Behaviour, Health and Welfare

Behavioural characteristics of fatal piglet crushing events under outdoor conditions

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HIGHLIGHTS

• The most frequent fatal posture changes were rolling (31%) and from standing to sternal lying (22%).
• Flopping was rare (7% of the fatal posture changes).
• Crushing against inventory was rare (1% of the fatal posture changes).
• One-third of the crushed pigs were weak or damaged before the fatal posture change.
• Differences between hybrids (DanBred and Topigs Norsvin) and parities (1st and 2nd).

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ABSTRACT

Piglets being crushed by the sow is a major welfare challenge in outdoor pig production. To develop interventions with the highest impact on mitigating crushing, it is necessary to know whether the major behaviour leading up to crushing can be considered mainly sow- or piglet-related or due to inappropriate housing conditions and thus whether the genetics of the sow is a factor of importance. In this observational study, piglets classified as fatally crushed based on necropsy were identified on video recordings. Seventy-two crushing events were observed on video in 32 litters. Forty of the events took place in 17 litters born by DanBred Landrace × Yorkshire hybrid sows while 32 events took place in 15 litters born by Topigs Norsvin TN70 hybrids (TN70). The fatal posture changes were rolling (31%), standing to sternal lying (22%), standing to lateral lying (11%, where half were classified as ‘flopping’), sitting to sternal lying (11%), stepping on a piglet (11%), minor movement (10%), sternal lying to standing (3%) and lateral lying to standing (1%). We hypothesised that a larger proportion of the fatal crushing events could be attributed to either inadequate maternal behaviour (no exploration of piglet location before lying down, ‘flopping’ or not responsive to squeezing a piglet), inappropriate housing (squeezing against inventory), low piglet vitality (weak/damaged before) or an unattractive creep area (piglets clustering near the sow). There were no detectable differences between parity and hybrid on whether the sow explored before or made a posture change after crushing. One-third of the crushed pigs were weak/damaged before and took up a larger proportion of the fatally crushed piglets in DanBred (38%) vs. TN70 (16%) sows. ‘Flopping’ and squeezing against inventory were rare (7% and 1%, respectively). The sow explored before lying down in 42% of the events. Exploring before occurred more often before lying sternal and before stepping on a piglet than for all other fatal sow posture changes (P < 0.01). In 18% of the fatal events, the sow made a new posture change within one minute. Based on the findings, options to reduce crushing are discussed, including genetic selection for maternal behaviour and more robust piglets, housing conditions to slow sow posture changes and/or by attracting piglets away from the danger zone.

1. Introduction

A major challenge in pig production with outdoor farrowing (organic and free-range) is high piglet mortality. In Europe, the piglet mortality in organic production is higher than in conventional indoor systems (Prunier et al., 2014a, 2014b) and close to one in three piglets die before

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Weary et al., 1996). Piglet screaming can make the sow respond with a
Piglets have been found to survive more than 4 min underneath the sow
before she lies down if she performs pre-lying behaviour directed to
calls varies a lot and low responsiveness may contribute to fatal crush
1990; Bonde et al., 2004).
behaviour. Flopping is a term describing an uncontrolled lying down
with attention from the sow before lying down. Such pre-lying behaviour consist of rooting and
pawing, which wake up and/or alarm the piglets, the sow moves around,
gathers the piglets on one side of her and then carefully lies down on the side opposite to the assembled piglets (Blackshaw and Hagelsø, 1990; Schmid, 1991). However, not all sows show these behaviours consist-
tently and some rather tend to ‘flop down’ without any prior pre-lying
behaviour. Flopping is a term describing an uncontrolled lying down
behaviour from standing to lateral that is particularly risky unless it
occurs away from where piglets are clustered (Blackshaw and Hagelsø, 1990; Bonde et al., 2004).

When a piglet is squeezed by the sow it may not immediately be fatal.
Piglets have been found to survive more than 4 min underneath the sow (Weary et al., 1996). Piglet screaming can make the sow respond with a posture change (Held et al., 2006). Sows’ responsiveness to piglet alarm calls varies a lot and low responsiveness may contribute to fatal crushing, although high responsiveness has not consistently been found to correlate with higher piglet survival (Held et al., 2006; Held et al., 2007; Melisová et al., 2014). Whether a piglet can alert the sow is likely to depend on how the piglet is squeezed; if its full body or head is beneath the sow’s body it is less likely to be audible.

The performance of pre-lying behaviour, the speed of the lying down sequence as well as the responsiveness to piglet alarm calls largely vary between sows. This may be due to differences in the condition of the sows at farrowing such as parity, exhaustion from farrowing lamenesses or poor body condition (Wüllers-Mindermann et al., 2002; Rang-
strup-Christensen et al., 2018a). The differences may however also reflect stable individual traits that can be used for genetic selection to improve maternal behaviour. The expressing of strong maternal behaviours may have been relaxed as a consequence of genetic selection in the sow population taking place under conditions where sows are crated and thus where maternal behaviours are less important for piglet survival (Rauw et al., 1998; Pruiner et al., 2010; Canario et al., 2013, 2014) and where high responsiveness may even cause more damage than good. A survey by Fruih et al. (2014) showed that the same hyper-prolific sow hybrids as those used in conventional indoor pro-
duction are widely used in organic and outdoor production. As piglet survival under outdoor conditions to a much larger extent relies on the sow’s maternal behaviour, breeding for improved maternal traits, e.g. high responsiveness to piglet crushing have been suggested by several authors (Held et al., 2006; Illmann et al., 2008; Melisová et al., 2014) as a lever to mitigate the risk of piglet crushing under more extensive farrowing conditions. The possibility to select directly for behavioural traits have increased through the use of genomic selection (Rydhmer and Canario, 2022). However, to pave the way for such breeding, more knowledge is needed to understand which maternal behaviours contribute the most to fatal crushing under outdoor conditions.

The piglet’s own vitality may be as important for its survival as the sow’s maternal behaviour. A vital pig will likely express a stronger alarm call during a fatal event than a weaker pig and thus is more likely to make the sow respond. Also, high birth weight piglets are less likely to suffer from hypothermia and/or low colostrum intake and are thus less motivated to stay close to the sow’s udder to get heat and stimulate milk let down. In contrast, piglets suffering from hypothermia and poor milk intake will be close to the sow’s udder and less likely to move away when the sow alerts them prior to lying down. Therefore, traits related to piglet’s own viability are also important contributors to piglet’s risk of being crushed. Piglet vitality is affected by genetic selection as well, where the most important traits contributing to high risk of crushing is low birth weight (Hermesch et al., 2001; Grandinson et al., 2002) and increased risk of hypothermia at birth (Herpin et al., 2004). These traits are phenotypically correlated with the number of piglets born in a litter (Baxter et al., 2020). As the prevalence of very large litters steadily in-
creases due to intense breeding for prolificacy, it is increasingly important to focus also on the role of piglet viability as a contributing factor to piglet crushing.

The primary aim of this study was therefore to quantify which forms of sow and piglet behaviours most frequently precede and follow fatal posture changes, and to study if two hyper-prolific sow hybrids (Dan-
Bred and Topigs Norsvin) differed in their behaviour preceding and following fatal crushing events during their two first parities to elucidate whether the crushing events could mainly be attributed to sow behav-
ior, piglet vitality or inappropriate housing conditions. Be aware that this study did not investigate the prevalence of risky posture changes between parity and hybrid (although this would also be highly import-
ant for futures studies to target genetic selection). We hypothesised that a larger proportion of the fatal crushing events would be a consequence of either (1) maternal inadequacies: (a) no exploration before lying down (b) flopping or (c) not responding to squeezing by changing posture, (2) inappropriate housing: squeezing against inventory, (3) low piglet vitality: weak/damaged piglet prior to the fatal posture change or (5) unattractive creep area: piglets clustering near the sow.

2. Materials and methods

2.1. Animals and housing

All fatal crushing events during the first three days after the start of farrowing were identified in 32 litters born by 1st and 2nd parity sows. Sows represented the two L x Y sow hybrids of DanBred or Topigs Norsvin TN70, shown by Schild et al. (2020b) to differ in birth weight (DanBred: 1284 ± 27 g, TN70: 1447 ± 27 g) and litter size (DanBred: 18.2 ± 0.57, TN70: 15.7 ± 0.55 total born) under organic conditions. The 32 litters were distributed over four batches with seven to nine sows per batch. See distribution of litters on sow parity and hybrid in Table 1. The sows were part of a larger study (Schild et al., 2019, 2020b) taking place at the organic research farm at the Department of Animal and Veterinary Sciences, Aarhus University (AU-Viborg), Denmark. The
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hut (see schematic of the hut design in Schild et al. (2019)). Each communal hut had four pens for individual housing with each of the four pens measuring 2.4 × 2.5 m. The pen separations in the communal hut consisted of solid walls that were 119 cm high. In each of the four pens, piglets had access to a covered and heated (Eleuther, Orbital A/S, Trykkerivej 5, 6900 Skjern, Denmark) piglet area separated from the sow area. The ground of the creep area was covered by an insulating rubber mat (AAG Aalborg Gummivarefabrik A/S, Sundsholmen 3, 9400 Narresundby, Denmark) (not present in batch 1). Details on the course of parturition is presented in Schild et al. (2019) and characteristics of the piglets and mortality rate for the two sow hybrids are presented in Schild et al. (2020b). Batches 1 and 2 represented first parity, while batches 3 and 4 represented second parity.

The study population consisted of all piglets that died during the first 3 days after birth and that based on necropsies were categorised with crushing as primary cause of death (Schild et al., 2020b). The exact time of each fatal event leading to fatal crushing was identified on the videos. The data set consisted of all crushed piglets in the given time period, except 15 that could not be identified on the videos. Typically, the procedure was to identify the dead piglet in the straw or ultimately when collected by the staff the following day. The video recordings were then backtracked from this point to determine the exact timing of the crushing event. The sow posture change that caused the fatal crushing event was observed from the beginning of that posture change (lasting up to 60 s before the crushing event, but typically 5–10 s) (see definition in Table 2). It was also recorded whether the sow explored before or made a posture change after the crushing event (Table 2). When the fatal posture change started (e.g. when the sow bended the first leg to lie down (Table 2), the number of piglets in each of the following positions were counted: number of piglets in the sow-shaped area where the sow had most previously been lying down (‘in nest’) and the number of piglets in the sow-shaped area where she was about to lie down (‘danger zone’). At the same time, the total number of piglets that were clumped were counted irrespectively of their position in relation to the sow (see definition in Table 3). In every crushing event at least one piglet was fatally crushed, but a number of piglets could be squeezed non-fatally in the same posture change. The number of pigs non-fatally squeezed and fatally crushed, but a number of piglets could be squeezed non-fatally in the same posture change. The number of pigs non-fatally squeezed and fatally crushed in each event was counted. It was further recorded what part of the fatty crushed piglets’ bodies were squeezed under the sow or between the sow and pen inventory (see Table 3). It was also recorded whether the piglet was new-born or already damaged or weak prior to the event (Table 3). One observer located the fatal crushing events on the videos, while another recorded the behaviours and state of the piglets. The observers were not blinded to sow hybrid or parity.

2.2. Data collection

2.2.1. Behavioural recordings

Behaviour was monitored continuously by use of one video camera per pen (IPC–HDBW4100EP–0360B, Dahua Technology Co., Queen Anne House. 25–27 Broadway, UK) with a fitted wide-angle lens above each pen, ensuring view of the entire pen. Video recordings were saved digitally and analysed by use of the S-VIDIA Client MegaPixel (M. Shafro & Co., Riga, Latvia).

The study was reviewed and approved by Ministry of Environment and Food of Denmark, Danish Veterinary and Food Administration J. nr. 2013–15–2934–00,822. Sows and litters were housed in a communal hut (see schematic of the hut design in Schild et al. (2019)). Each communal hut had four pens for individual housing with each of the four pens measuring 2.4×2.5 m. From the hut, each sow had free access to a fenced paddock of approx. 450 m². The pen separations in the communal hut consisted of solid walls that were 119 cm high. In each of the four pens, piglets had access to a covered and heated (Eleuther, Orbital A/S, Trykkerivej 5, 6900 Skjern, Denmark) piglet area separated from the sow area. The ground of the creep area was covered by an insulating rubber mat (AAG Aalborg Gummivarefabrik A/S, Sundsholmen 3, 9400 Narresundby, Denmark) (not present in batch 1). Details on the course of parturition is presented in Schild et al. (2019) and characteristics of the piglets and mortality rate for the two sow hybrids are presented in Schild et al. (2020b). Batches 1 and 2 represented first parity, while batches 3 and 4 represented second parity.

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2.3. Statistical analysis

The results are descriptively presented (frequencies, percentages, median and range) followed by inferential analysis where the dataset is large enough to be meaningful. The analyses were performed in R version 3.4.3 (R Core Team, 2022). The following models 1–3 (M1–3) were all generalised logistic regressions using the function ‘glm’ (‘stats’ package v 4.2.0) with family set to binomial.

2.3.1. Sow posture change and duration to lie down

In M1, the six tested response variables were whether the crushing event was one of the following fatal posture changes or not (i.e., any of the other postures): standing to sternal, standing to lateral, sitting to sternal, lateral to standing, rolling, and stepping on a piglet (not including lying to standing due to too few observations). The explanatory variables included in the model was parity, sow hybrid, protein level and the two-way interaction between parity and sow hybrid. Protein level was included in all models as a covariate as part of the larger study design, but results will not be presented. In M1, the duration to lie down was also analysed as a binomial, categorical variable of

Table 1
Summary of the number of fatal crushing events and the extent to which the piglet’s body was squeezed according to sow hybrid (DanBred and TN70 (Topigs Norvin) and parity (1st and 2nd)). Piglets that were squeezed but survived are not included in the table.

<table>
<thead>
<tr>
<th>Item</th>
<th>TN70 1st</th>
<th>TN70 2nd</th>
<th>DanBred 1st</th>
<th>DanBred 2nd</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fatal events (N = 72 events, 76 pigs)</td>
<td>20</td>
<td>12</td>
<td>19</td>
<td>21</td>
</tr>
<tr>
<td>1 (or 2) piglet(s)/event</td>
<td>19 (1)</td>
<td>11 (1)</td>
<td>19 (0)</td>
<td>19(2)</td>
</tr>
<tr>
<td>Litters (N = 32 litters)</td>
<td>8</td>
<td>7</td>
<td>8</td>
<td>9</td>
</tr>
<tr>
<td>Events/litter (median [range])</td>
<td>1.5</td>
<td>1</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Full body squeezed (46 events, 49 pigs)</td>
<td>14 (1)</td>
<td>5 (1)</td>
<td>11 (0)</td>
<td>13 (1)</td>
</tr>
<tr>
<td>Head squeezed (n = 8 events, 8 pigs)</td>
<td>1 piglet/event</td>
<td>1</td>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td>Body not head squeezed (n = 8 events, 8 pigs)</td>
<td>0 piglet/event</td>
<td>0</td>
<td>0</td>
<td>6</td>
</tr>
<tr>
<td>Squeezed between sow and inventory (n = 1 event, 1 pig)</td>
<td>1 piglet/event</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Stepped on (n = 8 events, 8 pigs)</td>
<td>1 piglet/event</td>
<td>3</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

* Excluding one event with two fatally squeezed piglets where one piglet was squeezed full body and the other with its' body but not head in a 1st parity TN70.
Table 2
Ethogram describing the fatal sow posture change crushing a piglet and the sow’s behaviour immediately before and after the event.

<table>
<thead>
<tr>
<th>Behaviour</th>
<th>Modifier</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Before crushing</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Exploration</td>
<td></td>
<td>The sow is rooting with her snout, scraping with her front legs in the nesting material and/or nudging the piglets with her snout immediately (&lt; 30 s) before the event.</td>
</tr>
<tr>
<td>The fatal posture change</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Standing to sternal</td>
<td>1</td>
<td>The sow changes posture from standing to lying sternal.</td>
</tr>
<tr>
<td>Standing to lateral</td>
<td>1</td>
<td>The sow changes posture from standing to lying lateral. The posture change was scored as either gradual or ‘Flopping’.</td>
</tr>
<tr>
<td>Gradual</td>
<td>2</td>
<td>The posture change is performed by having intermediate postures including sternal posture before rolling to lateral, sitting and/or kneeling for &gt; 2 s but &lt; 60 s.</td>
</tr>
<tr>
<td>‘Flopping’</td>
<td></td>
<td>Uncontrolled posture change from standing to lateral (without an intermediate position).</td>
</tr>
<tr>
<td>Lying to standing</td>
<td></td>
<td>The sow changes posture from either lateral or sternal lying to standing.</td>
</tr>
<tr>
<td>Sternal to lateral</td>
<td>1</td>
<td>The sow changes posture from lying sternal to lateral (i.e., rolling to expose udder).</td>
</tr>
<tr>
<td>Lateral to sternal</td>
<td>2</td>
<td>The sow changes posture from lying lateral to sternal (i.e., rolling to unexposed udder).</td>
</tr>
<tr>
<td>Lateral to opposite lateral</td>
<td>3</td>
<td>The sow changes posture from lateral on one side to the other side with &lt; 5 s in sternal position.</td>
</tr>
<tr>
<td>Sitting to sternal</td>
<td></td>
<td>The sow changes posture from sitting to lying sternal.</td>
</tr>
<tr>
<td>Stepping</td>
<td></td>
<td>The sow is standing/walking in the pen when a piglet is crushed under the sow’s hoofs.</td>
</tr>
<tr>
<td>Minor movement</td>
<td></td>
<td>The sow makes none of the above posture changes prior to the event, but a minor movement that crushes a piglet.</td>
</tr>
<tr>
<td><strong>After crushing</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Posture change afterwards</td>
<td></td>
<td>The sow makes a posture change within one minute of the crushing event to either standing, sitting or another lying posture.</td>
</tr>
<tr>
<td><strong>Modifier to crushing event</strong></td>
<td></td>
<td>The sow is giving birth (i.e., is between birth of the first and last piglet).</td>
</tr>
</tbody>
</table>

1 The posture change starts when the sow bends her first leg to kneel down and ends when the sow is in sternal position (i.e., the abdomen touches the ground). The time spent to lie down was recorded.
2 If more than 60 s passes between the sow bends her first leg until lying in lateral position, it is considered as two separate posture changes of standing to lateral followed by rolling from sternal to lateral, and only the latter is recorded as the fatal posture change.
3 Combined to rolling.

whether the duration was below or equal to the median duration of 7.5 s or above.

2.3.2 Sow and piglet state prior to and after crushing
In M2, the four investigated binary response variables were whether the sow explored before, made a posture change afterwards, the piglets were damaged/weak prior to the crushing event, or whether the sow was in birth during the event or not. The same explanatory variables were used as in M1 (parity, sow hybrid, protein level and the two-way interaction between parity and sow hybrid). Cruising during birth did not have observations on all levels of sow hybrid and parity (no cruising during birth for TN70 s parity), which meant the interaction was omitted from this analysis. Whether the sow was in birth and the piglet was scored as new-born was (not surprisingly) often coinciding and only whether the sows was in birth was analysed inferentially.

To analyse the association between the type of fatal posture change and whether the sow explored before lying down, made a posture change after the fatal posture change and whether the piglet was weak/damaged prior to the event, a Fisher’s exact test (‘stats’ package) was used. Also using Fisher’s exact test, it was analysed whether the sow explored before and making a posture change afterwards was correlated.

2.3.3 Piglet position
In M3, the binary response variable was the proportion of piglets in one of the following three positions: in nest vs. not in nest, in the danger zone vs. not in the danger zone, and clustered vs. not clustered of the total number of visible piglets in the pen. The same explanatory variables were used as in M1–2 (parity, sow hybrid, protein level and the two-way interaction between parity and sow hybrid).

The main effects of parity, sow hybrid and protein level were always kept in all the models even if statistically insignificant as they were part of the study design. Significance of fixed effects were tested by chi-squared likelihood ratio tests at a significance level of 5% and \( P < 0.1 \) was considered a trend. In M1–3, the estimated results are presented as the percentage of sows performing a specific posture change and the median of piglets being in a specific position (\( N = 72 \) events), and differences are presented as odds ratios (OR) with connected 95% confidence intervals (CI).

3. Results
The following percentages and comparisons of odds ratios show the proportion with which each type of postural changes triggered fatal events in the two sow hybrids and parities. It does not report whether a certain risky posture change occurred more often in a specific parity or sow hybrid.

Table 3
Ethogram of the location of visible piglets, the extent of which body parts were squeezed, the state of the crushed piglet before and the time until death. 1, 2

<table>
<thead>
<tr>
<th>Classification</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Visible 1</td>
<td>Number of piglets visible and alive within the pen. Piglets that are in the creep area (and therefore not visible) are not counted.</td>
</tr>
<tr>
<td>Piglet location 1</td>
<td></td>
</tr>
<tr>
<td>In nest</td>
<td>Number of piglets within or max. a piglet length from where the sow was most recently lying.</td>
</tr>
<tr>
<td>In danger zone</td>
<td>Number of piglets underneath the sow or less than one piglet’s length to the side from where the sow is going to lie down.</td>
</tr>
<tr>
<td>Clustered</td>
<td>Number of piglets at least three lying or standing with pig-to-pig contact or with less than a piglet’s width between them.</td>
</tr>
<tr>
<td>Part(s) of the piglet squeezed</td>
<td></td>
</tr>
<tr>
<td>Full body under sow</td>
<td>The fatally crushed piglet’s entire body including its head was covered by the sow’s body (yes/no).</td>
</tr>
<tr>
<td>Head under sow</td>
<td>The fatally crushed piglet’s head (not its body) was covered by the sow’s body (yes/no).</td>
</tr>
<tr>
<td>Body not head under sow</td>
<td>The fatally crushed piglet’s body (except its head) was covered by the sow’s body (yes/no).</td>
</tr>
<tr>
<td>Between sow and inventory</td>
<td>The fatally crushed piglet was squeezed between the sow and the pen inventory (yes/no).</td>
</tr>
<tr>
<td>Other pigs squeezed</td>
<td>Number of piglets non-fatally squeezed during the event.</td>
</tr>
<tr>
<td>Time until death 1</td>
<td>In every event at least one piglet was fatally crushed. The duration (s) from the crushing event occurred until the fatally crushed piglet stopped breathing and/or stopped struggling. The piglet was either still squeezed beneath the sow or had been released.</td>
</tr>
<tr>
<td>Piglet state before fatality</td>
<td></td>
</tr>
<tr>
<td>Damaged or weak</td>
<td>The fatally crushed piglet showed signs of weakness prior to the fatal event ((&lt; 30 ) s). Defined as showing signs of leg damage by limping, if they had open wounds e.g., from previous crushing events or if they did not move away with same speed as the remaining piglets when nosed/puffed at by the sow (yes/no).</td>
</tr>
<tr>
<td>New-born</td>
<td>The fatally crushed piglet(s) were wet from foster fluids (yes/no).</td>
</tr>
</tbody>
</table>

1 Recorded when the sow starts to perform the fatal posture change (i.e., bending the first leg).
2 When possible to determine.
3.1. Descriptive analysis

Eighty-eight crushed piglets were recorded by necropsy of which it was possible to identify the fatal event in 72 cases on the video. The 72 fatal events resulted in the death of 76 piglets, but also squeezed 20 pigs non-fatally. In 68 of the 72 fatal events (94%) only one piglet was fatally squeezed, while two piglets died in the remaining four events (6%) (see Table 1). In six of the 72 events, the piglets were found by the staff before dying and euthanised (still included as a fatal crushing event).

In 63% of the fatal events where only one piglet was fatally crushed, the full body of the dying pig was squeezed under the sow (Table 1), while in 12% only the body was squeezed and in 12% only the head was squeezed. Only 1% were squeezed between the sow and the inventory. The last 12% were stepped on. The distribution of number of piglets and events between sow hybrid and parity can be seen in Table 1. In 12% of the crushing events, it was possible to see that the piglet was still breathing and to some extent moving after the fatal trauma. The time until death was recorded to vary from 6 min to 10 h (median 12 min).

Three cases of crushing events are described in detail in the supplementary materials as they underline the challenges with proper maternal behaviour and how non-fatal squeezing may later become fatal.

3.1.1. Sow behaviour

The posture changes contributing the most to fatal crushing irrespective of hybrid and parity was rolling (31%), followed by standing to sternal (22%), standing to lateral (11%), sitting to sternal (11%), stepping on a piglet (11%), minor movements (10%), sternal to standing (2%) and lateral to standing (1%). Of the eight piglets that died from being stepped on, three of these were also squeezed and crushed in an immediately following posture change (either rolling or standing to sternal).

3.1.2. Association with piglet position

The percentage of visible piglets that were in the danger zone, in the nest and clustered when the fatal posture change started is visualised in boxplots for each of the eight posture changes in Fig. 1. The plots show that for most posture changes the median percentage of piglets were clustered, in the danger zone and in the nest although with considerable variation.

3.1.3. Flopping

The duration to lie down was numerically longer for standing to lateral (median 10.5 s, range: 4 to 39 s) than for standing to sternal (median 6.0 s, range 4 to 16 s). Within standing to lateral, flopping occurred in 63% of the events (7% of all fatal posture changes, n = 5).

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Fig. 1. The percentage of visible piglets (A) clustered (min. three piglets lying or standing with pig-to-pig contact or less than a piglet’s width between them) (B) in the nest (i.e., piglets present in the place in the pen where the sow was most recently lying), all counted when the fatal posture change started (i.e., the sow bending the first leg) for each of the fatal posture changes or (C) in the danger zone (i.e., piglets beneath or within one piglet’s length of the sow on the side the sow lies down. By definition, no piglets could be in the danger zone when the posture change was to get up (from sternal or lateral to standing) or a minor movement.
The flopping events took as a median 9.0 s (range 4.0 to 11), while the non-flopping events took as a median 23 s (range 11 to 39 s). When the fatal flopping events started, a median of 45% of the visible piglets were clustered (range 0 to 95%), 45% were in the nest (range 0 to 100%) and 60% in the danger zone (range 25 to 100%).

3.2. Inferential analysis

3.2.1. Association with parity

The odds were higher for first compared to second parity sows of a fatal event to occur during farrowing (M2: OR = 11.7, 95% CI [3.37; 40.6], P < 0.01), during minor movements (M1: OR = 12.1, CI [1.14; 127], P = 0.01) and during standing to sternal (M1: OR = 2.9, 95% CI [0.80; 10.2], P = 0.09). In contrast, the odds were higher for second compared to first parity sows of the fatal crushing event to occur during sitting to sternal (M1: OR = 16.2, 95% CI [1.71; 150], P < 0.01). Parity did not influence the odds of the piglets being weak or damaged prior to the event, or of the sow to explore before or to respond after a posture change (P > 0.1). The odds of the lying down duration to be above the median of 7.5 s tended to be higher for second compared to first parity sows (OR = 5.8, 95% CI [0.72; 46.7, P = 0.08]).

3.2.2. Association with hybrid

The odds of the fatal posture being from sitting to sternal was higher in TN70 compared to DanBred sows (M1: OR = 6.8, 95% CI [0.97; 47.3], P = 0.04). The odds of piglets being weak or damaged when involved in a fatal event was higher in DanBred compared to TN70 sows (M2: OR = 3.5, 95% CI [1.07; 11.7], P = 0.03). The odds of the fatal events occurring during a minor movement posture change (M1: OR = 7.2, 95% CI [0.74; 69.1] P = 0.05) or during standing to lateral (M1: OR = 5.9, 95% CI [0.65; 53.2], P = 0.07) tended to be higher for DanBred compared to TN70 sows. There was no effect of sow hybrid on the odds of the fatal crushing event occurring during rolling, stepping on a piglet, standing to sternal, or whether the posture change occurred during birth, the sow explored before or made a posture change afterwards (P > 0.1).

3.2.3. Association between behaviour before and after and the fatal posture change

Fig. 2 shows the proportion of each fatal posture change where the sow was exploring before, was making a posture change after or where piglets were damaged or weak prior to crushing. Irrespective of hybrid and parity, the sows explored before the fatal posture change in 42% of the events, which was correlated with the type of fatal posture change (P < 0.05). Most of the events where the sow explored before were when sows were moving from standing to lying (to sternal or lateral recumbency) or when stepping on a piglet (94% rooted before lying, 57% before stepping, 11% before other posture changes, Fig. 2). In 18% of the fatal posture changes, the sow made a posture change within a minute of the event. As can be seen from Fig. 2B, a posture change was made after in 100% of the fatal events of getting up from lying (lateral and sternal), while in 0% of the events of standing to lateral and minor movements. In 28% of the fatal posture changes, the piglet was weak or damaged prior to the event and the median was higher when the sow crushed a piglet by a minor movement and by getting up from sternal to standing (Fig. 2, P < 0.01).

3.3. Piglet position

3.3.1. Association with parity and sow hybrid

There was a significant two-way interaction between parity and sow hybrid on the odds of piglets being clustered when the fatal posture change started (P < 0.01, Table 4). The interaction showed that second parity TN70 had the highest odds of clustered piglets when the fatal posture change started. Within TN70, the second parity sows had higher odds of clustered piglets compared to the first parity sows, while within DanBred, there was no difference between parities.

3.3.2. Association with parity

The odds of piglets being in the danger zone when the fatal posture change started was higher for second parity compared to first parity sows (Table 4). The odds of piglets being in the nest when the fatal posture change started was not affected by parity (P > 0.1)

3.3.3. Association with sow hybrid

The odds of piglets being in the danger zone when the fatal posture change started tended to be higher for DanBred compared to TN70 sows (Table 4). The odds of piglets being in the nest when the fatal posture change started were not affected by sow hybrid (P > 0.1).

4. Discussion

The results presented in this paper are comparisons within the fatal crushing events from birth and the following three days. Be aware that it is not a comparison between all the sows’ posture changes (fatal and non-fatal) and does not say whether a certain risky posture change occurs more often in a specific parity or sow hybrid. The knowledge established in this study can be used to understand to what extent...
Table 4
Summary of the model output on the number of piglets in each location when the fatal posture change started. P-values are presented for the interaction or main effects of parity and hybrid, and the odds ratio (OR) and 95% confidence interval (CI) are presented for each level of the variables.

<table>
<thead>
<tr>
<th>Response Variable</th>
<th>P-value</th>
<th>Levels</th>
<th>OR</th>
<th>CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clustered vs. not</td>
<td>Hybrid ×</td>
<td>DanBred vs.</td>
<td>1.7 [0.95; 2.96]</td>
<td></td>
</tr>
<tr>
<td>not</td>
<td>Parity</td>
<td>TN70, 1</td>
<td>0.5 [0.28; 0.91]</td>
<td></td>
</tr>
<tr>
<td>Danger zone vs.</td>
<td>Hybrid</td>
<td>DanBred</td>
<td>1.3 [0.97; 1.83]</td>
<td></td>
</tr>
<tr>
<td>not</td>
<td>Parity</td>
<td>TN70, 1</td>
<td>2.3 [1.66; 3.16]</td>
<td></td>
</tr>
<tr>
<td>In nest vs. not</td>
<td>Hybrid</td>
<td>&gt; 0.1</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>not</td>
<td>Parity</td>
<td>&gt; 0.1</td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>

1 Clustered refers to the number of piglets where three or more piglets were lying or standing with pig-to-pig contact or with less than a piglet’s width between them, when the fatal posture change started.  
2 Danger zone refers to the number of piglets under or within one piglet’s length of the sow on the side the sow lies down on, when the fatal posture change started.  
3 In nest refers to the number of piglets within or max. a piglet’s length from where the sow was most recently lying, recorded when the fatal posture change started.

4.1. The fatal posture changes and thoughts on how to prevent them

Firstly, the present study found that piglets were visibly alive and breathing (but unviable) in up to 10 h (median 12 min) after the crushing event. This is both a major welfare and ethical issue that needs to be resolved. Yet, this also leaves the option that piglets may survive if the sow is alarmed and reacts. In 12% of the fatal events the head of the piglet was not squeezed beneath the sow, and a piglet scream should in these events be audible. Yet, it was only one of these events that was followed by a posture change within a minute. In total only 18% of the events were followed by a posture change. Genetic selection for higher maternal responsiveness may prove to be beneficial, although high responsiveness has not consistently been found to correlate with higher piglet survival (Held et al., 2006; Held et al., 2007; Melisiova et al., 2014).

Rolling and standing to sternal constituted the largest proportions of the fatal posture changes. Rolling and flopping from standing to lateral have in the literature been described as specifically risky posture changes in indoor loose housing. Standing to sternal is a very frequent behaviour which likely explains why it is often found to be risky. In the present study, the posture change from standing to sternal also occurred more quickly than the posture change from standing to lateral, making it less likely for piglets to have time to move away. While there were no observations of weak/damaged piglets prior to crushing where the sow changed from standing to lying lateral, 13% of the crushed piglets were scored as weak/damaged in crushing events where the sow changes from standing to lying sternal. Thus, indicating that lying down more slowly is beneficial for the survival of less viable piglets.

Although rolling is dangerous, reducing or preventing it may not be successful in mitigating piglet mortality. Rolling is an important posture change for sucking (i.e., giving access to teats) and also the gradual weaning process where rolling into a sternal lying posture is increasingly performed. Thus, focus should not be on preventing this posture change. Furthermore, the opportunity for the sow to be attentive to the presence of piglets when rolling from sternal to lateral is limited (she cannot see or root/explore in that direction). A genetic selection for increased attentive maternal behaviour seems unlikely to work on this posture change. Likely more success would come from reducing the number of piglets lying at the sow or from making the posture change slow, so piglets have time to move away. One option to slow or prevent movements like rolling or lying down could be via the housing conditions, but this is likely to lead to compromised sow welfare if it disrupts the sow’s behavioural freedom as known from crates in indoor production (Jarvis et al., 2006). The relevant question is whether inventory can slow her posture changes, so piglets in the danger zone have time to move away but without being a source of frustration and discomfort for the sow. Note that at no point in the present study (i.e. during the crushing events) was a sow clearly seen using the sloped wall to lie down, which is otherwise the main feature in indoor loose-housing to prevent crushing (Farrowing, 2021). This could be because using the slope wall always prevented farrowing or because it was rarely used. In a different hut design where the options were leaning against a non-sloped wall, a rail or a pendulum hanging in the middle of the pen, using no support to lie down was the most common way when all posture changes (fatal and non-fatal) where recorded during the first days after birth (Master thesis by Ancuta Tincuta Florinela Uras (2022)), suggesting these three options were sub-optimal. If in fact the sloped wall was rarely used in the present study, a different structure should be considered. In indoor loose housing systems, various structures placed in the middle of the pen like a pendulum (Hansen, 2018), mushroom or ball shaped flexible plastic installation popping up from the floor (Nielsen and Damm, 2000) or a round metal fenced piglet creep area in the middle of the pen (Mousten et al., 2007) have been attempted, but systematic studies on their effects are still lacking, and they would likely all compromise the sow’s free movements. Regardless of the sow’s use of the sloped wall, piglets were observed to successfully escape under the sloped wall in the present study (not recorded systematically).

Although only five flopping events were observed and interpretation from such limited data should be done with caution, the sows all flopped with piglets present in the danger zone. This shows that all these flopping events were truly risky behaviour as previously classified (Blackshaw and Hagelso, 1990; Wechsler and Hegglin, 1997). We speculated that flopping might not always be risky, as a quick lying down behaviour can be positive if performed away from the piglets. Yet, this observational study did not support this. Instead, our results indicate that the occurrences of flopping should either be prevented and/or attempts to attract the piglets away from the nest site might mitigate the risk of crushing during flopping events. The cause of flopping is still unknown. In a previous study, more occurrences of flopping were not found with longer births, which were expected to exhaust the sows, although more flopping occurred during the first 24 h after birth compared to 24–48 h and 48–72 h after birth (Thorsen et al., 2017). It may be that flopping is a consequence of the generally large, high-prolific sows and associated leg weakness (Pruiner et al., 2010; Pfeiffer et al., 2019) or pain from given birth. Energy depletion and exhaustion of the sow may also be involved in risky posture changes like flopping. An increased farrowing duration is positively associated with an increased litter size (Thorsen et al., 2017; Schild et al., 2019), which in turn is associated with smaller piglets at birth (Schild et al., 2020b; Winters et al., 2022), but to what extent a prolonged farrowing leads to an higher energy expenditure/tissue loss/pain is not clear. Under conventional conditions, blood glucose levels decrease with time since last feeding (Feyera et al., 2018). In addition, the need for farrowing assistance was positively associated with litter size but not associated with average piglet birth weight (Feyera et al., 2018), indicating that litter size was more problematic. In the present study, no sows were given farrowing assistance, but we speculate that a difficult farrowing would affect the sow’s subsequent behaviour. An option to reduce energy depletion may be to consider feeding rate and also the
location of the feeder. In Denmark, the most common practice is to feed outdoor sows once a day and often the feeder is placed away from the hut close to a driveway for practical reasons. Alternative hut designs where the sows are fed inside or adjacent to the hut may be beneficial to increase the likelihood of the sows being satiated and hydrated.

Stepping on piglets was a more frequent cause of death than expected (11%) and was also observed to occur non-fatally (not recorded systematically). Being stepped on is a likely cause of non-fatal fractures and organic pig are found to have 2-fold higher risk of bone fractures compared to conventional, indoor reared pigs at slaughter (56% of which were healed rib fractures) (Kongsted and Sørensen, 2017). Yet, to what extent stepping on piglets occurs may relate to hut design. Schild et al. (2019) found sows spent more time standing in communal huts compared to the traditional A-frame hut during the first three hours of birth. So, although this hut type has benefits with better possibilities for supervision and access to the animals, it is an issue if more standing in communal huts is associated with more inattentive walking and in turn stepping on piglets. However, it may be less of an issue if the sows are standing more because they actually have the space to perform attentive, maternal behaviour. In the present study, in half of the crushing events by stepping on a piglet, the sow was exploring/rooting, which gives no hint to whether they were attentive or not. In addition, stepping on piglets occurred equally for the two sow hybrids. Irrespectively, gives no hint to whether they were attentive or not. In addition, stepping on piglets occurred equally for the two sow hybrids. Irrespectively, limited space allowance is becoming increasingly problematic in conventional housing systems as the body size of sows (weight, height and length) have increased with genetic selection since the crates were designed (Moustsen et al., 2011; Nielsen et al., 2018). In this view the communal huts (6 m²/pen) in the present study, should be less problematic than the smaller A-frame huts (4 m²). Yet, as sows continue to grow up until parity 4–5 (Moustsen et al., 2011; Nielsen et al., 2018), investigations of maternal behaviour in different hut designs should also include older sows.

4.2. How parity and sow hybrid may mitigate crushing

No specific sow breeds exist specifically for organic production and thus organic producers use the same hyper-prolific sow hybrids as conventional producers (Früh et al., 2014). Genetic selected under conventional production conditions may have relaxed selection for maternal behaviours that are important for piglet survival in more extensive systems. There is increasing interest in specialised breeding to mitigate piglet mortality under organic conditions. The two hyper-prolific sow hybrids with different breeding traits investigated in the present study may already offer some of the benefits and shed light on the future direction for selection of organic sows. For example, both sow hybrids have traits for increasing longevity. From this study, several shortcomings in maternal behaviour may occur more often in first parity sows compared to second parity (and we speculate, also for older sows until a certain, unknown point). The first parity sows had a higher proportion of crushing during minor movements, during standing to sternal (as a trend) and had a higher proportion of fatal events during birth compared to second parity. However, a higher proportion of piglets were observed in the danger zone in second parity sows, and this was most pronounced in DanBred. This may relate to the larger litter size born as was arguably also the case for the higher stillborn and liveborn mortality found in second parity sows (Schild et al., 2020b). A higher proportion of crushing with a posture change from sitting to sternal was seen in second parity sows. Increased frequency of sitting between standing up or lying down may relate to the sows’ behavioural freedom being restricted (Anil et al., 2002). Second parity sows are larger than first parity (Moustsen et al., 2011; Nielsen et al., 2018) and TN70 sows about 20 kg heavier than the DanBred sows (Eskildsen, 2020), which may explain more sitting as part of the fatal posture change as a sign of hindered movement in second parity and TN70 sows.

The genetic selection of TN70 (in contrast to DanBred) includes a parameter for mothering ability (piglet survival, litter weight at 21 days, total number of teats, and reduction in inverted teats) (Topigs Norsvin CSR, 2019). Although not unambiguously, the DanBred compared to TN70 showed some shortcomings in maternal behaviour with a higher proportion of fatal events during minor movement (a trend) and during standing to lateral (a trend). In addition, DanBred had eight events where the body but not the head of the piglet was squeezed by the sow, where TN70 had zero. If we assume that the screams of these piglet were more audible than those squeezed full body, this observation could indicate that DanBred are less responsive to piglet screaming. On the other hand, the TN70 had a higher proportion of piglets crushed during sitting to sternal. In addition, one event of savaging was observed, performed by a first parity TN70, which is in line with previous studies finding that savaging occur more often in gilts (Harris et al., 2003; Chen et al., 2008). It is known from conventional, indoor production that maternal behaviour improves and develops over at least two parities (Thodberg et al., 2002). Yet, it may be that the larger litter size in second parity can overshadow the improved maternal behaviour, which the present study could indicate.

Previous results from the larger study, of which this was a subset of, showed that TN70 sows were more restless during birth particularly in first parity, but that this did not affect the liveborn piglet mortality the first three days after birth (Schild et al., 2019). On the contrary, TN70 had lower mortality compared to DanBred until weaning (Schild et al., 2020b). It was somewhat unexpected that Schild et al. (2019) found no influence on postnatal mortality of the frequency of posture changes during birth. Instead, the results suggested that crushing was more related to piglet vitality than to sow body movements and/or that crushing mainly occurs after birth is completed. In accordance with the latter, the present study found that 62% of the fatal events occurred after birth of the last piglet. Furthermore, the present study showed that in approximately one third of the fatal events, the piglets were weak or damaged before the fatal event and this was higher during minor movements and sternal to standing. This makes sense, as a vital pig should be able to escape from the sow for example shifting her leg or body posture slightly. More interestingly, the prevalence of weak/damaged piglets in crushing events was three-fold higher for DanBred sows compared to TN70 sows. The TN70 sow hybrid is selected for a slightly lower litter size than DanBred sows (although both are highly prolific) and slightly larger piglets are born by TN70 sows (Schild et al., 2020b). This fact may also be the cause of fewer weakened piglets crushed by TN70 in the present study. However, the remaining two third of piglets that were not weakened prior to the crushing event, suggest how increasing vitality in itself may not be enough and that more attentive maternal behaviour is also key to prevent crushing events.

4.3. Piglet position, parity, and sow hybrid

As expected, piglets were more often clustered and in the nest (i.e., the location where the sow most recently had been lying) compared to not in the nest. This is likely due to the residue warmth from the sow. In addition, a comparable high number of piglets were observed in the danger zone, where the sow was about to lie down. In this study, a heated creep area was present and was not enough to draw piglets away from the nest site or the danger zone. To attract piglets to the creep area can be a challenge (Vasdal et al., 2010). In conventional, indoor production, a radiant heat lamp can attract more piglets than an incandescent light bulb (Larsen and Pedersen, 2015) and increase piglets’ use of the creep area (Larsen et al., 2017). Preliminary results from outdoor huts show that a heated creep area attract new-born piglets quicker than an unheated one (Malmkvist and Pedersen, 2022). One option to consider in outdoor huts is to use some of the bedding the sow has used to nest build to insulate the creep area as the smell of the sow (Morrow-Tesch and McGlone, 1990) in addition to warmth from an electric or gas-driven heat lamp may attract more piglets. As piglets with lower rectal temperature after birth are less vigorous and in greater risk of dying (Baxter et al., 2008), increasing piglet body temperature even if
they are present in the nest site where the sow will lie down, may mitigate crushing by piglets being more responsive to sow movements. In indoor production, studies on increase room temperature and duration of floor heating can attract (Pedersen et al., 2007) and increase piglet body temperature and survival without causing signs of heat stress in the sows when loose-housed (Pedersen et al., 2013). Yet, we are not aware of any studies comparing the effects of different heating sources in outdoor production.

The proportion of clustered piglets was highest for TN70 within second parity (no difference between DanBred first and second parity). As a higher proportion of clustered piglets was not a simple main effect of higher parity, it does not seem to relate to the larger litter size born in second parity alone. Whether many clustered piglets can be considered positive or negative for survival depends on the sow’s reaction; if she lies down away from the cluster, it is likely to be beneficial, but if she does not orientate towards the piglets’ location, she may lie down on a large proportion of piglets. That more piglets were in the danger zone in DanBred compared to TN70 sows could indicate that the TN70 hybrid is more attentive to the location of the piglets and more often lies down in another place. It can be speculated that the higher proportion of clustered piglets but fewer in the danger zone in TN70’s parity may relate to a combination of developing maternal behaviour with increasing parity that is not seen in DanBred. Yet, when looking for support for this hypothesis in the other sow behaviour, the proportion of exploration before the fatal posture change that could either scatter or cluster piglets did not differ between parity and sow hybrid, offering no support for this hypothesis.

In general, these findings point to the need to improve the design of outdoor huts (with focus on attracting piglets to a location not available for sow resting), to improve the maternal behaviour of the sows (more attentiveness and orientation towards piglets) and/or to improve the vitality of the piglets (to move away before being squeezed, but also to alert the sow to squeezing) to reduce trauma and mortality. In relation to genetic selection, it could be relevant to investigate piglet and sow characteristics of even less prolific sow hybrids (or breeds), which are bred for other traits that could be beneficial in an outdoor farrowing system. It would be valuable to make a comparative study of the behavioural characteristics (total number of posture change, piglets in the danger zone etc.) between hybrids/breeds to see the consequences of different breeding goals on crushing.

5. Conclusion

In summary, this observational study recorded sow and piglet behaviour during 72 fatal crushing events in individual pens in a communal outdoor hut. The results showed a varied aetiology around fatal crushing but support previous findings that rolling, lying down from standing to sternal or lateral recumbency are main fatal posture changes. When the fatal posture change started, the piglets were often clustered in the area where the sow had last been lying, while this also often placed the piglets in the danger zone where the sow was about to lie down. The findings point to options to reduce crushing: genetic selection for more attentive maternal behaviour and more robust and vital piglets, housing conditions to slow sow posture changes and/or attract piglets away from the danger zone, and sow feeding strategy and location of feeder to prevent energy depletion. Although not definitive, these results point to a gain in maternal behaviour by minimising the number of first parity sows through increasing longevity and potentially by using the TN70 sow hybrid with more vital piglets.

CRediT authorship contribution statement

Cecilie Kobek-Kjeldager: Investigation, Visualization, Formal analysis, Methodology, Data curation, Writing – original draft. Lene Juul Pedersen: Funding acquisition, Project administration, Conceptualization, Writing – review & editing. Mona Lillian Vestbjerg Larsen: Conceptualization, Methodology, Visualization, Formal analysis, Writing – review & editing.

Declaration of Competing Interest

None.

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Supplementary materials

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