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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.

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

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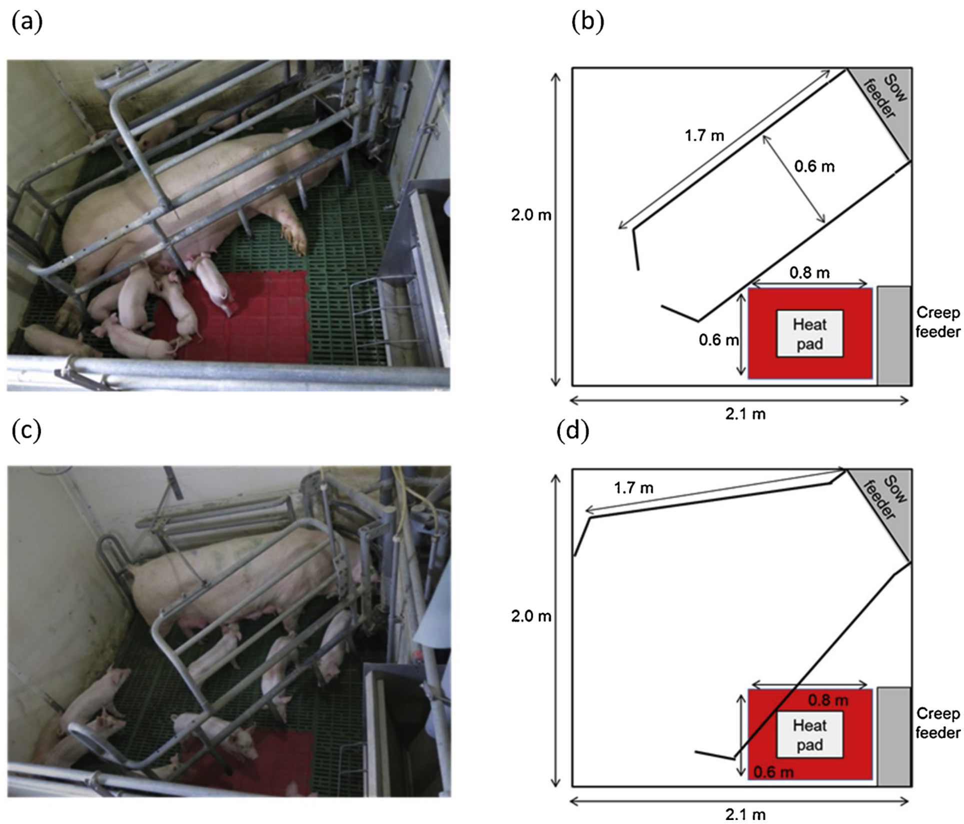

Fig. 1. Representative photograph and schematic of the pen with the hinged farrowing crate closed (a & b) or opened (c & d).

(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 × 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 × 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 (Fig. 1a & 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 (Fig. 1c & 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 8:00 h 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. 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 h), three (6:30, 11:00 and 15:00 h), four (6:30, 9:00, 11:00, 15:00 h) until five times per day (6:30, 9:00, 11:00, 15:00 and 23:57 h). 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 h 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, New Jersey, 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 3–8 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-h periods (from 6:00 h to 18:00 h) 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 8:00 h, 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-h video segment (180 instantaneous samples). Each observer scored three 2-h 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

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.

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 3–8 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®, 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 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 (Fig. 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 (Fig. 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 %) (Fig. 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

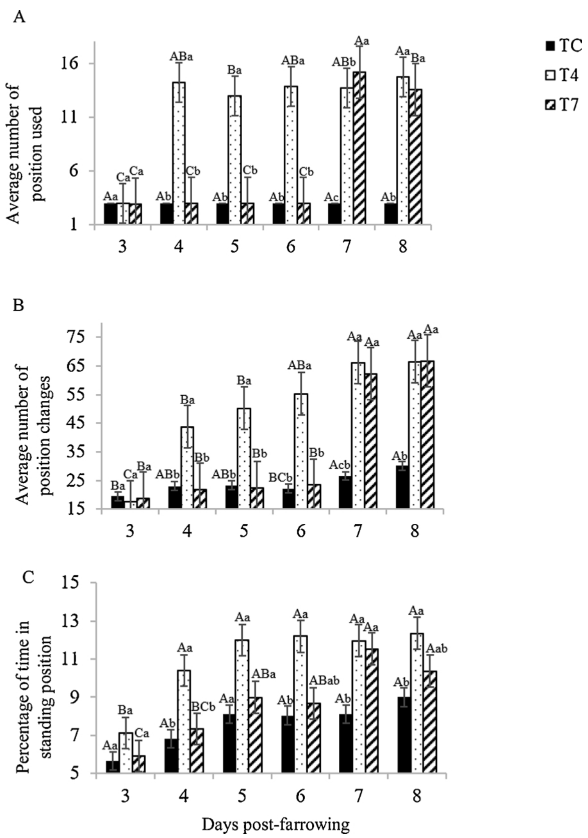

Fig. 2. Real means ± SEM of 12 h observation (from 6:00 h to 18:00 h) of: A. Average number of position used, B. Average number of position changes, and C. Percentage of time spent in standing position for each treatment (TC: sow permanently crated until weaning, T4: sows crated until the fourth day 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. $^{A-C}$ Means followed by the same uppercase letters in the same treatment are not statistically different (P > 0.05), by Tukey test.

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 only 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 (Fig. 3). Note that components derived from lesions measures with negative loadings would have increased in

Table 2
Real means ± SD of the proportion of time spent in ventral lying, lateral lying and sitting, and the average number of posture changes for each treatment (PC, 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]

Behavior	Treatment	N	day3	day4	day5	day6	day7	day8
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}	23.7 ± 8.8 ^{ABa}
	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}	22.6 ± 7.7 ^{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}	15.2 ± 8.8 ^{Bb}
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}	62.6 ± 11.2 ^{Bab}
	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}	61.1 ± 9.1 ^{Cb}
	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}	60.2 ± 12.3 ^{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}	4.0 ± 2.5^{Aa}
	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}	3.3 ± 2.9^{Aa}
	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}	4.8 ± 4.3^{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}	53.8 ± 19 ^{Aa}
	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}	60.2 ± 24.3 ^{Aa}
	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}	64.8 ± 2$^{9.0Aa}$

[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, investigating piglets and vacuum chewing, for each treatment (PC, 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]

Behavior	Treatment	N	day3	day4	day5	day6	day7	day8
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}	68.8 ± 5.5^{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}	66.8 ± 8.9^{ABa}
	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}	64.6 ± 6.2^{Ba}
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}	1.11 ± 1.4^{Aa}
	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}	2.90 ± 2.5^{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}	2.83 ± 2.4^{ACa}
Investigating 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}	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}	0.55 ± 0.3 ^{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}	0.57 ± 0.6 ^{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}	0.76 ± 1.51 ^{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}	1.38 ± 2.65 ^{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}	1.60 ± 2.17 ^{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}	16.85 ± 0.07 ^{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}	16.82 ± 0.05 ^{ABa}
	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}	17.76 ± 0.03 ^{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.

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 (Fig. 3).

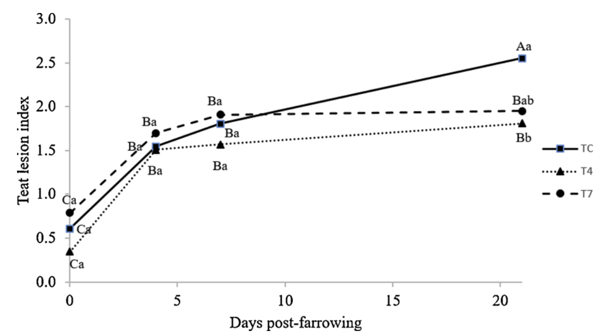

Fig. 3. Teat lesion index measure on days 0, 4, 7 and 21 post farrowing for each treatment (TC: sow permanently crated until weaning, T4: sows crated until the fourth day post-farrowing, and T7: sows crated until the seventh day post-farrowing). For display purposes, the original teat lesion indexes scores were re-scaled by inverting their signs and then adding 1.5 [1].
[1] Means $^{a-b}$ followed by the same lower case letters in the same day are not statistically different (P > 0.05), by Tukey test. $^{A-C}$ Means followed by the same uppercase letters in the same treatment are not statistically different (P > 0.05), by Tukey test.

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 her welfare compared to 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

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	−0.102	**−0.672**	−0.194
Deep teat lesions	−0.041	**−0.703**	0.062
Small superficial udder scratches	**−0.521**	−0.445	0.150
Large superficial udder scratches	**−0.578**	0.078	0.495
Small deep udder lesions	−0.274	−0.407	−0.361
Large deep udder lesions	−0.493	−0.019	−0.331
Small superficial body scratches	**−0.713**	0.277	−0.303
Large superficial body scratches	**−0.619**	0.377	−0.160
Large deep body lesions	−0.292	−0.085	**0.785**
Eigenvalues	1.92	1.54	1.29
% Variance	21.3	17.2	14.3

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-h 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 min, Chidgey et al. (2016) restricted their sampling to only 4 periods during the day, whereas we sampled every 2 min over the 12 h 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 18:00 hto 6:00 h 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, Herskin 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.

4.3. 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 2–5 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.

Declaration of Competing Interest

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

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.applanim.2020.105068.

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