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Welfare and performance of sows and piglets in farrowing pens with temporary crating system on a Spanish commercial farm

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ABSTRACT

The study aimed to compare the welfare and performance of sows and piglets in three different farrowing systems (farrowing crate (FC) and farrowing pen with temporary crating (TC): SWAP and JLF15). One batch of crossbred Duroc was followed in every season. There were 18 sows (183 piglets) in FC, 23 sows (243 piglets) in SWAP, and 23 sows (237 piglets) in JLF15. Farrowing day was Day (D) 0 and weaning occurred on D24. Crating period was from entry to weaning in FC, and from 1-day pre-expected farrowing day to D3 in TC. Social interactions between littermates, between sows and piglets, and exploration by sows and piglets were observed on D2, D4, D12, and D23. Video recordings of crushing events which led to piglets' death were studied. Piglets were weighed on D3 and D19, and foreleg abrasions were assessed on D19. Sow saliva samples were collected on 1 day before and after temporary confinement, D2, D4, D12, and D23 to evaluate cortisol (CORT) and chromogranin A (CgA) levels. TC piglets initiated naso-naso contacts with sows more frequently than FC on D2 ($P \leq 0.01$). TC sows interacted with piglets more frequently than FC on D12 ($P \leq 0.05$). TC sows explored the pens more frequently than FC on D4 ($P \leq 0.05$). Crushing rate (i.e. number of piglets per sow) of SWAP (1.2 ± 0.3) was higher than those of JLF15 (0.6 ± 0.2) and FC (0.3 ± 0.1) ($P \leq 0.02$), and crushing rate of JLF15 was higher than that of FC ($P < 0.0001$). Autumn batch showed the lowest crushing rate amongst different batches ($P < 0.001$). Number of crushing incidents was similar when TC sows were crated or loose ($P = 0.54$). The percentage of occasions when sows used a support from the pen when changing posture but still crushed the piglets was higher in FC than in TC ($P = 0.05$). No difference of growth and foreleg abrasion in piglets were found between systems. CORT in SWAP peaked on D2 ($P = 0.02$), and CgA in JLF15 peaked on D4 and remained elevated on D12 ($P \leq 0.05$). CORT and CgA in FC remained similar during lactation. Our results suggested that TC facilitated mother-young interactions; TC showed a higher crushing rate; sows changed their posture differently between systems and batches; the practice of temporary crating did not alter the level of stress biomarkers in sows.

1. Introduction

Farrowing crates (FC) were first developed in the 1950 s and became popular since then (Mellor et al., 2009). This space-saving design of the farrowing pen allows more sows to farrow per unit, permits easy inspection and safe intervention on sows and piglets by farm staff (Chidgey et al., 2015), and most importantly, it restricts sows' posture changes with the purpose of reducing piglet crushing (Baxter et al., 2018). As the loss of piglets is an economic and welfare concern (Chidgey et al., 2015), this highly cost-effective system has therefore been widely accepted and installed on pig farms all over the world (Hales et al., 2016). Within the European Union in particular, it is estimated that 95% of the pig farms are using FC (Johnson and Marchant-Forde, 2009). However, while it effectively prevents piglet's death from crushing (Nicolaisen et al., 2019), FC presents some welfare concerns for the sows because it limits the performance of some natural behaviors such as: body movement, nest building and maternal behavior (i.e. interaction with the piglets) (Baxter et al., 2012).

In natural conditions, the sow seeks an enclosed site to build a protective nest prior to giving birth (Jensen, 1986). Nest-building behavior is still observed in domestic pigs (Jensen, 1986), even when the sow is confined in FC, with redirected behavior towards the pen fixtures like

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floor, bars, and drinker, which is associated with nest-building (Baxter et al., 2018).

Research has found that the structure of FC prevents sows from fully expressing nest-building behavior, as it narrows sows' movements down to standing, sitting, lying, and rolling (Chidgey et al., 2016), which later may reflect on their poor reproductive performance, although not always (Hales et al., 2015; Hansen et al., 2017; Nowland et al., 2019; Lohmeier et al., 2020). Sows in FCs were found to have a longer farrowing duration (93 min longer in Oliviero et al., 2008; 77.6 min longer in Gu et al., 2011) and higher stillborn rates (Oliviero et al., 2010; Gu et al., 2011), compared with loose pen sows. On the other hand, satisfactory nest-building behavior has been associated with lower risk of crushing (Pedersen et al., 2003; Andersen et al., 2005), and greater suckling success for piglets due to an increased secretion of oxytocin by sows (Yun et al., 2013). The welfare concerns over farrowing sows have resulted in various designs of alternative farrowing systems in the past decades, farrowing pen with temporary crating system (TC) being one example. With the aim of improving the welfare of both sows and piglets, TC allows the sows to be loose during lactation, except for a few days peripartum to limit the sows' most dangerous movements to reduce piglet mortality (Moustsen et al., 2013; Hales et al., 2015), although it is difficult to reach the same level of mortality as in FC (Chidgey et al., 2015). Although TC has started to be implemented in some European countries, experience with these systems is still very limited. There are currently many commercially available TC in the market, but most of the studies compared the farrowing systems between FC and TC (e.g. Chidgey et al., 2015; Hales et al., 2015), or FC and loose pen (e.g. Hales et al., 2014), rather than between different designs of TC. The objective of the present study was to assess the effect of farrowing systems, including one FC and two types of TC, on the welfare and performance of sows and piglets on a commercial farm in Spain.

2. Materials and methods

2.1. Housing and experimental design

The study was conducted on a farrow-to-finish commercial farm (Gerfam SL; Girona, Spain). One week before the expected farrowing day, sows were moved from the gestation unit to one of the three farrowing systems tested in the present study: one conventional system with a FC (FC) and two commercially available TC: Sow Welfare and Piglet protection pen (SWAP) and JLF15 (both produced by Jyden; Sæby, Denmark). There were five FC pens in one farrowing unit, and six SWAP pens and six JLF15 pens in another farrowing unit. Fig. 1 illustrates the pen distribution and the key features of each farrowing system. The floor of both farrowing units was adapted to deep slurry system which is the commercial conditions in Spain. SWAP and JFL15 were equipped with plastic solid flooring for the creep area and the straw rack area, cast-iron slat flooring for the crating area, and plastic slat flooring for the rest of the pen. FC had cast-iron slat flooring for the sows, plastic slat flooring for the rest of the pen, and a heat mat for piglets. Two heat mats were installed at the floor of the creep area of SWAP and JLF15, and a lid at the top to retain the heat and to facilitate daily inspection of the piglets. A lock-in practice of the piglets is possible in SWAP and JLF15 by closing the creep area with a gate when necessary. Above the heat mat of FC and the creep area of SWAP and JLF15, lamps (150 W) as an additional heat source for piglets were installed. The straw racks in SWAP and JLF15 were refilled with hay twice a day (08:00 and 18:00 h) from sow entry to weaning. The temperature in the farrowing units was kept constant at ~20 °C, and the light was on from 07:00–18:00 h every day.

Four batches of crossbred Duroc sows ($n = 68$) were randomly allocated to the three farrowing systems (FC, SWAP and JLF15) in all four seasons between 2018 and 2019: autumn batch (November), winter batch (February), spring batch (May) and summer batch (July). Parity of the sows in each batch was balanced between the farrowing systems (FC: 3.2 ± 0.5; SWAP: 3.2 ± 0.4; JLF15: 3.3 ± 0.3). The study period started from sow entry and ended at weaning. The day of the farrowing of each pen was considered as Day (D) 0. Crating period of FC sows was from entry to weaning while that of SWAP and JLF15 was from 1-day pre-expected farrowing date to 3 days after farrowing (i.e. the crate opened on D3). Table 1 summarizes the technical details of each farrowing system.

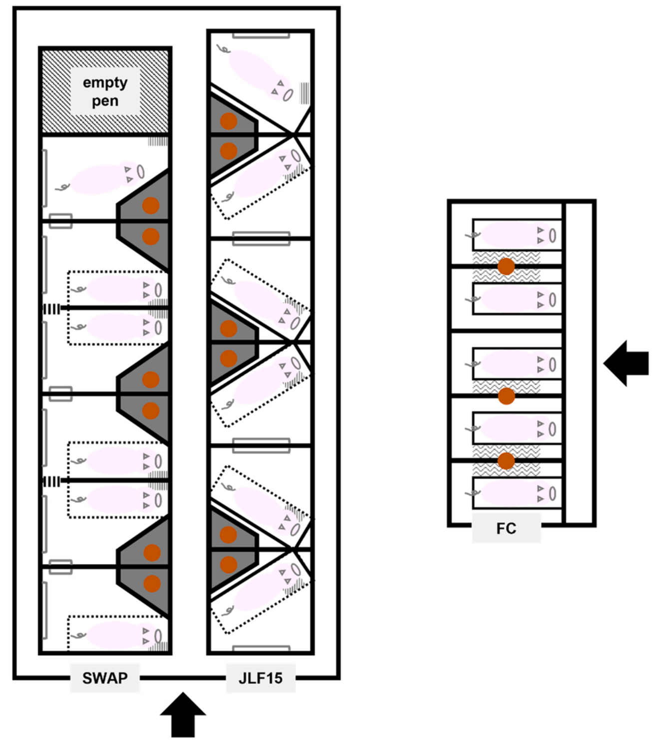

Fig. 1. Distribution of the farrowing systems tested in the present study. There were five pens of conventional system with farrowing crates (FC) in one farrowing unit, and six SWAP pens and six JLF15 pens which are the temporary crating systems in another farrowing unit. The arrows indicate the entrances to the farrowing units. The pig drawings indicate the location of the sows when being crated, except those on the top pens of SWAP and JLF15. The top pens of SWAP and JLF15 indicate the area available to the loose sows. The squares which confine the sows indicate the farrowing crates (the solid lines are the fixed sides, and the round-dotted lines are the swing-sides which are adjustable) (crating period for FC: from entry to weaning; for SWAP and JLF15: from 1-day pre-expected farrowing date to 3 days after farrowing). The orange circles indicate the lamps for piglets. The grey trapezoids in SWAP and JLF15 pens indicate the creep areas for piglets. The squares with the zig zag pattern filling in FC pens indicate the heating mats for piglets. The squares with the narrow vertical stripe pattern filling in SWAP and JLF15 pens indicate the straw racks. The bracket shapes in SWAP and JLF15 pens indicate the piglet protection rails. The squares with the dark vertical stripe pattern filling indicate the metal-barred gates in SWAP pens. The sloping walls in SWAP pens which are not indicated in the figure are installed at the fixed sides of the crates. Technical details of the pen and the creep sizes for each farrowing system are presented in Table 1.

2.2. Animals and management

Management routines and handling of sows and piglets were conducted in accordance with the routine husbandry of the farm. Shredded newspaper was provided at the end of the crate and the creep area in all pens before farrowing. Every hour, newborn piglets were inspected for their body conditions and the colostrum intake, and creep areas were monitored for the cleanliness and the temperature. Litter size was standardized at 10 piglets by cross-fostering within 72 h after birth. Piglets received an iron injection and were teeth-clipped following

Table 1
Technical details of each farrowing system tested in the study, including one conventional farrowing crate (FC) and two commercially available farrowing pens with temporary crating (SWAP and JLF15).

	FC	SWAP	JLF15
Farrowing system	Farrowing crate	Farrowing pen with temporary crating	Farrowing pen with temporary crating
Crating period	From entry to weaning	From 1 day before expected farrowing date to 3 days postpartum (D3[a])	From 1 day before expected farrowing date to 3 days postpartum (D3[a])
Number of pens per batch	5	6	6
Pen size (m x m)	2.65 × 1.50	3.00 × 2.00	2.40 × 2.40
Crate size (including the feed trough, m x m)	2.2 × 0.6	2.35 × 0.86	2.40 × 0.62
Creep area (m^2)	None, but a heating mat of 0.4	0.9	0.9
Straw rack (cm x cm x cm)	None	Yes, 50 × 50×21 (square shape)	Yes, 45 × 35×11 (half circle shape)
Piglet protection features from crushing	None	Two protection rails (130 and 50 cm) and one sloping wall (158 ×50 cm^2)	One protection rail (130 cm)

[a] The day of the farrowing was considered as Day (D) 0. Crates in SWAP and JLF15 were opened on D3

veterinary recommendation on D3 before the SWAP and JLF15 sows were set loose. Treatments and manual interventions during farrowing followed the usual routine of the farm and were performed by the same person. When the time interval between the birth of two piglets exceeded 1 h and the cervical canal was dilated, 1 mL of oxytocin (Hormonipira, HipraSA; Girona, Spain) was injected.

Lactating sows were fed twice a day (07:00 and 18:00 h). Piglets were supplemented with complementary liquid feed (Re-hydralab, Labiana; Terrassa, Spain) and creep feed (Nuscience; Ghent, Belgium) from D10 to weaning. Both sows and piglets had free access to water during the study period.

A total of 674 piglets, identified individually by a numeric ear tag, were included in the study. Piglets were weaned at 24 days of age and were moved to another unit of the farm equipped with conditioned infrastructures for young weaners.

2.3. *Direct behavioral observations*

Social interactions between sows and piglets, play in piglets, and exploration by piglets and sows, were recorded through direct observations by one observer. Behavioral observation took place on D2, D4, D12 and D23. Each observation day comprised six sessions, three in the morning (from 10:00–13:30 h) and three in the afternoon (from 14:00–17:30 h). All pens were observed in these six sessions. Behaviors were recorded by using 30-second scan-sampling for 3 min per pen in each session (i.e. 30-second scan-sampling for three times per pen per session). The observation order was rotated between the farrowing systems until all the pens were observed. Behavioral categories are described in Table 2.

Intra-observer reliability was calculated based on three pre-recorded 3-minute videos of each farrowing system (i.e. nine 3-minute videos in total), and carried out seven repetitions of the video behavioral observation at different points of the study.

2.4. *Saliva collection and stress biomarker analysis in sows*

Saliva samples were collected by introducing the cotton swabs, provided in the Salivette® tubes (Sarstedt, Aktiengesellschaft & Co., Nümbrecht, Germany), into the sows' mouths for 1 min. Six sampling points were determined: 1-day before temporary confinement (i.e. of the SWAP and JLF15 sows, FC sows remained crated), 1-day after temporary confinement (i.e. of the SWAP and JLF15 sows, FC sows remained crated), D2 (i.e. 1-day before opening the crate of the SWAP and JLF15 sows, FC sows remained crated), D4 (i.e. 1-day after opening the crate of the SWAP and JLF15 sows, FC sows remained crated), D12 and D23

Table 2
Behavior categories recorded through direct observations using scan sampling.

Category	Subject	Behavior	Description
Social interaction	Piglet towards piglet(s)	Social behavior (SB)	Piglet performing any physical contact, including positive and negative, with one or more piglets. Fighting, a chain of agonistic interactions by at least two individuals; the number of the event is recorded as the number of the individuals involved in the event. Positive and negative social interactions were pooled into one category due to the low number of events in each category observed in the pilot study.
	Piglet towards sow	Naso-naso contact (NNC)	Snout of the piglet approaching or gently touching the snout of its mother or the neighbor[a] sow.
		Sow contact (SC)	Piglet performing any physical contact with its mother or the neighbor[a] sow, such as nudging, chewing, climbing on another individual or huddling. Any behavior directed to the sow's snout or udder was excluded.
		Resting with sow contact (RSC)	Number of piglets resting next to the sow or approaching towards the sow to rest during the behavioral observation.
	Sow towards piglet(s)	Mother-young interaction (MYI)	Sow performing any physical contact with minimal or moderate force towards her piglet(s) or her neighbor's[a] piglet(s) such as naso-naso contact, sniffing or nudging. Nursing is excluded.
	Sow towards sow	Mother-mother interaction (MMI)	Sow performing any social interaction or physical contact with the neighbor[b] sow, such as naso-naso contact, sniffing, nudging or aggression. MMI is not possible in the conventional farrowing crates (FC).
Non-social interaction	Piglet	Locomotor/object play and exploration (PPE)	Piglet performing any locomotor play behaviors including scampering, pivoting, head tossing, flopping, hopping, rolling or gamboling (seeMartin et al., 2015 for each definition); object play and exploratory behaviors including sniffing or manipulating the nest-building materials, newspaper, pen facilities or other items; piglet's feed and water are excluded. Locomotor/object play and exploration were pooled into one category due to the low number of events in each category observed in the pilot study.
	Sow	Exploration (SEB)	Sow performing exploratory behavior including sniffing or manipulating the nest-building materials (i.e. hay), newspaper, pen facilities or other items; sow's feed and water are excluded. Sow performing exploratory behavior continuously for 5 s would count as one event.

[a] Metal-barred gates were installed in SWAP pens, so SWAP sows and piglets of the adjacent pens could interact with each other through the gates. On the other hand, JLF15 piglets could lift their upper part of the bodies through one of the piglet protection rails to interact with the sow from the adjacent pen.
[b] In both SWAP and JLF15 pens, sows of the adjacent pens could interact with each other when they were loose, as both types were installed with low solid walls of 90 cm (SWAP pens) or 50 cm (JLF15 pens) and two or three horizontal metal bars above the walls.

between 09:00 and 10:00. Saliva samples of the SWAP and JLF15 sows were obtained by introducing a long stick with the cotton swab attached on a clamp, without the sampler entering their pens. Saliva samples of the FC sows were obtained by the same technique (i.e. cotton swab on a clamp) but without the long stick and without entering their pens. All the sows were trained to be accustomed to the sampling technique before the first collection commenced. Samples were immediately centrifuged (Heraeus™ Labofuge™ 200 Centrifuge, Thermo Fisher Scientific GmbH, Dreieich, Germany) for 10 min at 3000 rpm and stored at −20 °C until analysis.

Cortisol (CORT) and chromogranin A (CgA) were selected as salivary stress biomarkers for measuring the crating stress in sows. CORT was detected by an automated chemiluminescence immunoassay (Immulite 1000 cortisol, Siemens Medical Solutions Diagnostics, Los Angeles, CA, USA) (as validated in Escribano et al., 2012). CgA was detected by time-resolved immunofluorometry assays (TR-IFMA) (as validated in Escribano et al., 2013).

2.5. Video recordings of the crushing events

Crushing events which led to the death of the piglets were confirmed by surveillance cameras (resolution: 1920 ×1080, 30 FPS) (IMX291, Megapixel Starvis, Sony). Surveillance cameras ($n = 9$) were installed on the ceiling of the farrowing units to monitor the sows and the piglets during the study, with three cameras covering all the pens in each farrowing system. Crushing events were analyzed through several parameters: 'batch,' 'parity,' 'crushing time,' 'sow was crated/loose,' 'crushing day,' 'body part of the sow,' 'posture change: from posture 1 to posture 2 (postures include stand, sternal/ventral recumbency, sit, and lateral recumbency),' and 'Did the sow use the pen fixture as an aid to change her posture? (yes/no)'. Detailed description for each parameter can be found in Table 6.

2.6. Weighing and foreleg abrasion assessment in piglets

After cross-fostering was completed, piglets were ear-tagged and weighed individually on D3. To calculate the average daily gain (ADG) in the pre-weaning period, piglets were weighed individually again on D19. On D3, piglets in SWAP and JLF15 were weighed first before their sows were set loose. Sows in SWAP and JLF15 were crated temporarily again on D19 during the weighing of their piglets. Additionally, while weighing piglets on D19, skin abrasion on the forelegs of the piglets was examined on a Yes (1) / No (0) basis (Johansen et al., 2004): "0" indicated no skin abrasion on any forelegs of the piglet, and "1" indicated at least one skin abrasion with a minimum size of 1 cm was observed on one of the forelegs of the piglet.

2.7. Statistical analysis

Data were analyzed in RStudio version 1.2.5033 (R Foundation, Austria). The farrowing pen (i.e. sow or litter) was the experimental unit for reproductive performance, direct behavioral observations, parameters used for the video recordings of the crushing events, and salivary stress biomarkers. The piglet was the experimental unit for foreleg abrasion. As for piglet growth performance, we ran two separate analyses using the farrowing pen or the piglet as the experimental unit. Statistical significance was set at $P \leq 0.05$, and a tendency was considered when $0.05 < P \leq 0.10$. Data are presented as means with standard error (± SE).

2.7.1. Descriptive data

Number of total born/born alive/stillborn/weaned piglets, crating period and equalized litter size between farrowing systems were analyzed with Kruskal-Wallis tests: the above-mentioned variables as the response variable, and farrowing system as the fixed effect.

2.7.2. Direct behavioral observations

Behavioral data collected in six sessions on each observation day were summed up for each behavioral category. Proportion of each behavior in each pen was calculated by dividing the amount of each behavior in a pen by the total amount of sample points in one day. Each behavior category was expressed as percentage. RSC for each observation day was obtained by calculating the average of six RSC sample points on each day. SB and PPE were normally distributed so were analyzed by linear mixed models (LMM). NNC, SC and MYI were log (1 +x) transformed and analyzed by LMMs. 84% of MMI and 45% of SEB were 0 s, so data were changed to the value of either 1 or 0 (i.e. Yes or No) and analyzed by general linear mixed models (GLMM) with a binomial distribution. RSC was analyzed by a GLMM with a Poisson distribution. All models had the behavior as the response variable, farrowing system, day and their interaction as the fixed effects, litter size as the covariate, and batch and pen as the random effects.

2.7.3. Concentration of salivary stress biomarkers in sows

Concentration of CORT and CgA were log transformed to be fitted into LMMs: concentration of CORT or CgA as the response variable, farrowing system, sampling day and their interaction as the fixed effects, basal level (samples collected on 1-day pre-expected farrowing day) as the covariate, and batch and sow as the random effects.

2.7.4. Number of crushed piglets per sow and video recordings of the crushing events

Number of crushed piglets per sow was analyzed by a general linear model (GLM) with a Poisson distribution: number of crushed piglets per sow as the response variable, farrowing system, batch, and parity (primiparous vs. multiparous) as the fixed effects, and litter size as the covariate.

As for the video recordings of the crushing events, two parameters used to analyze the crushing events, 'batch' and 'parity', were analyzed by the above-mentioned GLM. For the rest of the parameters (see Table 3), they were analyzed with several chi-square tests separately to compare the percentage of occurrence between farrowing systems. The parameter, 'crated or loose', was compared only between SWAP and JLF15.

2.7.5. Growth performance and foreleg abrasion in piglets

When using piglet as the experimental unit, body weight on D3 (BW_3), D19 (BW_{19}), and $ADG_{3–19}$ in the pre-weaning period were analyzed by LMMs: BW_3, BW_{19}, or $ADG_{3–19}$ as the response variable, farrowing system, sex and their interaction as the fixed effects, batch and sow as the random effects, and BW_3 as the covariate (except for the BW_3 model). On the other hand, when using litter as the experimental unit,

Table 3
Crating period, equalized litter size and selected reproductive parameters of sows by three farrowing systems: the conventional farrowing crate (FC) and two commercially available farrowing pens with temporary crating (SWAP and JLF15).

	FC	SWAP	JLF15	*P*-value
Number of sows	18	23	23	–
Crating period (number of days)[a]	31.8 ± 0.5	6.0 ± 0.4	5.3 ± 0.3	< 0.0001
Number of total piglets born per litter	11.2 ± 0.6	11.7 ± 0.5	12.4 ± 0.6	0.29
Number of piglets born alive per litter	10.6 ± 0.6	11.0 ± 0.5	11.3 ± 0.6	0.69
Number of stillborn piglets per litter	0.6 ± 0.2	0.6 ± 0.2	0.8 ± 0.2	0.27
Equalized litter size[b]	10.4 ± 0.5	10.3 ± 0.2	10.2 ± 0.3	0.83
Number of piglets weaned per litter	9.6 ± 0.4	9.0 ± 0.3	9.3 ± 0.3	0.34

[a] Crating period was not different between SWAP and JLF15 (P = 0.28).
[b] Establishment of the litter size (within 72 h after birth) after cross-fostering.

the statistical models were the same as mentioned above except including sex and the interaction between farrowing system and sex as the fixed effects. Foreleg abrasion was analyzed by a GLMM with a binomial distribution: foreleg abrasion (0/1) as the response variable, farrowing system and sex as the fixed effects, batch and sow as the random effects.

3. Results

One multiparous FC sow in the summer batch was excluded from the study due to savaging of her newborn piglets, which led to low number of live piglets. One multiparous FC sow in the summer batch and one multiparous JLF15 sow in the spring batch were also excluded from the study due to 1-week delay of farrowing. One multiparous SWAP sow in the summer batch was considered as an extreme outlier due to excessive crushing incidents, which led to eight piglets being crushed, and therefore was also excluded from the study.

Data of behavior, body weight and foreleg abrasion were collected only from the piglets with ear-tags (i.e. the live piglets after the establishment of the litter size). Data of number of total born/born alive/stillborn/crushed/weaned piglets were collected from all the piglets, including those died before the establishment of the litter size.

In the end, there were 18 sows (three primiparous and 15 multiparous) (and their 183 piglets) in FC, 23 sows (four primiparous and 19 multiparous) (and their 243 piglets) in SWAP, and 23 sows (two primiparous and 21 multiparous) (and their 237 piglets) in JLF15 in the study. Table 3 summarizes the crating period, the litter size after cross-fostering and selected reproductive parameters of sows in FC, SWAP and JLF15.

3.1. Direct behavioral observations

Intra-observer reliability test was considered acceptable (Cronbach's $\alpha = 0.98$). Percentages of exploration and social behaviors of piglets and sows in the three farrowing systems during lactation are presented in Table 4.

FC piglets performed more SB than SWAP and JLF15 piglets at an early age (D2 and D4), and this higher amount of social interaction between FC piglets tended to continue until weaning. In contrast, SWAP and JLF15 piglets performed more NNC than FC piglets on D2, and SWAP and JLF15 sows performed more MYI than FC sows on D12. Moreover, JLF15 and SWAP piglets tended to perform more SC than FC piglets on D2 and D4, respectively, and JLF15 sows tended to perform more MYI than FC sows on D4. Our results suggested that in general, there was a higher amount of social interaction between sows and piglets in TC during lactation, compared to FC. On D4, 1 day after opening the crate in TC, SWAP and JLF15 sows performed more SEB than FC sows.

Overall, SB was negatively and moderately correlated with NNC ($r = -0.36$), SC ($r = -0.34$), and MYI ($r = -0.41$) (all $P < 0.0001$), indicating that the more social interactions between littermates, the less social interactions between sows and piglets, and vice versa.

3.2. Concentration of salivary stress biomarkers in sows

Concentrations of CORT and CgA during lactation are presented in

Table 4
Percentage ((the amount of each behavior/total amount of sample points)*100%) of exploration and social interactions of piglets and sows in three farrowing systems during the lactation period (FC: conventional farrowing crate; SWAP and JLF15: farrowing pens with temporary crating). RSC is presented in number of piglets. Crates in SWAP and JLF15 were opened on Day 3.

	Social interaction						Non-social interaction	
	Piglet towards piglet(s)	Piglet towards sow			Sow towards piglet(s)	Sow towards sow	Piglet	Sow
	SB[a]	NNC[b]	SC[b]	RSC[c]	MYI[b]	MMI[d]	PPE[a]	SEB[d]
Day 2								
FC	**40.2 ± 4.3^{x}**	**3.6 ± 0.7^{x}**	11.9 ± 2.4^{+}	1.6 ± 0.3	4.7 ± 1.3	-	30.9 ± 3.4	3.2 ± 1.3
SWAP	**29.9 ± 3.3^{y}**	**9.6 ± 1.6^{y}**	15.8 ± 2.5^{+*}	1.0 ± 0.2	8.8 ± 2.2	-	33.3 ± 2.3	**2.6 ± 1.3^{a}**
JLF15	**30.7 ± 3.6^{y}**	**10.5 ± 2.8^{y}**	20.3 ± 2.7*	1.3 ± 0.2	5.6 ± 1.3	-	**25.9 ± 4.0^{a}**	7.0 ± 3.2
Day 4								
FC	**41.6 ± 3.4^{x}**	4.8 ± 1.2	12.7 ± 2.1^{+}	1.1 ± 0.2	4.7 ± 1.2^{+}	-	33.4 ± 3.7	**2.8 ± 1.5^{x}**
SWAP	**23.0 ± 2.4^{y}**	7.5 ± 1.2	21.5 ± 3.8*	0.9 ± 0.2	9.2 ± 1.7^{+*}	0.6 ± 0.3	28.2 ± 2.4	**9.9 ± 2.7^{y,b}**
JLF15	**31.5 ± 2.7^{y}**	9.0 ± 1.9	14.0 ± 2.1^{+*}	0.9 ± 0.1	10.3 ± 2.9*	0.4 ± 0.4	**28.2 ± 2.7^{a}**	**6.6 ± 1.7^{y}**
Day 12 (mid-lactation)								
FC	35.1 ± 4.0^{+}	4.6 ± 1.8	16.9 ± 3.2	1.0 ± 0.2	**2.4 ± 0.8^{x}**	-	29.9 ± 3.7	5.6 ± 4.1
SWAP	26.1 ± 1.9*	6.8 ± 0.8	20.4 ± 3.2	0.7 ± 0.2	**8.2 ± 1.2^{y}**	0.6 ± 0.2	32.4 ± 2.2	**5.6 ± 1.3^{b}**
JLF15	26.9 ± 1.6*	8.4 ± 1.3	19.8 ± 1.9	1.0 ± 0.1	**7.4 ± 1.3^{y}**	0.4 ± 0.2	**32.9 ± 2.8^{ab}**	4.2 ± 1.0
Day 23 (late lactation)								
FC	33.0 ± 2.3^{+}	3.6 ± 0.8	17.5 ± 2.5	0.9 ± 0.2	3.1 ± 0.7	-	39.6 ± 1.4	3.2 ± 1.2
SWAP	24.3 ± 1.8*	5.6 ± 0.6	19.6 ± 2.7	1.1 ± 0.2	7.3 ± 1.0	0.2 ± 0.1	35.5 ± 1.8	**7.4 ± 2.1^{ab}**
JLF15	23.7 ± 1.6*	5.6 ± 1.0	19.3 ± 2.6	1.3 ± 0.2	6.3 ± 1.1	0.2 ± 0.1	**39.2 ± 2.1^{b}**	5.8 ± 1.5
Global *P*-value								
Farrowing system	< 0.0001	< 0.0001	0.04	0.87	0.0002	0.16	0.49	0.006
Day	0.06	0.17	0.28	0.20	0.28	0.18	0.003	0.001
System x Day	0.50	0.79	0.40	0.78	0.80	0.61	0.26	0.48

Behaviors initiated by the piglets: SB = Social interactions between piglets. / NNC = Piglet initiated naso-naso contact with the sow. / SC = Piglet initiated physical contact (except the snout and the udder) with the sow. / RSC = Piglet resting in physical contact with the sow. / PPE = Piglet locomotor or object play, and exploration of the pen.
Behaviors initiated by the sow: MYI = Sow initiated physical contact with the piglet. / MMI = Mother-mother interactions. / SEB = Sow exploration of the pen.
Values with a different letter superscript are significantly different from each other ($P \leq 0.05$): $^{x, y}$ indicate difference between farrowing systems in the same behavior category on the same day; $^{a, b}$ indicate difference between days in the same behavior category and farrowing system.
Values with a different symbol superscript ($^{+}$, *) correspond to a tendency of difference between farrowing systems in the same behavior category on the same day ($0.05 < P \leq 0.10$).
[a] SB and PPE were normally distributed, so they were analyzed by linear mixed models.
[b] NNC, SC and MYI were log(1+x) transformed and analyzed by linear mixed models.
[c] RSC was analyzed by a general linear mixed model with a Poisson distribution.
[d] Values of MMI and SEB were changed to 1/0 (i.e. Yes/No) and analyzed by general linear mixed models with a binomial distribution.

Table 5
Concentration of salivary cortisol (CORT) (μg/dL) and chromogranin A (CgA) (μg/mL) of sows in the three farrowing systems on different sampling days during the lactation period (FC: conventional farrowing crate; SWAP and JLF15: farrowing pens with temporary crating). Crates in SWAP and JLF15 were opened on Day 3.

	-1D crating[a]	+ 1D crating[b]	Day 2[c]	Day 4[d]	Day 12 (mid-lactation)	Day 23 (late lactation)	Global *P*-values Farrowing system Day System x Day
CORT, μg/dL							
FC	0.48 ± 0.14	0.49 ± 0.15	$\mathbf{0.35 \pm 0.09^{x}}$	0.38 ± 0.05	0.66 ± 0.19	0.69 ± 0.29	0.008
SWAP	$\mathbf{0.68 \pm 0.16^{ab}}$	$\mathbf{0.48 \pm 0.11^{a}}$	$\mathbf{1.27 \pm 0.37^{y,b}}$	$\mathbf{0.55 \pm 0.08^{ab}}$	$\mathbf{0.72 \pm 0.11^{ab}}$	$\mathbf{0.84 \pm 0.18^{ab}}$	< 0.0001
JLF15	0.56 ± 0.11	0.52 ± 0.09	$\mathbf{0.64 \pm 0.22^{x}}$	1.10 ± 0.33	0.75 ± 0.14	0.67 ± 0.11	0.19
CgA, μg/mL							
FC	0.65 ± 0.23	0.73 ± 0.30	0.52 ± 0.12	0.95 ± 0.33	1.18 ± 0.27	0.69 ± 0.18	0.51
SWAP	0.81 ± 0.18	0.62 ± 0.14	0.68 ± 0.18	1.01 ± 0.24	0.81 ± 0.18	0.97 ± 0.23	< 0.0001
JLF15	$\mathbf{0.41 \pm 0.10^{a}}$	$\mathbf{0.52 \pm 0.10^{ab}}$	$\mathbf{0.55 \pm 0.16^{ab}}$	$\mathbf{1.11 \pm 0.27^{b}}$	$\mathbf{1.16 \pm 0.29^{b}}$	$\mathbf{0.98 \pm 0.26^{ab}}$	0.59

Values with a different letter superscript are significantly different from each other ($P \leq 0.05$): [x, y] indicate difference between farrowing systems on the same sampling day; [a, b] indicate difference between sampling days in the same farrowing system.
[a] -1D: 1 day before crating.
[b] + 1D: 1 day after crating.
[c] Day 2: 1 day before crate opening.
[d] Day 4: 1 day after crate opening.

Table 5. CORT and CgA in FC remained similar throughout the lactation period. However, CORT in SWAP peaked on D2, compared to + 1D crating ($P = 0.02$). Additionally, CgA in JLF15 peaked on D4 and remained elevated on D12, compared to − 1D crating ($P = 0.05$ and 0.02, respectively).

3.3. Number of crushed piglets per sow and parameters for analyzing the crushing events

Number of crushed piglets per sow between farrowing systems were as follows: 0.3 ± 0.1 in FC, 1.2 ± 0.3 in SWAP, and 0.6 ± 0.2 in JLF15. Crushing rate of SWAP was higher than FC ($P < 0.0001$) and JLF15 ($P = 0.02$), and that of JLF15 was also higher than FC ($P < 0.0001$).

There were in total 49 crushed piglets during the study period. Table 6 lists the details of the parameters used for analyzing these 49 crushing events. Crushing rate in the autumn batch was significantly lower than in other batches, including the winter batch ($P < 0.0001$), the spring batch ($P < 0.0001$), and the summer batch ($P = 0.007$). As shown in Table 6, crushing events occurred similarly before and after opening the crate in SWAP and JLF15 ($P = 0.54$). Additionally, almost two third (63.3%) of the crushing events occurred when the sows used an aid from the pen while changing posture, and the percentage in FC was higher than in SWAP and in JLF15 ($P = 0.05$).

3.4. Growth performance and prevalence of foreleg abrasion in piglets

Growth performance in piglets is presented in Table 7. No difference was found between farrowing systems in BW_3 ($P = 0.71$ and 0.48), BW_{19} ($P = 0.28$ and 0.41), and $ADG_{3–19}$ ($P = 0.23$ and 0.43), using either piglet or litter as the experimental unit respectively. BW_3 had an effect on BW_{19} and $ADG_{3–19}$ (both $P < 0.05$).

Prevalence of foreleg abrasion on D19 in piglets between farrowing systems was as follows: 66.3 ± 3.6% (n = 175) in FC, 67.5 ± 3.2% in SWAP (n = 209), and 73.5 ± 3.0% in JLF15 (n = 219). No difference was found between farrowing systems in the prevalence of foreleg abrasion ($P = 0.28$).

4. Discussion

In the present study, we compared the behavior, stress physiology and performance of sows and piglets in three farrowing systems, including one conventional farrowing crate system (FC), and two farrowing pens with temporary crating system (TC, i.e. SWAP and JLF15) which are available in the market. The study was conducted on a commercial farm in Spain, in which the results are expected to provide further insight on the feasibility of TC on commercial conditions in warm climates.

In terms of the difference between two TC, the creep area of SWAP is designed near the head of the sow to facilitate a 'nest-like' situation. SWAP pen is equipped with a sloping wall, as it is preferred by the sows when they lie down (Damm et al., 2006), to create an environment that is preferred by the sow and protects the piglets. In addition, the design of SWAP is based on a loose housed system where a simple type of confinement – only one wing – is implemented. On the other hand, JLF15 is based on the traditional crate system where there are two wings but allowing it to open up for the sows to move around. In JLF15, there is no preferred support for the sows but the wings and the rail are the design for piglet protection for the sows to lean against when they lie down. The design of JLF15 is not based on the sows' biological needs and has no preferred lying or dunging areas like SWAP where they can divide in zones.

4.1. Mother-young interactions, social interactions between piglets, and exploration in piglets and sows

On D4, one day after the sows were set loose from the temporary crates, SWAP and JLF15 sows were exploring the pens 10-times and six-times more than FC sows respectively. Exploration in SWAP and JLF15 sows was similar due to similar setups in TC (i.e. similar space allowance and access to the nest-building materials). Exploration in TC sows also reached the peak on D4. This finding is in agreement with Chidgey et al. (2016) and Goumon et al. (2018), where exploration is highly motivated due to curiosity when the environment changes (e.g. increased space allowance, presence of newborn piglets) (Wood-Gush and Vestergaard, 1989). In mid-lactation, SWAP and JLF15 sows interacted with the piglets six-times and five-times more than FC sows respectively, which also agrees with the studies of Chidgey et al. (2016) and Singh et al. (2017). As Chidgey et al. (2017) stated, mother-young interactions are determined by the farrowing environment. Due to a larger and open floor space without the restriction of the crate structure in both TC, loose sows can better orient themselves towards piglets. Sow-piglet nose contacts occur frequently when they are in an open space (Portele et al., 2019), and the result of NNC (i.e. piglet-initiated naso-naso contact with the sow) confirms the findings by Jarvis et al. (2004) and Bolhuis et al. (2018), in which they found that piglets housed in loose house systems had more NNC with their mother sows. Although all the sows were confined on D2, a narrower crate length and width in FC may force the sows to lay under the feed trough which makes it difficult for FC piglets to express NNC.

On the other hand, FC piglets interacted with littermates more than

Table 6
Parameters used for analyzing all the crushing events ($n = 49$) in the three farrowing systems during the study period (from November 2018 to July 2019) (FC: conventional farrowing crate; SWAP and JLF15: farrowing pens with temporary crating). These crushing events all led to the death of the piglets, which was confirmed by the surveillance cameras. Except crushing rate, data are presented in number of piglets. The sum of each parameter in each farrowing system adds up to the number of crushed piglets in each farrowing system.

	FC	SWAP	JLF15	
Number of crushed piglets	6	28	15	
Number of live born piglets	191	252	259	
Crushing rate (%) in each system	3.1	11.1	5.8	
Parameters	**FC**	**SWAP**	**JLF15**	***P*-value**
Batch[1]	0	3	4	< 0.0001
Autumn	4	7	4	
Winter	1	6	4	
Spring	1	12	3	
Summer				
Parity[1]	1	3	1	0.74
Primiparous	5	25	14	
Multiparous				
Crushing time[2]	2	9	8	0.30
Daytime (07:01–18:00 h)	3	19	6	
Night (18:01–07:00 h)	1	0	1	
Unknown				
Sow was crated/loose[a,3]	6	9	7	0.54
Crated	-	19	8	
Loose				
Crushing day[b,2]	4	10	7	0.52
Before Day 3	0	5	1	
Day 3	2	13	7	
After Day 3				
Body part of the sow[2]	1	1	1	0.49
Front (head to front legs)	2	16	10	
Middle (trunk)	2	11	3	
Back (hind legs to tail)	1	0	1	
Unknown				
Posture[c] **change – from posture 1**[2]	4	13	5	0.33
Stand	0	6	1	
Sternal/ventral recumbency	1	3	4	
Sit	0	6	4	
Lateral recumbency (i.e. lie)	1	0	1	
Unknown				
Posture change – to posture 2[2]	0	0	0	0.46
Stand	4	14	8	
Sternal/ventral recumbency	0	0	0	
Sit	1	14	6	
Lateral recumbency (i.e. lie)	1	0	1	
Unknown				
Did the sow use the pen fixture as an aid	4	8	3	0.05
to change her posture?[d,2]	1	20	10	
Yes	1	0	2	
No				
Unknown				

[a] FC sows could only be crated during the study.
[b] Day 0: the day of farrowing. Day 3: Opening of the crates in SWAP and JLF15 pens.
[c] List of sow postures is adopted from Wischner et al. (2009).
[d] FC sows could only use the crate structure to change the posture during the study.
[1] Analyzed by a general linear model with a Poisson distribution: number of crushed piglets per sow as the response variable, farrowing system, batch and parity time as the fixed effects, and litter size as the covariate.
[2,3] Analyzed with chi-square tests: comparing the percentage of occurrence of each parameter between [2]FC, SWAP and JLF15; between [3]SWAP and JLF15.

TC piglets on D2 and D4. As we found negative correlations between SB (i.e. social interactions between piglets) vs. NNC and MYI (i.e. sow initiated physical contact with the piglet), higher SB in FC might suggest a different time budget in those piglets as they spent more time interacting with their littermates instead of the sow, due to the structure of the crate. Moreover, SB may increase when the space allowance is small, which may also suggest an inadequate FC pen size for the piglets. As reported by Turner et al. (2000), number of skin lesions increased in pigs housed in low space allowance, indicating an increased aggression within the group; aggression is considered as a SB in the present study.

Table 7
Body weight (kg) on Day 3 (BW_3) and 19 (BW_{19}), and average daily gain ($ADG_{3–19}$) (g/day) of piglets in the three farrowing systems during the lactation period (FC: conventional farrowing crate; SWAP and JLF15: farrowing pens with temporary crating).

	Farrowing system	*n*	Mean	SEM	*P*-value
Using piglet as the experimental unit					
BW_3, kg	FC	183	2.02	0.03	0.71
	SWAP	243	1.88	0.03	
	JLF15	237	1.97	0.03	
BW_{19}, kg	FC	175	5.11	0.08	0.28
	SWAP	209	5.21	0.09	
	JLF15	219	5.15	0.08	
$ADG_{3–19}$, g/day	FC	175	176.88	4.20	0.23
	SWAP	206	189.49	4.77	
	JLF15	219	179.99	4.38	
Using litter as the experimental unit					
BW_3, kg	FC	18	2.02	0.06	0.48
	SWAP	23	1.89	0.05	
	JLF15	23	1.98	0.07	
BW_{19}, kg	FC	18	5.12	0.15	0.41
	SWAP	23	5.20	0.20	
	JLF15	23	5.16	0.14	
$ADG_{3–19}$, g/day	FC	18	177.49	8.55	0.43
	SWAP	23	186.57	10.80	
	JLF15	23	180.25	9.26	

Regarding PPE (i.e. piglet locomotor or object play, and exploration of the pen), we did not observe any difference between farrowing systems in the present study. However, Singh et al. (2017) found an increased play behavior and a reduced manipulative behavior (i.e. manipulative behavior would be considered as a SB in our study, a negative social interaction) in loose pen piglets. Chaloupková et al. (2007) and Oostindjer et al. (2011) also found an increased play behavior in piglets living in an enriched and enlarged pre-weaning environment. However, in our study, locomotor play, object play, and exploration were not distinguished, so it would be difficult to draw any conclusion on the effect of farrowing systems on play behavior. In addition, apart from an enlarged space, SWAP and JLF15 piglets did not receive regular enrichment (i.e. straw bedding) like in Chaloupková et al. (2007). Oostindjer et al. (2011) also stated that development of foraging related behaviors was positively influenced by early environmental enrichment, but less by sow housing.

4.2. Salivary stress biomarkers in sows during lactation

In the present study, we did not find any difference in salivary stress biomarkers, cortisol (CORT) and chromogranin A (CgA), between farrowing systems during lactation, except CORT in SWAP on D2, which was higher than in FC and JLF15 on the same day. This lack of significant differences between farrowing systems suggests that both temporary confinement (no difference between −1D and +1D crating) and removal of confinement (no difference between D2 and D4) did not elevate the stress level (i.e. similar adrenal reactivity) in sows in SWAP and JLF15. Similarly, Goumon et al. (2018) did not find the effect of removal of confinement after 24 h in CORT. Level of CORT seems inconclusive in sows in early lactation as some studies found no difference between farrowing crate and farrowing pens (Cronin et al., 1992; Biensen et al., 1996), whereas other studies found a higher (Oliviero et al., 2008) or lower (Hales et al., 2016) level of CORT in crated sows. As CORT is known to be released quickly within 30 min after a stressor is introduced, the fact that we did not see a change in CORT after temporary confinement or removal of confinement could be due to a short-lasting effect (Goumon et al., 2018). A higher CORT in SWAP sows on D2 may be linked to the sow's inability to avoid piglets' call for nursing (a higher frequency of NNC in SWAP on D2) due to crating, as shown in the crated sows in Oliviero et al. (2008). It may reflect that nursing is difficult for both sows and piglets when the sow is lying with the udder facing towards the sloping wall, making the space for nursing/suckling crowded.

A peak of CgA in JLF15 sows on D4 and D12 suggested that there was a stress response which activated the SAM (sympathetic-adreno-medullar) axis (Ott et al., 2014) before saliva sampling. Few studies investigated the level of change in CgA after an acute stressor was applied in pigs (e.g. immobilization/nose snare, Escribano et al., 2013 and Huang et al., 2017; mixing and feed deprivation, Ott et al., 2014; psychosocial stress (i.e. regrouping or isolation), Escribano et al., 2015; weaning, Ko et al., 2020), but these acute stressors did not apply to our study. Additionally, CORT in JLF15 sows also showed a peak on D4 and D12 (but not significant), which might indicate that some uncontrollable stressor occurred before saliva sampling that cannot be confirmed from the rest of the results. This unknown stressor (e.g. from handling or from the environment) might have had activated the SAM axis (CgA as the indicator) to a greater extent than the HPA (hypothalamic–pituitary–adrenal) axis (CORT as the indicator), which altered the CgA level significantly more than the CORT level. Further research which also analyzes different salivary biomarkers, such as IgA and oxytocin, is recommended to better understand the general reactivity of the stress level in sows in FC and TC during lactation.

4.3. Crushing in farrowing crates vs. farrowing pens with temporary crating system

Sows in TC were set loose from D3 (i.e. the 4th day postpartum), which was a day earlier than Moustsen et al. (2013) recommended, but as Goumon et al. (2018) suggested. In the present study, both TC showed a higher crushing rate than FC during lactation. A higher number of crushed piglets in SWAP is likely to reflect the fact that the crate was wider than both FC and JLF15, meaning that SWAP sows were not as restricted as FC and JLF15 sows. A sloping wall on one side in SWAP could also block the piglets to escape from the sows if the piglets were resting at the wall side. On the other hand, in FC and JLF15, there was relatively more space on both sides of the sows. Crushing rate in TC was similar before and after D3, which was different from Chidgey et al. (2015) and King et al. (2019), where both studies reported an increased crushing rate after crate opening. One of the reasons for this could be due to a relatively low number of animals involved in the study (64 sows in the present study; 732 sows in Chidgey et al., 2015; 168 sows in King et al., 2019). Additionally, different from most of the studies which used hyper-prolific sows with lower birth weight piglets, our study used a rustic breed with an average of 10–11 piglets born alive with a relatively high birth weight. As Melišová et al. (2011) stated, piglets in better body condition can afford to stay close the sow without being crushed, which may be the case in our study.

In the present study, piglet crushing mostly occurred in FC in the winter batch and in SWAP in the summer batch, even though the percentages were very low. However, most of the crushing events in FC happened even when the sows used the crate as a support to change their posture. Heat sources for piglets in the farrowing systems generally include the heating mat, the lamp and sow's udder. Lack of space in FC may result in crowding (Rangstrup-Christensen et al., 2018) in winter, where piglets occupied the heating mat under the lamp and rested next to sow's udder, making the sow difficult to change her posture without overlaying the piglets, even using the pen fixture (i.e. crate in this case) as a support. On the contrary, piglets in SWAP and JLF15 were able to rest in the creep area with the heating mats and the lamp in winter where the sow had no access to, possibly reducing the chance of being overlaid by the sow. On the other hand, due to incorrect management, the temperature in the creep area in summer might have been too high for piglets, which made them use the creep area for defecating and urinating, and rest outside with the sow, and thus increased the risk of being crushed (Marchant et al., 2001). It is possible that there were more litters in SWAP resting outside than JLF15 litters, as the percentage of crushing in the summer batch in SWAP is twice more than in JLF15, and thus resulting in a higher percentage in SWAP than in JLF15 in average even after the crate opening. Although we did not find any difference in RSC between farrowing systems on the same observation day, it could be that we only counted the piglets that were in actual physical contact with the sow. Therefore, unless crowding in piglets occurred and most of the piglets were in physical contact with the sow, the numbers we collected could not reflect the crowding situation well. It is thus indispensable to adjust the temperature of the creep area regularly to encourage piglets resting inside to avoid being crushed.

4.4. Growth performance and foreleg abrasion in piglets

Unlike previous studies (Pedersen et al., 2011; Melišová et al., 2014), we did not find any effect of the farrowing system on weight gain in piglets, even though there was a 211 g (from D3 to D19) of difference between FC and SWAP numerically. Similar growth performance may suggest an undisturbed suckling and nursing behaviors in a short- and long-term with regard to crate removal (Goumon et al., 2018), but the amount of creep feed intake may also contribute to pre-weaning weight gain (Oostindjer et al., 2010), which is a parameter we did not measure in the present study.

Prevalence of foreleg abrasion in piglets in the present study was between 66% and 73%, which was relatively high, compared to Mouttotou et al. (1999) (36%, highly associated with part-concrete, part-round-mesh flooring) in the UK, Hoy et al. (1999) (54–84%) in Germany, and Johansen et al. (2004) (46%, cast iron slats) in Denmark. Cushioning and minimizing friction with mineral oil impregnated-neoprene sponge at the suckling flooring area were reported to greatly reduce leg injuries (Phillips et al., 1995). More research focusing on optimal flooring design for indoor farrowing systems to avoid the development of foreleg abrasion is needed.

5. Conclusions

Farrowing pens with temporary crating system enhanced sow-piglet interactions and sow explorative behavior. Neither the farrowing system per se nor the opening of the temporary crates altered sows' salivary stress biomarkers. Crushing rate was higher in temporary crated sows than in crates in the summer batch, emphasizing the importance of a correct management of the piglets' creep area. Average daily gain in piglets during lactation was similar across farrowing systems. Farrowing pens with temporary crating system are feasible to house crossbred Duroc sows and piglets on commercial farms in the Mediterranean region. Knowledge-exchange strategies on sow and piglets management around farrowing should be further enhanced to ensure the suitability of temporary crating systems under commercial conditions in Spain and elsewhere.

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Conflicts of interest

Janni Hales works at SKIOLD JYDEN which produces the SWAP and JLF15 pens, but only participated in the housing design of the SWAP and JLF15 pens of the study, interpretation of data, and assisted in the writing of the manuscript. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

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References

Andersen, I.L., Berg, S., Bøe, K.E., 2005. Crushing of piglets by the mother sow (Sus scrofa)—purely accidental or a poor mother? Appl. Anim. Behav. Sci. 93 (3–4), 229–243. https://doi.org/10.1016/j.applanim.2004.11.015.

Baxter, E.M., Lawrence, A.B., Edwards, S.A., 2012. Alternative farrowing accommodation: welfare and economic aspects of existing farrowing and lactation systems for pigs. Animal 6 (1), 96–117. https://doi.org/10.1017/S1751731111001224.

Baxter, E.M., Andersen, I.L., Edwards, S.A., 2018. Sow welfare in the farrowing crate and alternatives. In: Advances in Pig Welfare. Woodhead Publishing, Duxford, United Kingdom, pp. 27–72. https://doi.org/10.1016/B978-0-08-101012-9.00002-2.

Biensen, N.J., von Borell, E.H., Ford, S.P., 1996. Effects of space allocation and temperature on periparturient maternal behaviors, steroid concentrations, and piglet growth rates. J. Anim. Sci. 74 (11), 2641–2648. https://doi.org/10.2527/1996.74112641x.

Bolhuis, J.E., Raats-van den Boogaard, A.M.E., Hoofs, A.I.J., Soede, N.M., 2018. Effects of loose housing and the provision of alternative nesting material on peri-partum sow behaviour and piglet survival. Appl. Anim. Behav. Sci. 202, 28–33. https://doi.org/10.1016/j.applanim.2018.01.004.

Chaloupková, H., Illmann, G., Bartoš, L., Špinka, M., 2007. The effect of pre-weaning housing on the play and agonistic behaviour of domestic pigs. Appl. Anim. Behav. Sci. 103 (1–2), 25–34. https://doi.org/10.1016/j.applanim.2006.04.020.

Chidgey, K.L., Morel, P.C., Stafford, K.J., Barugh, I.W., 2015. Sow and piglet productivity and sow reproductive performance in farrowing pens with temporary crating or farrowing crates on a commercial New Zealand pig farm. Livest. Sci. 173, 87–94. https://doi.org/10.1016/j.livsci.2015.01.003.

Chidgey, K.L., Morel, P.C., Stafford, K.J., Barugh, I.W., 2016. Observations of sows and piglets housed in farrowing pens with temporary crating or farrowing crates on a commercial farm. Appl. Anim. Behav. Sci. 176, 12–18. https://doi.org/10.1016/j.applanim.2016.01.004.

Chidgey, K.L., Morel, P.C.H., Stafford, K.J., Barugh, I.W., 2017. Sow and piglet behavioral associations in farrowing pens with temporary crating and in farrowing crates. J. Vet. Behav. 20, 91–101. https://doi.org/10.1016/j.jveb.2017.01.003.

Cronin, G.M., Smith, J.A., 1992. Suckling behaviour of sows in farrowing crates and straw-bedded pens. Appl. Anim. Behav. Sci. 33 (2–3), 175–189. https://doi.org/10.1016/S0168-1591(05)80006-1.

Damm, B.I., Moustsen, V., Jørgensen, E., Pedersen, L.J., Heiskanen, T., Forkman, B., 2006. Sow preferences for walls to lean against when lying down. Appl. Anim. Behav. Sci. 99 (1–2), 53–63. https://doi.org/10.1016/j.applanim.2005.09.014.

Escribano, D., Fuentes-Rubio, M., Cerón, J.J., 2012. Validation of an automated chemiluminescent immunoassay for salivary cortisol measurements in pigs. J. Vet. Diagn. Invest. 24, 918–923. https://doi.org/10.1177/1040638712455171.

Escribano, D., Soler, L., Gutiérrez, A.M., Martínez-Subiela, S., Cerón, J.J., 2013. Measurement of chromogranin A in porcine saliva: validation of a time-resolved immunofluorometric assay and evaluation of its application as a marker of acute stress. Animal 7, 640–647. https://doi.org/10.1017/S1751731112002005.

Escribano, D., Gutiérrez, A.M., Tecles, F., Cerón, J.J., 2015. Changes in saliva biomarkers of stress and immunity in domestic pigs exposed to a psychosocial stressor. Res. Vet. Sci. 102, 38–44. https://doi.org/10.1016/j.rvsc.2015.07.013.

Goumon, S., Leszkowová, I., Šimečková, M., Illmann, G., 2018. Sow stress levels and behavior and piglet performances in farrowing crates and farrowing pens with temporary crating. J. Anim. Sci. 96 (11), 4571–4578. https://doi.org/10.1093/jas/sky324.

Gu, Z., Gao, Y., Lin, B., Zhong, Z., Liu, Z., Wang, C., Li, B., 2011. Impacts of a freedom farrowing pen design on sow behaviours and performance. Prev. Vet. Med. 102 (4), 296–303. https://doi.org/10.1016/j.prevetmed.2011.08.001.

Hales, J., Moustsen, V.A., Nielsen, M.B.F., Hansen, C.F., 2014. Higher preweaning mortality in free farrowing pens compared with farrowing crates in three commercial pig farms. Animal 8, 113–120. https://doi.org/10.1017/S1751731113001869.

Hales, J., Moustsen, V.A., Nielsen, M.B.F., Hansen, C.F., 2015. Temporary confinement of loose-housed hyperprolific sows reduces piglet mortality. J. Anim. Sci. 93, 4079–4088. https://doi.org/10.2527/jas.2015-8973.

Hales, J., Moustsen, V.A., Nielsen, M.B.F., Hansen, C.F., 2016. The effect of temporary confinement of hyperprolific sows in Sow Welfare and Piglet protection pens on sow behaviour and salivary cortisol concentrations. Appl. Anim. Behav. Sci. 183, 19–27. https://doi.org/10.1016/j.applanim.2016.07.008.

Hansen, C.F., Hales, J., Weber, P.M., Edwards, S.A., Moustsen, V.A., 2017. Confinement of sows 24h before expected farrowing affects the performance of nest building behaviours but not progress of parturition. Appl. Anim. Behav. Sci. 188, 1–8. https://doi.org/10.1016/j.applanim.2017.01.003.

Hoy, S., Ziron, M., Iben, B., 1999. Origin and effects of skin erosion in piglets and possibilities for their prevention. Prakt. Tierärzt. 80, 698–706.

Huang, Y., Liu, Z., Liu, W., Yin, C., Ci, L., Zhao, R., Yang, X., 2017. Salivary haptoglobin and chromogranin A as non-invasive markers during restraint stress in pigs. Res. Vet. Sci. 114, 27–30. https://doi.org/10.1016/j.rvsc.2017.02.023.

Jarvis, S., Reed, B.T., Lawrence, A.B., Calvert, S.K., Stevenson, J., 2004. Peri-natal environmental effects on maternal behaviour, pituitary and adrenal activation, and the progress of parturition in the primiparous sow. Anim. Welf. 13 (2), 171–181.

Jensen, P., 1986. Observations on the maternal behaviour of free-ranging domestic pigs. Appl. Anim. Behav. Sci. 16 (2), 131–142. https://doi.org/10.1016/0168-1591(86)90105-X.

Johansen, M., Alban, L., Kjærsgård, H.D., Bækbo, P., 2004. Factors associated with suckling piglet average daily gain. Prev. Vet. Med. 63 (1–2), 91–102. https://doi.org/10.1016/j.prevetmed.2004.01.011.

Johnson, A.K., Marchant-Forde, J.N., 2009. Welfare of pigs in the farrowing environment. In: The Welfare of Pigs. Springer, Dordrecht, the Netherlands, pp. 141–188. https://doi.org/10.1007/978-1-4020-8909-1_5.

King, R.L., Baxter, E.M., Matheson, S.M., Edwards, S.A., 2019. Temporary crate opening procedure affects immediate post-opening piglet mortality and sow behaviour. Animal 13 (1), 189–197. https://doi.org/10.1017/S1751731118000915.

Ko, H.L., Chong, Q., Escribano, D., Camerlink, I., Manteca, X., Llonch, P., 2020. Pre-weaning socialization and environmental enrichment affect life-long response to regrouping in commercially-reared pigs. Appl. Anim. Behav. Sci. 229, 105044 https://doi.org/10.1016/j.applanim.2020.105044.

Lohmeier, R.Y., Grimberg-Henrici, C.G.E., Büttner, K., Burfeind, O., Krieter, J., 2020. Farrowing pens used with and without short-term fixation impact on reproductive traits of sows. Livest. Sci. 231, 103889 https://doi.org/10.1016/j.livsci.2019.103889.

Marchant, J.N., Broom, D.M., Corning, S., 2001. The influence of sow behaviour on piglet mortality due to crushing in an open farrowing system. J. Anim. Sci. 72 (1), 19–28. https://doi.org/10.1017/S135772980005551X.

Martin, J.E., Ison, S.H., Baxter, E.M., 2015. The influence of neonatal environment on piglet play behaviour and post-weaning social and cognitive development. Appl. Anim. Behav. Sci. 163, 69–79. https://doi.org/10.1016/j.applanim.2014.11.022.

Melišová, M., Illmann, G., Andersen, I.L., Vasdal, G., Haman, J., 2011. Can sow pre-lying communication or good piglet condition prevent piglets from getting crushed? Appl. Anim. Behav. Sci. 134 (3–4), 121–129. https://doi.org/10.1016/j.applanim.2011.06.015.

Melišová, M., Illmann, G., Chaloupková, H., Bozděchová, B., 2014. Sow postural changes, responsiveness to piglet screams, and their impact on piglet mortality in pens and crates. J. Anim. Sci. 92 (7), 3064–3072. https://doi.org/10.2527/jas.2013-7340.

Mellor, D.J., Patterson-Kane, E., Stafford, K.J., 2009. In: Agricultural Sciences and Animal Welfare, first ed. The Sciences of Animal Welfare, Herts, UK, pp. 15–33.

Moustsen, V.A., Hales, J., Lahrmann, H.P., Weber, P.M., Hansen, C.F., 2013. Confinement of lactating sows in crates for 4 days after farrowing reduces piglet mortality. Animal 7 (4), 648–654. https://doi.org/10.1017/S1751731112002170.

Mouttotou, N., Hatchell, F.M., Green, L.E., 1999. The prevalence and risk factors associated with forelimb skin abrasions and sole bruising in preweaning piglets. Prev. Vet. Med. 39 (4), 231–245. https://doi.org/10.1016/S0167-5877(99)00006-9.

Nicolaisen, T., Lühken, E., Volkmann, N., Rohn, K., Kemper, N., Fels, M., 2019. The effect of sows' and piglets' behaviour on piglet crushing patterns in two different farrowing pen systems. Animals 9 (8), 538. https://doi.org/10.3390/ani9080538.

Nowland, T.L., van Wettere, W.H.E.J., Plush, K.J., 2019. Allowing sows to farrow unconfined has positive implications for sow and piglet welfare. Appl. Anim. Behav. Sci. 221, 104872 https://doi.org/10.1016/j.applanim.2019.104872.

Oliviero, C., Heinonen, M., Valros, A., Hälli, O., Peltoniemi, O.A.T., 2008. Effect of the environment on the physiology of the sow during late pregnancy, farrowing and early lactation. Anim. Reprod. Sci. 105 (3–4), 365–377. https://doi.org/10.1016/j.anireprosci.2007.03.015.

Oliviero, C., Heinonen, M., Valros, A., Peltoniemi, O., 2010. Environmental and sow-related factors affecting the duration of farrowing. Anim. Reprod. Sci. 119 (1–2), 85–91. https://doi.org/10.1016/j.anireprosci.2009.12.009.

Oostindjer, M., Bolhuis, J.E., Mendl, M., Held, S., Gerrits, W., van den Brand, H., Kemp, B., 2010. Effects of environmental enrichment and loose housing of lactating sows on piglet performance before and after weaning. J. Anim. Sci. 88 (11), 3554–3562. https://doi.org/10.2527/jas.2010-2940.

Oostindjer, M., van den Brand, H., Kemp, B., Bolhuis, J.E., 2011. Effects of environmental enrichment and loose housing of lactating sows on piglet behaviour before and after weaning. Appl. Anim. Behav. Sci. 134 (1–2), 31–41. https://doi.org/10.1016/j.applanim.2011.06.011.

Ott, S., Soler, L., Moons, C.P.H., Kashiha, M.A., Bahr, C., Vandermeulen, J., Janssens, S., Gutiérrez, A.M., Escribano, D., Cerón, J.J., Berckmans, D., Tuyttens, F.A.M., Niewold, T.A., 2014. Different stressors elicit different responses in the salivary biomarkers cortisol, haptoglobin, and chromogranin A in pigs. Res. Vet. Sci. 97 (1), 124–128. https://doi.org/10.1016/j.rvsc.2014.06.002.

Pedersen, L.J., Damm, B.I., Marchant-Forde, J.N., Jensen, K.H., 2003. Effects of feed-back from the nest on maternal responsiveness and postural changes in primiparous sows during the first 24h after farrowing onset. Appl. Anim. Behav. Sci. 83 (2), 109–124. https://doi.org/10.1016/S0168-1591(03)00116-3.

Pedersen, M.L., Moustsen, V.A., Nielsen, M.B.F., Kristensen, A.R., 2011. Improved udder access prolongs duration of milk letdown and increases piglet weight gain. Livest. Sci. 140 (1–3), 253–261. https://doi.org/10.1016/j.livsci.2011.04.001.

Phillips, P.A., Fraser, D., Pawluczuk, B., 1995. Effects of cushioned flooring on piglet leg injuries. Trans. ASAE 38 (1995), 213–216. https://doi.org/10.13031/2013.27832.

Portele, K., Scheck, K., Siegmann, S., Feitsch, R., Maschat, K., Rault, J.L., Camerlink, I., 2019. Sow-piglet nose contacts in free-farrowing pens. Animals 9 (8), 513. https://doi.org/10.3390/ani9080513.

Rangstrup-Christensen, L., Krogh, M.A., Pedersen, L.J., Sørensen, J.T., 2018. Sow level risk factors for early piglet mortality and crushing in organic outdoor production. Animal 12 (4), 810–818. https://doi.org/10.1017/S1751731117002178.

Singh, C., Verdon, M., Cronin, G.M., Hemsworth, P.H., 2017. The behaviour and welfare of sows and piglets in farrowing crates or lactation pens. Animal 11 (7), 1210–1221. https://doi.org/10.1017/S1751731116002573.

Turner, S.P., Ewen, M., Rooke, J.A., Edwards, S.A., 2000. The effect of space allowance on performance, aggression and immune competence of growing pigs housed on straw deep-litter at different group sizes. Livest. Prod. Sci. 66 (1), 47–55. https://doi.org/10.1016/S0301-6226(00)00159-7.

Wischner, D., Kemper, N., Stamer, E., Hellbruegge, B., Presuhn, U., Krieter, J., 2009. Characterisation of sows' postures and posture changes with regard to crushing piglets. Appl. Anim. Behav. Sci. 119 (1–2), 49–55. https://doi.org/10.1016/j.applanim.2009.03.002.

Wood-Gush, D.G.M., Vestergaard, K., 1989. Exploratory behavior and the welfare of intensively kept animals. J. Agric. Environ. Ethics 2, 161–169. https://doi.org/10.1007/BF01826929.

Yun, J., Swan, K.-M., Vienola, K., Farmer, C., Oliviero, C., Peltoniemi, O., Valros, A., 2013. Nest-building in sows: effects of farrowing housing on hormonal modulation of maternal characteristics. Appl. Anim. Behav. Sci. 148 (1–2), 77–84. https://doi.org/10.1016/j.applanim.2013.07.010.