The welfare and productivity of sows and piglets in group lactation from 7, 10 or 14 days postpartum[1]

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ABSTRACT: Transferring sows and their litters to group lactation (**GL**) after an initial period of farrowing crate housing (**FC**) could enhance the viability of GL for commercial production. Group lactation from 7 days post-partum would reduce the time sows spend in confinement, but the effects of early mixing on animal welfare and productivity requires examination. Two experiments were conducted on sows and piglets kept in GL from 7, 10 or 14 days post-partum, compared to FC. Experiment 1 utilized 180 sows and 1887 piglets over 5-time replicates (n = 60 sow and litter units per treatment) comparing GL from 7 or 14 days post-partum to FC. In experiment 2, 108 sows and 1179 piglets were studied over 3-time replicates (n = 36 sow and litter units per treatment) comparing GL from 10 or 14 days post-partum to FC. All sows farrowed in FC. Group lactation sows were transferred to pens (one pen of 5 sows at 8.4 m^2/sow and one pen of 7 sows at 8.1 m^2/sow, per GL treatment and replicate) with their litters at 7 (GL_7), 10 (GL_{10}) or 14 (GL_{14}) days post-partum. Farrowing crate sows and their litters remained in their FC. Data were collected on sow feed intake and reproduction, piglet mortality (from day 6 post-partum), and sow and piglet weight changes, plasma cortisol concentrations and injuries. Piglet mortality was greater in the GL_7 (17 ± 1.8%) and GL_{10} treatments (12 ± 0.9%) compared to GL_{14} (8.3 ± 1.8% $P \leq 0.001$ and 8.1 ± 0.9% $P \leq 0.001$ in experiments 1 and 2), and greater in GL overall compared to FC (2.7 ± 1.5% and 1.8 ± 0.9% in FC in experiments 1 and 2; $P \leq 0.001$). Piglet from GL_7 were also lighter at weaning than GL_{14} piglets ($P < 0.001$), whereas GL_{10} and GL_{14} did not differ ($P > 0.05$). Overall, piglets in GL were lighter at weaning than piglets in FC ($P \leq 0.01$). Sows from GL_7 were heavier at weaning ($P = 0.001$), and GL_{10} sows tended to be heavier at weaning ($P = 0.08$), than GL_{14} and FC sows. Post-mixing, sow cortisol ($P \leq 0.01$), and sow and piglet injuries ($P \leq 0.02$) were greater in GL than FC. Treatment had no effect on sow feed intake or reproductive performance ($P > 0.05$). Under the conditions of this research, the known benefits of two-stage GL housing were achieved at a cost particularly to piglets in terms of increased piglet mortality and injuries after mixing, and reduced piglet growth. The risk of piglet mortality decreased with older age at mixing.

Keywords injuries; pig; piglet mortality; rearing; socialization; two-stage lactation.

INTRODUCTION

Transferring sows and their litters to group lactation housing after an initial period of farrowing crate housing (i.e., 'two-stage group lactation' housing systems) is one available strategy that could protect piglets from crushing when they are most vulnerable, thus enhancing the ethical and economic viability of group lactation systems for commercial production. The mixing of sows and litters into groups in two-stage group lactation systems has typically been done around 14 days post-partum (Wattanakul et al., 1997a; Dybjaer et al., 2001; Dybkjær et al., 2003; Verdon et al., 2016). However, sows will begin to communally nurse their piglets between 7 and 14 days post-partum under natural conditions (Jensen, 1988) and, when possible, commercial conditions (Arey and Sancha, 1996; Schrey et al., 2018). One benefit of mixing sows and litters into group lactation at 7 rather than 14 days post-partum is a reduction in the time sows spend in confinement, and mixing at a younger age has few effects on sow or piglet behavior (Verdon et al., 2019a). However, it is important to understand whether mixing before 14 days post-partum has implications for other indicators of animal welfare and productivity.

In two experiments, this research examined the effect of housing sows and their litters in group lactation pens from 7 (experiment 1), 10 (experiment 2), or 14 (experiments 1 and 2) days postpartum until weaning at 26 days post-partum on sow and piglet welfare and productivity, in comparison to conventional farrowing crate housing throughout lactation. The hypothesis being tested was that the welfare and productivity of sows and piglets will be improved (assessed using cortisol, injuries, piglet mortality, weight changes and sow reproduction) when mixed into group lactation at 7 or 10 rather than 14 days post-partum, and in group lactation compared to farrowing crates.

MATERIALS AND METHODS

Ethical statement

All animal procedures were conducted with prior institutional animal ethics approval under the requirement of the New South Wales Prevention of Cruelty to Animals Act (1979) in accordance with the National Health and Medical Research Council/Commonwealth Scientific and Industrial Research Organisation/Australian Animal Commission Australian Code of Practice for the Care and Use of Animals for Scientific Purposes (NHMRC, 2013).

The present research originally aimed to examine the effects of group lactation from 7 or 14 days post-partum, in comparison to FC housing throughout lactation. Housing piglets in group lactation from 7 days of age was discontinued after 5 time-replicates due to high piglet mortalities (see results). The final 3 time-replicates examined piglets housed in group lactation from 10 or 14 days, compared to FC throughout lactation. These data are presented as two separate experiments.

Animals and housing

Experiments 1 and 2 were conducted consecutively over 8 and 3 months, respectively, at the same large commercial farrowing and lactation unit at a piggery in southern New South Wales (NSW), Australia. The experimental building had a galvanised roof and thermostatically controlled blinds that targeted an optimum internal shed temperature of 21ºC. The average mean daily ambient temperature for the region and experimentation periods of experiments 1 and 2 were 27.3 and 23.4 ºC, respectively. Cool drippers over FC as well as over the dunging area of the GL pens were activated (3 min on and 15 min off) if the internal temperature exceeded 26ºC. Creep heat lamps automatically turned off when the room temperature exceeded 24 ºC.

Landrace × Large-White breed pigs (PrimeGro™ Genetics, Corowa, NSW) were studied. Details relating to the animals utilized in each experiment are summarized in Table 1. For both experiments, 36 multiparous sow and their litters were studied in each time replicate. Sow and litter units were selected at approximately 6 days postpartum from a larger cohort of an average of 39 sows (range 37 to 41 sows) on the basis that sows had farrowed in the same shed and within 4 days of each other, were healthy (not injured, sick or lame) and had approximately 10 healthy piglets [piglets were not excluded based on size; but piglets that were not thriving (i.e., very small or skinny), sick or lame were excluded from the experiment]. Housing treatments were balanced for sow parity and weight as well as litter size (Table 2), and there were no treatment differences at selection in piglet weight or within treatment variation in sow parity and sow weight (Table 1; ANOVA P > 0.05). In experiment 1, the three treatments differed in male to female piglet sex ratio, which was greatest in farrowing crates and lowest in litters mixed into group lactation at 7 days post-partum (Mean ± sd were 1.5 ± 0.35, 0.9 ± 0.28 and 1.2 ± 0.24 for farrowing crate, group lactation from 7 and group lactation from 14 days post-partum treatments, respectively; ANOVA $F_{2,27}$ = 10.1 P = 0.004). In experiment 2, male to female sex ratio did not differ between treatments (Grand mean ± sd of 1.1 ± 0.32; ANOVA P > 0.05). Animal remained in their treatment pens until weaning at 25.5 ± 2.1 days (range 22-31 days).

Lactation housing. Pregnant sows were moved from group gestation housing (static groups of 80 sows per pen) with electronic sow feeders to farrowing crates (**FC**) 7 days before expected parturition. The bottom bars of FC (crate 2.3 × 0.6 m, total area 2.3 × 1.7 m) operated on a hydraulic ram so that the sides swung in when the sow stood and slowly slide out when the sow lies down. Farrowing crates contained a creep area that was heated using a mat below (1.1 × 0.40 m) and a lamp overhead. Piglets were tail docked and received an iron injection within 24 h of birth, and given an ear tag for individual identification at day 4 postpartum, as per standard commercial practices. Minimal cross fostering was conducted, and, when it was required, piglets were fostered onto non-trial sows within 24 h of birth.

The four group lactation (**GL**) pens utilized were in a single room of the same shed that contained the FC. Two of the GL pens housed 5 sows and their litters at 8.4 m^2/sow (6.0 × 7.0 m), while the other two GL pens housed 7 sows and their litters at 8.1 m^2/sow (6.0 × 9.5 m). Each pen had a solid partition (to facilitate active avoidance between sows and to separate active and resting areas) with sloped walls, while one longitudinal wall in the resting area also had sloped walls (Fig. 1). The sloped walls were designed to protect piglets as sows transitioned from standing to lying. Also included were two heated piglet creep areas with lids and rice hulls for bedding, and a third open and un-heated piglet creep that contained creep feed and a water trough. In the pens of 7 sows and litters a hay rack was positioned on the wall between the third piglet creep and the sow feeder, but to reduce congestion around the sow feeder in the pens of 5 sows their litters the hay rack hung from the vertical bars partitioning the third piglet creep (Fig. 1). It did not affect piglet entry or exit to the creep in this position. From replicates 1 to 3 of experiment 1, the creep area was protected using vertical bars along the entrance (approximately 20 cm distance between bars allowing piglets to pass through) and a horizontal anti-crush bar along the bottom of the entrance to the creep (10-15 cm from ground level). In replicates 4 and 5 of experiment 1 and in experiment 2, the creep entrance was modified to better retain heat using a solid wooden barrier that included an entry and exit doorway for piglets. The vertical protection bars and horizontal anti-crush bar remained. The flooring of the GL pens was partially slatted and rice hulls were scattered on the solid portion of the flooring weekly.

During lactation, sows were fed a standard pelleted lactation diet *ad libitum* (14.9 MJ DE/kg and 16.2% crude protein). For sows in FC, this was provided up to three times daily, based on individual sow intake. The GL pens were fitted with a single *ad libitum* feed hopper with the capacity to feed two sows simultaneously. The bowl of the feed hopper was positioned approximately 40 cm from ground level. Piglets were not able to access the sow feeder. Water was supplied *ad libitum* via one nipple drinker per GL and FC and one water trough per GL pen. Piglets in all housing treatments were offered creep feed from 14 days of age. Animals in FC and GL were managed by the same stock people, who had 3+ years experience managing sows and piglets in FC and in GL from day 14 of lactation.

Experimental design and procedures

All sows farrowed in standard FC. The 12 FC sows (and their litters) studied per replicate remained in their FC from birth until weaning. Animals in the FC treatment were assessed as two cohorts of six sow and litter units (cohorts balanced for sow parity, sow weight and litter size). For each replicate, 12 sows (and their litters) were transferred from FC to one of the two GL pens (one pen of 5 sow/litter units and one pen of 7 sow/litter units) at 7 (**GL_7**, experiment 1; mean ± s.d., 7.3 ± 1.2 days) or 10 (**GL_{10}**, experiment 2; mean ± s.d., 10.1 ± 1.2 days) days post-partum. At 14 days post-partum (**GL_{14}**, mean ± s.d; 13.5 ± 1.4 days in experiment 1; 13.9 ± 0.9 days in experiment 2), the 12 GL_{14} sows (and their litters) studied per replicate were transferred from FC to one of the remaining two GL pens (one pen of 5 sow/litter units and one pen of 7 sow/litter units). After mixing, GL sow and litter units remained in their respective group pens until weaning. Sow parity, weight and litter size were balanced between GL pens within replicates, but commercial records did not enable treatments to be balanced based on familiarity (i.e,. sows that had been housed together during gestation).

Mixing of GL treatments proceeded as follows. Firstly, piglets were transferred from FC to two piglet creep areas located in the allocated GL pen. The exit of the creep into the GL pens was blocked and the lid left open to prevent over-heating. The transfer of sows from their FC to GL commenced after litters had been relocated. Mixing of sows and their litters into GL occurred between 0730 and 0930 h and was completed within approximately 30 min.

Pens were mixed sequentially and the allocation of GL treatments to pens alternated per replicate. Sows could manipulate the timber blocking the exit of the creep meaning that attempts to confine piglets to the creeps for 1 h post-mixing were unsuccessful, so piglets and sows were mixed simultaneously. Dybkjær et al. (2003) found that the method of introduction to group lactation (i.e., individual sows with their litters sequentially, all sows and piglets simultaneously, all sows followed by all piglets 2 h later) had no effect on sow aggression or piglet mortality. Researchers monitored animals for 1 h post-mixing in the present experiment and interventions to prevent piglet injury or death due to crushing in this period were not required. Researchers did not interrupt aggressive behavior between sows.

During weaning, sows were removed from FCs and GL pens and taken to dry sow housing before piglets were relocated to grower facilities located on the same farm.

Data collection

Focal animals. Four focal sows (two of high and two of low parity, relative to the mean; mean ± s.d. of 5.6 ± 1.5 and 2.5 ± 0.8 in experiment 1, and 5.8 ± 1.2 and 1.9 ± 0.73 in experiment 2, for high and low parity sows respectively) and two focal piglets per focal sow (one male and one female of average weight; mean weight at day 6 post-partum ± s.d. of 3.0 ± 0.7 and 2.8 ± 0.5 kg in experiment 1, and 3.0 ± 0.6 and 2.7 ± 0.6 kg in experiment 2, for males and females respectively) per treatment and replicate were selected at approximately day 6 post-partum for analysis of skin injuries and plasma cortisol concentration (see "Data collection"). Each GL pen contained one focal sow of high parity, one focal sow of low parity, and four focal piglets. Of the four FC focal sows studied per replicate, one high and one low parity sow (as well as the two focal piglets per sow) were selected from each of the two FC cohorts. Focal animals from the first FC cohort were assessed on the same days as GL_7 (labelled $\mathbf{FC_7}$ cohort) in experiment 1 or GL_{10} (labelled $\mathbf{FC_{10}}$ cohort) in experiment 2, while focal animals from the second FC cohort were assessed on the same days as GL_{14} (labelled **FC_{14}** cohort). Different symbols were marked on the back of focal piglets and sows using stock paint to allow for individual identification and this was re-applied weekly. The same focal sows were observed throughout lactation. A similarly sized littermate of the same sex replaced focal piglets that died or were removed for injury/illness during lactation (8 and 5 focal piglets in experiments 1 and 2, respectively).

Cortisol concentration. Blood samples were collected from focal sows and piglets 4 h post-mixing of GL treatments and on the day before weaning via jugular venipuncture (6-mL lithium-heparinized tubes for sows, 2-mL lithium-heparinized tubes for piglets; BD Vacutainer BD, Belliver Industrial Estate, Plymouth, UK). Sows in FC were not fed for 1 hr before sampling. Sows were restrained with a snout snare for blood collection, while piglets were restrained on their backs. Sampling by 4 technicians commenced at 1200 h and it took an average of 30 minutes to sample all focal sows and piglets. Piglets from all treatments were sampled before sows. For each animal, a maximum of 2 min from first restraint was allowed to obtain the blood sample. This was so that an acute stress response associated with handling and blood sampling could be avoided, which would influence concentrations of plasma cortisol (Broom and Johnson, 1993). Over experiments 1 and 2 respectively, blood samples were obtained within 2 minutes of restraint for 93 and 94% of piglets and 88 and 89% of sows. Seventy-seven percent of sows (median 1 minute, range 0-8 minutes) and 78% of piglets (median 1 minute, range 0-8 minutes) in experiment 1, and 83% of sows (median 1 minute, range 0-6 minutes) and 80% of piglets (median 1 minute, range 0-10 minutes) in experiment 2, were sampled within 2 minutes technicians entering the pen.

The individual samples were centrifuged for 10 min at 1,912 × *g* at 4°C, and the plasma was transferred to individual microtubes and stored at –20°C until analysed. Plasma cortisol was measured using a commercial radioimmunoassay kit (Cortisol GammaCoat RIA kit CA-

1549, Dia Sorin Inc., Stillwater MN, USA). Experiments 1 and 2 were analysed by the same technician in a single laboratory, with CV < 5% between duplicates, and the intra- and inter-assay CVs were 10.6 and 13.5%, respectively.

Skin injuries. The assessment described by Verdon et al. (2016) was used to assess skin injuries for focal sows and piglets on the day after mixing of GL pens (day 2) and the day before weaning (pre-weaning). Lesions were scored by counting and to the total number of lesions on the zones of the body: the front (head, neck, shoulders and front legs), the middle (flanks and back) and the rear (rump, hind legs and tail). The number of lesions in each zone were then summed to produce a whole-body lesion count. Only skin injuries categorized as fresh (scratches, abrasions and cuts) were recorded.

Piglet mortality. The identity and reason (overlay or other) for piglet deaths were recorded daily from day 6 post-partum until weaning. Piglets with visible signs of crushing or that were found underneath the sow, or both, were assessed as "overlaid" by experienced stockpeople. All other piglets that died were defined as "other". This data was used to calculate the proportion of total piglet mortalities, and the proportion of mortalities due to overlay per GL pen or FC.

Piglet growth. All piglets were weighed at day 6 post-partum and on the day before weaning. These data were used to calculate piglet weight gain (g/day) from day 6 to weaning. The coefficient of variation in piglet weight at weaning was also calculated for pens and FC cohorts.

Sow live weight and P2 back fat. Sow live weight and back fat measurements at the P2 site (65 mm down the left side from the midline at the level of the head of the last rib) were taken upon entry to the farrowing accommodation (7 days before parturition) and again at weaning. Changes in live weight (kg/day) and backfat (mm/day) over this period were then calculated.

Sow feed intake. The quantity of feed provided and refused was recorded each day for individual sows in FC and for groups of sows in GL pens. Records commenced on the day that the GL_7 treatment was mixed in experiment 1, or that the GL_{10} treatment was mixed in experiment 2. These data were used to calculate the average daily feed intake per sow (ADFI, kg/day). Because sows were housed individually or in groups or both, depending on treatment, ADFI was calculated one of three ways, as described below:

(1) For sows in GL_7 or GL_{10} treatments, ADFI was calculated by averaging the feed intake of the entire pen over the observation period by the number of days in the observation period, and then by the number of sows in that pen.

(2) Feed intake data for GL_{14} sows were recorded for individual sows until they were mixed into groups at 14 days post-partum, after which data were collected for groups. To calculate ADFI per sow for GL_{14} pens, the daily intake of each individual sows in that pen (obtained before mixing) and the daily intake of the GL pen (obtained after mixing) were summed to calculate the total intake over the observation period. This value was averaged by the number of days in the observation period, and then by the number of sows in that pen.

(3) For sows in the FC treatment, individual sow intake over the entire lactation period was determined and averaged over the number of observation days to calculate ADFI. This was then averaged per FC cohort.

Sow reproduction. The following sow reproductive variables from the subsequent gestation were obtained from production records: wean-to-mate interval, percent of sows that were removed for non-reproductive reasons (culled or euthanized), and number of reproductive failures (negative pregnancy test, abortions, returns). Data on reproductive failures were used to calculate the farrowing rate of sows (percent of sows that farrowed, excluding those removed for non-reproductive reasons).

Statistical analysis

One GL_{14} sow was euthanized because of a leg injury 5 days after being mixed into the GL pen of 5 sows in experiment 1. Her litter was removed from the GL pen after her euthanasia. In total, two FC piglets (0.4% of FC piglets), four GL_7 piglets (0.8% of GL_7 piglets) and 15 GL_{14} piglets (2.9% of GL_{14} piglets) were removed from experiment 1 for injury or ill-thrift. Eight focal piglets had to be replaced with a similarly sized littermate of the same sex in experiment 1. In experiment 2, two GL_{10} piglets (0.5% of GL_{10} piglets) were removed for injury or ill-thrift, and four focal piglets had to be replaced.

Experiments 1 and 2 were analyzed separately. All statistical analyses were carried out using the SPSS statistical software package (SPSS 22.0, SPSS Inc., Chicago, Illinois, USA). Variables were assessed for normality using visual methods (quantile-quantile plots and histograms) in combination with Shapiro-Wilks normality tests. Cortisol and injury data were not normally distributed and were logarithmically transformed prior to analysis so that residual variation was homogenous between time replicates and treatments. The significance level α was set at $P \leq 0.05$.

Data were obtained for individual sows or piglets and then averaged over the number of sows or piglets in each GL pen and FC. Data per FC were then averaged over the 6 crates in the FC cohort. Thus, the GL pen or FC cohort were the experimental unit used for statistical analysis.

Cortisol and injuries. Data collected from focal sows and piglets were analysed using linear mixed models (LMMs). Data collected early post-mixing and data collected pre-weaning were analysed separately. For these analyses, fixed effects of lactation housing

(‘Housing’: FC or GL), litter age at GL mixing (‘Age’: 7 or 14 days in experiment 1; 10 or 14 days in experiment 2), and their 2-way interaction were included in the model. Sex ratio was included in the analysis of data collected in experiment 1 as a covariate while time replicate and group lactation pen were included in the model as random factors. Using this model, differences in injuries and cortisol concentrations of sows and piglets in GL_7, GL_{14} and FC treatments would be evident through a significant Housing × Age interaction. Non-significant interactions were removed from the model so that the main effects could be better interpreted. Raw means ± SEM are presented, with transformed means (and backtransformed means) presented in Supplementary Table S1.

Weights, piglet mortality and sow feed intake. Variables relating to sow and piglet weights, piglet mortality and sow feed intake were analysed using LMM. This is except for the proportion of piglet mortalities due to overlay in experiment 1, which could not be normalized and were analysed using Kruskal-Wallis test. Each model included lactation housing treatment (FC, GL_7 or GL_{14} in experiment 1; FC, GL_{10} or GL_{14} in experiment 2) as fixed factors with replicate and pen fitted as random factors. Sex ratio was included in experiment 1 analyses as a covariate. For piglets that died during lactation, weight at day 6 post-partum was analysed using a LMM. Piglet death (0/1), lactation housing treatment and their interaction were included in the model as fixed factors with time replicate and pen fitted as random factors.

Sow reproduction. The following sow reproduction variables were binary: whether a sow farrowed, was culled or experienced reproductive failure in the subsequent gestation, or not. These variables were analysed using a generalized linear mixed model with an underlying binomial distribution and logit link. Treatment was specified as a fixed effect and replicate and pen were controlled for as random variables. The wean-to-mate interval could not be normalized with transformation and was analysed using a Kruskal-Wallis test.

RESULTS

Sow and piglet cortisol

There were no significant Housing × Age interactive effects on sow or piglet cortisol in either experiment.

Group lactation sows had greater plasma cortisol concentrations than FC sows 4h post-mixing (experiment 1 $F_{1,23} = 7.86$ $P = 0.01$; experiment 2 $F_{1,15} = 20.9$ $P \leq 0.001$) but there were no effects of housing on sow cortisol pre-weaning (experiment 1 $F_{1,13.6} = 0.06$ $P = 0.81$; experiment 2 $F_{1,13} = 1.34$ $P = 0.27$; Figs 2A and 2E). Sow cortisol concentrations were not affected by litter age at 4-h post-mixing (experiment 1 $F_{1,23} = 0.01$ $P = 0.91$; experiment 2 $F_{1,15} = 0.88$ $P = 0.36$) or pre-weaning (experiment 1 $F_{1,21.5} = 0.47$ $P = 0.50$; experiment 2 $F_{1,13} = 0.06$ $P = 0.82$; Fig 2A and 2E).

There was no effect of housing on piglet cortisol concentrations 4 h post-mixing (experiment 1 $F_{1,13.8} = 0.83$ $P = 0.38$; experiment 2 $F_{1,10} = 2.05$ $P = 0.18$; Figs 2C and 2G). In experiment 1, GL piglets had greater cortisol than FC piglets pre-weaning ($F_{1,8.9} = 7.2$ $P = 0.025$; Fig 2C) but in experiment 2 GL and FC piglets did not differ in cortisol pre-weaning ($F_{1,15} = 1.23$ $P = 0.29$; Fig 2G). In both experiments, GL_7 and FC_7 piglets had significantly greater cortisol concentrations 4 h post-mixing than GL_{14} and FC_{14} piglets (experiment 1 $F_{1,20.6} = 18.9$, $P < 0.001$; experiment 2 1 $F_{1,3.48} = 17.2$, $P = 0.019$), but there was no effect of age at mixing on cortisol concentrations pre-weaning (experiment 1 $F_{1,21.2} = 2.5$ $P = 0.13$; experiment 2 1 $F_{1,15} = 4.03$ $P = 0.063$; Fig 2C and 2G).

Sow and piglet injuries

There were no significant Housing × Age interactive effects on sow or piglet skin injuries in either experiment.

Group lactation sows sustained more injuries than FC sows at day 2 post-mixing (experiment 1 $F_{1,23} = 87.5$ $P \leq 0.001$, experiment 2 $F_{1,11} = 60.1$ $P \leq 0.001$; Figs 2B and 2F). In experiment 1, GL sows had more injuries than FC sows pre-weaning ($F_{1,18} = 5.8$ $P = 0.027$; Fig 2B) but in experiment 2 GL and FC sows did not differ in injuries pre-weaning ($F_{1,10.4} = 1.23$ $P = 0.29$; Fig 2F). There was no effect of age at mixing on sow injuries at day 2 (experiment 1 $F_{1,23} = 1.04$ $P = 0.32$; experiment 2 $F_{1,14} = 0.38$ $P = 0.55$) or pre-weaning (experiment 1 $F_{1,18} = 1.52$ $P = 0.23$, experiment 2 $F_{1,10.7} = 0.27$ $P = 0.62$; Figs 2B and 2F).

Group lactation piglets had greater skin injuries than FC piglets at day 2 (experiment 1 $F_{1,15.7} = 4.88$ $P=0.042$; experiment 2 $F_{1,13} = 6.18$ $P=0.027$), but there were no effects of housing on piglet injuries pre-weaning (experiment 1 $F_{1,16.5} = 1.58$ $P=0.23$; experiment 2 $F_{1,15} = 3.10$ $P=0.10$; Figs 2D and 2H). In neither experiment did age at mixing effect piglet injuries at day 2 (experiment 1 $F_{1,21.3} = 1.01$ $P = 0.33$; experiment 2 $F_{1,13} = 0.08$ $P = 0.78$) or pre-weaning (experiment 1 $F_{1,21.6} = 1.22$ $P = 0.28$, experiment 2 $F_{1,15} = 2.16$ $P = 0.16$; Figs 2D and 2H).

Piglet mortality and growth

Mortalities were significantly greater when piglets were mixed at a younger age (i.e., 7 days in experiment 1 and 10 days in experiment 2) than when mixed at 14 days of age (Table 2). In both experiments and regardless of treatment, piglets that died during lactation were lighter at day 6 post-partum than piglets that continued in the experiment (LSM ± SEM in experiment 1 were 2.3 ± 0.16 vs. 2.8 ± 0.16 kg, $F_{1,75} = 31.9$ $P < 0.001$; and in experiment 2 were 2.2 ± 0.09 vs. 2.7 ± 0.07 kg, $F_{1,147} = 23.6$ $P < 0.001$). A descriptive inspection of the data shows a trend for a decline in mean piglet mortalities over replicates for GL treatments in experiment 1 (Fig 4A) but not in experiment 2 (Fig 4B). In both experiments, there was a significantly greater piglet mortality from day 6 of age until weaning in GL compared to FC (Table 2). The proportion of mortalities that were caused by overlay did not differ between treatments in either experiment (Table 2).

In both experiments, GL piglets gained less weight during lactation and were lighter at weaning than FC piglets (Table 2). In experiment 1, GL_7 piglets gained less weight during lactation and were lighter at weaning than GL_{14} piglets, while the ADG of GL_{14} piglets was intermediate between FC and GL_7 treatments. There was no difference in weight at weaning between GL_{10} and GL_{14} piglets in experiment 2 (Table 2). There was no effect of treatment on the coefficient of variation (CV) in piglet weight at weaning in experiment 1, but in experiment 2 CV was higher in the GL_{10} treatment compared to the GL_{14} and FC treatments (Table 2).

Sow productivity

In experiment 1, GL_7 sows lost less weight and were heavier at weaning than FC and GL_{14} sows, and lost less fat at the P2 position than FC sows, while GL_{14} sows also lost less weight than FC sows (Table 4). However, ADFI did not differ between the treatments in experiment 1 (Table 4). There were no effects of treatment on ADFI, live weight and P2 back fat at weaning, or loss in weight and P2 fat in experiment 2 (Table 4). There was no effect of treatment on subsequent gestation farrowing rate, wean-to-mate interval or the percent of sow culls in either experiment (Table 4).

DISCUSSION

Compared to FC, GL resulted in lower piglet growth and greater piglet mortality. The younger the litters were when mixed into GL, the greater the risk of piglet mortality. Early after mixing into GL, sow cortisol concentrations and sow and piglet skin injuries were greater compared to sows and piglets that remained in FC. However, few differences in cortisol and injuries were observed between GL and FC housing on the day prior to weaning, suggesting short-term effects.

Sow and piglet cortisol

Disrupted nursing and social stress related to agonistic interactions between sows is likely to explain the greater cortisol post-mixing in GL compared to FC sows (Verdon et al., 2019a). That cortisol did not differ between GL and FC sows prior to weaning suggests that GL sows either adapted to their environment, that the stressful period was confined to early post-mixing, or both.

Piglets mixed into GL experience a new social environment, which includes unfamiliar piglets and sows, a new physical environment and severe disruptions to the suckling routine (Verdon et al., 2019a). Presumably the cumulative experience of these events is stressful. Thus, it is of interest that no effect of GL or FC housing was found on the cortisol of piglets 4 h post-mixing in either experiment. The presence of familiar conspecifics (i.e., littermates) and the biological mother may have had a buffering effect on stress induced HPA activity, as has been found during the social deprivation of young piglets (Kantiz et al., 2014) and during a novel environment test using pre-weaned guinea pigs (Hennessy et al., 2006). Alternatively, piglets may cope better with the stressful events involved in GL mixing than sows. Results could also vary with a different time sampling regime to study the cortisol response.

Sow and piglet skin injuries

Sows and piglets housed in GL had a greater number of skin injuries the day after mixing than sows and piglets that remained in FC. Other experiments have reported increased aggression, and particularly fights, when mixing unfamiliar sows (Thomsson et al., 2015;

Verdon et al., 2019a) and piglets (Wattanakul et al., 1997b; D'Eath, 2005) during lactation. Schrey et al. (2018) found GL sow skin injuries to decline over days, while the present research and that of others (van Nieuwamerongen et al., 2015; Verdon et al., 2016) report no effects of GL or FC housing on piglet skin injuries at weaning. In sows this decline is likely related to a reduction in high intensity aggression and fighting over time (Verdon et al., 2019a), which is typically associated with the formation of a hierarchy, whereas in piglets the decline could be due to the positive effects of social experience on the development of the aggressive phenotype. Indeed, piglets from GL systems deliver less aggression and have fewer injuries than FC piglets when mixed at weaning (Li and Wang, 2011; Verdon et al., 2016, 2019b).

There was no effect of litter age at mixing on sow or piglet skin injuries in the present research. This finding is supported by research that has found levels of aggression to be comparable between sows mixed at 7 and 14 days post-partum (Thomsson et al., 2015; Verdon et al., 2019a). Salazar et al. (2018) found increased aggression but not injuries when piglets were mixed with an unfamiliar litter at 7 days post-partum in comparison to piglets in a single-litter FC, but the opposite was true when piglets were mixed at 14 days post-partum. This discrepancy may be due to differences in the systems studied by the present research (piglets mixed in GL) and by Salazar et al. (2018) (piglets mixed in FC).

Piglet mortality

Piglet mortality was greater in GL than FC in the present research, and the younger piglets were mixed into GL, the greater the mortality. Thomsson et al. (2016) similarly found piglet mortality from grouping until 6 weeks of age to decrease from 12% when mixed at 7 days of age to 1.7% when mixed at 21 days of age, and most of these deaths occurred within 7 days of mixing. Other research has also reported increased piglet mortality in GL pens compared to FC, largely due to increased crushing (Wattanakul et al., 1997a; Dybkjær et al., 2003; Kutzer et al., 2009; van Nieuwamerongen et al., 2015). Thus, high piglet mortality in loose-farrowing and lactation systems continues to be one of the greatest barriers to high piglet welfare and productivity in loose-sow systems (Baxter and Edwards, 2018).

Verdon et al. (2019a) found that piglets spend less time in the creep early after mixing, when they are at their smallest and most vulnerable to crushing, and that GL sows are more active than FC sows. These factors may increase the risk of piglet crushing. Disrupted suckling (e.g., Verdon et al., 2019a) leading to missed milk ejection may have further exacerbated the risk of mortality in GL, particularly for very young piglets. Thomsson et al. (2016) found that when piglets were mixed into GL at 7 days of age, 70% of crushed piglets were thin and 40% had no stomach contents, whereas when mixed at 14 days no crushed piglets were thin and all had stomach contents. Piglets that were not thriving (i.e., lame, scours, appearing sickly or unusually thin) were excluded from the present research but piglets were not excluded based on size, and mortality risks were higher for piglets that were smaller at day 6 post-partum, regardless of treatment. Research is required to ensure that GL systems are suitable for all piglets, rather than those that are larger and more robust, and to clarify the causes of piglet mortality in GL systems, e.g. more piglets missing milk ejection, low creep occupation, impaired sow-piglet communication.

It was not possible to control or balance for sows that had reared litters in GL pens previously in this research. Sow experience could potentially contribute to piglet survival and welfare in alternative systems, as has been observed by other research on loose-sow farrowing and lactation system (Wechsler and Brodmann, 1996; Hales et al., 2014; King et al., 2018). For example, transitioning sows and their litters to GL pens after 11 days in FCs tends to result in greater mortality than transitioning from loose-sow single litter lactation pens to GL (Dybjaer et al., 2001). In addition to the experience of the sow, the experience of stock people is integral to the success of GL systems. As reviewed by van Nieuwamerongen et al. (2014), piglet mortality generally declines as the stockpeople become more experienced with group housing (also see Wechsler, 1996; Li et al., 2010; Grimberg-Henrici et al., 2016). This may be evidenced by the effects of replicate on piglet mortality in experiment 1, which declined over time for GL treatments.

Piglet growth

In experiment 1 of the present research, GL_7 piglets had a lower ADG and were lighter than GL_{14} piglets at weaning, but in experiment 2 GL_{10} and GL_{14} piglets did not differ. By contrast, Thomsson et al. (2016) found no effect of age at mixing in GL (7, 14 or 21 days post-partum) on piglet weight at weaning or weight gain from birth to weaning. The weaning of piglets at 6 weeks of age in the research of Thomsson et al. (2016), compared to approximately 3.5 weeks in the present research, may have provided greater opportunity for piglet weights to equalize between the treatments through the consumption of creep feed.

Several factors may have contributed to the reduced weight of GL piglets at weaning compared to FC piglets in the present research. Firstly, GL piglets may have consumed less creep feed than those in FC. Providing piglets with the opportunity to observe and interact with the sow while she eats can increase pre-weaning consumption of creep feed (Oostindjer et al., 2011) resulting in similar weaning weights for piglets in GL and FC systems (e.g., van Nieuwamerongen et al., 2015). However, in GL pens where piglets cannot observe the sows eating, such as those utilized in the present research, GL piglets are lighter at weaning than FC piglets (Wattanakul et al., 1997a; Verdon et al., 2016). Weary et al. (2002) found that piglets that mingled in groups during lactation consumed more creep feed, but nursed less frequently and gained less weight, than piglets that remained in single-litters. Given this, a second explanation is that cross-suckling disrupts sow nursing in GL (Wattanakul et al., 1997a; Verdon et al., 2019a), thus limiting the opportunity for piglets to suckle successfully (Pedersen et al., 1998). Finally, piglets were more active in GL than FC (Verdon et al., 2019), which may also contribute to the reduced weight gain of GL piglets.

In experiment 2 there was less variation in piglet weight at weaning in the GL_{14} treatment than the GL_{7} or FC treatments, and in experiment 1 there was a tendency for the same effect. These findings contrast with previous research that reports no difference in variation between individual piglet weights at weaning in GL compared to FC (Wattanakul et al., 1997a), and when housed in GL from 7, 14 or 21 days of age (Thomsson et al., 2016). Differences between treatments in the present research were small (< 5% difference in variation), and thus further research with a larger sample size is required.

Sow productivity

Sows in the GL_{7} treatment lost less weight and P2 backfat than GL_{14} and FC sows, and were consequently heavier at weaning, and GL_{10} sows tended to be heavier than GL_{14} and FC sows at weaning. Wattanakul et al. (1997a) found sows transferred from FC to GL at 14 days postpartum had a lower feed intake and consequently lost more weight and backfat than FC sows in one experiment, but not in a second experiment. There was no effect of treatment on sow feed intake in either experiment of the present research. Thus, an alternative explanation for these results is that GL sows utilize less fat reserves for milk production, given that lactation is energetically expensive (Curry, 2010) and nursing behavior is disrupted by GL housing (Dybjaer et al., 2001; Verdon et al., 2019a).

While sow reproduction in the subsequent gestation was not affected by lactation housing in either experiment of the present research (n=180 and n=108 sows in experiments 1 and 2, respectively), Thomsson et al. (2018) found shorter wean-to-mate interval for sows mixed into GL at 14 or 21, but not 7, days post-partum (n=43 sows). As discussed by Thommson et al. (2018), lactational anestrus is maintained until sow-piglet nursing bonds weaken. Verdon et al. (2019a) found that sows in FC have more successful nursing bouts, but those in GL interact with their piglets more often. We speculate that these maternal behaviours both act to extend lactational anestrus. The inconsistencies between the present research and Thommson et al. (2018) highlight how little is known about the effects of group lactation on sow reproduction, and the need for further research with increased replication.

CONCLUSION

Under the conditions of the present experiment, the known welfare benefits of two-stage GL housing (i.e., reduced sow confinement, better development and expression of behaviour, improved piglet performance post-weaning) are achieved at a welfare cost to piglets in terms of piglet mortality, piglet growth, and injuries early post-mixing. Transferring piglets from FC to GL before 14 days of age further increases the risk of piglet mortality. These results raise ethical questions on whether the welfare benefits of loose-housing of sows and litters in groups outweigh the welfare costs, particularly in terms of piglet mortality. Research to understand the cause of greater piglet mortality (e.g., piglets missing milk ejection, low creep occupation, sow experience) and reduced piglet growth (e.g., reduced nursing frequency, cross-suckling, low creep feed intake), along with refinements to pen design (e.g., increase creep attractiveness, provide sows opportunities to separate from piglets particularly later in lactation) may help reduce the welfare costs of two-stage GL and thereby allow these systems to achieve their ethical and economical potential.

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Table 1. Details relating to animals studied in experiments 1 and 2.

	Experiment 1	Experiment 2
Treatments[1]	GL_7 GL_{14} FC	GL_{10} GL_{14} FC
Time replication	5	3
Experimental unit[2]	GL pen or FC cohort	GL pen or FC cohort
Number of experimental units	30	18
Number of sows	180	108
Number of focal sows[3]	60	36
Number of piglets	1887	1179
Number of focal piglets[3]	120	72
Sow parity[4]	3.3 ± 1.9	4.4 ± 1.8
CV sow parity (%)[5]	68 ± 21	44 ± 11
Sow weight (kg)[4]	276 ± 14	274 ± 43
CV sow weight (%)[5]	15 ± 4.7	15 ± 4.7
Litter size, day 6 post-partum[4]	10.5 ± 0.7	10.6 ± 1.4
Piglet weight per litter, day 6 post-partum (kg)[4]	2.7 ± 0.35	2.6 ± 0.26
Weaning age, days post-partum	25.5 ± 2.2	25.8 ± 1.8

[1]GL_7, GL_{10} and GL_{14} = group lactation housing from 7, 10 or 14 days post-partum, respectively. FC = farrowing crate housing from birth until weaning.
[2]Six sows and litters per FC cohort (2 focal sows and 4 focal piglets per cohort). One pen of 5 and one pen of 7 sow and litter units per GL_7 or GL_{14} treatment, per replicate.
[3]Focal animals used for measures of stress physiology and skin injuries.
[4]Grand mean ± standard deviation
[5]CV = coefficient of variation, within GL pens or FC cohorts. Grand mean ± standard deviation.

Table 2. For experiments 1 and 2, the effects of lactation housing (farrowing crates, FC; group lactation housing from 7, 10 or 14 days of age, GL_7, GL_{10} or GL_{14}, respectively) on variables related to sow and piglet weight and piglet mortalities. Least square means (per sow or piglet and GL pen or FC cohort) ± pooled standard error of the mean (SE_P) are presented.

	Treatment			SE_P	Test statistic	*P*-value
	FC	[1]GL_X	GL_{14}			
Experiment 1						
Piglets						
Proportion mortalities	0.03^{a}	0.17^{b}	0.08^{c}	0.07	$F_{2,19.2} = 36.1$	< 0.001
Proportion of mortalities due to overlay[3]	0.67 (15.4)	0.79 (15.2)	0.68 (15.9)	0.06	$H_2 = 0.035$	0.98
ADG (kg)[4]	0.34^{a}	0.29^{b}	0.32^{c}	0.01	$F_{2,20.2} = 11.5$	< 0.001
Weaning weight (kg)	6.93^{a}	5.92^{b}	6.38^{c}	0.22	$F_{2,23} = 10.8$	< 0.001
CV weaning weight	0.23	0.25	0.22	0.01	$F_{2,27} = 2.77$	0.08
Sows						
Litter size[2]	10.8	10.5	10.4	0.17	$F_{2,175} = 1.0$	0.37
Start weight (kg)[2]	273	282	270	3.1	$F_{2,176} = 1.49$	0.23
Parity[2]	3.8	3.9	3.7	0.14	$F_{2,176} = 0.21$	0.81
Weight loss (kg/day)	0.96^{a}	0.57^{b}	0.75^{c}	0.09	$F_{2,23} = 18.2$	< 0.001
Weight at weaning (kg)	242^{a}	264^{b}	244^{a}	5.3	$F_{2,23} = 9.51$	0.001
P2 loss (mm/day)	0.11^{a}	0.06^{b}	0.08^{ab}	0.02	$F_{2,23} = 3.65$	0.04
P2 at weaning (mm)	26.6	25.5	28.1	1.1	$F_{2,23} = 2.10$	0.15
ADFI (kg)[5]	6.2	6.6	5.7	0.34	$F_{2,23} = 3.07$	0.07
Experiment 2						
Piglets						
Proportion mortalities	0.02^{a}	0.12^{b}	0.08^{c}	0.01	$F_{2,14.2} = 29.9$	< 0.001
Proportion of mortalities due to overlay	0.45	0.77	0.61	0.07	$F_{2,13} = 1.96$	0.18
ADG (kg)[4]	0.25^{a}	0.21^{b}	0.19^{b}	0.01	$F_{2,13.9} = 12.7$	< 0.001
Weaning weight (kg)	7.03^{a}	6.35^{b}	6.14^{b}	0.25	$F_{2,13} = 6.61$	0.01
CV weaning weight	0.24^{a}	0.25^{a}	0.20^{b}	0.01	$F_{2,13} = 5.8$	0.02
Sows						
Litter size[2]	10.6	10.5	10.6	0.14	$F_{2,104} = 0.09$	0.94
Start weight (kg)[2]	278	276	267	4.2	$F_{2,104} = 0.65$	0.52
Parity[2]	4.5	4.9	4.2	0.18	$F_{2,107} = 0.18$	0.83
Weight loss (kg/day)	0.73	0.39	0.40	0.10	$F_{2,6.9} = 3.4$	0.09
Weight at weaning (kg)	251	260	254	10.5	$F_{2,12.3} = 3.2$	0.08
P2 loss (mm/day)	0.08	0.04	0.06	0.03	$F_{2,13} = 0.92$	0.42
P2 at weaning (mm)	24.9	26.0	25.0	0.46	$F_{2,15} = 0.53$	0.60
ADFI (kg)[5]	7.0	7.1	7.2	0.26	$F_{2,6.4} = 0.35$	0.72

[1]GL_7 experiment 1; GL_{10} experiment 2

[2]ANOVA with FC, GLx or GL_{14} treatment as fixed effect. Data for individual animals utilised. Litter size and sow parity taken at day 6 post-partum, sow start weight taken at entry to farrowing house.

[3]Analysed using Kruskal-Wallis. Raw means for the proportion of piglet mortalities that were caused by overlays ± pooled standard error of the mean (SE_P), with rank presented in parenthesis.

[4]Average daily growth

[5]Average daily intake

Table 3. For experiments 1 and 2, the effects of lactation housing (farrowing crates, FC; group lactation housing from 7, 10 or 14 days of age, GL_7, GL_{10} or GL_{14}, respectively) on sow reproduction for the subsequent gestation. Least square means (per sow and GL pen or FC cohort) ± pooled standard error of the mean (SE_P) are presented.

	Treatment			SE_P	Test statistic	*P*-value
	FC	[1]GL_X	GL_{14}			
Experiment 1						
Farrowing rate %	90.4	80.9	83.0	6.7	$F_{2,149} = 0.67$	0.51
Culls or deaths %	10.5	20.3	10.5	3.0	$F_{2,170} = 1.50$	0.23
Wean-to-mate interval, days[2]	5.7 (68.3)	7.5 (87.1)	8.5 (82.2)	0.55	$X^2(2) = 5.42$	0.07
Experiment 2						
Farrowing rate %	85.2	93.9	90.9	10.3	$F_{2,90} = 0.66$	0.52
Culls or deaths %	22.9	5.7	10.8	4.3	$F_{2,104} = 2.15$	0.12
Wean-to-mate interval, days[2]	4.5 (40.6)	5.0 (50.7)	5.9 (53.2)	0.41	$X^2(2) = 4.13$	0.13

[1]GL_7 experiment 1; GL_{10} experiment 2

[2]Analysed using Kruskal-Wallis. Raw means are presented, with rank presented in parenthesis. SE_P for raw values are presented.

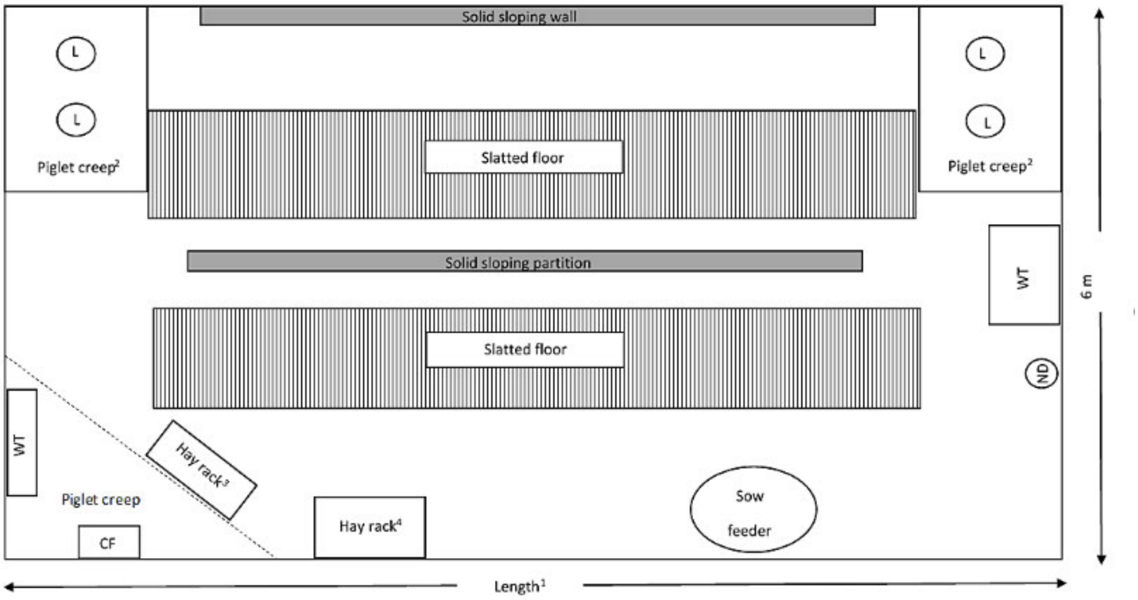
Figure captions

Figure 1. Layout of group lactation pens. [1]Length was 9.5 m for pens of 7 sow/litter units and 7 m for pens of 5 sow/litter units. [2]Heated creep dimensions were 2.0 × 1.2 m for pens of 7 sow/litter units and 2.1 × 0.85 m for pens of 5 sow/litter units. Position of hack rack in pens of [3]5 sow/litter units and pens of [4]7 sow/litter units. CF = creep feed, WT = water trough, L = heat lamp, ND = nipple drinker.

Figure 2. The effects of lactation housing (Housing: GL or FC), litter age at mixing (Age: 7 or 14 days postpartum) and observation day (Day: day 2 post-mixing or the day prior to weaning; x-axis) on sow and piglet cortisol (ng/mL) and injuries, in experiment 1 (A-D) and 2 (E-F). Data for sows mixed into group lactation at 7 (GL_7; ▬) or 14 days (GL_{14}; ▪▪▪), and for those that remained in farrowing crates but recorded at the same days as GL_7 (FC_7; ▬) or GL_{14} (FC_{14}; ▪▪▪) treatments are indicated by separate lines. Raw means ± 1 SEM are presented. Transformed means ± pooled SE can be viewed in Supplementary Table 1. When there is a significant interactive effect, means with different superscript letters within days [a,b] or between days [c,d] differ at $P \leq 0.05$..

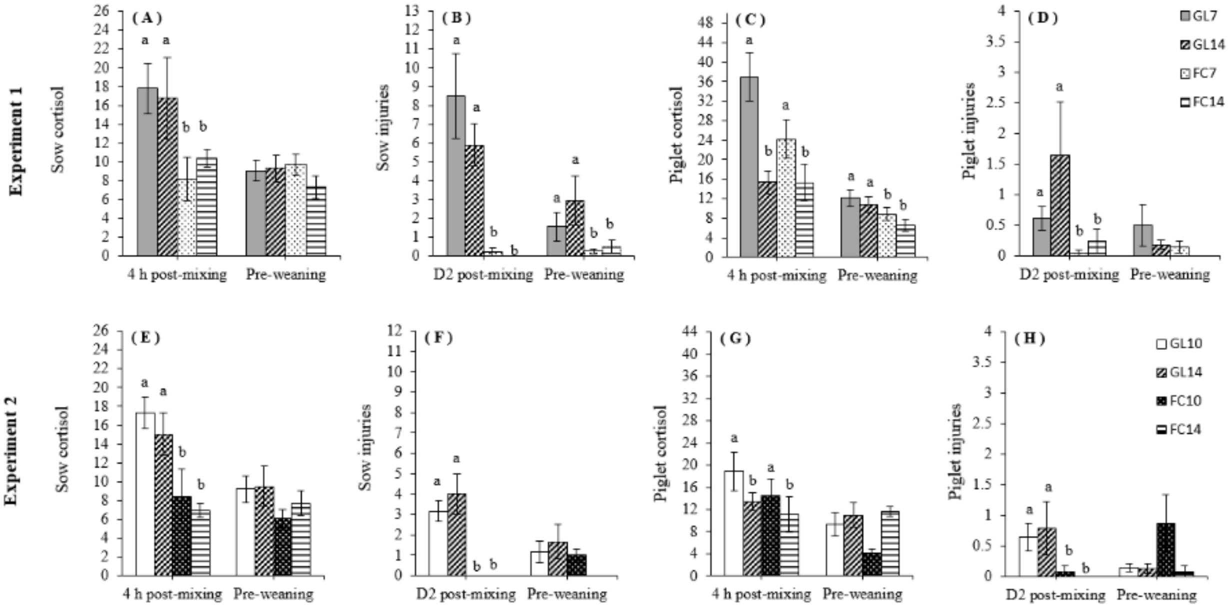
Figure 3. Boxplots representing raw proportions of piglet mortality (per GL pen or FC cohort) over (A) 5 time replicates in experiment 1 and (B) 3 time replicates in experiment 2. Boxplots show the median and the first and third quartiles (25 and 75% of data) with whiskers extending to the lowest and highest values (when different to the first and third quartiles).

Figure 1



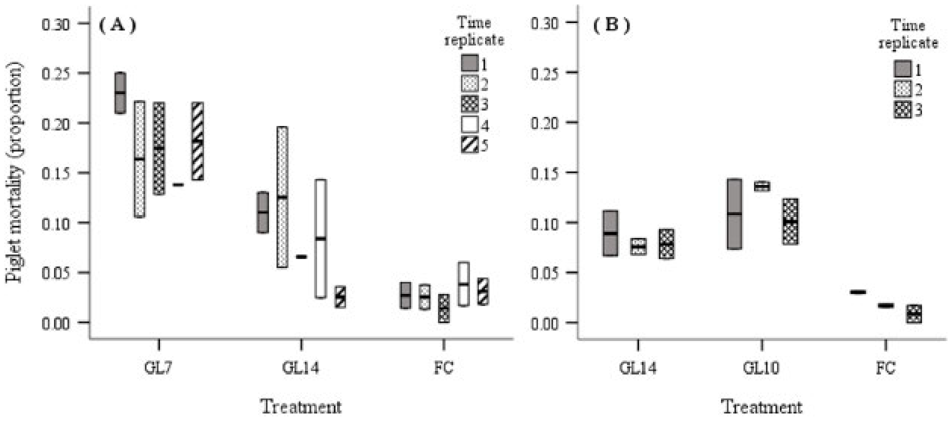
Solid sloping wall
L
L
Piglet creep²
L
L
Piglet creep²
Slatted floor
Solid sloping partition
WT
6 m
Slatted floor
ND
WT
Hay rack³
Piglet creep
CF
Hay rack⁴
Sow
feeder
Length¹

Figure 2



Experiment 1
Experiment 2
(A)
(B)
(C)
(D)
(E)
(F)
(G)
(H)
Sow cortisol
Sow injuries
Piglet cortisol
Piglet injuries
4 h post-mixing
Pre-weaning
D2 post-mixing
GL7
GL14
FC7
FC14
GL10
FC10

Figure 3



(A)
(B)
Piglet mortality (proportion)
0.30
0.25
0.20
0.15
0.10
0.05
0.00
Time replicate
1
2
3
4
5
GL7
GL14
FC
GL10
Treatment