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Animal Welfare 2014, 23: 343-351
ISSN 0962-7286
doi: 10.7120/09627286.23.3.343

Effect of gestation management system on gilt and piglet performance

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Abstract

Individual gestation housing of pregnant sows in stalls from four weeks after mating is banned in the EU. Two experiments were conducted to study the effect of two gestation management and housing systems (STALL: gilts housed in stalls and PEN: gilts loose-housed in pens with increased feed ratio) on gilt and piglet performance during lactation. Thirty-seven PEN and 33 STALL gilts were used. Backfat, litter pre-weaning mortality and total feed intake (TFI) during lactation were recorded in gilts. Weight and rectal temperature was recorded in piglets. In Exp 1 the behaviour of a subsample of gilts was videotaped during lactation. In Exp 2 saliva cortisol in gilts, thyroid stimulating hormone (TSH) and T4 hormones in piglet blood were measured. PEN gilts had more backfat when moved to the farrowing stalls. PEN gilts tended to have higher cortisol concentration 24 h after entering the farrowing stall and to spend more time sitting or standing up one day before parturition than STALL gilts. PEN piglets had higher bodyweight (BW) on day 0 (Exp 2) and lower T4 concentration than STALL piglets. However, STALL piglets showed higher rectal temperature 60 min after birth and lower mortality at day 2. In Exp 2, STALL piglets also had higher BW and average daily gain at weaning. During lactation, PEN gilts lost more backfat and weaned less piglets. Gilts loose-housed with increased feed ratio during gestation might be more stressed when housed in farrowing stalls than those kept in stalls during gestation, thus compromising their offsprings' thermoregulatory capacity and growth however, from our results, it is difficult to differentiate the effect of feed level from the effect of allocation during gestation.

Keywords: *animal welfare, gilt, housing system, mortality, piglet, thermoregulation*

Introduction

According to EU Directive 2001/88/CE, group housing of pregnant sows as of four weeks after mating until one week before farrowing became mandatory as of January 1, 2013. Gestation management and housing systems have implications for animal welfare. During gestation, sows in groups encounter greater welfare challenges in the early stages of gestation than sows that are housed in stalls, with more aggression and higher cortisol levels, whereas the opposite is true in late gestation (Marchant & Broom 1994; Anil *et al* 2005; Karlen *et al* 2007). Many studies have also looked at the possible effects of loose housing during gestation on sow welfare at and after farrowing. Inability to show maternal behaviour near farrowing leads to more active and restless sows when loose-housed during pregnancy compared to those kept in stalls (Marchant & Broom 1993; Baxter *et al* 2012). Cortisol levels have also been shown to be higher when loose-housed sows are moved to farrowing crates compared to those moved to farrowing pens (Oliviero *et al* 2008). Conversely, loose housing at gestation may help to improve delivery performance of sows due to exercise (Hemsworth 1982) although McGlone *et al* (2004) concluded that there are no differences in farrowing performance between pen- and stall-housed pregnant sows. Some studies have also looked at different effects of gestation housing on piglet performance and welfare during and after farrowing. Kranendonk *et al* (2007) observed that offspring can be negatively affected not only by elevated maternal cortisol concentration during gestation but also by a low social rank of their mother during gestation. On the other hand, Schenk *et al* (2008) found that gilts with no exercising during gestation had increased pre-weaning litter mortality.

A proper control of gestating sows' nutrition and body condition in group-housing systems is also a concerning issue. As reviewed by Spoolder *et al* (2009), underfeeding in group-housing systems with floor feeding may be a particular problem in submissive and/or slow-eating sows. Increasing feeding levels in pen-housed gilts improves their body condition and decreases cortisol levels during gestation (Amdi *et al* 2013). However, few studies on sows with increased feed ratio during gestation in group-housing systems have been done. Van der Peet *et al* (2004) found

that during gestation in a group-housing system, *ad libitum*-fed sows did not differ in their reproductive performance from restricted-fed sows over three reproductive cycles, but more information is required to optimise the transition of gilts and sows from gestation pens to farrowing stalls.

We hypothesised that a transition from pen housing to farrowing stalls in gilts with increased feed ratio during gestation should not negatively impact gilt reproductive performance. Thus, the objective of these experiments was to compare two gestation systems already in use before the introduction of the EU Directive 2001/88/CE, differing in their housing and feeding ratio management, focusing on their effect on gilts' adaptation to farrowing stalls and on piglet performance and physiological development. Results from this work should help better understand the impact of gestation management systems that are being implemented by producers under the new legislation.

Materials and methods

Experimental design and treatments

Two experiments were conducted on a 6,000-sow commercial farm in Lleida, Spain, after being approved by the Institutional Animal Care and Use Committee of the Universitat Autònoma de Barcelona (UAB). Gilts (Large white × Landrace) were stall-housed from service to 28 days after service. Following confirmation of pregnancy by ultrasound, gilts were moved to the gestation room and randomly allocated to one of two gestation housing systems (see below).

Gilts loose-housed in pens with increased feed ratio (PEN)

Gilts in group pens were housed in four pens of nine gilts each (36 gilts total). Pens were concrete floored (6.4 × 7.5 m [length × width]; 4.8 m^2 per gilt) including a slatted dunging area (7.5 × 1.1 m) and an automatic feeding system (Evofeed® feeder, Erra Tecni-Ram SL, Spain) with one feeder per pen. The feeder detected the presence of an animal via laser detector, delivering a small amount of feed every 30 s as soon as the animal introduced its head into the feeder. Once the sow removed the head from the feeder, it stopped feed delivery. Farmers were able to set the number of sows in the group, along with the kg of feed per sow, per day. In the present experiment the system was set for nine gilts with an average ingestion of 2.5 kg of feed per sow per day, aiming to slightly increase animals' feed ratio. While eating, gilts were not protected or isolated from their pen-mates.

Gilts housed in stalls with regular feeding ratio (STALL)

Gilts were housed in individual, concrete-floored steel stalls (2.0 × 0.6 m; 1.2 m^2 per gilt) including a 0.5 m^2 slatted dunging area. Feed was provided twice a day with automatic feeders following a standardised feeding pattern. Gilts were fed 2.1 kg per day per gilt until day 90 of pregnancy and 2.8 kg per day per gilt afterwards, resulting in a mean intake of 2.2 kg per day per gilt. Feeders were volume-regulated and calibrated for the particular feed used in the trial.

The two systems shared environmental conditions. Temperature was not regulated except for a forced ventilation system set to 20ºC. All animals in the gestation room were fed a commercial diet based on wheat, sunflower meal, wheat bran and rice bran (133 g CP, 5.4 g Lys and 12.2 MJ ME per kg as fed) to meet or exceed their nutritional requirements (NRC 1998). Water was available *ad libitum* throughout gestation by a nipple drinker opposite the feeder in each pen. On day 109 of gestation all gilts were moved to a climate-controlled (25ºC) farrowing room. A total of six farrowing rooms with 14 individual farrowing pens each were used. Gilts from the two treatments were evenly distributed within each room. Farrowing pens (4.37 m^2) were distributed in two rows with a central alley and had plastic slat flooring and a farrowing stall (1.20 m^2) in the centre. Each pen was provided with a creep area for piglets (0.42 m^2) on one side of the pen. In accordance with the farm's usual feeding protocol, on farrowing day gilts' feeders were emptied and gilts were not offered any feed for the following 24 h. The amount of daily feed was increased each day until reaching *ad libitum* after one week of lactation. Twice daily gilts were given a dry feed based on wheat, barley, soybean meal and wheat bran (15 g CP, 8.2 g Lys and 13.4 MJ ME per kg as fed) that met or exceeded nutritional requirements (NRC 1998). Leftovers were removed from the feeder and weighed to record ingestion. Gilts and piglets had *ad libitum* access to water in separated nipple drinkers. Procedures performed on piglets included the administration of a 1 ml iron supplement subcutaneously (Ferrovial, MEVET, Lleida, Spain), tail docking and clipping an identification tag in the right ear on the third day, post partum. Weaning was carried out at 23 (± 2) days of age and throughout the experiment animals were checked twice daily for health or eating problems. Gilts included in the experiment were selected from all the gilts that farrowed within three days after the start of the experiment.

Experiment 1

A total of 27 gilts were included in the PEN group and 24 in the STALL group. Backfat thickness was measured on the P2 spot (last rib, 65 mm from the dorsal middle line) on both sides of the body using a Renco Lean Meater ultrasound system (Renco Corporation®, North Minneapolis, MN, USA) after they entered the farrowing room and at day 20 after farrowing. The numbers of piglets born alive, stillborn and mummified were recorded after completion of farrowing (expulsion of the placenta). Each farrowing event was monitored individually and the birthing time for each piglet recorded. Assistance was provided for gilts still attempting contractions 45 min after delivery of the last piglet (an interval of 45 min elapsed between each piglet), and gilts that needed assistance during delivery were registered. Piglets were ear-notched after birth (339 piglets for PEN group and 331 piglets for STALL group) for individual identification and weighed on day 0, 1 (18 to 24 h after birth), 2 (42 to 48 h after birth) and 20 (end of the experimental trial). Piglets were cross-fostered within treatment groups on day 2 so that litters had 12.0 (± 0.08) piglets per litter, aiming for a minimum number of piglets transferred within litters. When necessary, transfers were performed based on piglets' bodyweight (BW). The extra piglets were

https://doi.org/10.7120/09627286.23.3.343 Published online by Cambridge University Press

transferred to sows not included in the experiment. Litter pre-weaning mortality and gilts' total feed intake (TFI) were recorded via daily checks of litters and gilts' feeders during the first 18 days of lactation.

The behaviour of ten PEN and eight STALL gilts was videotaped continuously in two rooms with two Network IP7142 cameras (Vivotek®, San Jose, CA, USA) two days before and two days after farrowing. Gilts' number of movements, ie the number of times the gilt changed from one posture to another, and time spent in each posture were recorded. Postures were described as: lying in sternal, ventral or lateral recumbence; sitting partially upright on stretched front legs with caudal end of body in contact with the floor; or standing on extended legs with only hooves in contact with the floor (modified from Wischner *et al* 2009). Video recordings of gilt behaviour were assessed by the same observer who was blind to treatments.

In order to assess piglet distribution in the farrowing pens during the first day of lactation, piglets from 13 litters (five litters from PEN gilts and eight from STALL gilts) were videotaped with eight Network IP7142 cameras (Vivotek®, San Jose, CA, USA) during the first 20 h post partum. Cameras were programmed for scan-sampling (30-s recordings every 10 min) starting after delivery of the last part of placenta and the first clear image of each recording was used. Sow position was recorded as either lying with the udder exposed to the creep area, or exposed to the other side of the pen. Piglet distribution was recorded according to the number of piglets in the following areas: i) mammary gland area, including any piglet standing, suckling, massaging the udder, lying, or sleeping next to or in contact with the udder (not differentiating among these activities); ii) creep area, including any piglet standing, lying, or sleeping in the creep area; and iii) other areas including any piglet being in an area of the farrowing pen not previously described. Video recordings of piglet distribution throughout the farrowing pen were assessed by the same observer who was blind to treatments.

Experiment 2

Saliva samples to measure cortisol were collected from 12 gilts from the PEN group and 19 from the STALL group, 24 h after entering the farrowing rooms and again during the last week of lactation. Saliva samples were collected between 1000 and 1200h using cotton swabs (Salivette®, Stardedt, Nümbrecht, Germany). Gilts were allowed to chew on the Salivette® for approximately 30 s. Samples were centrifuged at 3,000× g for 15 min at 5ºC and stored frozen at –22ºC until analysed. Cortisol was measured in salivary samples with a luminescence immunoassay kit (DRG Instruments, Marburg, Germany).

From the initial 12 and 19 gilts sampled for saliva, we could only individually monitor the farrowing (as described for Exp 1) of ten gilts in the PEN group and nine in the STALL group. The variables recorded for the individually monitored sows during lactation in Exp 2 were the same as described for Exp 1. Shortly after birth, piglets from the individually monitored sows were ear-notched for individual identification (117 piglets for PEN group and 102 for STALL groups) and their rectal temperature recorded 1 (RT1), 24 (RT24) and 48 h (RT48) after birth (MSR® thermometer, Measure Technology Co Ltd, Taipei, Taiwan, with a display resolution of 0.01ºC and an ± 0.1ºC accuracy). Piglets were weighed on days 0, 1, 2 and 17 (end of the experimental trial). Cross-fostering was performed at 48 h of age obtaining litters with 12.4 (± 0.18) piglets per litter as described in Exp 1. Mortality was registered as described in Exp 1. Then, all piglets that died within the first 48 h of life were weighed and classified as culled, crushed with colostrum or milk in the stomach, crushed without colostrum or milk in the stomach, or starved to death. All piglets that died after the first 48 h of life were classified as crushed, starved to death, dead following diarrhoea and dead from other causes. A piglet was classified as crushed when internal or external traumas were visible. A 3 ml blood sample from two piglets from each monitored gilt was obtained when the umbilical cord was severed (20 piglets from the PEN group and 18 from the STALL group). Blood was centrifuged at 2,000× g for 10 min at 18ºC within 30 min and the serum was stored at –22ºC for thyroid stimulating hormone (TSH) and thyroid hormone (TH) T4 analysis. TSH was measured in serum samples with a third generation TSH Immulite® kit (Siemmens, Deerfield, USA) and T4 was measured in serum samples with a total T4 Immulite® kit (Siemmens, Deerfield, USA). The sensitivity for TSH and T4 was 0.01 μ IU mL^{-1} and 1.0 μg dL^{-1}, respectively. The intra- and inter-assay CV were, respectively, 8.5 and 15.1% for TSH, and 5.6 and 9.7% for T4. Ranges were 0.011–0.097 μ IU mL^{-1} for TSH and 1.0–11.0 μg dL^{-1} for T4.

Statistical analysis

All statistical analyses were carried out using SAS 9.2 (SAS Inst Inc, Cary, NC, USA). All data were examined to determine distribution using Univariate procedure of SAS. For piglets' data, sow or litter was introduced as random effect in the models and nested within main treatment effect. The alpha level of significance was set at 0.05. Data from sows (BF, farrowing duration, feed intake, reproductive performance traits, piglets weaned) and mortality were analysed merging the two experiments and including 'Exp' in the model as random effect. Piglets' BW and growth were analysed for each experiment separately because measuring moments or days differed between experiments. Obviously, data measured exclusively in one of the two experiments were analysed independently (sows' behaviour, piglet distribution, rectal temperature, cortisol, TSH, T4). Differences between treatments for BF, BF loss during lactation, duration of farrowing, mortality, number of piglets weaned and sows' TFI were analysed by generalised linear mixed models using the GLIMMIX procedure of SAS. The model included the treatment as a fixed effect for all variables, farrowing room was also included in the model and removed if not significant, and the assistance at farrowing was included as a fixed effect for the duration of farrowing. Number of piglets per sow after cross-fostering was introduced as covariate for the number of weaned piglets. Total number of piglets born alive, stillborn and mummified were

Table 1 Effect of gestation management system on gilt's back fat, farrowing duration, reproductive performance, total feed intake during lactation and litter mortality (Exp 1 and Exp 2).

Variable	PEN	STALL	SEM	$F_{1, 60}$	*P*-value
N	37	33	–		
Initial BF (mm)†	19.4	15.0	0.78	34.53	< 0.001
Final BF (mm)‡	15.7	13.1	0.64	18.27	< 0.001
BF loss (mm)§	3.7	1.9	0.39	21.43	< 0.001
First ten piglets (min)#	118	134	19.1	3.48	0.067
Farrowing duration (min)¶	167	189	15.9	3.87	0.054
Lactation total feed intake (kg)	109	113	6.0	3.94	0.052
Litter size					
Born alive	13.3	13.8	0.04	0.94	0.337
Stillbirth	0.78	0.77	0.244	0.33	0.567
Mummified foetuses	0.78	0.77	0.276	0.00	0.974
Mortality (%)					
First 48 h of life	11.5	8.7	0.38	0.50	0.482
From day 2 to weaning	6.5	1.9	0.40	11.68	0.001
Total mortality	18.9	11.8	0.07	78.01	< 0.001

† Backfat thickness measured when entering the farrowing facilities.
‡ Backfat thickness measured at the end of the experiment (day 20 after farrowing).
§ Initial BF – Final BF.
# ME between the birth of the first and tenth piglet.
¶ Time between the birth of the first and the last piglet.

analysed by generalised linear mixed models using the MIXED procedure of SAS following a negative binomial distribution and with treatment as the main effect, farrowing room was also included in the model and removed if not significant. Cause of death of the piglets was analysed using a non-parametric test with NPAR1WAY procedure. Sow cortisol concentration in saliva and piglet serum concentration of TSH and T4, BW, BW gain and rectal temperature parameters were analysed by generalised linear mixed models using MIXED procedure of SAS. The model included treatment and farrowing room as fixed effects. For BW and rectal temperature, initial BW was introduced as a covariate and sow as random effect nested within main treatment. The interaction between treatment and initial BW was also included in the model.

The percentage of piglets in each area of the pen were analysed as repeated measures by generalised linear mixed models using the GLIMMIX procedure of SAS. The model included treatment and posture of the gilt (udder exposed towards the creep area or udder exposed towards the opposite side of the pen) as fixed effects and the interaction between them was also included. Behavioural traits for gilts were also analysed by repeated measures using the MIXED procedure of SAS. The model included treatment and day of sampling as fixed effects and the interaction between treatment and day of sampling were also included.

Results

Gilts' performance and litter mortality results obtained after merging the data from the two experiments are presented in Table 1. When entering the farrowing rooms, gilts from the PEN group had higher BF than gilts from the STALL group ($F_{1,60} = 34.53$, $P < 0.001$). Although PEN gilts lost more BF than STALL gilts ($F_{1,60} = 21.43$, $P < 0.001$) during lactation, PEN gilts still had more BF than STALL gilts at weaning ($F_{1,60} = 18.27$, $P < 0.001$). There was a tendency for PEN gilts to have shorter total farrowing time (interval between the birth of the first and the last piglet) than STALL gilts ($F_{1,60} = 3.87$, $P = 0.054$) and also a tendency for lesser time between the birth of the first and tenth piglet ($F_{1,60} = 3.48$, $P = 0.067$). No differences were observed between treatments for reproductive performance traits (piglets born alive, stillborn and mummified). STALL gilts tended to have higher TFI during lactation than PEN gilts ($F_{1,60} = 3.94$, $P = 0.052$). Piglet mortality during the first two days of lactation (before cross-fostering) did not differ between groups ($F_{1,60} = 0.50$, $P = 0.482$), but from cross-fostering (at 48 h post partum) to the end of lactation, mortality was higher in PEN than in STALL litters ($F_{1,60} = 11.68$, $P = 0.001$). Overall, pre-weaning mortality was also higher in PEN litters ($F_{1,60} = 78.01$, $P < 0.001$). Accordingly, at the end of lactation, STALL gilts weaned more piglets than PEN gilts (11.9 vs 11.1 [± 0.02]; $F_{1,60} = 12.92$, $P < 0.001$).

https://doi.org/10.7120/09627286.23.3.343 Published online by Cambridge University Press

Table 2 Effect of gestation management system on piglets' performance during lactation (Exp 1)†.

Item	PEN	STALL	SEM	$F_{1, 51}$	*P*-value
N	27	24			
BW (kg)					
After farrowing (day 0)	1.30	1.28	0.012	0.49	0.485
Day 1	1.37	1.39	0.013	0.51	0.475
Day 2	1.39	1.44	0.028	1.59	0.207
Day 20	5.50	5.60	0.002	0.72	0.397
BW gain the first 24 h post partum (kg)	0.042	0.059	0.0033	3.56	0.059
ADG from day 2 to 20 of life (kg per day)	0.220	0.227	0.0021	1.76	0.185

† All data presented as LSmeans

Table 3 Effect of gestation management system on the activity of gilts during the 2 days before and after parturition, recorded for a 24-h period each day (Exp 1).

Item	PEN	STALL	SEM	χ^2_1	*P*-value
N	10	8			
Number of movements					
Day 2 before parturition	68	49	5.5	2.03	0.154
Day 1 before parturition	206	154	13.5	3.01	0.083
Day 1 after parturition	53	38	5.9	1.11	0.291
Day 2 after parturition	52	47	4.6	2.87	0.090
Time spent sitting or standing (min)†					
Day 2 before parturition	102 (7.1%)	72 (5.0%)	10.1	0.57	0.451
Day 1 before parturition	280 (19.4%)	230 (16.0%)	28.1	3.62	0.057
Day 1 after parturition	91 (6.3%)	78 (5.4%)	13.3	0.20	0.646
Day 2 after parturition	94 (6.5%)	77 (5.3%)	19.6	0.21	0.644

† Minutes spent by gilts in sitting or standing position of a total of 1,440 min recorded (percentage of the total time recorded).

Results from piglet productive performance in Exp 1 are presented in Table 2. There were no differences between experimental groups for piglet BW after birth (day 0), at day 1 and at day 2, but piglets born from STALL gilts tended to grow faster than PEN piglets during the first 24 h of life ($F_{1,51} = 3.56$, $P = 0.059$). However, at the end of the lactation period, there were no differences between groups for piglet performance, and piglets from both groups did not differ in BW ($F_{1,51} = 0.72$, $P = 0.397$) or average daily gain (ADG) ($F_{1,51} = 1.76$, $P = 0.185$) at day 20. Behavioural data (Table 3) show that gilts from both experimental groups spent most of the day lying, but lying time was reduced when farrowing approached (on average 22–23 h and 19–20 h of day on day 2 and day 1 before parturition, respectively). On day 1 before parturition, the number of movements per day increased in both groups, and on day 1 and day 2 after parturition gilts from both groups showed a number of movements per day similar to day 2 before parturition. There was no effect of treatment in the number of movements during day 2 before parturition and day 1 after parturition ($\chi^2_1 = 2.03$, $P = 0.154$ and $\chi^2_1 = 1.11$, $P = 0.291$, respectively). However, PEN gilts tended to perform more movements during day 1 before parturition and day 2 after parturition ($\chi^2_1 = 3.01$, $P = 0.083$ and $\chi^2_1 = 2.87$, $P = 0.090$, respectively). During day 1 before parturition, gilts from the PEN group tended to spend more time in sitting or standing positions ($\chi^2_1 = 3.62$, $P = 0.057$) than gilts in the STALL group. As regards piglet distribution in the farrowing pen, there was a higher percentage of piglets in close contact to the udder during the first 20 h of life in STALL gilts than in PEN gilts (64.7 [± 1.02] vs 53.1 [± 1.19]%; $F_{1,11} = 6.11$, $P = 0.031$).

Results from piglet productive parameters and rectal temperature in Exp 2 are presented in Table 4. Piglets born from STALL gilts had higher RT1 ($F_{1,17} = 9.49$, $P = 0.007$), RT24 ($F_{1,17} = 7.57$, $P = 0.026$) and RT48 ($F_{1,17} = 9.52$, $P = 0.007$) than piglets born from PEN sows. Piglets born from PEN

Table 4 Effect of gestation management system on piglets' rectal temperature and growth performance during lactation (Exp. 2)[†].

Item	PEN	STALL	SEM	$F_{1, 17}$	*P*-value
N	10	9	–		–
Rectal temperature (°C)					
60 min after birth	37.0	38.1	0.27	9.49	0.007
24 h after birth	38.3	38.6	0.03	7.57	0.026
48 h after birth	39.0	39.2	0.03	9.52	0.007
BW (kg)					
After farrowing (day 0)	1.43	1.23	0.019	6.74	0.019
Day 1	1.33	1.37	0.021	1.63	0.222
Day 2	1.39	1.47	0.022	9.48	0.008
Day 17	3.74	4.37	0.079	6.08	0.028
BW gain the first 24 h post partum (kg)	–0.001	0.044	0.0004	1.90	0.189
ADG from day 2 to 17 of life (kg per day)	0.140	0.178	0.004	6.40	0.025

[†] All data presented as LSmeans.

gilts had higher BW on day 0 than piglets born from STALL gilts ($F_{1,17} = 6.74$, $P = 0.019$). However, piglet BW on day 1 and BW gain from day 0 to day 1 did not differ between groups ($F_{1,17} = 1.63$, $P = 0.222$ and $F_{1,17} = 1.90$, $P = 0.189$, respectively). Piglets born from STALL gilts had higher BW on day 2 ($F_{1,17} = 9.48$, $P = 0.008$), higher BW on day 17 ($F_{1,17} = 6.08$, $P = 0.028$) and an increased ADG at the end of the trial ($F_{1,17} = 6.40$, $P = 0.025$) than PEN piglets. During the first 48 h post partum, the number of piglets culled, crushed without colostrum or milk in the stomach, crushed with colostrum or milk in the stomach, or starved to death did not differ between experimental groups ($\chi^2_1 = 2.42$, $P = 0.118$; $\chi^2_1 = 2.14$, $P = 0.143$; $\chi^2_1 = 0.73$, $P = 0.392$; $\chi^2_1 = 0.04$, $P = 0.836$, respectively). After cross-fostering and until day 17 of lactation, the number of piglets found crushed, starved to death, dead with diarrhoea symptoms, or dead by an unknown reason did not differ between groups ($\chi^2_1 = 1.13$, $P = 0.206$; $\chi^2_1 = 2.70$, $P = 0.100$; $\chi^2_1 = 0.52$, $P = 0.471$; $\chi^2_1 = 2.29$, $P = 0.164$, respectively).

Cortisol levels obtained from saliva samples collected 24 h after entering the farrowing room tended to be higher in PEN gilts than in STALL gilts (10.21 [± 1.050] vs 8.17 [± 0.668] nM l^{-1}; $F_{1,27} = 3.56$, $P = 0.070$), whereas no difference between PEN and STALL gilts was observed in the last week of lactation for cortisol levels (5.80 [± 0.658] vs 6.35 [± 0.656] nM l^{-1}; $F_{1,27} = 0.23$, $P = 0.639$). Piglets born from STALL gilts tended to have higher levels of serum T4 than piglets born from PEN gilts (7.91 [± 0.480] vs 6.75 [± 0.393] mg dl^{-1}; $F_{1,16} = 3.54$, $P = 0.078$). However, no differences were found between STALL and PEN piglets in TSH levels in serum (0.035 [± 0.0056] vs 0.038 [± 0.0057] mgU ml^{-1}; $F_{1,16} = 0.06$, $P = 0.814$).

Discussion

As we expected, in our study PEN gilts entered the farrowing facilities in higher body condition than STALL gilts. Sows that eat more than their physiological need will gain more weight and more BF than required (Spoolder *et al* 2009). During lactation, PEN gilts lost more BF compared to STALL gilts and showed a tendency for a lower feed intake during lactation. Yang *et al* (1989), Eissen *et al* (2000) and van der Peet-Schwering *et al* (2004) found that sows with higher BW and BF at the end of gestation lost more BW and BF during lactation with no reduction in feed intake. However, Amdi *et al* (2013) showed that a higher ingestion during gestation induced a higher body condition at farrowing and a reduction in lactation feed intake.

Reproductive performance did not differ between groups. McGlone *et al* (2004) in their meta-analysis of 35 scientific papers found no differences between pen and stall gestation housing systems in reproductive performance (total number of piglets born, piglets born alive and stillborn piglets). Van der Peet-Schwering *et al* (2004) also failed to find differences in reproductive performance between stall- and group-housed sows. However, Jansen *et al* (2007) reported that stall-housed sows tended to have larger litter size. Jansen *et al* (2007) had the sows in groups of 50 with 32 drop-feeders supplying three feeder troughs, and reported the feeding time as an important factor for aggression among sows while, for example, van der Peet-Schwering *et al* (2004) had their sows in groups of ten with an electronic sow feeding station. The higher levels of feeding time aggression during gestation described in Jansen *et al* (2007) could explain the reduction of litter size

https://doi.org/10.7120/09627286.23.3.343 Published online by Cambridge University Press

in group-housed sows not observed by van der Peet-Schwering *et al* (2004). The gestation management system used in the present study was more comparable to the one in the study of Jansen *et al* (2007). According to Spoolder *et al* (2009), higher weight and BF gains during gestation does not seem to affect short-term reproductive performance; however Amdi *et al* (2013) showed a lower number of piglets born alive, but not a higher number of stillbirths, in gilts fed more than recommended. It might be possible that the higher feed ingestion during gestation could cause early embryonic loss, thus reducing the number of piglets born alive per litter in the Amdi *et al* (2013) experiment, and increasing their birth bodyweight as we observed in Exp 2 (but not in Exp 1), where PEN piglets had higher BW on day 0 than STALL piglets. Differences observed among studies for reproductive performance suggest the complexity of comparing stall and pen allocation of sows during gestation without considering the potential role of the feeding system used in group-housed sows.

In accordance with Hemsworth (1982) and Oliviero *et al* (2008, 2010) there was a trend for faster delivery in PEN gilts for both the first ten piglets born and the total farrowing time. In both experiments here, piglets from the STALL group showed a better growth during the first 24 h of life and, in Exp 2, such differences were also observed at day 2 and at the end of the lactation period. Litters from the STALL group also had lower mortality. These differences may be related to the differences observed for RT after birth and also on the following days. Differences in RT shortly after birth indicate a greater thermoregulatory capacity in STALL piglets than in PEN piglets. Cold stress at birth reduces the vigour of the piglet, leading to a less active nursing behaviour and reduced colostrum intake (Herpin *et al* 2002; Alonso-Spilsbury *et al* 2007; Baxter *et al* 2008), which provides newborn piglets with energy and immunoglobulins, therefore playing an essential role in piglet survival (Quesnel 2011). The higher thermoregulatory capacity shown in STALL piglets may improve their suckling ability enhancing piglets' growth during the first days of life, and also enhancing survival from day two to weaning as observed in the study. As observed in Exp 1, the presence of more piglets at the udder during the first hours of life in STALL litters could enhance their suckling chances and, according to Kammersgaard *et al* (2011), also help the piglet to keep its body temperature. The lack of difference between groups for the cause of death, especially for deaths due to starvation and the increased mobilisation of BF during lactation by PEN gilts may suggest that milk yield might not be impaired.

Alonso-Spilsbury *et al* (2007) pointed out that piglets suffering from asphyxia had lower rectal temperatures 1 h after birth. In our study, however, it is unlikely that asphyxia was causing the differences in RT 1 h after birth because PEN gilts had faster deliveries than STALL gilts, whereas STALL piglets showed a higher RT 1 h after birth. Piglets born from PEN gilts tended to have a lower concentration of T4 than STALL piglets. Thyroid hormones are known to increase metabolic rate and thermogenesis in homothermic species (Hampl *et al* 2006; Silva 2006; Litten *et al* 2008). Berthon *et al* (1993) found that piglets with lower plasma level of T4 during the first 6 h of life also showed a greater drop in RT after birth. As described by Finsten *et al* (1998) TH are released by the thyroid gland in response to stimulation by TSH from the hypophysis which is, in turn, stimulated by the hypothalamic tripeptide thyrotropin-releasing hormone (TRH) secreted by the hypothalamo-pituitary-adrenocortical axis (HPA). Maternal prenatal stress has been observed to affect behavioural and physiological aspects of the offspring by altering the HPA-axis (McCormick *et al* 1995; Kaiser & Sachser 2001; Kranendonk *et al* 2007).

In Exp 1, gilts showed an increase in activity one day before farrowing compared to the other days of the study. These results are in accordance with those observed by Mainau *et al* (2009). Concerning treatments, PEN gilts tended to spend more time standing up or sitting up and also tended to change position more often than STALL gilts on day one before farrowing. Other authors have reported that sows that have been housed in pens during gestation are more active and restless when they are moved to farrowing stalls as a consequence of adapting their behaviour to the new environment (Marchant & Broom 1993; Beattie *et al* 1995; Harris & Gonyou 1998; Boyle *et al* 2000). In addition, different authors have highlighted the importance of the novelty of confinement for gilts that are allocated to farrowing stalls for the first time after being group-housed during gestation, thus responding more strongly to the stress of crating (Cronin *et al* 1996; Pedersen & Jensen 2008). Lawrence *et al* (1994) suggested that close confinement at farrowing of previously loose-housed gilts could induce psychological stress by interfering with the expression of maternal behaviour. However, Biensen *et al* (1996) related detrimental maternal behaviours in sows to a prolonged time interval between piglet births. We did not find a similar effect for PEN gilts in the present study, even though we did find increased cortisol in PEN gilts. The expected improved muscular condition of PEN gilts may counteract the negative effect of crating interfering with the maternal behaviour on parturition length. Nevertheless, the higher saliva cortisol concentration showed by PEN gilts 24 h after entering the farrowing stall may indicate a higher stress level, an idea supported by the higher activity level described above. Increase in feed intake during gestation has been shown to decrease cortisol levels in gilts (Amdi *et al* 2013) however, moving PEN gilts to farrowing stalls still increased cortisol levels more than for STALL-housed gilts. The lack of behavioural and physiological differences between groups at the end of lactation suggests that PEN gilts are able to adapt to the new situation during lactation.

Furthermore, PEN gilts' higher prenatal stress may be impairing the early thermoregulation of piglets through a stress-induced reduction in T4 at birth. Darwish and Ashmawy (2011) found that ewes that were stressed at lambing delivered lambs with lower T4 levels and lower

rectal temperature compared with non-stressed ewes. Berthon *et al* (1993) also found that thyroid function during the late intra-uterine period has a large effect on thermoregulatory capacity after birth.

In summary, group-housed gilts with increased feed ratio during gestation did not have worse farrowing performance than stall-housed gilts with regular feeding ratio. However, the greater stress suffered in gilts that have been housed in pens with increased feed ratio during pregnancy when moved to farrowing stalls, compared to gilts that have been housed in stalls with regular feeding ratio, may have impaired the thyroid function of piglets before birth and reduced their thermoregulatory capacity. Additionally, the consequence of late introduction to farrowing crates in previously group-housed gilts has been found to be stronger than for previously group-housed sows by Pedersen and Jensen (2008), therefore pen housing systems may need longer adaptation periods for gilts when moved to farrowing facilities or may work better combined with pen farrowing systems instead of farrowing crates. The results of this study contribute to manifest the welfare implications of gilts' transition to conventional farrowing stalls from a group-housing system during gestation. The present study only compared two gestation systems as a whole not separating different factors. Further studies are needed to study the effect of several feeding levels in each one of the existing feeding systems.

Acknowledgements

This study was supported by grants from the Agència de Gestió d'Ajuts Universitaris i de Recerca of the Generalitat de Catalunya No 2010 FI B 00993 and grant no PET2008_0003 from the Ministerio de Educación, Cultura y Deporte in España. We thank SAT La Vall (Lleida, Spain) and its employees, especially Salamó Villanova Gori, for their participation in this study.

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