Animal (2015), **9:8**, pp 1373–1378 © The Animal Consortium 2015
doi:10.1017/S1751731115000889

animal

Confinement of sows for different periods during lactation: effects on behaviour and lesions of sows and performance of piglets

C. Lambertz[1†], M. Petig[2], A. Elkmann[3] and M. Gauly[1]

[1]*Faculty of Science and Technology, Free University of Bozen-Bolzano, Universitätsplatz 5, 39100 Bolzano, Italy;* [2]*Department of Animal Sciences, University of Göttingen, Albrecht-Thaer-Weg 3, 37075 Göttingen, Germany;* [3]*Big Dutchman Pig Equipment GmbH, Auf der Lage 2, 49377 Calveslage, Germany*

(Received 10 September 2014; Accepted 22 April 2015; First published online 21 May 2015)

Alternatives to farrowing crates with continuous confinement of the sow are urgently needed because the animal welfare is negatively impacted. Given the increase of herd sizes, practical experience with loose-housing is needed to force the implementation of these systems in the field. Next to aspects of labour efficiency, detrimental piglet mortality rates that may occur during the first days postpartum *(*pp*) is a major criticism. Therefore, loose-housing after a crating period limited to the first days* pp *might be a feasible alternative to improve welfare under intensive production conditions. The aim was to investigate the effect of crating sows during lactation for different periods on their behaviour and integument alterations and on piglets' performance. Gilts from a commercial herd were observed from 5 to 26 days* pp *and housed in farrowing crates (1.85 × 2.50 m) that could be altered between confinement crates and loose-housing pens. Animals were divided into three groups, that were either crated continuously from birth until weaning (Group A,* n *= 55), until 14 days* pp *(Group B;* n *= 54) or 7 days* pp *(Group C,* n *= 59). The behaviour of six randomly selected gilts per group was video recorded from 5 to 26 days* pp *and analysed by time sampling technique. Lesions on the legs, shoulder and lumbar vertebra were scored on days 7, 14 and 25* pp*. Piglets were weighed weekly, causes of losses recorded and weight losses of gilts measured. Not different between groups (*P *> 0.05), animals spent 72 to 76% lying laterally, 14 to 17% lying in abdominal or semi-abdominal position, 9 to 10% standing and 1 to 3% sitting. B-sows were lying longer in week 3 and 4 of lactation compared to A- and C-sows (*P *< 0.05). The incidence of slight shoulder lesions rose from <1% on day 7 to 4% on day 14 and 14% on day 25* pp*. On day 25* pp*, 5% of all studied gilts showed moderate shoulder lesions. Piglet mortality rates were 11.4%, 12.9% and 13.3% for groups A, B and C, respectively (*P *> 0.05), whereas almost 90% of the losses occurred in the first week* pp*. In conclusion, loose-housing of lactating gilts after a reduced postnatal crating period of 7 days affected neither the activity level of the gilts and lesions on the integument nor pre-weaning mortality. Therefore, it is recommended to allow sows to move around to some extent during the later lactation period.*

Keywords: behaviour, farrowing crate, integument, loose-housing, sow

Implications

During lactation sows are most commonly kept in farrowing crates with a limit to move freely. Though piglet crushing can be minimized in this system, sows cannot express their full natural behaviour. Our study showed that loose-housing after a short postnatal period affected neither the number of piglet crushings nor the activity level of the gilts and integument alterations nor pre-weaning mortality. Therefore, it is recommended to allow sows to move around to some extent during the later lactation period.

† E-mail: Christian.Lambertz@unibz.it

Introduction

The major reason for keeping lactating sows in farrowing crates in intensive production is to avoid crushing of the piglets. Compared to loose-housing, these systems require also less space and are easier to manage, that is handling of animals and manure removal (Blackshaw *et al.*, 1994; Barnett *et al.*, 2001; Baxter *et al.*, 2012; Hales *et al.*, 2013). Nevertheless, crates are currently under discussion because the movement of the sows, and thus the natural animal behaviour and welfare are highly impaired (Lawrence *et al.*, 1994; Jarvis *et al.*, 1997). As a consequence, in countries like Norway, Sweden or Switzerland farrowing crates are already

forbidden by law. A general ban of farrowing crates by European Union legislation in the near future seems to be feasible. Therefore, alternative housing systems to farrowing crates with continuous confinement that improve the animal welfare are urgently needed. An important instrument for estimating the welfare of an animal is the analysis of its behaviour (Lidfors *et al.*, 2005). Another problem of farrowing crates is that they can cause serious skin lesions (Boyle *et al.*, 2002).

Various studies proved the feasibility of loose-housing sows during the lactation period as piglet mortality and piglet weight gain did not differ from crating systems (Cronin *et al.*, 2000; Marchant *et al.*, 2000; Moustsen and Poulsen, 2004; Pedersen *et al.*, 2011; Moustsen *et al.* 2013). Nevertheless, crating for at least the first 4 days *postpartum* (*pp*) seems to be necessary (Moustsen *et al.,* 2013); otherwise piglet crushing might be detrimental (Hales *et al.*, 2014). In the study of Baumgartner *et al.* (2007), loose-housed sows tended to be more active than crated ones, whereas weaning weights were not affected. Kamphues (2004) observed a higher proportion of sitting in the group of crated sows compared to the loose-housed group. Allowing the sow to move freely in the farrowing pen, could also motivate piglets to suckle and consequently benefit the weight gain of the litter (Pedersen *et al.*, 2011). Melisova *et al.* (2014) demonstrated a higher activity level of sows in pens when compared to crates, while crushing rates did not increase and weight gain of piglets benefitted from free farrowing pens. Therefore, a system that can be altered between confinement and loose-housing of the sows might be most feasible to increase the sow's ability to move without leading to higher piglet mortality rates (Marchant *et al.*, 2000; Pedersen *et al.*, 2006) and still offering a sufficient safety for the farmer while handling animals during lactation (Moustsen *et al.*, 2013). Thus, the aim of this study was to investigate the effect of crating sows during lactation for different periods on their behaviour and integument alterations and on piglets' performance.

Material and methods

Animals and housing

The study was conducted in a commercial herd with 1280 sows of Hypor Libra origin (Hypor, Boxmeer, The Netherlands), which was located in Thuringia, Germany. Artificial inseminations were conducted using Duroc semen. Only gilts ($n = 168$) were included in the study to avoid correlations with earlier experiences of the sows. In the mating units, the animals were kept in individual crates. Pregnant sows were housed in groups with an electronic feeding station and moved to the farrowing unit 5 days before the calculated farrowing date. The pens measured 1.85×2.50 m and were fully slatted with plastic coated metal wire. They were equipped with crates that could be used to fix the sow (Figure 1). When crated, the sows had 1.4 m^2 of space allowance and when loose-housed 2.8 m^2. The crate

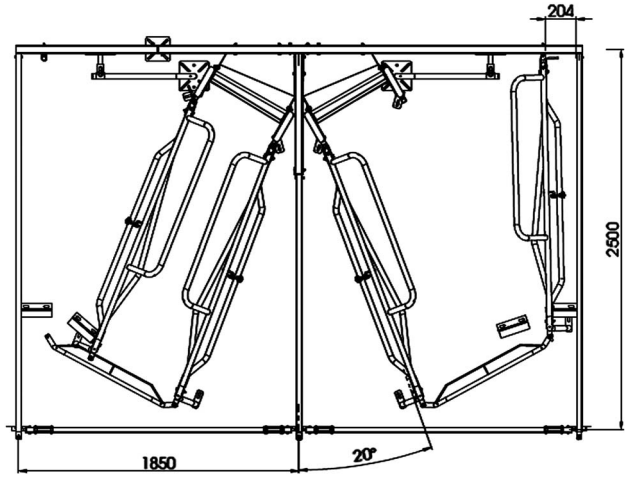

Figure 1 Layout of the farrowing pen (left: farrowing crate closed; right: farrowing crate open).

measured 110 cm in height and 200 cm in length. The width could be altered from 55 to 70 cm. Litters were equalized by cross-fostering piglets born within the same day.

A diffuse ventilation was installed with the barn temperature adjusted to 21°C. The creep area had floor heating and a heat lamp (125 W) that was installed until 7 days *pp*. Twice a day the sows were fed by an automatic liquid feeding system. The diet was based on barley, wheat and soya bean meal and contained 13.2 MJ ME/kg and 17.5% protein. Until day 2 *pp*, gilts received 1.5 kg per day. Thereafter, the amount was increased by 0.5 kg every second day until it reached 4.5 kg per day on day 12 *pp*, and by 0.5 kg daily until day 15 *pp*.

The gilts were randomly allocated to one of the following three treatment groups: A: animals were housed in continuous confinement from 0 to 26 days *pp* ($n = 55$); B: animals were confined until 14 days *pp* and then loose-housed until day 26 *pp* ($n = 54$); and C: animals were confined until day 7 *pp* and then loose-housed until day 26 *pp* ($n = 59$).

Behavioural observations

The behaviour of 18 randomly selected gilts (6 from each group) was observed from day 5 to 26 *pp*. Video recording took place in a farrowing unit accommodating 59 lactating gilts. Three digital cameras (Mobotix M24M Allround L22, Langmeil, Germany) were connected to a notebook and three CCTV cameras (Panasonic WV-BP330, Osaka, Japan) in connection with a time lapse recorder (Panasonic recorder model AG TL 750 S-VHS/S, Osaka, Japan) were installed at the ceiling above the pens. The Multi-Video-Processor (model MVP-104GX, Anaheim, USA) allowed the simultaneous use of three cameras in connection with only one recorder. One camera recorded the behaviour of three sows simultaneously. At night an emergency lighting was available. Videos were analysed using instantaneous sampling using 10 min intervals. The behavioural variables that were recorded are described in Table 1. The proportion the different behaviours were performed per day was calculated for each gilt.

Table 1 *Definition of the behavioural variables*

Behaviour	Description
Lying in lateral position	Sow lies in side position, all four legs are visible.
Lying in abdominal or semi-abdominal position	Sow lies on her sternum or semi-lateral. Not more than two legs are outstretched
Standing	Sow is standing or moving in standing position.
Sitting	Sow is sitting on the hindquarters.

Integument scoring

Integuments of all gilts were evaluated on days 7, 14 and 25 *pp*. Therefore, lesion scores were recorded for the body regions legs and lumbar vertebra with the following binomial score: 0 = no lesions; 1 = lesions visible. Lesions at the shoulder were scored 0 = no lesions; 1 = slight lesions (<2 cm); 2 = moderate lesions (>2 to <5 cm). The score of the left and right shoulder was summed as well as the score of the four legs.

Performance parameters

Gilts were weighted when they were placed in the farrowing unit and at weaning on day 26 *pp*. The individual body weights of piglets were recorded on day 1, 7, 14 and 25 *pp*. Losses of piglets were daily documented with a date and the cause of death as judged by the staff. Causes were differentiated between crushed (open-mouthed, swollen tongues, patterns of the slatted floor on the body and blue discoloration of the skin), culled, streptococcal infection (inflammations of the central nervous system disorders), starved (extreme emaciation), bitten (significant bite marks), anomaly (abnormalities and congenital malformations), and other. All dead piglets were weighted.

Statistical analysis

The program package SAS version 9.3 (SAS Institute Inc., Cary, NC, USA) was used for the statistical analysis. The gilt as the experimental unit was applied. Statistical significance was accepted at $P < 0.05$.

Data on mortality, which were recorded as a binomial trait, were analysed with the GLIMMIX procedure including the fixed effect of the treatment group. Performance variables were analysed with the MIXED procedure including the treatment (A, B, C) and week (1, 2, 3) as fixed effect and the gilt as random effect. The behavioural variables were arcsin square root-transformed before analysis to adjust data for normality. The model statement included the treatment (A, B, C) and week (1, 2, 3) as fixed effect and the gilt as random effect. Least squares means were separated by the probability of differences option (PDIFF) with Bonferroni adjustment. Treatment effects for the integument scoring were tested by applying the Exact-Fisher-test within the FREQ procedure. Because treatments did not differ significantly, frequencies summed over all treatments are presented.

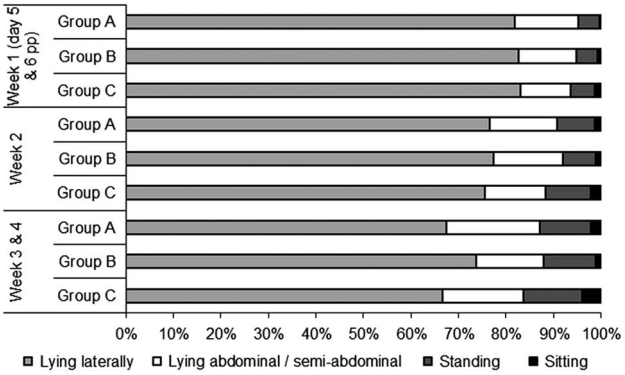

Figure 2 Time budgets during different periods of gilts that were crated continuously from day 0 to 26 *pp* (A), until day 14 *pp* (B) and until day 7 day *pp* (C). *pp* = *postpartum.*

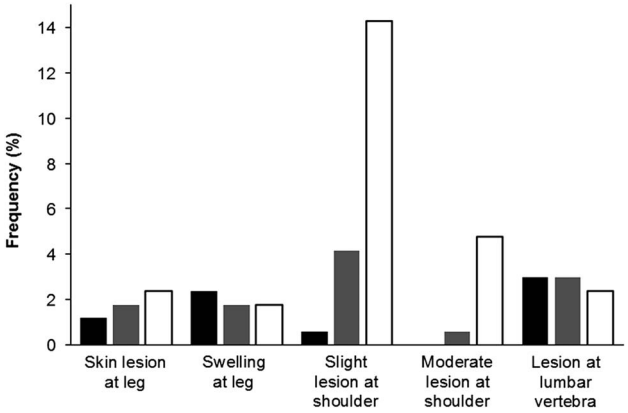

Figure 3 Frequency of abnormal integument scores of gilts ($n = 168$) on day 7 (black bars), 14 (grey bars) and 25 *postpartum* (white bars) at the legs, shoulder and lumbar vertebra.

Results

Behavioural parameters

The time budgets of the different postural behaviour patterns separated for the different weeks of lactation are presented in Figure 2. From week 1 to week 3 and 4 of lactation, the proportion of lying laterally decreased. Concurrently, the time spent lying in abdominal/semi-abdominal position increased. During the second half of the lactation period B-gilts more frequently laid laterally (73.8%) than A-gilts (67.4%) and C-gilts (66.7%) ($P < 0.05$). For the other behaviours no differences between weeks were noted.

Integument scoring

One week after farrowing 7% of the gilts were found with at least one lesion at the legs, shoulder or lumbar vertebra; this proportion increased to 11% on day 14 and 26% on day 26. Differences between the treatment groups were not found ($P > 0.05$). The rising incidence was mainly caused by shoulder lesions, which accounted for 75% of all lesions on day 26. As shown in more detail in Figure 3, particularly the incidence of slight shoulder lesions rose from <1% on day 7 to 4% on day 14 and 14% on day 25 *pp*. At the latest scoring date 5% of all studied gilts even showed moderate lesions at

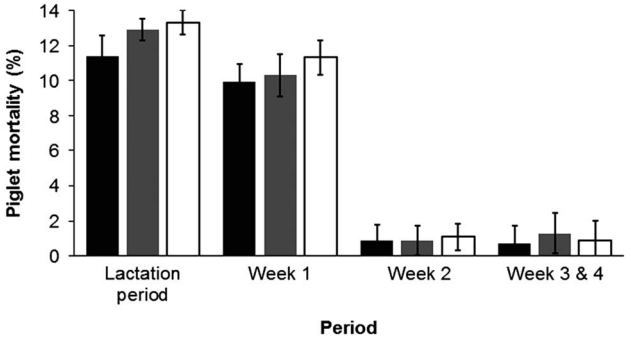

Figure 4 Piglet mortality rates in gilts crated continuously from day 0 to 26 *pp* (A, black bars), until day 14 *pp* (B, grey bars) and until day 7 *pp* (C, white bars). *pp* = *postpartum.*

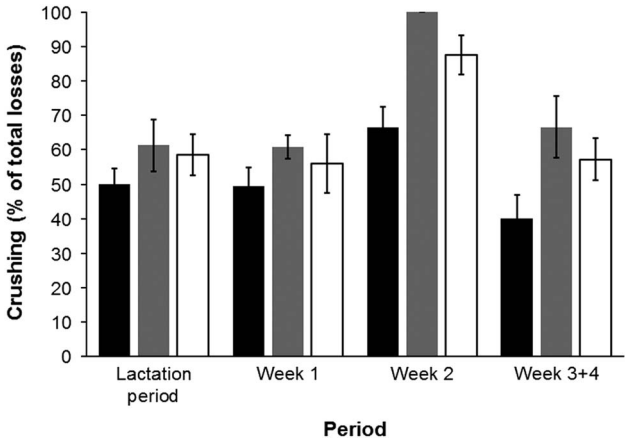

Figure 5 Proportion of piglet crushing on the total losses in gilts crated continuously from day 0 to 26 *pp* (A, black bars), until day 14 day *pp* (B, grey bars) and until day 7 *pp* (C, white bars). *pp* = *postpartum.*

the shoulder. For the other body regions the integument score remained below 4% over the lactation period.

Performance parameters

On average, the 168 gilts had a litter size of 12.8 ± 3.6 live-born and 0.8 ± 1.2 stillborn piglets. After the lactation period of 26 days 11.2 ± 1.1 piglets were weaned per litter. The piglet mortality rates for the whole lactation period were 11.4, 12.9 and 13.3% for groups A, B and C, respectively ($P > 0.05$; Figure 4). In all treatment groups losses occurred in about 90% of the cases in the first week *pp*. In total, 272 piglet losses were recorded. Crushing was the most frequent cause of death. The percentage of crushings averaged over the whole lactation period varied between 50% in A-gilts and 59 and 61% in B- and C-gilts ($P > 0.05$; Figure 5). The highest proportion of crushings of at least 67% was recorded in the second week *pp* in all groups, but during this week the piglet mortality was lower than 1% in all groups ($P > 0.05$; Figure 5).

The daily weight gain of the piglets during the lactation period did not differ significantly between the experimental groups ($P > 0.05$), neither for the whole lactation nor within the individual weeks (Table 2). Averaged over the entire lactation period, piglets gained 220 to 225 g/day. The litter weights at the four weighting times did not differ between the housing variations. Focusing on the values of day 14 and 26, groups ranged between 45.7 to 46.8 and 78 to 78.5 kg, respectively (Table 2). During lactation, gilts of group A, B and C lost 16.9, 15.8 and 15.7% of the pre-farrowing weight, respectively ($P > 0.05$).

Table 2 *Litter weights on day 1, 7, 14 and 26* pp *and gilts' weight losses during lactation when crated continuously from day 0 to 26* pp *(A), until day 14* pp *(B) and until day 7 day* pp *(C)*

	Group					
Trait	A	B	C	r.s.d.	*n*	*P*-value
Litter weight (kg)						
Day 1 *pp*	15.2	14.3	14.5	3.87	167	0.48
Day 7 *pp*	28.0	27.9	27.8	5.47	167	0.60
Day 14 *pp*	45.7	46.2	46.8	8.36	167	0.83
Day 26 *pp*	78.5	78.0	78.3	13.64	167	0.82
Weight loss of gilts (kg)	33.0	30.8	31.7	13.9	167	0.86

pp = *postpartum.*

Discussion

Pen design

Animal welfare of sows during the lactational period is an increasing concern and the widely used farrowing crates are under discussion. Nevertheless, most lactating sows in the developed world are still crated (Barnett *et al.*, 2001). Marchant *et al.* (2000) and Moustsen *et al.* (2013) investigated farrowing systems which represent a compromise between free farrowing and continuous confinement of the sow. In these systems the sows are only crated for the first days *pp* when the danger of piglet crushing is most serious. For the remaining lactation period the crates are opened and the sow is loose-housed. As pointed out by Moustsen *et al.* (2013), crating can be limited to the first 4 days *pp* in order to avoid unnecessary crushings. In the present study a newly developed pen which also allows temporary crating was under investigation. In fact, this farrowing system was developed for intensive production systems, in which the abrupt change from continuous confinement as practiced at the moment to free farrowing is not an option; mainly due to increased management requirements. Even under optimized management regimen excessive piglet mortality might arise (Hales *et al.*, 2014) and this limits the implementation of free farrowing pens in the field. Given the compromise between the ability of the sow to express its natural behaviour and the consequences this might have on the piglets in terms of crushings, the pen under study is able to provide the sow with a certain additional area to move and turn around, but not to the same extent as several of the recently developed free farrowing pens exceeding sizes of 5 m^2 (Weber *et al.*, 2007; Hales *et al.*, 2014). Nevertheless, the sow had twice the space allowance (2.8 m^2) when the crate was opened compared to the closed crate in our study. However, the

optimal space allowance for sows in loose housing pens is still unknown and effects on piglet mortality in relation to the pen size and dimensions are warranted to be evaluated. In order to avoid excessive piglet crushings the crates were opened in the present study at 7 or 14 days *pp* as other previous studies identified the first week *pp* as the most important period in terms of piglet crushings (Moustsen *et al.*, 2013; Hales *et al.,* 2014).

Behaviour

Regarding the activity level of the sows, lying in lateral and abdominal/semi-abdominal position was, at almost 90% of the time, the predominant postural position. In the literature similar time budgets with lying accounting for >85% are commonly found (Johnson *et al.*, 2001; Kamphues, 2004). The percentage of the lateral position on the total lying time was in the range (70%) reported by Kamphues (2004). During the suckling period the proportion of lying decreased from 95% in the first week to 86% in the third and fourth week. The decline in the total lying time was accompanied by a reduced proportion of lying in the lateral position and increased proportion of lying in the abdominal/semi-abdominal position. This development has been described by Johnson *et al.* (2001) as a kind of 'piglet avoidance strategy'. The experimental groups did not differ in the proportion of lying in the abdominal position, but gilts that were confined until 14 days *pp* were lying more often in the lateral position and less in the abdominal/semi-abdominal position in the second half of the suckling period. Comparing farrowing crates with loose-housing pens, Boyle *et al.* (2002) found the loose-housed animals lying longer on the first day in the farrowing pen when compared to the crated ones. During the later lactation period, differences in the time spent lying were not noted.

On average, the observed gilts spent approximately a tenth of their time standing, which widely agrees with the time budgets of previous studies (Kamphues, 2004; Baumgartner *et al.*, 2007). In general, standing can be associated with activity or the motivation for activity. It is also a sign of attention and vitality (Baumgartner *et al.*, 2007). However, opening the crate, thus doubling the space allowance, did not motivate the animal to be more active. Even though not possible when using the time sampling method, recording the number of postural changes would have been a valuable indicator to assess whether loose-housed sows are standing up more frequently, too. Although not increasing the activity level, the possibility of turning around enabled the sows to interact with their environment and should be considered as highly beneficial for the animal. This is of major importance when optimizing farrowing pens because pigs are bored during most of the day in their barren environments (Puppe *et al.*, 2007). During the lactation period the time of standing doubled from ~5 to >10%. This increase can be explained mainly by a recovery of the sows from birth and the 'piglet avoidance strategy' as already mentioned above (Blackshaw *et al.*, 1994; Johnson *et al.*, 2001; Valros *et al.*, 2003). Recent results of Melisova *et al.* (2014) support an increasing activity level of sows kept in pens compared with crates, which is not associated with increased piglet crushing rates, partly due to better body conditions of piglets.

Similarly to standing, the time of sitting, which analogous to standing, rose throughout the suckling period and was not significantly different between the treatments. Similarly, Blackshaw *et al.* (1994) also did not find any difference in sitting or standing up between sows in a farrowing crate and a farrowing pen.

To further improve the welfare of the sows in the farrowing unit, the studied pen also allows to loose-house the sows from the time they enter the farrowing unit until farrowing starts. Particularly, when nest building material such as straw is provided in addition, nest building could be performed at least to a limited extent. This in combination with the loose-housing during the period that was studied here, might lead to more pronounced effects on the sow behaviour, integument alterations and also piglet weight gain than found with the present study design, where the sow was also confined during the nest building period.

Integument lesions

The incidence of lesions at the legs, shoulder or lumbar vertebra increased steadily with a quarter of the gilts showing at least one lesion at the end of the lactation period independent of the treatment group. This emphasizes that farrowing crates are not only problematic in terms of behavioural restrictions but also in terms of health. Currently, there are no studies available that compare skin lesions in loose-housing and crating systems. The fact, that shoulder lesions are a major problem in farrowing crates becomes clear from the present study as well as the study of Bonde *et al.* (2004), who even found a prevalence of 20% in farrowing crates. There is evidence that lesions that occur at different points of the production cycle have negative impacts on the reproductive performance, and thus longevity, of the sows (Pluym *et al.*, 2013). If lesions that are caused by crate fixtures could be minimized by loose-lactating, benefits might outweigh the additional management efforts during periods of loose-housing.

Performance

Given the fact that gilts in all treatments were crated at least until 7 days *pp*, the piglet mortality did not differ between the groups due to the fact that >90% of the losses occurred within this period. Expectedly, piglet crushing was the main reason causing losses. Using similar farrowing pens with integrated crates as used in this study, Moustsen *et al.* (2013) observed a higher piglet mortality rate in pens where sows were loose-housed throughout the whole lactation period than in those that were crated during the first 4 or 7 days *pp*; suggesting that crating for just 4 days *pp* is sufficient to avoid unnecessary crushings. Comparing farrowing crates with free farrowing pens, Hales *et al.* (2014) found greater mortality rates in pens than in crates, even though pen sizes were, at 5.3 to 6.3 m^2, considerably larger than in this as well as the aforementioned study. Contrarily, Weber *et al.* (2007) found similar mortality rates in crates and loose-farrowing systems;

but the proportion of crushed piglets was higher in loose-housed than in crated sows. Under practical farming conditions, KilBride *et al.* (2012) found a similar overall pre-weaning mortality of 12% in farrowing crates, loose-housed systems and the system that was studied here, with crating during the first days *pp*, whereas crushings more frequently occurred when sows were continuously loosed-housed. In summary, piglets are at higher risk of death when sows are loose-housed. Nevertheless, the design of the pens has been modified in such a way that this risk can be minimized. Furthermore, pre-weaning mortality depends on a number of other factors that have to be taken into account, too, whenever loose-housing systems are evaluated. While litter size was not associated with mortality (Hales *et al.*, 2014), parity, birth weight and piglet sex are determining factors (Hales *et al.*, 2013).

Although indications exist that prove superior weight gains of piglets in free farrowing pens related to the motivation of piglets to suckle (Melisova *et al.*, 2014), the limited space allowance in the pen under study might not have been sufficient to induce significant differences in piglet performance. Furthermore, the fact that feed intake was restricted to the same amount for all treatments, limits overall conclusions on the weight development of the sows as well as the piglets.

Conclusion

This study showed that loose-housing of gilts during the lactation period after they were crated until 7 or 14 days *pp* affected neither the activity level of the gilts and integument alterations nor pre-weaning mortality. Therefore, it is recommended to allow sows moving around to some extent during the later lactation period.

Acknowledgements

The authors thank the owner and staff of the participating farm for their collaboration.

References

Barnett JL, Hemsworth PH, Cronin GM, Jongman ED and Hutson GD 2001. A review of the welfare issues for sows and piglets in relation to housing. Australian Journal of Agricultural Research 52, 1–28.

Baumgartner J, Ofner J, Quendler E and Winckler C 2007. Evaluation of different farrowing systems regarding productivity and animal welfare. Paper presented at the 58th Annual Meeting of the European Association for Animal Production, 26 to 29 August 2007, Dublin, Ireland.

Baxter EM, Lawrence AB and Edwards SA 2012. Alternative farrowing accommodation: welfare and economic aspects of existing farrowing and lactation systems for pigs. Animal 6, 96–117.

Blackshaw JK, Blackshaw AW, Thomas FJ and Newman SW 1994. Comparison of behaviour patterns of sows and litters in a farrowing crate and a farrowing pen. Applied Animal Behaviour Science 39, 281–295.

Bonde M, Rousing T, Badsberg JH and Sørensen JT 2004. Associations between lying-down behaviour problems and body condition, limb disorders and skin lesions of lactating sows housed in farrowing crates in commercial sow herds. Livestock Science 87, 179–187.

Boyle LA, Leonard FC, Lynch PB and Brophy P 2002. Effect of gestation housing on behaviour and skin lesions of sows in farrowing crates. Applied Animal Behaviour 76, 119–134.

Cronin GM, Lefebure B and Mc Clintock S 2000. A comparison of piglet production and survival in the Werribee Farrowing Pen and conventional farrowing crates at a commercial farm. Australian Journal of Experimental Agriculture 40, 17–23.

Hales J, Moustsen VA, Nielsen MBF and Hansen CF 2013. Individual physical characteristics of neonatal piglets affect preweaning survival of piglets born in a noncrated system. Journal of Animal Science 91, 4991–5003.

Hales J, Moustsen VA, Nielsen MBF and Hansen CF 2014. Higher preweaning mortality in free farrowing pens compared with farrowing crates in three commercial pig farms. Animal 8, 113–120.

Jarvis S, Lawrence AB, Mc lean KA, Deans LA, Chirnside J and Calvert SK 1997. The effect of environment on behavioural activity, ACTH, beta-endorphin and cortisol in pre-farrowing gilts. Animal Science 65, 465–472.

Johnson AK, Morrow-Tesch JL and McGlone JJ 2001. Behaviour and performance of lactating sows and piglets reared indoors or outdoors. Journal of Animal Science 79, 2571–2579.

Kamphues B 2004. Comparison between different farrowing systems in particular consideration of animal behaviour and economy. Thesis PhD, Göttingen University, Göttingen, Germany.

KilBride AL, Mendl M, Statham P, Held S, Harris M, Cooper S and Green LE 2012. A cohort study of preweaning piglet mortality and farrowing accommodation on 112 commercial pig farms in England. Preventive Veterinary Medicine 104, 281–291.

Lawrence AB, Petherick JC, Mc Lean KA, Deans LA, Chirnside J, Vaughan A, Clutton E and Terlouw EMC 1994. The effect of environment on behavior, plasma-cortisol and prolactin in parturient sows. Applied Animal Behaviour Science 39, 313–330.

Lidfors L, Berg C and Algers B 2005. Integration of natural behaviour in housing systems. Ambio 34, 325–330.

Marchant JN, Rudd AR, Mendl MT, Broom DM, Meredith MJ, Corning S and Simmins PH 2000. Timing and causes of piglet mortality in alternative and conventional farrowing systems. Veterinary Record 147, 209–214.

Melisova M, Illmann G, Chaloupkova H and Bozdechova B 2014. Sow postural changes, responsiveness to piglet screams, and their impact on piglet mortality in pens and crates. Journal of Animal Science 92, 3064–3072.

Moustsen VA and Poulsen HL 2004. Sammenligning af produk Sammenligning af produktionsresultater opnået i henholdsvis en traditionel kassesti og en sti til løsgående farende og diegivende søer. (Comparison of production results in traditional crates and pens for loose farrowing and lactating sows). Meddelelse 679. Videncenter For Svineproduktion. Retrieved on 1 September 2014 from http://vsp.lf.dk/Publikationer/Kilder/lu_medd/2004/679.aspx

Moustsen VA, Hales J, Lahrmann HP, Weber PM and Hansen CF 2013. Confinement of lactating sows in crates for 4 days after farrowing reduces piglet mortality. Animal 7, 648–654.

Pedersen LJ, Jørgensen E, Heiskanen T and Damm BI 2006. Early piglet mortality in loose-housed related to sow and piglet behavior and to the process of parturition. Applied Animal Behaviour Science 96, 215–232.

Pedersen ML, Moustsen VA, Nielsen MBF and Kristensen AR 2011. Improved udder access prolongs duration of milk letdown and increases piglet weight gain. Livestock Science 140, 253–261.

Pluym LM, Van Nuffel A, Van Weyenberg S and Maes D 2013. Prevalence of lameness and claw lesions during different stages in the reproductive cycle of sows and the impact on the reproduction results. Animal 7, 1174–1181.

Puppe B, Ernst K, Schön PC and Manteuffel G 2007. Cognitive enrichment affects behavioural reactivity in domestic pigs. Applied Animal Behaviour Science 105, 75–86.

Valros A, Rundgren M, Spinka M, Saloniemi H and Algers B 2003. Sow activity level, frequency of standing-to-lying posture changes and anti-crushing behavior – within sow-repeatability and interactions with nursing behaviour and piglet performance. Applied Animal Behaviour Science 83, 29–40.

Weber R, Keil NM, Fehr M and Horat R 2007. Piglet mortality on farms using farrowing systems with or without crates. Animal Welfare 16, 277–279.