Rolling behaviour of sows in relation to piglet crushing on sloped versus level floor pens

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ABSTRACT

The study focused on the rolling behaviour of sows and the crushing of piglets by sows’ rolling behaviour. The experiment examined the influence of sloped floor in loose housed farrowing pens on the rolling behaviour of sows and crushing of piglets. The experimental unit was made up of 24 pens. There were two experimental pen designs with piglet creep in the corner of the pen and piglet creep across the end of the pen, respectively. Both of the experimental pen designs had a 10% sloped floor in the sow’s resting area. The two control pen designs were identical to the experimental pen designs, but with a level floor. Behaviour of 85 sows and their litters was continuously video recorded. Behavioural observations were made from birth of the first piglet and until 3 days after birth of the first piglet. Rolling behaviour of sows caused significantly more trapped piglets under the sow than lying down from standing (P=0.04). Rolling behaviour caused 64% of the trapped piglets and lying down from standing caused 36% of the trapped piglets. Rolling from udder to side without protection trapped significantly more piglets than rolling from udder to side near slanted wall or piglet protection rails and rolling from side to udder (P<0.001). With a certain pen design sloped floor reduced rolling from udder to side without protection (P=0.007) and reduced the number of trapped piglets (P=0.01), but results concerning lying behaviour showed that sloped floor pushed sows to rest on the level part of the floor. The results indicate that rolling behaviour that crushes piglets can be reduced, and sows prefer to lie on a level floor.

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Farrowing pen
Sow behaviour
Crushing

1. Introduction

Crates can be stressful for farrowing sows with an increased number of stillborn piglets and impaired maternal behaviour as consequences (Lawrence et al., 1994; Pedersen and Jensen, 2008). In some countries this has lead to an increased public attention to sow welfare issues in intensive pig production systems. Thus, in those countries there is increased political and public interest in loose housing systems for farrowing and lactating sows. In Denmark, for instance, a working group established by the government recommended (Ministry of Justice, 2010) that the end goal should be that all farrowing and lactating sows and gilts are loose housed, and that a decision to ban the use of crates should be made 10 years from now followed by an appropriate additional transitional period.

The pig industry thus faces a challenge because it will expectedly in the foreseeable future be necessary to develop reliable pens for loose housed farrowing and lactating sows. However, for such systems to compete with crates with regards to piglet mortality, deaths due to crushing have to be reduced as mentioned by Damm et al. (2005a), who also...
notice that piglet mortality tends to be even more of a problem in loose-housed systems. Piglets are crushed by sows in relation to postural changes where lying down and rolling behaviour are the most important activities resulting in piglets being crushed. This has been studied in details in a thorough review by Damm et al. (2005a). The review has served as very important background information for the present study, and among the observations and conclusions presented in the review by Damm et al. (2005a) the following are particular relevant for the present study:

- In pens, very different figures have been reported for mortality rates for live born piglets from 11 to 16% (Cronin et al., 2000; Weber, 2000) up to 25–33% (Marchant et al., 2000; Pedersen et al., 1998).
- Crushing by the sow is a predominant cause of death both in crates and pens (Damm et al. 2005b; Dyck and Swierstra, 1987; English and Smith, 1975; Fraser, 1990; Marchant et al., 2000).
- Among the crushed piglets, rolling behaviour accounted for 18–36% in some studies (Marchant et al., 2001; Vieuille et al., 2003) whereas in other studies it accounted for as many as 65–75% (Weary et al., 1996; 1998).
- Based on Weary et al. (1996, 1998) it is noticed in the review that rolling from lateral to sternal position is far less riskful to the piglets as other kinds of rolling.

In the review, Damm et al. (2005a) also conclude that the discrepancies regarding piglets crushed by rolling behaviour seem large enough to suggest that environmental aspects may be involved, and they mention particularly floor type as one such environmental factor based on a study by Weary et al. (1998).

Thus, based on the observations reported by Damm et al. (2005a), there seems to be a potential for reducing piglet mortality in farrowing pens by influencing the rolling behaviour of sows. Furthermore, environmental aspects like floor type appear to be of considerable importance.

McGlone and Morrow-Tesch (1990) found that fewer piglets were crushed and more piglets were weaned when the loose farrowing system had an 8% sloped floor as opposed to a level floor. Collins et al. (1987) found no differences in piglet mortality between a 10% sloped floor in a farrowing pen and a level floor crate. McGlone and Morrow-Tesch (1990) recorded the lying down behaviour, but not the rolling behaviour. Reduced piglet mortality in sloped floor pens may therefore be attributable to changes in the sows’ rolling behaviour. However, more knowledge is needed about sows’ behaviour in pens with a sloped floor.

The aim of the present experiment was therefore to investigate the effect on the lying down and rolling behaviour of sows on a partly sloped floor in a farrowing pen. The aim was furthermore to examine the sows’ rolling behaviour and the influence on piglet crushing.

2. Materials and methods

The experiment was carried out on a commercial farm with 300 sows from April 2008 to October 2008.

2.1. Animals and housing

During gestation sows were housed in groups in a deep litter section and fed once a day in groups. All sows had been group housed in all parities during gestation, and sows had to exercise in order to move up to the feeding unit. The sows were moved to the farrowing unit 4 to 5 days before expected farrowing date and were weaned 5 weeks after farrowing. In the farrowing unit sows were fed four times a day. The sows were fed according to Danish standards (Jakobsen and Danielsen, 2006).

The number of total born piglets per litter ranged from 4 to 22 with an average of 14.5 (std. 3.7). From 12 to 24 h after farrowing the litters were equalised so that sows and gilts each had 12 or 13 piglets. We observed all sows for a period of equal length (72 h from birth of first piglet (BFP)). As a consequence the litter size varied between sows. However, this variation was limited to the first 12–24 h until litter size were equalised. In this period the litter size increased as number of piglets born increased, so the actual period with a high number of piglets was shorter than the 12–24 h. And in this period the sows changes posture in a limited number of times — according to the thorough review by Damm et al. (2005a) ‘Sows lie down in lateral recumbency most of the time during parturition and the first day after parturition’ (Jarvis et al., 1999; Pedersen et al., 2003; Petersen et al., 1990; Vieuille et al., 2003).

At the same time as cross fostering, the piglets were orally supplied with iron-paste. At 3 days of age, all piglets had tails docked and were vaccinated and the male piglets were castrated. The tails were docked because of observed problems with tail biting in the herd.

The pens measured 290 × 175 cm and had a partly slatted floor and a covered piglet creep area separated from the sow. In the resting area of the pen, the pen had a slightly slanted wall offering the sows support when lying down and protecting the piglets (Damm et al., 2006). The rest of the pen walls had piglet protection rails. The slanted wall and the protection rails are sketched in the illustrations of Fig. 3. The farrowing room had diffuse ventilation and no cooling. The time-period for the experiment was April to October, so it is possible that it was warmer in the farrowing rooms than recommended. However, because all four groups were represented in all farrowing batches, potential heat stress would also affect all four groups.

The experimental unit was made up of 24 pens. There were two different designs of experimental pens with a 10% sloped floor in the sow’s resting area, and two control pen designs identical to the experimental pen designs, but with a level floor. The experimental pen design CCS had a covered piglet Creep area in the Corner of the pen and a Sloped floor (Fig. 1). The experimental pen design CAS had the covered piglet Creep area in the Corner of the pen and a Level floor (Fig. 2). The control pen design CCL had the covered piglet Creep area in the Corner of the pen and a Level floor (Fig. 1). The control pen design CAL had the covered piglet Creep Area across the pen and a Level floor (Fig. 2). There were eight of each of the experimental pen designs and four of each of the control pen designs. In both pen designs the area of the sloped floor had a width of 80 cm. If the sow was lying with the back against the wall, then the sow was...
lying with all of its body on the slope floor. The sows in the experiment were randomly assigned to either sloped or level floor pens.

A total of 63 sows and 22 gilts of the breed Danish Landrace–Yorkshire were included in the experiment. The sows were mainly in the second, third or fourth parities.
was suspended over two pens and connected to a computer before farrowing until 3 days after farrowing. A video camera was pen design piglet Creep in the Corner of the pen and Level floor pens corresponding to the same area). CAS was pen design piglet Creep Across the pen and Sloped floor. CCS was pen design piglet Creep across the Creep in the Corner of the pen.

### Table 1

<table>
<thead>
<tr>
<th>Animals:</th>
<th>Sloped floor</th>
<th>Level floor</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CCS&lt;sup&gt;a&lt;/sup&gt;</td>
<td>CAS&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Gilts</td>
<td>5</td>
<td>8</td>
</tr>
<tr>
<td>Sows</td>
<td>18</td>
<td>14</td>
</tr>
<tr>
<td>Sum</td>
<td>23</td>
<td>22</td>
</tr>
<tr>
<td>Litter size:</td>
<td>Average total born per litter (min–max)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>16.9 (12–22)</td>
<td>13.4 (4–18)</td>
</tr>
</tbody>
</table>

<sup>a</sup> CCS was pen design piglet Creep in the Corner of the pen and Sloped floor. CAS was pen design piglet Creep Across the pen and Sloped floor. CCL was pen design piglet Creep in the Corner of the pen and Level floor. CAL was pen design piglet Creep Across the pen and Level floor.

There were four sows that were in the fifth, sixth or seventh parities. The four sows were evenly distributed in the four pen types. The distribution of animals and pens can be seen in Table 1.

### 2.2. Behavioural observations

The sows were continuously video-recorded from 2 days before farrowing until 3 days after farrowing. A video camera was suspended over two pens and connected to a computer using the MSH video system (M. Shafro & Co., www.guard.ly). Behavioural observations were made from birth of the first piglet (BFP) until 3 days after BFP. The camera surveillance was analysed using the All Occurrence Sampling method with exact time for each occurrence (Martin and Bateson, 2007). See Table 2 for definitions. The light was on during day time.

During night time the light from the heating lamp in the creep area was sufficient to illuminate the pen and make it possible to register sow behaviour on the video recording.

Rolling behaviour was defined as the number of movements from side to udder or from udder to side without the sow having any other postures in the movement. Before registration of the behaviour of the sows, rolling behaviour was categorised according to the position of the sow in the pen and if the sow rolled from udder to side or side to udder as illustrated in Fig. 3. If the sow was lying on the udder against the slanted wall or against the piglet protection rails, the piglets would be protected by the wall/rail when the sow was rolling from udder to side with the back against the wall or protection rails (protected rolling). Conversely, there would be no kind of protection of the piglets when the sow was rolling from udder to side if the back turned away from the wall or the protection rails (risky rolling). The last category defined corresponds to the naturally occurring rolling from side to udder at the termination of nursing (nursing termination rolling).

In the following we use the term “crushing” to denote an incident where a piglet dies as a direct consequence of being trapped under the sow. Piglets are given the term crushed when they are observed to be dead after being trapped under the sow, even though crushing often is a consequence of piglets being weak or of starvation. Piglets are given the term trapped when they are trapped under the sow and they escape by themselves or if the sow reacts and let them free.

### 2.3. Statistical analysis

All sows were observed for a period of equal length – 72 h from BFP. As a consequence the litter size varied between sows. However, this variation was limited to the first 12–24 h until litter size were equalised. In this period the litter size was recorded.

### Table 2

Definitions of the behavioural elements observed from birth of first piglet and three days ahead.

<table>
<thead>
<tr>
<th>Behaviour</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lying laterally</td>
<td>Sow is lying on the side with one shoulder or hind quarter/ham touching the floor. Three or four legs can be seen on one side of the sow.</td>
</tr>
<tr>
<td>Lying sternally</td>
<td>Sow is lying on the belly without a shoulder touching the floor.</td>
</tr>
<tr>
<td>Rolling</td>
<td>Sow rolls from sternal to lateral recumbancy or reverse without any other posture involved.</td>
</tr>
<tr>
<td>Sitting/standing/walking</td>
<td>Both feet on the sow’s front legs as well as the sow’s posterior are touching the floor.</td>
</tr>
<tr>
<td>Lying on sloped floor</td>
<td>Sow stands on all four legs.</td>
</tr>
<tr>
<td>Lying partly on sloped floor</td>
<td>Sow is lying on the part of the floor with a slope (for the level floor pens corresponding to the same area).</td>
</tr>
<tr>
<td>Lying away from sloped floor</td>
<td>Sow is lying in the middle of the pen with both sloped floor and level floor (for the level floor pens corresponding to the same area).</td>
</tr>
<tr>
<td>No pigs near the sow</td>
<td>No pigs near the sow when the sow is lying down from standing, sitting or rolling.</td>
</tr>
<tr>
<td>Less than half of the pigs near the sow</td>
<td>Less than half of the pigs are near the sow when the sow is lying down from standing or sitting. When the sow is rolling less than half of the pigs are near the sow on the side where the sow is rolling.</td>
</tr>
<tr>
<td>More than half of the pigs near the sow</td>
<td>More than half of the pigs are near the sow when the sow is lying down from standing or sitting. When the sow is rolling more than half of the pigs are near the sow on the side where the sow is rolling.</td>
</tr>
<tr>
<td>Trapping, crushing, lying down</td>
<td>Sow traps or crush a piglet in lying down movement&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Trapping, crushing, rolling</td>
<td>Sow traps or crush a piglet in rolling movement&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Piglet born</td>
<td>Registration of piglets born alive or stillborn.</td>
</tr>
</tbody>
</table>

<sup>a</sup> Trapping or crushing of piglets included the following incidents: the piglet is trapped under the sow, but escaped because of reaction of the sow; the piglet is trapped under the sow, but escaped by itself; the piglet is crushed under the sow and dies.

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size increased as number of piglets born increased, so the actual period with a high number of piglets was shorter than the 12–24 h. The exact litter size was not known at the time of each posture change by the sow, therefore litter size was not included in the model. The four treatments are equally influenced by this.

The number of trapped piglets per sow per day varied from 0 to 11. The effect of behaviour of the sow on the number of trappings was analysed using generalised linear models assuming that the number of trapped piglets follows a Poisson distribution. The following generalised linear model was used to analyse trapping incidents by PROCEDURE GENMOD, using SAS® version 9.13 of SAS Institute Inc.:

\[
\ln EY = \mu + a_i + b_j + c_l + S_m + (ab)_{ij} + (ac)_{il} + (bc)_{jl}
\]

where \(Y\) is the number of trapped piglets, \(\mu\) is the expected value, \(a_i\) is the systematic effect of \(i\)th pen design (CCS, CCL, CAS, and CAL), \(b_j\) is the systematic effect of \(j\)th number of piglets around the sow (either lying down versus rolling or rolling category, i.e. USPR, USNP, and SUNT), \(c_l\) is the systematic effect of \(l\)th day after farrowing \((0, 1, 2)\), \(S_m \sim N(0, \sigma^2_S)\) is the random effect of \(m\)th sow \((1, \ldots, 85)\). The same model was used to analyse the number of crushings (i.e. trappings where the piglet dies) per sow per day. The model was reduced by removal of non-significant effects, and for the analysis comparing lying down versus rolling, the final model was:

\[
\ln EY = \mu + a_i + b_j + c_l + S_m + (bc)_{jl},
\]

For the analysis comparing the three rolling categories, the model was reduced to:

\[
\ln EY = \mu + a_i + b_j + c_l + S_m,
\]

The rolling behaviour of the sow was measured as the number of times the sow performed risky rolling per day (USNP). USNP was a count data variable that varied from 1 rolling per day to 40 rollings per day. The effect of pen design on the number of USNP was analysed using generalised linear models assuming that the number of USNP follows a Poisson distribution. The following generalised linear model was used to analyse trapping incidents by PROCEDURE GENMOD, using SAS® version 9.13 of SAS Institute Inc.:

\[
\ln EY = \mu + a_i + b_j + c_l + S_m + (ab)_{ij} + (ac)_{il} + (bc)_{jl}
\]

Where \(Y\) is the number of times the sow performed USNP, \(\mu\) is the expected value, \(a_i\) is the systematic effect of \(i\)th pen design (CCS, CCL, CAS, and CAL), \(b_j\) is the systematic effect of \(j\)th number of piglets around the sow (none, less than half of...
the litter, more than half of the litter), $c_i$ is the systematic effect of $i$th day after farrowing (0, 1, 2), $S_m \sim N(0, \sigma^2_m)$ is the random effect of $m$th sow (1, ..., 85). After removal of non-significant effects, the model was reduced to:

$$\ln EY = \mu + a_i + b_j + c_i + S_m + (bc)_{ij}$$

(3)

For analysis of the influence of the sloped floor on the number of piglets trapped by rolling, the following count data model assuming a Poisson distribution was applied by use of the PROCEDURE GENMOD (SAS® version 9.13 of SAS Institute Inc.):

$$\ln EY = \mu + a_i + b_j + c_i + S_m + (ab)_{ij} + (ac)_{ij} + (bc)_{ij}$$

where $Y$ is the number of piglets trapped by rolling, $\mu$ is the expected value, $a_i$ is the systematic effect of $i$th pen design (CCS, CCL, CAS, and CAL), $b_j$ is the systematic effect of $j$th number of piglets around the sow (none, less than half of the litter, more than half of the litter), $c_i$ is the systematic effect of $i$th day after farrowing (0, 1, 2), $S_m \sim N(0, \sigma^2_m)$ is the random effect of $m$th sow (1, ..., 85). After removal of non-significant effects, the model was reduced to:

$$\ln EY = \mu + a_i + c_i + S_m$$

(4)

The number of piglets around the sow (none, less than half of the litter, more than half of the litter) when she performed rolling behaviour (1: protected rolling, 2: risky rolling, 3: rolling from side to udder) was analysed with a $\chi^2$-test under the hypothesis that the number of piglets was independent of the rolling behaviour.

The time spent by the sow lying stenially or laterally in different parts of the pen (sloped floor/near the wall, level floor/near the gangway, in the middle of the pen or in front of the piglet creep area) was analysed by

$$Y_{ijlm} = \mu + a_i + b_j + c_i + S_m + (ab)_{ij} + (ac)_{ij} + (bc)_{ij}$$

$$+ (abc)_{ij} + e_{ijlm},$$

where $Y_{ijlm}$ is the time the sow spent lying stenially or laterally on the floor, $\mu$ is the expected value, $a_i$ is the systematic effect of $i$th design (CCS, CCL, CAS, and CAL), $b_j$ is the systematic effect of $j$th area of the pen (Sloped floor/slanted wall, Level floor/gangway, middle of the pen or in front of the piglet creep area), $c_i$ is the systematic effect of $i$th day after farrowing (0, 1, 2), $S_m \sim N(0, \sigma^2_m)$ is the random effect of $m$th sow (1, ..., 85), $e_{ijlm} \sim N(0, \sigma^2)$ is the residual. After removal of non-significant effects, the model of time sows spent lying in the different areas was reduced to

$$Y_{ijlm} = \mu + a_i + b_j + c_i + S_m + (ab)_{ij} + e_{ijlm}.$$  

(5)

### 3. Results

For all of the 85 sows, a total of 263 risky incidents where piglets were trapped under the sow were observed. In 75 of the risky incidents the piglet died. Death due to crushing was in 63% of the incidents a consequence of piglets being trapped when sows performed rolling behaviour, and in 37% of the incidents a consequence of sows lying down from standing or sitting to sternal or lateral lying position (see Table 3).

In Table 4, the number of trapped and crushed piglets for each category of the rolling behaviour as defined in Fig. 3 is shown. Most of the crushing and trapping of piglets resulted from risky rolling behaviour (USNP). Among the piglets being crushed by the sows’ rolling behaviour 85% were caused by risky rolling behaviour (USNP). Thus, only 13% were crushed as a result of a nursing termination rolling from side to udder (SUNT), and only 2% of piglets were crushed when sows performed protected rolling behaviour (USPR).

Table 5 shows the distribution of the number of pigs near the sow (none, less than half, more than half) against the

### Table 3

Number of piglets being trapped and crushed under the sow from birth of first piglet and 3 days ahead, when sows perform rolling behaviour and when sows were lying down from standing to sternal or lateral lying.

<table>
<thead>
<tr>
<th>Rolling behaviour</th>
<th>Trapped piglets</th>
<th>Crushed piglets</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Number</td>
<td>Percent</td>
</tr>
<tr>
<td>Lying down from</td>
<td></td>
<td></td>
</tr>
<tr>
<td>standing or sitting</td>
<td>95a</td>
<td>36</td>
</tr>
<tr>
<td>Rolling behaviour</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>168b</td>
<td>64</td>
</tr>
<tr>
<td>2</td>
<td>263</td>
<td>100</td>
</tr>
</tbody>
</table>

$a$ Numbers having different superscripts (in the same column) differ significantly ($P=0.04$) when analysed according to a generalised linear model (model 1).

### Table 4

Number of piglets being trapped or crushed under the sow from birth of first piglet and 3 days ahead as a result of the rolling behaviour by category (cf. Fig. 3).

<table>
<thead>
<tr>
<th>Rolling behaviour</th>
<th>Trapped piglets</th>
<th>Crushed piglets</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Number</td>
<td>Percent</td>
</tr>
<tr>
<td>USPR, Udder to side</td>
<td>6a</td>
<td>3</td>
</tr>
<tr>
<td>protected rolling</td>
<td></td>
<td></td>
</tr>
<tr>
<td>USNP, Udder to side</td>
<td>124b</td>
<td>74</td>
</tr>
<tr>
<td>non protected</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SUNT, Side to udder</td>
<td>38c</td>
<td>23</td>
</tr>
<tr>
<td>nursing termination</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sum</td>
<td>168</td>
<td>100</td>
</tr>
</tbody>
</table>

$a,b,c$ Numbers having different superscripts (in the same column) differ significantly ($P<0.001$) when analysed according to a generalised linear model (model 2).

### Table 5

Percent of incidents the sow rolled when there were no piglets, less than half of the piglets or more than half of the piglets near the sow. The observations were made from birth of first piglet and 3 days ahead.

<table>
<thead>
<tr>
<th>Rolling behaviour</th>
<th>No piglets near the sow</th>
<th>Less than half of the piglets near the sow</th>
<th>More than half of the piglets near the sow</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Number</td>
<td>Percent</td>
<td>Number</td>
</tr>
<tr>
<td>USPR, Udder to side</td>
<td>86</td>
<td>10</td>
<td>3</td>
</tr>
<tr>
<td>protected rolling</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>USNP, Udder to side</td>
<td>45</td>
<td>36</td>
<td>19</td>
</tr>
<tr>
<td>non protected</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SUNT, Side to udder</td>
<td>10</td>
<td>18</td>
<td>72</td>
</tr>
<tr>
<td>nursing termination</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*a* The distribution was analysed with $\chi^2$-test, $P<0.001$.
three categories of rolling behaviour (USPR, USNP, and SUNT). When the sows rolled, there were large differences between the numbers of piglets near the sow depending on which rolling behaviour the sows performed. When sows performed USPR with their back against the slanted wall or piglet protection rails, in 86% of the incidents no piglets were at risk of getting crushed. As opposed to USNP where in 36% of the risky incidents less than half of the piglets were near the sow and in 19% of the incidents more than half of the piglets were near the sow. When sows performed the "nursing termination" rolling (SUNT) more than half of the piglets were near the sow in 72% of the incidents. The three distributions differ significantly ($P < 0.001$).

As the rolling USNP accounts for the largest risk of being trapped and crushed, the following results will mainly represent this type of rolling.

There was a significant effect of pen design (model 3, $P = 0.007$) on the number of USNP (see Fig. 4). Thus, sows in CCS had significantly fewer risky rollings per day than sows in CCL. There were no significant differences between CAL and CAS as shown in Fig. 4. Thus, there was only an effect of sloped floor on risky rolling behaviour in CC pens and not CA pens.

There was a significant interaction between days after BFP and the number of piglets near the sow when the sow performed USNP. When the sow performed USNP, there were more piglets near the sow on day 0 and 1 BFP than day 2 BFP (model 3, $P = 0.007$).

Fig. 5 shows the number of piglets trapped by rolling per sow from BFP and 3 days after BFP. Sows in CCS had significantly fewer trapped piglets by rollings in the time period from BFP until 3 days after BFP than sows in CCL ($P = 0.01$). There were no significant differences between CAL and CAS as shown in Fig. 5. As for risky rollings, there was only an effect of sloped floor on trapped piglets in CC pens and not CA pens.

Fig. 6 shows the number of hours the sows were lying sternally or laterally in the different areas of the pen for the four different pen designs. The sows were resting approximately 20 h per day from BFP until 3 days after BFP. There were significant differences between the pen designs as to where the sows were resting. The sows in sloped floor pens rested significantly less on the area with sloped floor/slanted wall and significantly more in the middle of the pen and on the area with level floor/gangway than the sows in level floor pens ($P < 0.001$). The pens were too narrow for sows to lie in their full length across the pen. Therefore, the sows were mainly lying lengthwise in the pen with few exceptions. In 61% of the lying down behaviour, sows were lying down with

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their head pointing towards the piglet creep and in 33% of the lying down behaviour, sows were lying with their head pointing towards the back wall.

4. Discussion

A major cause of piglet mortality was crushing when sows were lying down or rolling. There are differences in previous studies as to whether rolling behaviour compared to the posture change lying down from standing is a considerable cause of crushed piglets (Damm et al., 2005a). However, the present study is in accordance with Weary et al. (1996) and Weary et al. (1998) from indoor loose housed sows, which showed that crushed piglets as a consequence of rolling behaviour, make up for about 65% of the crushings and lying down from standing caused the remaining 35%, as opposed to outdoor huts where only 25% of the piglets were crushed as a consequence of rolling (Vieuille et al., 2003).

Previous studies indicated that the risk of crushing depends on which type of rolling behaviour the sow performed. In this experiment, 87% of the piglets crushed by rolling were crushed when sows were rolling from udder to the side. This is in accordance with Weary et al. (1996) and Weary et al. (1998) who found that rolling behaviour from udder to side accounts for more crushed piglets than rolling behaviour from side to udder. Sows take up more space in the pen when they are lying on the side compared to lying on the udder. Piglets can be trapped when sows change posture from lying on the udder to lying on the side because sows take up the space where piglets were lying and lie down on top of the piglets. Rolling behaviour from udder to side, being more risky than rolling behaviour from side to udder, can also be a consequence of the sow's udder being less controllable and thereby reduce the risk of crushing. The reduced risk for the piglets when sows were performing rolling behaviour near piglet rails and slanted walls (USPR) can be because piglets choose not to lie in these areas of the pen. Sows might avoid the sloped floor and choose to lie on the slanted part of the pen, which might be unattractive for the piglets, and thereby reduces the risk of being crushed. This is in accordance with the results. In 86% of the USPR, there were no piglets near the sow.

The litters were balanced within the first 24 h. There is not a precise registration of time of balancing the litters, other than 12 to 24 h after BFP. Therefore there will be a period from parution until balancing the litters when some sows have a litter larger than 12 to 13 piglets, just as there will be a period during parution when there are fewer than 12 to 13 piglets. There is also great variation between sows as to how long the parturition lasts. Therefore the number of piglets near the sow during the first 24 h will vary. This could affect the number of crushed and trapped piglets during this period, as sows with a large litter size are associated with a higher incidence of crushing (Weary et al., 1998).

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The results indicate that sloped floor in the resting area of the pen combined with a certain pen design can reduce the number of USNP and the number of trapped piglets. It would be beneficial to reduce the risky rolling behaviour as it causes most crushed piglets. The sloped floor might alter the movement of the sow and thereby reduce the risky rolling behaviour as it might be uncomfortable for the sow to perform rolling behaviour without any support from pen walls or piglet rails. According to McGlone and Morrow-Tesch (1990) sloped floor reduces piglet mortality, which is in resemblance with the results from the reduced number of trapped piglets in CCS compared with CCL. Collins et al. (1987) found no differences in piglet mortality between a sloped floor pen and a crate. The reduced number of USNP and trapped piglets was only evident in CC pens and not in CA pens. In both types of pens sows chose to rest away from the intended resting area with sloped floor and chose to rest on the level part of the floor instead. Therefore the effect on rolling behaviour and trapped piglets in CCS pens is confounded with the lying behaviour. The effect on rolling behaviour and trapped piglets could be caused by sows avoiding the sloped floor by lying on the level part and making protected rollings (USPR) near the piglet rails instead of non-protected rollings (USNP) onto the sloped floor.

The different results obtained on sloped floor between the two pen designs may be attributed to differences in the design of the pen and in how the sows and piglets use the pen. The results indicate that the sows in sloped floor pens chose to lie and rest more on the level floor area. There are no registrations on the effect of sloped floor on the behaviour of the piglets. If the piglets also tend to avoid the sloped floor, they might be faster to migrate into the piglet creep, and thereby reduce the number of trapped piglets. The sloped floor might be pushing the sows to rest in other places in the pen than the intended resting area. This is in contrast to results from Arey (1993) who found that growing pigs had a preference for sloped floor. The difference can be caused by differences in the gradient on the sloped floor. The gradient on the sloped floor in the test with growing pigs was 6% as opposed to 10% in the present study. Sows might find the 10% gradient uncomfortable to lie on. Growing pigs have a preference for sloped floor and were generally lying with their heads pointing up or down the slope and seldom across (Arey, 1993; Bruce, 1990). In the present study, sows were not able to lie with their head up- or downhill. This position has led to increased piglet mortality for farrowing and lactating sows in sloped floor crates (McGlone and Morrow-Tesch, 1990). In the present study, sows were able to lie on the sloped floor with their back uphill, which Collins et al. (1987) observed was the preferred position for farrowing and nursing sows in sloped floor pens. Sows choosing to lie away from the resting area with the sloped floor can be an effect of sows not being used to the sloped floor. Preference tests have shown it takes up to 1 week for sows to get used to a new type of floor (Phillips et al., 1996). As sows in the present study were moved into the farrowing pen 4 to 5 days before expected farrowing date, the sows might not have got used to the sloped floor.

5. Conclusion

Rolling behaviour of sows was the cause of most crushed piglets. Rolling behaviour caused 64% of the crushed piglets and lying down from standing caused 36% of the crushed piglets. Rolling behaviour can be divided into three different parts of rolling behaviour. Rolling from udder to side without protection (USNP) crushed significantly more piglets than rolling from udder to side near slanted wall or piglet protection rails (USPR) and rolling from side to udder (SUNT). Sows in CCS performed significantly fewer USNP than sows in CCL. Likewise the number of trapped piglets was significantly lower in CCS than CCL. The lower frequency of USNP was most likely the cause of fewer trapped piglets. For sows in CA pens there were no differences in the frequency of USNP and the number of trapped piglets. The results indicate that in the pen CCS, risky rolling behaviour can be reduced with sloped floor. On the other hand the results on lying behaviour showed that sloped floor pushed sows to rest on the level part of the floor. Therefore an apparent coherence between sloped floor and rolling behaviour cannot be established. More investigation is needed to examine rolling behaviour of sows and behaviour on sloped floor pens.

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