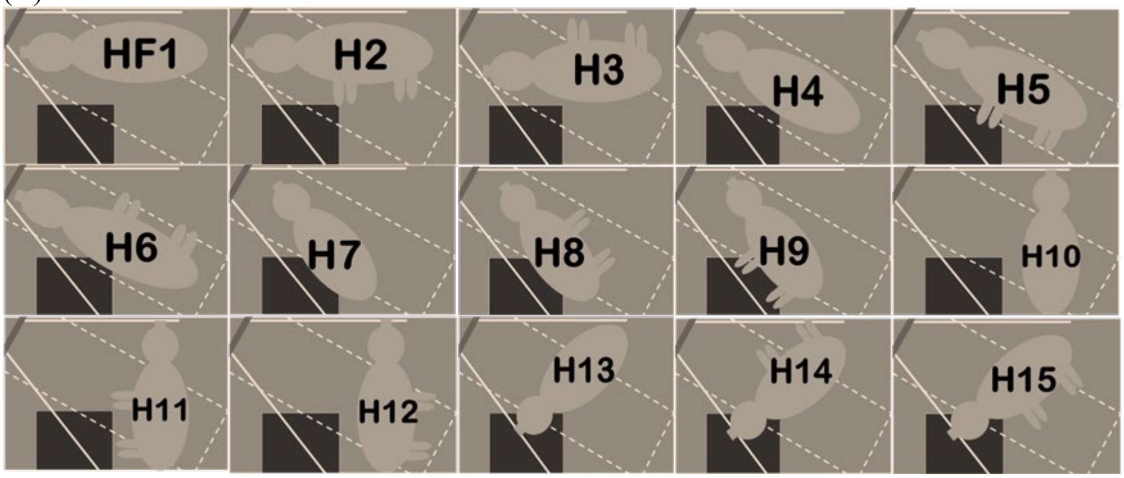
Figure 3. Teat lesion index along the assessment days (d0, d4, d7 and d21 post farrowing) for each treatment (control - TC, four days of opening - T4 and seven days of opening - T7). For display purposes, the original teat lesion index scores were rescaled by inverting their signs and then adding 1.5 [1].



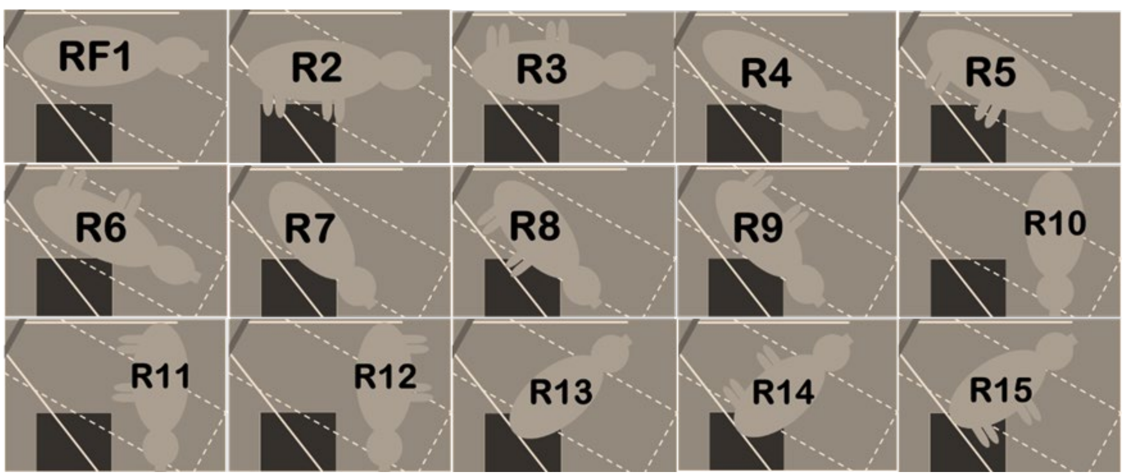
[1] Means $^{a-c}$ followed by the same lower case letters in the same day are not statistically different (P > 0.05), by Tukey test. $^{A-D}$ Means followed by the same uppercase letters in the same treatment are not statistically different (P > 0.05), by Tukey test.

Supplemental material 1. Representative schematic of the locations/positions of the sow within the pen with the head facing the feeder (A) and with the rear facing the feeder (B).

(A)



(B)



Appendix II

Findings from the study that determined the effect of timing of the opening of a hinged farrowing crate on piglet mortality.

Impact of duration of farrowing crate closure on physical indicators of sow welfare and piglet mortality

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Abstract

The aim of this study was to identify the effect of opening a hinged farrowing crate 4 or 7 days post-farrowing on piglet mortality and physical indicators of sow welfare. A total of 696 sows were studied. The sows were randomly allocated to 1 of 3 treatment groups: PC- crate remained closed until weaning, T4- crate was opened on day 4 post-farrowing, and T7- crate opened on day 7 post-farrowing. Piglet mortality and four physical indicators of sow welfare were examined: body condition score (BCS), lameness, shoulder lesion and teat lesions, measured on loading day and the day before weaning. The total percentage of piglet mortality was higher for T4 litters (27.8 %) than T7 (23.9%), however, neither treatment differed from the PC group (25.9%) ($P < 0.05$). In addition, the risk of piglets being laid on varied by treatment at different times during lactation. No difference in the risk of being laid on was found in the period 1-3 days post farrowing when all crates were closed ($P > 0.05$). For the period 4 - 6 days post-farrowing, piglets in T4, the only treatment with the crate open, were at higher risk of being laid on, compared to PC (IRR= 2.5, $P < 0.05$), and T7 (IRR=2.3, $P < 0.05$). For the period 7-15 days post farrowing, the risk of piglets dying from being laid on was higher in the open crate treatments, T4 and T7, compared to PC (T4: IRR= 3.89, T7: IRR = 3.5, $P < 0.05$). We found no association between treatment and three of the sow physical welfare indicators evaluated in the study: BCS, lameness and shoulder sores ($P > 0.05$), but we found a higher risk for teat lesions in PC sows at weaning ($P< 0.05$). Our results indicate that crating the sows immediately post-farrowing for seven days, when piglets are most vulnerable to crushing, has the potential to maintain a similar total percentage of piglet mortality, compared with crated conditions, while improving the sow's welfare.

Keywords: farrow, housing, lactation, hinged farrowing crate

Implications

Concerns about the welfare of lactating sows housed in farrowing crates have emerged. In a hinged crate, the sow is initially crated, but when piglets reach a designated age, the crate is opened, providing the sow additional space. However, concerns related to piglets arise, as they die early in life by getting laid-on, and hinged crates could negatively influence mortality. Our results indicate that crating the sows for seven days post-farrowing maintains a similar total percentage of piglet mortality, compared with crated conditions, while improving sow's welfare. Thus, our results bring information of general interest applicable to the pork industry.

Introduction

The farrowing crate was developed to reduce piglet losses and to facilitate human intervention by limiting sow's movements during parturition and lactation (Robertson et al., 1966; Edwards and Fraser, 1997). Most piglets die early in life (Hellbrügge et al., 2008) by getting laid on under the sow (Marchant-Forde et al., 2000; Kilbride et al., 2012). As crushing can result in injuries and suffocation, pre-weaning mortality is both a production and welfare challenge. Farrowing crates are an attempt to balance the welfare of the piglets with the physical restriction of the sow. However, the mismatch between sow's behavioral needs and the farrowing crate design results in a compromise to the welfare of the sow (Ceballos et al., 2020). Additionally, there is increasing concern regarding the welfare of the sow during lactation (Council directive 2008/120/EC, Baxter et al., 2018).

There are approximately nine different options for housing a lactating sow and her piglets, which range from the conventional crate, the hinged crate, to the open pen and communal pen systems (Johnson and Marchant-Forde, 2009). There are advantages and disadvantages to each of these housing systems concerning sow and piglet welfare during parturition and lactation (Johnson and Marchant-Forde, 2009). In a hinged crate system, the sow is initially crated, but when the piglets reach a designated age, the crate is opened, providing the sow additional space. The hinged crate, though it does not provide the same physical freedom to the sow that a farrowing pen provides, fits in a similar footprint to a standard farrowing crate and protects the piglets for a designated period of time early in life when mortality risk to the piglet is the greatest.

The hinged crate, therefore, may be a practical solution for farmers. Several studies have reported that closed crate sows weaned more pigs than open crate sows (Verhovsek et al., 2007; Pedersen et al., 2011; Chidgey et al., 2015). However, Mack et al. (2017) reported that hinged crates could yield similar pre-weaning mortality to a closed crate. Similarly, Moustsen et al. (2013) observed no differences in mortality or litter size at weaning. Pedersen et al. (2011) only fixed the sows in the crates during farrowing; Verhovsek et al. (2007) opened the crates when the pigs were 2 days of age; Chidgey et al. (2015) and Moustsen et al. (2013) opened the crates at 4 days of age; and Mack et al., (2017) opened them at 14 days of age. These results suggest that 2 days closed is not sufficient for piglet protection and that, although 4 days may be long enough, piglet mortality may be lower with longer crate closure duration. In order to extend the findings of previous work, the aim of this study was to examine the effect of opening a hinged farrowing crate 4 or 7 days post-farrowing on piglet mortality and physical indicators of sow welfare. We hypothesized that we would find no differences in total piglet mortality between treatments and that we would see improvement in the physical indicators of sow welfare when hinged crates were opened earlier in lactation.

Animals, Material and methods

Animals, housing and experimental design

The study was conducted on a 5000-sow commercial farm located in the north central region of Pennsylvania, USA, between April and June 2019. A total of 696 sows, Line 200 or 241 (DNA Genetics, Columbus, NE, USA), with parity 2 ± 1.9 (range: 0 – 7), were initially included in the study. Sixty-six sows were removed from the study before completion due to illness or death. Prior to farrowing, sows were housed in large gestation pens, containing approximately 250 sows, where they were fed via electronic sow feeding (ESF). At approximately gestational day 113 (Loading day), sows were moved into a farrowing room. In total, six weekly farrowing cohorts of approximately 114 individuals were studied and housed in six identical rooms (35 x 20.5 m). Each room had 6 rows of 19 farrowing pens, or 114 pens per room, each of which was equipped with a hinged farrowing crate. The hinged crate could be opened to provide the sow additional space and freedom of movement, including being able to turn around. The farrowing pen dimensions were 2.36 x 1.70 m and provided 4.0 m2 in total area. The farrowing pen layout included a triangular creep area with a hover (0.9 × 1.56 x 1.8 m), and a farrowing crate with hinged sides with dimensions of 0.635 × 2.13 m located diagonally within pen (Figure 1). Both solid and partially open partitions were used as walls of the pens between sows. All sows and piglets were housed on perforated plastic flooring.

Upon entry to the farrowing rooms, sows were loaded into a hinged farrowing in the closed configuration. All sows were blocked by parity and randomly allocated in to three treatment groups: PC - sow permanently crated until weaning (n= 177 sows), T4 – sows crated until the fourth day post farrowing, when the crate was opened and remained so until weaning (n= 185 sows) and, T7 - sows crated until the seventh day post farrowing, when the crate was opened and remained so until weaning (n= 161 sows) (Table 1). Upon entry to the farrowing rooms, sows were fed once a day 4 pounds of a lactation diet that met or exceeded the National Research Council (NRC) guidelines (NRC, 2012). Two days post-farrowing, sows were started on ad libitum feeding of up to 32 pounds per day. The feed system was automatic, filling four times a day a tube with a capacity of 8 pounds. The number of functional teats was determined for each sow prior to farrowing. Farm practice was to induce up to 20 sows per day to farrow if they reached day 116 of gestation without farrowing by giving a 5 mg injection of dinoprost tromethamine (Lutalyse ®, Zoetis, Parsippany, NJ, USA). A total 179 sows or 29.7% of the study sows were induced to farrow.

The piglets received creep feed five days before weaning. All sows and their litters had free access to water via nipple drinker (one for the sows and one for the piglets). The creep area was maintained at approximately 35°C by a radiant heat lamp (100 W), and another lamp (175 W) was maintained in the back of the pen for the first three days post farrowing (prior to the opening of the hinged farrowing crate). No bedding or other substrate was provided in the farrowing area. Cross fostering of piglets between litters was carried out during the first 24 hours post-farrowing if the number of live piglets farrowed by a sow exceeded her number of functional teats. Baby pig processing, including castration, was completed by Day 3 post-farrowing. The same caretakers performed the handling of all study sows and litters. From all sows involved in the study, 63 were early weaned for lactating poorly and recorded as a nurse off event (31, 10 and 22 from PC, T4 and T7 respectively). 135 sows had their lactation extended, a nurse on event, when they received piglets from a nurse off event (38, 39 and 58 from PC, T4 and T7 respectively).

Productivity measures

A piglet was classified as having died from being laid on if they were found with their body flattened and cyanotic and the date of death was documented. Other causes of death including starvation, rupture, savaged, deformed, joint problem, lame, scrotal and belly rupture, blind anus, and no teats were also coded. The sow's parity, farrowing date and weaning date were recorded for each dead piglet. For each litter, the number born alive, total born, total mummies, total weaned, cross fostering events, nurse on events, and nurse off events were recorded.

Sow welfare indicators

Assessment of sow physical indicators included the measurement of body condition score (BCS), lameness, shoulder lesion and teat lesions. BCS was evaluated using a standard visual scale based on the quantity of backfat and prominence of hipbones and spine using the following scale: 1:

emaciated; 2: thin; 3: ideal; 4: fat; and 5: overly fat (Coffey et al., 1999). Lameness was scored as absence or presence of any sign of lameness. The shoulder lesion was scored with the following scale 1: the absence of a shoulder lesion; 2: start of a shoulder lesion (when there was a lesion, but limited to the epidermis, and the skin was not open), and 3: the presence of a shoulder lesion (ulcerated dermis, sometimes covered with a scab) (Meyer et al. 2019). Teat lesions were quantified by counting the number of teats each sow had with either deep or superficial wounds. All indicators were measured on loading day and the day before weaning (on average 19 ± 3 days after farrowing).

Statistical analysis

The total percent of piglet mortality was compared between treatments by fitting the data with generalized linear mixed models using PROC GLIMMIX in SAS, version 9.4 (SAS Institute Inc., Cary, NC, USA). All models included treatment (PC, T4 or T7), parity (0-7) and sow genetic line (241 or 200) as fixed effects. The interaction between parity and treatment was evaluated, and no interaction was found, so it was not included in the final model. Cohorts (1-6) and whether the sow was induced to farrow were included in the model as random effects. Litter size after equalization (total born alive + foster in – foster off) was included as a covariate. Only data for sows that nursed their litter for at least 15 days after farrowing were included. From the original 630 study sows, 107 were nursed off before 15 days post-farrowing, or were used as nurse sows for other litters so after these exclusions, 523 sows were included. The outcome variable evaluated was total percent mortality, for the period from farrowing to weaning. Means were compared using post hoc Tukey test.

Mixed effect Poisson regression models were used to assess the risk of piglet mortality for the recorded reasons including low viability, laid on, scours, and other reasons. Other included starvation, rupture, savaged, deformed, joint problem, lame, deformed, scrotal and belly rupture, blind anus, and no teats, which were combined as each category represented less than 5% of the mortalities. Poisson models included treatment (PC, T4 or T7), parity (0-7) and litter size after equalization as fixed effects and room as random effects. Estimated coefficients were transformed and reported as incidence-rate ratios. A Bonferroni correction was used to account for multiple comparisons between the 3 treatments.

As one of the main concerns of using hinge farrowing crates is the mortality due to piglets being laid on, mixed effect Poisson regression models were used to assess the risk of piglets getting laid on in 3 different periods. These periods included day 0 to 3, where all treatments had the farrowing crates closed, day 4 to 6, where only the day 4 group (T4) had their crate opened, and days 7 to 15, where both the 7 day (T7) and 4 day group (T4) had their crates opened but before any litters had been early weaned (day 0= day of birth). Poisson models included treatment (PC, T4 or T7), parity (0-7) and litter size after equalization as fixed effects and room as random effects. Estimated coefficients were transformed and reported as incidence-rate ratios. A Bonferroni correction was used to account for multiple comparisons between the 3 treatments.

For the sow physical indicators, body condition score at weaning was analyzed with an ordinal regression model including treatment and body condition at loading into farrowing as fixed effects. For lameness scores, due to the low number of animals scored as a 2 for lameness (n=5), and no animal scored as a 3, lameness at weaning was condensed to lame (score > 0) or not lame (score = 0). Lameness at weaning was assessed with a binomial regression model including treatment, parity, and lameness score at loading into farrowing as fixed effects. Whether a sow had a shoulder sore at weaning was analyzed using a binomial model with treatment, parity and shoulder sore score at loading into farrowing as fixed effects. Number of lesioned teats at weaning was assessed using a Poisson regression model with treatment, parity and number of lesioned teats at loading into farrowing as fixed effects. A Bonferroni correction was used to account for multiple comparisons between the 3 treatments.

Poisson, binomial, and ordinal modeling was done using STATA version 15 (StataCorp LP, College Station, TX, USA). To determine whether to retain a variable in the final model, univariate methods were used for each factor, and the factor included if $P<0.35$ (Niranjan et al., 2005). The sow was the experimental unit for statistical analysis. A P-value of <0.05 was treated as significant.

Results

Productivity

Total percentage of mortality was significantly different between treatments ($F_{2, 448} = 3.51$, $P=0.03$), with the higher percentage of mortality for T4 (27.8 a ± 19), which did not differ from PC (25.9 ab ± 20), and the lowest for T7 (23.9 b ± 16), which did not differ from PC. The causes that represented the largest proportion of the total mortality were laid on, low viability, and scours for all treatments. The percentage of mortality associated with each cause is shown in table 2.

Risk of piglet death

For piglet mortalities recorded as low viability, no differences in the risk of death was found when comparing T4 or T7 to PC ($P > 0.05$). For laid on, other reasons, and mortality including all reasons, T4 piglets were at higher risk of dying, compared to PC and T7 ($P < 0.05$), which did not differ between them ($P > 0.05$). For scours, the risk of piglets dying was lower for T7, compared to PC and T4 ($P < 0.05$), which did not differ significantly ($P > 0.05$). Table 3 describes the effect of treatment on the incidence rate ratio (IRR) of total piglet death for each recorded mortality reason.

Risk of piglet death from being laid on in different time periods

For period 0 - 3 days when all crates were closed, no differences in the risk of being laid on was found when comparing T4 or T7 to PC ($P > 0.05$). For the period 4 - 6 days post-farrowing, T4 piglets were at higher risk for being laid on, compared to PC (IRR= 2.5 ± 0.7, CI 95%= 1.48 to 4.38, P < 0.05) and T7 (IRR= 2.3 ± 1.3, CI 95%= 0.70 to 7.28, P < 0.05). T7 had no significant difference with PC (P > 0.05) for this period. For the period 7-15 days after birth, when the T4 and T7 crates were open, the risk of piglets dying from being laid on was higher compared to PC for T4 (IRR= 3.89 ± 1.1; CI 95% = 2.21 to 6.8, P < 0.05) and T7 (IRR = 3.5 ± 1.0; CI 95% = 1.95 to 6.28, P < 0.05) (see Figure 2). Table 4 describes laid on mortality as a percentage of the mortality in different periods.

Sow welfare indicators

Treatment had no effect on lameness, shoulder sores, or BCS (P > 0.05) at weaning. There was a significant effect of BCS at loading on BCS at weaning (P < 0.001). On loading into farrowing, 1.90, 1.95 and 2.53 % of the sows had shoulder lesion, and at weaning day it increased to 25.0, 23.5 and 24.2 % of sows with shoulder lesion for PC, T4 and T7, respectively. The average BCS at Loading day and weaning day was 3.85 ± 0.4 and 3.80 ± 0.5 for PC, 3.84 ± 0.4 and 3.87 ± 0.4 for T4, and 3.84 ± 0.38 and 3.86 ± 0.5 for T7. The percentage of sows with lameness at loading day was 13.68, 12.20 and 9.55 % for PC, T4 and T7, respectively and that percentages decreased at weaning day to 6.83, 5.78 and 5.37 % for PC, T4 and T7, respectively.

Treatment also impacted the risk of lesioned teats. There was a decreased risk for lesioned teats in T4 sows compared to PC sows (IRR = 0.59 ± 0.21, CI 95% 0.40 to 0.88, P < 0.05), but no difference in risk between the T7 group and PC (P > 0.05) or the T4 group and the T7 group (P>0.05). The average number of lesioned teats at weaning was highest in the PC group (0.74 ± 1.3) compared to the T4 group (0.44 ± 0.9) and the T7 group (0.50 ± 1.2) (Table 5).

Discussion

Decreasing sow confinement during lactation allows her more freedom of movement, increases the diversity of her behaviors (Singh et al., 2017) and improves sow welfare, as measured by different welfare indicators (Ceballos et al., 2020). However, the choice to eliminate confinement, or only temporarily confine a sow during lactation, has a potential influence on piglet welfare and survival. Here we examined the impact of opening a hinged farrowing crate at 4 or 7 days post-farrowing on the total percentage of piglet mortality, the risk of piglet death due to crushing and other causes, and physical indicators of sow welfare. In the present study, litters were equalized shortly after birth based on individual sow functional teat counts and low viability and starve out pigs were promptly removed by barn staff for euthanasia in accordance with the pre-existing farm protocols. Consequently, all piglets that were evaluated in this study were viable and with no specific risk of dying due to being laid on.

We found that the total percentage of piglet mortality was higher for T4 litters than T7, however, neither treatment differed from the PC group. This is consistent with studies that have found no differences in piglet survival when comparing loose housed sows with crated sows (Weber et al. 2007, Pedersen et al. 2011, KilBride et al. 2012, Zhang et al. 2020). In contrast, a meta-analysis by Glencorse et al. (2019), found that the risk of total piglet mortality was 14% higher for animals raised in pens compared with those in crates. Even with higher mortality, the same meta-analysis also found that there were no differences in the number of piglets weaned. The authors argue that most piglet mortality occurs before cross-fostering, a common husbandry technique adopted by commercial farms 24h after farrowing, where dead piglets can be replaced. Spicer et al., (1986) states that most piglet mortality occurs during the first 36 hours post-farrowing. With most mortality occurring during the first 36 hours post farrowing, cross fostering practices could equalize mortality regardless of housing system.

There are different causes of piglets' mortality. KilBride et al. (2012), in an epidemiological study in the United Kingdom involving 2826 piglets in different farrowing systems, found that crushing of healthy piglets was the cause of death most frequently reported, with 54.8%, and the subsequent causes were low viability (13.8%), starvation (6.8%), crushed while sick (4.7%) and diarrhea (3.5%). Considering the entire lactation period, we found that T4 presented a higher risk of piglet mortality caused by all reasons together recorded in this study, and also for being laid on and other reasons (including starvation, rupture, savaged, deformed, joint problem, lame, deformed, scrotal and belly rupture, blind anus, and no teats), compared to PC and T7. While no differences were found in the risk of piglets' death due to low viability between treatments, T7 presented a lower risk of death due to scours, compared to PC and T4.

Farrowing crates are designed to protect piglets from death by being laid on from the sow, however, other studies have found different farrowing systems can impact other causes of piglet death during lactation. For example, Weber et al. (2007) found significantly higher piglet mortality due to being laid on in loose farrowing pens, compared with crates, however the number of piglet deaths due to other reasons was higher in crates (including diarrhea, runts, bitten to death, etc.). The same tendency was found by KilBride et al. (2012), where they conclude that farrowing crates reduce the risk of piglet mortality due to being laid on, compared to alternative farrowing systems (including crate/loose), however the risk of deaths due to other causes was increased in farrowing crates. Our results corroborated with those studies with respect to T4. However, T7 differed from prior studies as the risk of mortality from scours was lower, while all other reasons did not differ, compared to PC treatment. Our results agree with those of Chidgey et al. (2015) who found no differences in deaths due to diarrhea between the standard crate and hinged crates opening them at 4 days post farrowing. Many studies evaluating the effect of farrowing systems on piglet mortality add together all the causes other than being laid on (Weber et al. 2007, KilBride et al. 2012, Olsson et al, 2018). It is difficult to find an explanation for the findings that scour deaths decreased in T7 and that risk of mortality for other reasons increased in T4, and further research should be done to see if there is any specific influence of the farrowing systems on the risk of death due to other reasons than piglets being laid on.

Considering the three different lactation periods proposed here to evaluate piglets mortality due to being laid on, one of the biggest concerns of farmers when using hinged farrowing crates, we found that the highest percentage of mortality was found in the first 3 days post farrowing (when all treatments had the crates in the closed position) and, as expected, no differences in the risk of piglets being laid on was found between the treatments during this time period. Olsson et al. (2018), working with temporary crates (opened at day 4) and loose crates, King et al. (2018b) also working with temporary crates but opening them at day 7, as well as Moustsen et al. (2013), working with loose and temporary crates opening at 4 days and 7 days, found that the higher live-born piglet mortality occurred between 0 and 4 days. KilBride et al. (2012), an epidemiological study carried out on 112 breeding pig farms in the UK, comparing different farrowing systems (crate, crate/loose, loose, or outdoor) found that, in the first 48 hours post farrowing, the higher mortality was found in crated and outdoor systems, compared with indoor loose and crate/loose systems. Pedersen et al. (2011), comparing crates and loose pens, found that the higher quantity of piglets deaths from being laid on occurred in the first 3 days of life. Nicolaisen et al. (2019) found that most laid on events occurred during the first three days postpartum in loose housing pens and group-housing system, compared to the conventional crates. During this sensitive period, piglets are still gaining locomotor function, learning and understanding their environment. Nicolaisen et al. (2019) evaluated piglet behavior during the first 3 days of life and found a reduced use of the creep area that left piglets in hazardous areas during the body posture changes of the sow. Our study is consistent with other studies indicating that reducing piglet mortality in the immediate post-partum period remains a challenge regardless of lactation housing type.

In the present study, mortality due to being laid on decreased from day 4 through the end of lactation (from almost 4.5% for the first 3 days to 2.81% from day 4 until weaning for all sows). KilBride et al. (2012) found that the risk of death in piglets decreases as the piglets get older. However, even though mortality decreased as the piglets aged, there was a treatment effect on the risk of piglets being laid on within different time periods. After opening the crates, piglets from T4 and T7 had a higher risk of being laid on, compared with the closed crate litters. Previous studies have differing results on the risk of piglet death by being laid on when sow confinement is removed. Similar to our results, Chidgey et al. (2015), comparing temporary crates (opening at day 4) with conventional farrowing crates, found that after opening the crate, a greater proportion of piglets died by being laid on. In contrast to our findings, other studies, such as Singh et al. (2017), Pedersen et al. (2011), Nicolaisen et al. (2019) and Zhang et al. (2020) did not find a significant effect of housing on piglet mortality from being laid on.

Being laid on is typically one of the most common reasons for pre-weaning mortality, especially early in lactation. KilBride et al. (2012) found that around 55% of the total death was caused by being laid on. In our study, the highest percentage of mortality due to being laid on was found for T4 (31%) followed by T7 (30%) and PC (24%). These proportions are even lower than the proportion of laid on piglets found in crated sows by Nicolaisen et al. (2019) who reported a total of 36.1% of deaths from being laid on. Rosvold et al. (2017) studied different management routines influencing piglets' survival in loose-housed sow herds, and they identified the high degree of staff presence during farrowing as one of the important factors leading to reduced piglet mortality. Baxter et al. (2012) mention that when judging any farrowing system, it must be emphasized that the quality of stockpeople handling and the maternal characteristics of the sow will be integral to its success. Husbandry practices on the study farm dictated systematic management routines during the first days of farrowing, but only one person was available to assist farrowing of two rooms of 114 sows, which could not be enough to assist all the sows as desired.

Differences between farm facilities, staffing, and husbandry practices likely can all contribute to inconsistencies in findings between different studies. Anti-crush embellishments such as sloping walls or bars in the farrowing pens are essential to reduce the risk of piglets being laid on (Damm et al., 2005). The farm where this study was carried out had a pen design with anti-crush bars, to create space for the piglet to escape out from under a sow if they were trapped against a wall. It was not enough, however, to diminish the risk of piglets being laid on when the sow had total access to the pen space. The differences in the risk of being laid on could be influenced too by the individual maternal behavior expressed by sows (Baxter et al., 2012), and also their lack of experience with this alternative farrowing system. King et al. (2018a) found that after the sows have experience with an alternative farrowing system, their piglet mortality reduces on subsequent farrowing. The sows of our study never experienced farrowing in this kind of crate, and the experience was novel for staff as well. The change for both the animals and stockpeople could have influenced our results.

We found no association between treatment and three of the sow physical welfare indicators evaluated in the study: BCS, lameness and shoulder sores. The BCS of the sows at weaning was not influenced by treatment. Sows from the three treatments entered and left the farrowing room with 3.8 average BCS indicating that sows did not have problems with feed intake regardless of the crate position. On entering farrowing, 12% of the sows had a lameness score greater than 0 compared to 6% of the sows leaving the farrowing rooms, with no differences between treatments. Finally, 2% of the sows entered farrowing with shoulder sores, and 24% of them had a shoulder sore at weaning with no differences between treatments. Our results are similar to those of Meyer et al. (2019) where the prevalence of shoulder lesion was 23% in sows defined as non-at-risk to develop this condition, after 3 weeks of lactation, in closed crates. Other studies have shown a lower prevalence of shoulder lesions (around 14%) in the same lactation time period (Lambertz et al., 2015, Ceballos et al., 2020), independent of the housing system where the sow was being kept. There are a lot of environmental and animal-related risk factors for shoulder ulcers in sows (Rioja-Lang et al., 2018) and the three most relevant sow-related risk factors are BCS, lameness, and parity (Meyer et al., 2019). Since we blocked by parity, and BCS and lameness were not different between treatments, our results agree with these previous studies where confinement duration is not a risk factor for shoulder lesions.

We found a higher risk for lesioned teats lesions in PC sows at weaning. Sows from PC presented 40% and 32% more lesioned teats compared to T4 and T7 sows respectively. Our results confirm those found by other researchers who found a lower incidence of teat lesions in sows loose housed during lactation, compared to sows crated during lactation (Verhovsek et al., 2007, Lohmeier et al., 2019, Ceballos et al., 2020). There are different possible explanations for these results. First, that sows cause abrasions to the teats with their hind limbs when getting up and lying down inside the closed crates, due to the restrictions imposed by the limited space allowed to them (Verhovsek et al., 2007) and second, that in the confinement of the closed farrowing crate, sows are unable to avoid unwanted nursing events, compared to an open farrowing crate (Ceballos et al., 2020).

Even though the risk of crushing due to being laid on in different periods is higher for the opened farrowing crates, the total percentage of piglet mortality did not differ from the closed crate and the total risk of mortality was higher only for T4. This indicates that crating the sows immediately post-farrowing for seven days, when piglets are most vulnerable to crushing, has the potential to maintain a similar total percentage of piglet mortality, compared with crated conditions, while improving the sow's welfare. Along with increased square footage allowed by the opened crate, we found an improvement in a physical welfare indicator in the hinged farrowing crates, as we found a lower incidence of teat lesions. Based on our results, the hinged farrowing crate should be considered. Combining our results and practical considerations related to baby pig processing, castration, and vaccination strategies, which are easier in a closed crate condition, we suggest opening the crate at day 7 post-farrowing. Future studies focusing on sow maternal behavior and the best handling practices related to hinged farrowing crates should be researched in the future.

Ethics approval

This observational research study was carried out on a commercial farm certified by the Pork Quality Assurance Plus Program. The guidelines of this program directed animal care on the farm and the study was conducted without changing farm animal handling and care routines.

Data and model availability statement

None of the data were deposited in an official repository. Available upon request.

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Declaration of interest

None.

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Table 1

Number of animals and farrowing performance across treatment groups. Real means ± SD.

Variables	Treatment		
	PC	T4	T7
Sows (n)	177	185	161
Sow parity order	1.8 ± 1.8	1.9 ± 1.9	2.0 ± 1.9
Total born / litter (n)	16.3 ± 5.9	16.2 ± 6.8	14.7 ± 6.8
Live born / litter (n)	14.5 ± 3.4	14.4 ± 3.5	13.8 ± 3.9
Stillborn / litter (n)	1.1± 1.4	1.6 ± 2.4	1.2 ± 1.9

PC = sow permanently crated until weaning; T4 = sows crated until the fourth day post-farrowing; T7 = sows crated until the seventh day post-farrowing

Table 2

Means ± SD of total mortality by reason.

Treatment	PC	T4	T7
Sows (n)	177	185	161
Total Mortality (%)	25.9 ± 20	27.8 ± 19	23.9 ± 16
(%) laid on	6.2 ± 8.2	8.5 ± 9.1	7.2 ± 8.6
(%) low viability	9.0 ± 10.6	7.9 ± 10.1	7.6 ± 9.4
(%) scours	6.5 ± 14.3	6.1 ± 12.3	4.5 ± 9.3
(%) other	4.2 ± 7.9	5.3 ± 8.6	4.5 ± 7.4

PC = sow permanently crated until weaning; T4 = sows crated until the fourth day post-farrowing; T7 = sows crated until the seventh day post-farrowing

Table 3

Effect of treatment on the relative risk of piglet death for each recorded mortality reason from birth to weaning. Risk is denoted as incidence rate ratio (IRR) ± SE and confidence interval (CI) for each treatment.

Mortality Reason	Treatment	IRR (SE)	CI (95%)	z	P > |z|
Laid on	T4	1.31±0.14	1.06 to 1.61	2.54	0.01
	T7	1.16±0.13	0.94 to 1.46	1.38	0.17
	PC	RC	RC	RC	RC
Low viability	T4	0.96±0.11	0.79 to 1.16	-0.45	0.65
	T7	0.97±0.11	0.80 to 1.18	-0.29	0.77
	PC	RC	RC	RC	RC
Scours	T4	1.09±0.12	0.87 to 1.36	0.75	0.45
	T7	0.76±0.10	0.59 to 0.98	-2.08	0.04
	PC	RC	RC	RC	RC
Other[1]	T4	1.37±0.19	1.05 to 1.80	2.32	0.02
	T7	1.13±0.17	0.84 to 1.51	0.81	0.81
	PC	RC	RC	RC	RC
All	T4	1.13±0.06	1.02 to 1.26	2.28	0.02
	T7	0.98±0.06	0.87 to 1.10	-0.35	0.55
	PC	RC	RC	RC	RC

PC = sow permanently crated until weaning; T4 = sows crated until the fourth day post-farrowing; T7 = sows crated until the seventh day post-farrowing; RC = Reference class.

[1] Includes starvation, rupture, savaged, deformed, joint problem, lame, scrotal and belly rupture, blind anus, and no teats.

Table 4

Percentage of piglet mortality (mean ± SD) due to being laid on across different periods post farrowing.

Variables	Treatment		
	PC	T4	T7
Sows (n)	177	185	161
Total mortality (%) from being laid on			
0 – 3 days post-farrowing[1]	4.99 ± 7.5	4.14 ± 6.9	4.24 ± 6.6
4 – 6 days post-farrowing[2]	0.59 ± 1.9	1.59 ± 3.7	0.61 ± 2.3
7 – 15 days post-farrowing[3]	0.57 ± 1.9	2.71 ± 5.4	2.37 ± 5.0

PC = sow permanently crated until weaning; T4 = sows crated until the fourth day post-farrowing; T7 = sows crated until the seventh day post-farrowing

[1] Where all treatments had the farrowing crates closed.

[2] Where the day 4 group had their crate opened.

[3] Where both the 7 day and 4 day group had their crates opened but before any litters had been early weaned.

Table 5

Body condition score (BCS), lameness and shoulder sores odds ratio (OR) ± SE, incidence rate ratio (IRR) ± SE of teat lesions, and confidence interval (CI) for each treatment at loading and at weaning.

Indicator	**Treatment**	**OR (SE)**	**CI (95%)**	**z**	**P > |z|**
BCS	T4	1.41±0.46	-0.75 to 2.66	1.07	0.28
	T7	1.65±0.57	-0.83 to 3.26	1.44	0.15
	PC	RC	RC	RC	RC
Lameness	T4	0.83±0.39	0.33 to 2.08	-0.40	0.69
	T7	0.85±0.42	0.32 to 2.24	-0.34	0.73
	PC	RC	RC	RC	RC
Shoulder Sores	T4	0.89±0.23	0.53 to 1.49	-0.45	0.65
	T7	0.91±0.25	0.53 to 1.57	-0.33	0.74
	PC	RC	RC	RC	RC
Indicator	Treatment	IRR (SE)	CI (95%)	z	P > |z|
Teat lesions	T4	0.59±0.21	0.40 to 0.88	-2.55	0.01
	T7	0.68±0.23	0.43 to 1.05	-1.73	0.08
	PC	RC	RC	RC	RC

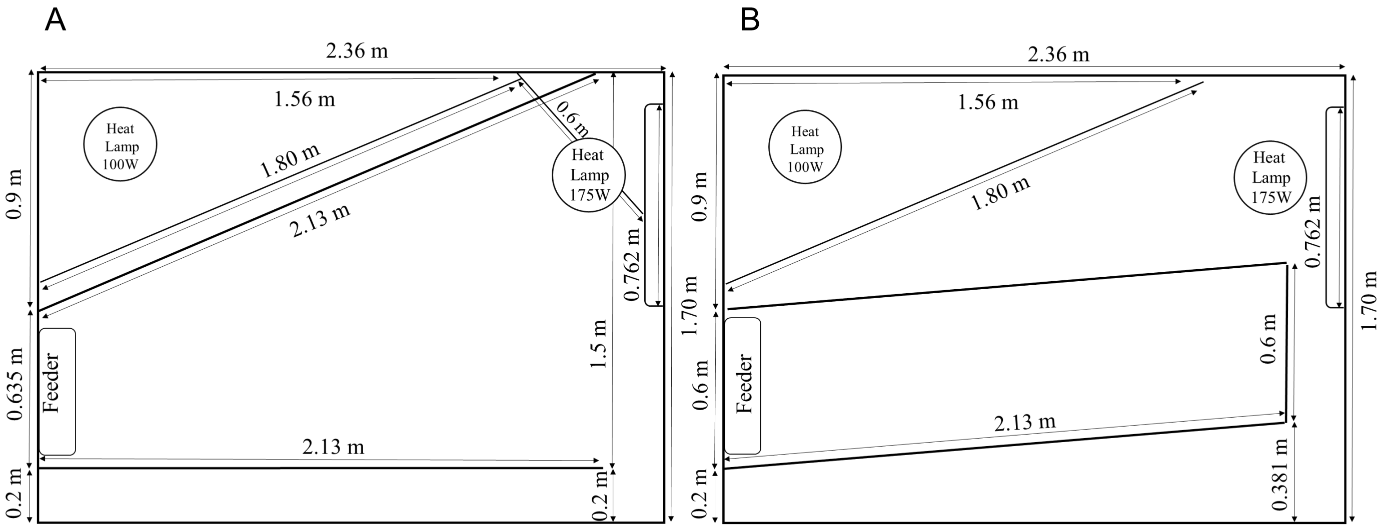
PC = sow permanently crated until weaning; T4 = sows crated until the fourth day post-farrowing; T7 = sows crated until the seventh day post-farrowing; RC = Reference class.

Figure captions

Fig. 1. Schematic of pen equipped with a hinged farrowing crate. A) Closed. B) Open.

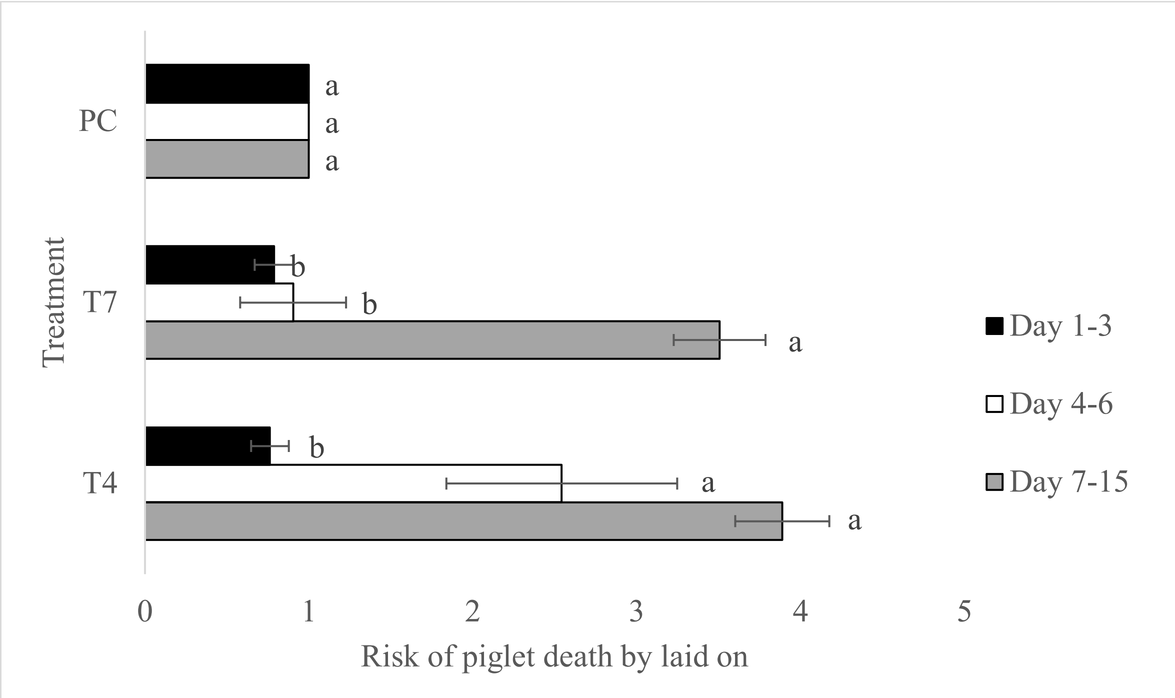
Fig. 2. Effect of treatment on the relative risk (95% CI) of piglet death from being laid on, on three different periods: day 0 to 3, where all treatments had the farrowing crates closed, day 4 to 6, where the day 4 group had their crate opened, and days 7 to 15, where both the 7 day and 4 day group had their crates opened but before any litters had been early weaned. Treatment groups are denoted as PC, sow permanently crated until weaning, T4, sows crated until the fourth day post-farrowing, and T7, sows crated until the seventh day post-farrowing. Values a - b followed by the same lower-case letters in the same period are not statistically different ($P>0.05$).

Figure 1



A
2.36 m
1.56 m
0.6 m
Heat Lamp 100W
Heat Lamp 175W
1.80 m
2.13 m
0.9 m
0.762 m
1.70 m
1.5 m
0.635 m
Feeder
2.13 m
0.2 m
0.2 m
B
2.36 m
1.56 m
Heat Lamp 100W
Heat Lamp 175W
1.80 m
0.9 m
0.762 m
1.70 m
1.70 m
0.6 m
0.6 m
Feeder
2.13 m
0.381 m
0.2 m

Figure 2



PC
T7
T4
Treatment
a
a
a
b
b
a
b
a
a
0
1
2
3
4
5
Risk of piglet death by laid on
Day 1-3
Day 4-6
Day 7-15

Appendix III

Methodological differences between the original project proposal and implementation of project NBP 17-068

The original project identified two objectives for the study.

Objective 1: To examine the effect of opening the hinged crate at different time points on sow welfare parameters.

Objective 2: To determine the effect of timing of the opening of a hinged farrowing crate on piglet mortality.

Both of these objectives have been realized and now are in manuscript form. The paper describing Objective 1 was published earlier this year in the noted behavior and welfare journal, Applied Animal Behaviour Science, and that manuscript is included in Appendix I. The paper describing Objective 2 is under review in a major animal science peer-reviewed journal at the moment and a confidential draft of the manuscript can be found in Appendix II.

The original proposal suggested that both of these objectives would be pursued on two large commercial farms. Unfortunately, shortly after being notified for the funding for the project, availability of the originally proposed commercial farms became complicated. The production company with which were working elected to make changes on the proposed study farms including changing farrowing pen design and changing sow genotype. It became clear that there would quite some delay (years) before we would have two commercial farms with similar farrowing equipment, genetics, and herd parity structure. As such we elected to start the welfare objective at the Penn Vet Swine Teaching and Research Center where we could likely conduct these detailed physiological and behavioral studies in a more controlled fashion than on commercial farms. As stated above that work yielded the published manuscript included in Appendix I. In the end, we chose to carry out Objective 2 on the first commercial farm with appropriate farrowing facilities that offered a mature herd parity profile to ensure that these findings would be as applicable as possible (i.e. not influenced by a skewed parity structure). This work yielded the manuscript under review that is included in Appendix II.

One consequence of these changes to the experimental plan was the possible reduction in sample size. In some cases, this was true that we ended up collecting less data on some variables than originally proposed. However for some of the physiological and behavioral variables, we were able to carried out more in depth studies because these questions were examined at our Swine Teaching and Research Center and this allowed for more frequent sampling. We also performed more detailed analysis on piglet mortality than originally proposed. Despite being shy on some of our original proposed sample size in these studies, we are able to find several statistical differences between treatments suggesting that the number of samples proposed in our original proposal may have been unnecessarily ambitious.

In sum, despite changes to experimental protocol, the project goals were met and or even exceeded. Below is a detailed description of methodological changes, deletions and additions between the original proposal and the actually studies.

Physiological Measures

Cortisol

Proposed: Saliva samples collected from 48 sows per treatment per farm on days 4, 7, and weaning.

Actual: Saliva samples were collected from a total of 36 sows (13, 12 and 11 per treatment, respectively) on day 3, 4, 5, 6, 7 & 8.

Given that this proportion of the study was carried out at our Swine Teaching and Research Center, we able to increase the number of samples per sow by collecting saliva samples on 6 consecutive days across the critical period of crate openings and in theory allowing us to be more sensitive to any systematic changes in cortisol levels associated with the housing changes. We did not see any meaningful changes in cortisol levels - consistent with many other farrowing housing studies (see discussion in Appendix I) likely due to the lack of specificity that cortisol measures offer given the complex role that the hypothalamic–pituitary–adrenal axis plays during lactation in sows.

Piglet lesion scores

Proposed: Piglets were to be evaluated for skin lesion score on their anterior, middle and posterior region.

Actual: We were not able to monitor piglet skin lesions.

During the field trial on the commercial farm if proved hard to maintain individual identities of piglets needed to track piglet lesions over time. Further discussion elucidated that while it would have been nice to have this data that it was somewhat peripheral to the main objectives of the study - sow welfare and piglet mortality - as skin lesions on piglets were more indicative on interactions between the piglets and less likely to be impacted by sow housing practices.

Sow Body Condition, Skin Lesions, and Lameness Scores

Proposed: Sow body condition, lameness and lesion scores were proposed to be evaluated on days loading, 4, 7, 14 and weaning.

Actual: We evaluated these parameters on days loading, 4, 7 and weaning in both the study on the commercial farm and the study conducted at our Swine Teaching and Research Center.

We determined that because the day 14 assessment did not correlate to any of the housing changes associated with the different treatments that it could be eliminated.

Behavioral Measures

Data collection strategies

Proposed: We proposed to evaluate the behavior of 144 sows over a 24-hour period on days 3, 6, 13 and the day before weaning by coding 30 seconds every 30 minutes. This resulted in a total of 48 sampling points per day x 4 days of observation corresponding to a total of ~230 hours of video data -- 96 minutes per sow x 144 sows.

Actual: We evaluated 36 sows for 12-hour period each day from day 3 to day 8 post-farrowing, by coding with two-minute scan sampling protocol. This resulted in a total of 360 sampling points per day x 6 days of observation corresponding to a total of ~2592 hours of video data -- 4320 minutes per sow.

For the behavioral variables, the changes in protocol actually resulting in an increase in the amount of behavioral data collection. The data collections was limited to day time recording (6 AM to 6 PM) when the sows are most active and their behaviors were likely where the most relevant information to the study questions. Preliminary studies revealed that sows are relatively inactive at night. We also determined that the two-minute scan sampling paradigm optimized the relationship between coding time and the ability to observe short duration behaviors. Behavioral data was compare for the loss information between continuous sampling and scan sampling at 30 s, 1 min, 2 min and 5 min. Taken together the data collected as part of this study shows a more comprehensive understanding of sow behavior in these different housing systems than originally proposed.

Ethogram

Proposed: Behavioral variables to analyze:

1. frequency of postural changes;
2. frequency of standing up;
3. the proportion of time lying in sternal recumbency;
4. the proportion of time sitting;
5. the proportion of time being in lateral recumbency as well as
6. the proportion of time spent on environment-oriented behaviors and
7. proportion of time spent on piglet-oriented behavior.
8. average nursing frequency and duration,
9. frequency of lying-down events (number of times the sow went from a standing to a lying position during 24 hours)
10. carefulness score (adapted from Valros et al., 2003).

Actual: We evaluated sow activities, posture, and position in the pen and we calculated the frequency of:

1. posture changes
2. quantity of positions used
3. position changes

We also calculated the proportion of time

4. Nursing
5. Vacuum Chewing
6. Resting/sleeping
7. Investigate piglet

8. Nose piglet
9. Biting fixture
10. Exploring environment
11. Standing
12. Sitting
13. Lateral Lying
14. Ventral Lying

As we elected to use a 2-minute fixed sampling interval, it did not allow us to perform two of the originally proposed variables (frequency of lying-down events and carefulness score) as they require continuous coding. However in addition to the scan sampling allowing us to collect a more granular data set for analysis, we also included more variables related to the use of the space by the sow (posture changes, quantity of position used, position changes).

Note we also tracked the exact location of the sows during the behavioral sampling. That data awaits further analysis but promises to tell us if sows have preferred locations to lie in the farrowing pens or preferred patterns of lying over time.

Production measures

Proposed:

Piglets weight 24 hours and weaning
Mortality and the weights of dead piglets
Sow parity, farrowing date and weaning.
For each litter - the number born alive, total born, total weaned and any cross fostering.

Actual:

We recorded the day and cause of death, the sow's parity, farrowing date and weaning date. For each litter, the number of born alive, total born, total mummies, total weaned and any cross fostering were recorded as well as nurse on and nurse off events when they occurred.

As mentioned above, we had difficulties identifying individual live piglets on the commercial farms. Furthermore, we believe that piglet wean weight while always interesting to have was not that related to the objective of the study. Sow with smaller litters often weaning heavier piglets and thus if treatment resulted increased morality it could also result in increased average piglet weaning weight. Extending what was proposed in the original grant, we used the information about piglet death to analyze the relative risk of pig mortality in the different treatment groups. These findings are described in the manuscript in Appendix II.