Available online at www.sciencedirect.com
SCIENCE DIRECT®
ELSEVIER
Applied Animal Behaviour Science 99 (2006) 53–63
APPLIED ANIMAL BEHAVIOUR SCIENCE
www.elsevier.com/locate/applanim

Sow preferences for walls to lean against when lying down

Birgitte I. Damm [a], Vivi Moustsen [b], Erik Jørgensen [c], Lene J. Pedersen [d,*], Teresia Heiskanen [a], Björn Forkman [a]

[a] *The Royal Veterinary and Agricultural University, Department of Large Animal Sciences, Grønnegårdsvej 8, 1870 Frederiksberg C, Denmark*
[b] *The Danish Applied Pig Research Scheme, The National Committee for Pig Production, Axeltorv 3, 1609 Copenhagen V, Denmark*
[c] *Danish Institute of Agricultural Sciences, Department of Animal Breeding and Genetics, P.O. Box 50, 8830 Tjele, Denmark*
[d] *Danish Institute of Agricultural Sciences, Department of Animal Health, Welfare and Nutrition, P.O. Box 50, 8830 Tjele, Denmark*

Accepted 29 September 2005
Available online 18 November 2005

Abstract

It has previously been shown that when sows lie down in the open there is a much greater risk of piglet crushing than when they lie down alongside a wall, probably because the wall provides support and/or a piglet escape zone. Therefore, walls in farrowing pens should be attractive to the sow, so that she chooses to use them when lying down. EU-regulations state that farrowing pens must be given ''some means of protecting the piglets, such as farrowing rails''. Walls with farrowing rails may, however, not be the most appropriate option as they may be unattractive to the sows.

We tested sow preferences for lying down alongside a plain wall, a sloping wall or a wall with a farrowing rail. Beforehand, we tested preferences for three sloping wall designs (plain, curved and multiple bars) in order to use the preferred one in the later choice experiment. In both experiments, 4×6 pregnant second–seventh parity individually housed sows were used over a 3-day training and a 4-day testing period. In both experiments, the three types of walls were balanced on position in the pen.

* Corresponding author. Tel.: +45 89 99 13 64; fax: +45 89 99 15 00.
E-mail address: Lene.juulpedersen@agrsci.dk (L.J. Pedersen).

0168-1591/$ – see front matter
doi:10.1016/j.applanim.2005.09.014

In both tests, the sows predominantly lay down alongside the walls (on average, 80 ± 4 and 86 ± 3% of lying down events, respectively). In the test of the three sloping wall designs, the sows had no significant preferences for wall designs. For practical reasons the plain sloping wall was used in the subsequent test. Here, there was a significant effect of wall type (on average, 16 ± 5% of lying down events alongside the wall with the farrowing rail, 48 ± 8% alongside the plain wall and 36 ± 8% alongside the plain sloping wall ($P < 0.025$)). The sows lay down alongside the wall with the farrowing rail less than alongside the plain or the plain sloping wall ($P < 0.01$), but the preference for the two latter wall types did not differ significantly. Irrespective of the wall type, the sows had a significant preference for the back wall of the pen ($P < 0.001$ in both experiments).

In conclusion, walls with farrowing rails appear to be less attractive to lie down against than other wall designs. Although farrowing rails provide piglets with escape zones they may not be optimal for piglet survival because they do not encourage the sow to lie down alongside a wall, rather than in the open. Moreover, they may not be optimal from a sow welfare perspective due to lack of support for the sow when lying down.

Keywords: Sows; Lying down; Support; Wall; Piglet protection rail

1. Introduction

In farrowing crates, average piglet mortality among the liveborn is usually around 10–15% (Pedersen et al., 1998; Marchant et al., 2000; Weber, 2000; Cronin et al., 2000; Barnett et al., 2001). Piglet mortality in pens ranges from rates similar to those in crates (Weber, 2000; Cronin et al., 2000; Damgaard et al., 2003) to rates as high as 25–33% (Pedersen et al., 1998; Marchant et al., 2000). In both pens and crates piglet crushing is a predominant cause of death (Dyck and Swierstra, 1987; Fraser, 1990; Marchant et al., 2000; Damm et al., 2005). Most crushing seems to occur when the sow lies down from standing (Weary et al., 1998; Marchant et al., 2001; Vieuille et al., 2003).

The frequent reports of high piglet mortality in pens are the main reason why crates cannot be banned or phased out, even though it is widely recognised that they compromise sow welfare severely (Anon., 1997; Barnett et al., 2001). In order for pens to be able to compete with crates, piglet mortality in pens has to be reduced, particularly the frequent deaths due to crushing. One approach may be to encourage sows to lie down by leaning against a supportive surface. As demonstrated by Marchant et al. (2001) this is likely to decrease the risk of crushing. In this study 36% of lying down occurrences were dangerous and 15% resulted in piglet deaths when sows lay down in the middle of a pen without using support, but only 4% were dangerous and 0.5% resulted in piglet deaths when sows lay down by leaning against a vertical or sloping surface (Marchant et al., 2001).

Previous studies suggest that sows prefer to use support when lying down. In pens, 70% of lying down events were carried out using a wall with several rails that sows could use to slide down along, whereas 30% were carried out in the open (Hesse, 1992). Similarly, 89% of lying down events were carried out using either a sloping wall, a wall fitted with a piglet protection rail or a piglet creep (Marchant et al., 2001), whereas only 11% were carried out

in the open. The use of support in pens with sloping walls and pens with rails was not discriminated between in the latter study, but sows seem to be less willing to use walls with a single low rail. In studies where sows could either lie down in the open or alongside a wall with a single low rail, they used the wall only in 5–16% of the lying down events (Blackshaw and Hagelsø, 1990; Hesse, 1992).

With the aim of encouraging sows to use support when lying down, we carried out two experiments investigating their preferences for various types of walls. Using sows in late pregnancy, we tested: (1) which type of sloping wall is most attractive to sows (a plain sloping wall, a curved sloping wall or a railed sloping wall) and (2) whether sows prefer to use the chosen sloping wall, a plain vertical wall or a plain vertical wall fitted with a piglet protection rail.

2. Materials and methods

2.1. Animals

A total of 48 multiparous (2nd–7th parity) late pregnant (last trimester) Landrace × Yorkshire sows were used. Two experiments were carried out, and each experiment used four replicates of six sows. Late pregnant sows were used instead of farrowing or lactating sows in order not to confound the location of the test walls with the location of the nest and/or the piglets. It has previously been shown that pregnant sows do use support for lying down (Marchant and Broom, 1996; Harris and Gonyou, 1998).

All the sows derived from the experimental farm where the investigation took place and prior to the experiment they were housed and managed according to common Danish production standards. In brief, these included birth by a crated sow, weaning at 4 weeks of age, loose housing in groups until mating at approximately 7 months of age, housing in stalls during all matings, housing in stalls or in groups during gestations, and housing in crates during farrowing and lactation (4 weeks).

2.2. Experimental housing and care

Six pens (length = 2.85 m, width = 2.25 m, height = 1.13 m) located in the same room were used. The pens had concrete slatted floor. Each pen had three solid walls and a partition wall of vertical galvanised iron bars to the neighbouring pen (distance between bars 8.5 cm). As can be seen in Fig. 1, the back wall of all the pens and one sidewall of the two outer pens were the solid high wall of the building. The solid partitions between the pens were lower plywood walls. On the bar partition wall a drinker and a feeding automat (0.3 m × 0.25 m × 1 m) were fitted. The indoor climate was regulated by negative pressure ventilation and the room temperature was kept at 18 °C. In addition to natural daylight, the room was lit by 24 h artificial lighting to enable video recording. Twice daily, the sows were fed a standard sow ration according to recommendations for their gestational stage and they were given a handful of long-stemmed straw. There was access to ad libitum water from the drinker.

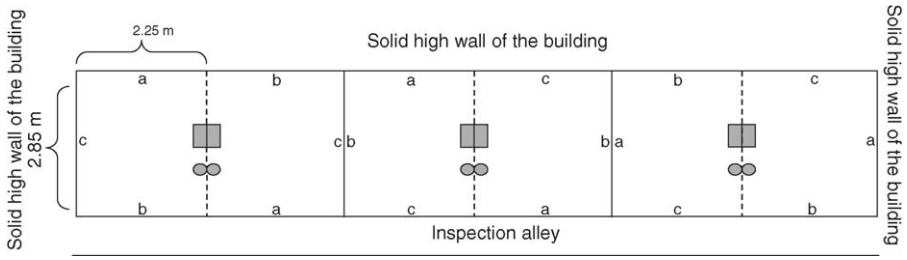

Fig. 1. Schematic drawing of the six experimental pens. Each pen had slatted floor, three test walls (a–c) and a wall of vertical bars (- - -) fitted with a feed trough (▭) and a nipple drinker (⬭). The back wall of all the pens and one sidewall of the two outer pens were the solid high wall of the building fitted with the experimental walls. The solid partitions between the pens were lower plywood walls also fitted with the experimental walls. In addition, there was a railed partition between the pens. In experiment 1, the three solid walls were fitted with a plain sloping wall (a), an outward curved sloping wall (b), and a railed sloping wall (c). In experiment 2, the three test walls were a plain sloping wall (a), the plain vertical wall fitted with a single low piglet protection rail (b), and the plain vertical wall (c).

2.2.1. Experiment 1

In the six pens, the three solid walls were fitted each with a different design of sloping wall (see Fig. 1). To minimise the effects of possible preferences for lying in certain areas within the pen, the position of the three types of sloping walls was balanced on the six pens. All the sloping walls were made of 10 cm thick plywood, had a gradient of 18°, started at a height of 1.13 m and ended 20 cm above the floor. The following types of walls were used in each pen:

(a) A plain sloping wall (Fig. 2): this was chosen because of previous reports of successful use of sloping walls (Baxter, 1991; Bradshaw and Broom, 1999; Cronin et al., 2000; Marchant et al., 2001, and personal communication).
(b) An outward curved sloping wall (Fig. 3): this was a modification of the plain sloping wall, which was used because it might better support the last sliding movement of the sow's hindquarter to the ground.
(c) A rail wall (Fig. 4): seven birch wood rails (2.5 cm in diameter) were fitted onto the sloping plywood wall. This wall was used because of previous reports of sows' willingness to use such a wall (Hesse, 1992) and because (in a final design) it might have practical advantages, i.e. be easier to clean and provide a better overview of the piglets than solid sloping walls.

2.2.2. Experiment 2

Experiment 2 was carried out in the same way as experiment 1, except that the three test walls were now fitted with:

(a) A sloping wall: wall "a" described above (the wall was chosen on the basis of the results of experiment 1).
(b) A plain vertical wall: this was the plain wall of the pen.

Fig. 2. The plain sloping wall, which was used in experiments 1 and 2.

Fig. 3. The outward curved sloping wall, which was used in experiment 1.

Fig. 4. The rail wall, which was used in experiment 1.

(c) A wall with a piglet protection rail: the rail was a 2-m long galvanised iron tube (8 cm in diameter) positioned 15 cm from the wall and 22 cm above the floor.

2.3. Behaviour recording

In both experiments, the sows were given 3 days of acclimatisation to the pen. On the morning of the sows' 4th day in the pen, 24-h time-lapse video recording was started. The sows were video recorded for four consecutive 24-h periods. On the basis of the recordings the following were noted for each 24-h period: (a) the number of times the sow lay down from standing, (b) the position of the sow in the pen, when she lay down, and (c) whether she leaned against one of the test walls when lying down (or lay down only few centimetres from it, as this could not be discriminated from leaning).

2.4. Statistical analysis

Data from both experiments were analysed using a generalised linear mixed model with a log-link function. The model included random effects of batch, pen within batch, and position within batch and pen to take the repeated observation of sows within pen into account. The GLMM function in the R package lme4 was used for the calculation with the second order Laplace approximation used for integration with respect to the random effects (Bates and Sarkar, 2004; R Development Core Team, 2004). The observed number of laying down behaviours is assumed Poisson distributed $Y_{ijklm} \sim \text{Poisson}(\lambda_{ijklm} t_{ijklm})$, where

t_{ijklm} is the length of the observation period and λ_{ijklm} is the relative frequency of the lying down behaviour. The model was:

$$\log(\lambda_{ijklm}) = \mu + G_i + S_{ij} + \alpha_k + \beta_m + \gamma_l + (\alpha\beta)_{km} + (\alpha\gamma)_{km} + (\beta\gamma)_{lm} + (\alpha\beta\gamma)_{klm}$$

where G_i is the random effect of batch $i \in \{1, 2, 3, 4\}$, S_{ij} the random effect of pen j within batch $i, j \in \{1, \ldots, 6\}$, α_k the effect of the kth day after introduction to the pen, β_m the effect of position m, and γ_l is the effect of wall type l, with corresponding interactions. G_i and S_{ij} were assumed independent and normal distributed with variance σ_G^2 and σ_S^2, respectively. The relative use of each wall type was estimated as $\exp(m_l)/(\sum_i \exp(m_i))$, where m_i is the least square mean of $\log(\lambda)$ with respect to wall type. Approximate standard errors were calculated using Taylor approximation. The higher order interaction terms were removed sequentially from the model if they were not significant at the 0.05 level. The model comparisons were made using likelihood ratio tests. The results are given as means and standard errors.

3. Results

3.1. Experiment 1

On average, the sows lay down alongside pen walls 80 ± 4% of the times they lay down and in the open 20 ± 4% of the times. The only significant effect on choice of wall was that of the position of the wall in the pen ($\chi^2 = 44.6$, d.f. = 2, $P < 0.001$). Irrespective of the wall type, the sows had a strong preference for the back wall over both side walls (marginal likelihood ratio test for each side walls tested against the back wall: $P < 0.001$ for both tests). The sow's use of the various walls can be seen in Table 1.

3.2. Experiment 2

In experiment 1, the sows used the walls, but the experiment revealed no significant preferences. The purpose of experiment 1 was to test whether sows would use sloping walls

Table 1
Sow preferences for different types of walls to lean against when lying down

Wall type		*P*-value
Experiment 1		
Plain sloping (%)	33 ± 6	N.S.
Curved sloping (%)	46 ± 7	
Railed sloping (%)	21 ± 5	
Experiment 2		
Plain sloping (%)	36 ± 8	0.025
Plain vertical (%)	48 ± 8	
Vertical with piglet protection rail (%)	16 ± 5	

Preferences are shown as the mean percentage (and S.E.) of times the sow chose the walls out of all the times she lay down alongside a wall during a 4-day observation period.

Table 2
Sow preferences for lying down along walls with different positions in the pen

	Wall position			*P*-value
	Back (%)	Side (%)	Front (towards alley) (%)	
Experiment 1	76 ± 5	6 ± 2	18 ± 5	<0.001
Experiment 2	74 ± 6	9 ± 3	17 ± 5	<0.001

Preferences are shown as the mean percentage (and S.E.) of times the sow chose the walls out of all the times she lay down alongside a wall during a 4-day observation period.

to lie down against and to enable further study of a sloping wall that the sows would willingly use. As the sows had shown no clear preference, we chose the plain sloping wall for practical reasons. It was considered to be the wall that it would be easiest and cheapest to manufacture both in the current experiment and in future farrowing pens.

Overall, the sows lay down alongside pen walls 86 ± 3% of the times they lay down and in the open 14 ± 3% of the times. There were significant effects of position ($\chi^2 = 19.5$, d.f. = 2, $P < 0.001$) and wall type ($\chi^2 = 7.4$, d.f. = 2, $P = 0.025$) on the percentage of time the sows lay down alongside the various walls (see Tables 1 and 2). Furthermore, there was a tendency for an interaction between day and position ($\chi^2 = 12.5$, d.f. = 6, $P < 0.052$). However, there was no systematic pattern in this interaction. In addition, the model selection procedure was made both for a model including and excluding the ''day × position'' interaction, with similar results with respect to the main treatment factor. Therefore, the most parsimonious model was preferred, with only position and wall type included as fixed effects. The probability of selecting the wall with the farrowing rail was significantly lower than the probability of selecting the other types (marginal likelihood ratio tests for rail tested against both types of sloping walls: $P < 0.01$). The difference between the plain wall and the sloping wall was not significant (marginal likelihood ratio test: $P > 0.05$). Irrespective of the wall type, the sows had a strong preference for lying down along the back wall compared to both sidewalls (marginal likelihood ratio test: $P < 0.001$ for both tests).

4. Discussion

There was no difference in preference for the three sloping walls (experiment 1). However, in experiment 2 the sows showed avoidance of the wall with a farrowing rail as compared to the plain sloping walls and the plain vertical wall.

Even though the sows in experiment 1 showed no preference for any of the walls, it is clear that they willingly used the walls to lie down alongside (80% of the times they lay down). It is likely that the walls were too similar for the sows to distinguish between, and/or that the walls provided the same degree of support. The purpose of the initial experiment was to find an attractive sloping wall to test against a wall with a traditional piglet protection rail and a plain wall. As the walls seemed to be used for support by the sows, but also to be equally attractive, we chose the plain sloping wall. This was done for practical reasons as it was considered the wall that it would be easiest and cheapest to manufacture both in experiment 2 and in future farrowing pens.

In experiment 2, the sows used the wall with a piglet protection rail significantly less than they did the plain and the sloping walls. This suggests that a wall with piglet protection rail does not provide support or that it is otherwise uncomfortable to lie down against. Sows seem to have considerable difficulty controlling the end of the lying down sequence and they may drop the hindquarter fast and hard to the ground—a movement referred to as flopping (Blackshaw and Hagelsø, 1990; Marchant and Broom, 1993; Wechsler and Hegglin, 1997). When late pregnant sows (this experiment) or newly farrowed sows (unpublished data) lie down alongside or close to walls with piglet protection rails, they often drop the hindquarter onto the rail hard and fast during the final stage of lying down. If piglets are underneath the hindquarter, it is likely that they will be crushed unless they are provided with the escape zone created by the rail. It may, however, be highly unpleasant or even painful for the sow to lie down this way. Hence, both the lack of support and the smashing of the hindquarter into the rail may motivate sows to lie down against other support features when they are present (experiment 2, e.g. Marchant et al., 2001). When no alternatives are present it may motivate sows to lie down in the open as suggested by the previously reported finding that sows in this situation use walls to lie down against only 5–16% of the times they lie down (Blackshaw and Hagelsø, 1990; Hesse, 1992). This is unfortunate as it involves a far greater risk to the piglets than supported lying (Marchant et al., 2001).

EU-regulations state that farrowing pens must be given "some means of protecting the piglets, such as farrowing rails" (Anon., 2001). We have been unable to find scientific documentation that farrowing rails reduce piglet mortality. This, in combination with the greater safety for piglets at supported lying and the apparent tendency in sows not to use walls with piglet protection rails for support, suggests that piglet protection rails may not be the best solution to the EU requirement—neither in terms of piglet survival, nor in terms of sow welfare.

In both experiments, the sows had a strong preference for lying down along the back wall of the pen. Apart from the different walls, we attempted to make the pens as uniform as possible in relation to factors that might attract the sows to particular lying places. Thus, there was concrete slatted floor throughout the pen and no bedding was provided as this has previously been shown to interact with the use of support (Clough, 1984; Clough and Baxter, 1984). Moreover, three of the four pen walls were solid, so that the caretakers could not be seen by the sows before entering the pen, as it might prompt the sows to lie where they could best anticipate this. However, each pen had a partitioning wall of vertical bars to the neighbouring pen, which was fitted with a feed trough and a drinker and allowed a view to the neighbouring sow. This wall was always in the same position in relation to the back wall (see Fig. 1) and it cannot be excluded that it was part of the attraction of the back wall. It is however, not a very likely explanation because the partition wall (and thus the neighbouring sow, the feed trough and the drinker) could be seen from all positions in the pen, and the relatively small size of the pen meant that none of the other walls were far from the partitioning wall and the resources that it was associated with. Another possibility is that the sows preferred the solid high wall of the room that constituted the back wall relative to the lower plywood walls. It may have provided a greater sense of security and it was farthest from the inspection alley where the caretaker would approach the pen and thus might be smelled and heard, although not seen. A final explanation might be that the natural

daylight from the small window high on the back wall or small drafts undetectable by us increased the attractiveness of the back wall or reduced that of the other walls. In any case, the finding emphasises the need to consider other factors of importance for the sows' choice of resting place when positioning a supportive wall in, e.g. a farrowing pen.

5. Conclusion

Sows showed no preferences for three types of sloping walls, but they did choose to use a wall with a piglet protection rail less than a plain wall or sloping wall. Hence, further studies should be directed at designing an alternative to the rail wall, i.e. a supportive wall that the sow will lie down against as often as possible. This may in itself increase piglet safety when the sow lies down, but an escape zone may also be included as a feature of the supportive wall, e.g. by ending the wall some 20 cm above the floor. A systematically developed wall should subsequently be tested for sow preferences relative to lying down in the open and for piglet survival, and the results compared to those found by using walls with piglet protection rails. Current knowledge suggests that it should be possible to find alternatives to the piglet protection rail, and that this might at the same time improve sow welfare and piglet survival in pens.

Acknowledgements

We thank Ernst Nielsen (The National Committee for Pig Production) for technical assistance with video recording and the staff at Grønhøj experimental pig farm (The National Committee for Pig Production) for care of the animals and for helping with the practicalities of the study. Moreover, we are grateful to Tine Park (industrial design student) for ideas for various types of supportive walls. The study was financed by a grant from The Directorate for Food, Fisheries and Agro Business under the Ministry of Food, Agriculture and Fisheries, Denmark, supplemented by funding from The National Committee for Pig Production.

References

Anon., 1997. The Welfare of Intensively Kept Pigs. Report of the Scientific Veterinary Committee of European Commission, DOC XXIV/B3/ScVC/0005, 1997.

Anon., 2001. Commission Directive 2001/93/EC of 9 November 2001 Amending Directive 91/630/EEC laying down Minimum Standards for the Protection of Pigs.

Barnett, J.L., Hemsworth, P.H., Cronin, G.M., Jongman, E.C., Hutson, G.D., 2001. A review of the welfare issues for sows and piglets in relation to housing. Aust. J. Agric. Res. 52, 1–28.

Bates, D., Sarkar, D., 2004. lme4: Linear Mixed-Effects Models Using S4 Classes. R Package Version 0.6–9.

Baxter, M.R., 1991. The 'Freedom' farrowing system. Farm Build. Prog. 104, 9–15.

Blackshaw, J.K., Hagelsø, A.M., 1990. Getting-up and lying-down behaviours of loose-housed sows and social contacts between sows and piglets during day 1 and day 8 after parturition. Appl. Anim. Behav. Sci. 25, 60–70.

Bradshaw, R.H., Broom, D.M., 1999. A comparison of the behaviour and performance of sows and piglets in crates and oval pens. Anim. Sci. 69, 327–333.

Clough, C.E., 1984. Environmental Design for Piglet Protection. MAFF, pp. 8.

Clough, C., Baxter, M., 1984. Has the crate had its day? Pig Farming 32, 49.

Cronin, G.M., Lefébure, B., McClintock, S., 2000. A comparison of piglet production and survival in the Werribee farrowing pen and conventional farrowing crates at a commercial farm. Aust. J. Exp. Agric. 40, 17–23.

Damgaard, L.H., Rydhmer, L., Løvendahl, P., Grandison, K., 2003. Genetic parameters for within-litter variation in piglet birth weight and change in within-litter variation during suckling. J. Anim. Sci. 81, 604–610.

Damm, B.I., Pedersen, L.J., Heiskanen, T., Nielsen, N.P., 2005. Long stemmed straw as an additional nesting material in modified Schmid pens in a commercial breeding unit: effects on sow behaviour, and on piglet mortality and growth. Appl. Anim. Behav. Sci. 92, 45–60.

Dyck, G.W., Swierstra, E.E., 1987. Causes of piglet death from birth to weaning. Can. J. Anim. Sci. 67, 543–547.

Fraser, D., 1990. Behavioural aspects on piglet survival. J. Reprod. Fert. Suppl. 40, 355–370.

Harris, M.J., Gonyou, H.W., 1998. Increasing available space in a farrowing crate does not facilitate postural changes or maternal responses in gilts. Appl. Anim. Behav. Sci. 59, 285–296.

Hesse, D., 1992. Beurteilung unterschiedlicher Haltungsverfahren für ferkelführende Sauen. KTBL-Schrift 351, current work on appropriate livestock management, 1991. In: Proceedings of 23rd International Conference on Applied Ethology in Livestock, Freiburg am Breisgau, Germany, 21–23 November, 1991, pp. 199–208.

Marchant, J.N., Broom, D.M., 1993. Effects of dry sow housing conditions on lying behaviour of sows. In: Nichelmann, M., Wierenga, H.K., Braun, S. (Eds.), Proceedings of International Congress on Applied Ethology, K.T.B.L., Darmstadt, Germany, pp. 455–458.

Marchant, J.N., Broom, D.M., 1996. Factors affecting posture-changing in loose-housed and confined gestating sows. Anim. Sci. 63, 477–485.

Marchant, J.N., Rudd, A.R., Mendl, M.T., Broom, D.M., Meredith, M.J., Corning, S., Simmens, P.H., 2000. The timing and causes of piglet mortality in alternative and conventional farrowing systems. Vet. Rec. 147, 209–214.

Marchant, J.N., Broom, D.M., Corning, S., 2001. The influence of sow behaviour on piglet mortality due to crushing in an open farrowing system. Anim. Sci. 72, 19–28.

Pedersen, B.K., Jensen, K.H., Nielsen, N.P., 1998. Farrowing systems for the future. In: Proceedings of the 15th IPVS Congress, Birmingham, England, 5–9 July, pp. 273–280.

R Development Core Team, 2004. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria, ISBN: 3-900051-07-0 http://www.r-project.org.

Vieuille, C., Berger, F., Le Pape, G., Bellanger, D., 2003. Sow behaviour involved in the crushing of piglets in outdoor farrowing huts—a brief report. Appl. Anim. Prod. Sci. 80, 109–115.

Weary, D.M., Phillips, P.A., Pajor, E.A., Fraser, D., Thompson, B.K., 1998. Crushing of piglets by sows: effects of litter features, pen features and sow behaviour. Appl. Anim. Behav. Sci. 61, 103–111.

Weber, R., 2000. Alternative housing systems for farrowing and lactating sows. In: Blokhuis, H.J., Ekkel, E.B., Wechsler, B. (Eds.), Improving Health and Welfare in Animal Production. Wageningen Pers, Wageningen, The Netherlands (EAAP Publication No. 102), pp. 109–115.

Wechsler, B., Hegglin, D., 1997. Individual differences in the behaviour of sows at the nest-site and the crushing of piglets. Appl. Anim. Behav. Sci. 51, 39–49.