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1 **Temporary crate opening procedure affects immediate post-opening piglet mortality**
2 **and sow behaviour**

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9 Short title: Crate opening procedure affects piglet mortality

10 **Abstract**

11 Producers are interested in utilising farrowing systems with reduced confinement to
12 improve sow welfare, however concerns of increased mortality may limit commercial
13 uptake. Temporary confinement systems utilise a standard crate which is opened 3-7
14 days post-partum, providing protection for neonatal piglets at their most vulnerable
15 age and later increased freedom of movement for sows. However, there is anecdotal
16 evidence that piglet mortality increases immediately after the temporary crate is
17 opened. The current study aims were to determine if piglet mortality increases post-
18 opening, to trial different opening techniques to reduce post-opening piglet mortality
19 and to identify how the different opening techniques influence sow behaviour. Three
20 opening treatments were implemented across 416 sows: two involved opening crates
21 individually within each farrowing house when each litter reached seven days of age,
22 in either the morning or afternoon (AM or PM), with a control of the standard method
23 used on the farm to open all crates in each farrowing house simultaneously once the
24 average litter age reached seven days (ALL). Behavioural observations were

25 performed on five sows from each treatment during the six hours after crate opening,
26 and during the same six hour period on the previous and subsequent days. Across all
27 treatments, piglet mortality was significantly higher in the post-opening than pre-
28 opening period ($P < 0.0005$). Between opening treatments, there were significant
29 differences in piglet mortality during the two days after crate opening ($P < 0.05$),
30 whilst piglet mortality also tended to differ from crate opening until weaning ($P =$
31 0.052), being highest in ALL and lowest in PM. Only sows in the PM treatment
32 showed no increase in standing behaviour but did show an increased number of
33 potentially dangerous posture changes after crate opening ($P = 0.01$), which may be
34 partly attributed to the temporal difference in observation periods. Sow behaviour
35 only differed between AM and ALL on the day before crate opening, suggesting the
36 AM treatment disrupted behaviour pre-opening. Sows in AM and PM treatments
37 showed more sitting behaviour than ALL, and therefore may have been more alert. In
38 conclusion, increases in piglet mortality after crate opening can be reduced by
39 opening crates individually, more so in the afternoon. Sow habituation to disturbance
40 before crate opening may have reduced post-opening piglet mortality, perhaps by
41 reducing the difference in pre- and post-opening sow behaviour patterns.

42 **Keywords:** Pig, welfare, crushing, farrowing, temporary confinement

43 **Implications**

44 Temporary confinement systems may be a commercially viable alternative to
45 farrowing crates that can improve sow welfare. However, piglet mortality remains a
46 welfare and economic concern for such systems. Knowledge of how the crate
47 opening procedure affects piglet mortality and sow behaviour will enable
48 stockpersons to manage these systems more effectively to reduce piglet mortality.
49 This will contribute to improving the viability of temporary confinement systems,

50 increasing commercial uptake and potentially improving the welfare of breeding sows
51 globally that are currently housed in farrowing crates throughout lactation.

52 **Introduction**

53 The prolonged confinement of sows in crates during farrowing and lactation remains
54 common practice across commercial indoor breeding units. The confinement of sows
55 in crates has severe implications for sow welfare, such as restricting the capacity to
56 turn around, perform pre-partum nesting behaviours and maintain attachment with
57 the litter (Pedersen *et al.*, 2013; Melišová *et al.*, 2011), resulting in increased
58 physiological stress for the sow (Jarvis *et al.*, 2006). However, farrowing crates were
59 primarily introduced to improve piglet welfare by protecting new-born piglets from
60 fatal or injurious crushing. Whilst a greater respect for the biological needs of the sow
61 during farrowing and lactation is required to improve welfare standards (Baxter *et al.*,
62 2011), the safety of piglets from injury and death must also be considered. Although
63 more recent studies on commercial farms suggest total piglet mortality can be
64 comparable between confined and unconfined farrowing systems (Weber *et al.*,
65 2007; KilBride *et al.*, 2012), concerns remain that piglet mortality may worsen in less
66 confined farrowing systems (Farm Animal Welfare Committee, 2015).

67 Considering that the majority of piglet mortality occurs during the first 48-72 hours
68 post-partum, and over 80% within the first seven days (Marchant *et al.*, 2000;
69 KilBride *et al.*, 2012), confining the sow beyond this period may not be of significant
70 benefit for piglet survival. Therefore temporary confinement systems, consisting of an
71 openable crate within individual farrowing pens, can be used to protect the neonates
72 immediately post-partum. After this period, the crate is opened to provide additional
73 space for the sow, providing a compromise between the needs of the farmer, the sow
74 and her piglets. Whilst temporary confinement systems can reduce early piglet

75 mortality in comparison to no confinement (Moustsen *et al.*, 2013; Hales *et al.*, 2015;
76 Chidgey *et al.*, 2015), anecdotal reports from commercial farms suggest piglet
77 mortality increases during the first 24 hours immediately after crate opening. In order
78 to improve animal welfare, along with the economic viability and commercial uptake
79 of temporary confinement systems, it is necessary to understand if the immediate
80 post-opening period (24-48 hours after crate opening) creates a higher risk of piglet
81 mortality and, if so, to identify suitable interventions to reduce the impact of crate
82 opening.

83 The way in which crates are opened may cause different amounts of disturbance to
84 the sow and litter, in turn affecting their immediate post-opening behaviour. Increased
85 disturbance from human activity may cause increased restlessness (Chaloupková *et al.*
86 *et al.*, 2008), and therefore increase the incidence of dangerous posture changes and
87 the subsequent risk of accidental piglet crushing. Sows are also responsive to the
88 vocalisations of trapped piglets, especially in less confined systems (Melišová *et al.*,
89 2014). However, sows which respond excessively to the distress vocalisations of
90 piglets in neighbouring litters risk causing unnecessary injuries within their own litter
91 (Baxter *et al.*, 2011). Therefore, as we expected crushing incidence to increase post-
92 opening, it was hypothesised that opening crates individually would reduce
93 behavioural disturbance by minimising the peak contagion effect of sow
94 responsiveness to crate opening and piglet vocalisations. It was also hypothesised
95 that opening crates in the afternoon, immediately before stockpersons left for the
96 day, would evoke a shorter sow response period as there would be no subsequent
97 stockperson disturbance, and opening is performed closer to night-time when lights
98 are dimmed and sows perform fewer posture changes (Hales *et al.*, 2016).

99 The current study aimed to determine a) if piglet mortality increases immediately
100 after, compared to immediately before, crate opening; b) if crate opening procedure
101 affects post-opening piglet mortality; and c) if crate opening procedure affects sow
102 behaviour. Knowledge of these outcomes will enable the most efficient opening
103 procedure within temporary confinement systems to be adopted, and may identify
104 which sow behaviours are associated with increased piglet mortality.

105 **Material and methods**

106 *Animals and dry sow management*

107 The experiment was conducted on a commercial pig breeding unit in the north east of
108 England. The farm consisted of 1 300 Camborough (Genus PIC, Basingstoke)
109 breeding gilts and sows bred with Hampshire semen. During gestation, all animals
110 were kept in straw pens in groups according to age, for gilts, or by size for
111 multiparous sows. The farm utilised 250 farrowing places; 168 of which were
112 temporary crate accommodation used for this study (360⁰ Freedom Farrower™,
113 Midland Pig Producers, Burton-on-Trent). The date of moving into the farrowing
114 accommodation and farrowing date were recorded for inclusion in statistical models.

115 *Farrowing sow housing and management*

116 Each farrowing pen contained a stainless steel crate (closed=2.55m x 0.90m,
117 open=2.55m x 1.50m) within a 2.55m x 1.80m pen (Figure 1a). Each pen had plastic
118 slatted flooring with a solid sow lying area containing drainage slots plus a 1.80m x
119 0.40m hot water heat pad along one side of the pen as the piglet resting area. Of the
120 168 temporary crates, 120 were located in six "Portapig" cabins containing
121 20 farrowing places each (cabins) and a further 48 were in a converted farrowing
122 house of three rooms containing 16 farrowing places each (rooms), with pen
123 arrangement, and therefore crate opening procedure, differing between cabins and

124 rooms (Figures 1b and 1c, see Supplementary Figure S1 and S2 for images of pen
125 arrangement). To open the crate, a lever on one side released the crate side to be
126 manually adjusted vertically, whilst the other side was released to drop open
127 obliquely. In the cabins, one person had to lean over each crate to operate the lever,
128 allowing both persons to push the far side of the crate open before releasing the drop
129 down side closest to the passageway. In the rooms, each crate was opened by two
130 stockpersons, one in the central and one in the side passageway, without the need to
131 lean over each crate.

132 The temporary crates were closed from entry into the farrowing house at
133 approximately 2-5 days pre-partum. No sows had artificial induction of farrowing.
134 Farrowing houses were kept at $22 \pm 1^{\circ}\text{C}$, with the heat pad kept at 36°C . Farrowing
135 house temperature gradually reduced automatically to $18 \pm 1^{\circ}\text{C}$ by day ten post-
136 partum and to $16 \pm 1^{\circ}\text{C}$ by weaning, whilst heat pad temperature reduced to 30°C by
137 weaning. Farrowing houses were ventilated via a central extractor fan and had full
138 artificial lighting during working hours (05:30-14:30), with dimmed lighting outside of
139 these hours.

140 Sows were fed once daily in the morning until all sows in the farrowing house had
141 farrowed, after which sows were fed twice a day (commencing 05:30 and 13:30; diet
142 contained 15.98% CP, 13.69 DE MJ/Kg). Cabins were hand fed via a Groba Ad-
143 Lib feeder above the trough (Finrone Systems Ltd, Londonderry), whilst rooms
144 contained a semi-automatic system (www.360farrower.com) feeding all sows
145 simultaneously. Feed was gradually increased from 2kg to 10kg per sow per day
146 during lactation. Sow drinkers were located inside the feed trough, with smaller piglet
147 drinkers provided at the front of the pen on the opposite side to the heat pad (see
148 Figure 1a).

149 *Piglet management and procedures*

150 In accordance with veterinary recommendation, piglets were tail docked, teeth
151 clipped, and injected with 1ml of Gleptosil (Ceva Animal Health Ltd,
152 Amersham) and 0.5ml of Betamox (Norbrook Laboratories Ltd, Newry) within 24
153 hours of birth. The placentae and deceased piglets were removed, with live litter size
154 equalised for both piglet number and size by cross-fostering piglets of a similar age.
155 Super Dry Klenz powder (A-One Feed Supplements Ltd, Thirsk) was distributed
156 across each pen daily. Additional dish drinkers with water were provided for smaller
157 or weaker litters, and were removed before crate opening. A handful of creep feed
158 (Primary Diets, AB Agri Ltd, Peterborough; followed by Flat Deck, A-One Feed
159 Supplements Ltd, Thirsk) was provided once daily on the heat mat from approx. ten
160 days of age until weaning. The farm's management routines included piglet fostering
161 throughout lactation as necessary to ensure piglet and litter sizes remained similar.

162 *Experimental design*

163 The study compared three different crate opening treatments. The standard
164 procedure on the farm of opening all crates within each house on the same morning
165 when average litter age reached seven days (ALL) remained as a control treatment.
166 Alternatives investigated in the experiment involved crates being opened individually
167 when each litter reached seven days of age, either in the morning (AM) or afternoon
168 (PM). Crate opening occurred at 08:30-09:30 in the AM and ALL treatments, and
169 13:30-14:30 for the PM treatment. All sows in a farrowing house were allocated the
170 same crate opening treatment, which was alternated per batch, according to a
171 balanced design to control for farrowing house effects.

172 Due to researcher absence, the final treatment allocations were split across two
173 batches; cabin one, cabin two and cabin three data were collected from batch three
174 whilst data for the remaining locations were collected in batch four. Data from any
175 crates which were not opened within two days of the expected opening date due to
176 poor performing litters deemed at greater risk of crushing (n=19), crates being
177 opened and subsequently closed due to sow aggression towards stock people (in the
178 cabins only, due to the close proximity of sows to the central passageway; n=2), and
179 from sows which farrowed later than expected and had to be relocated to a different
180 room to better match litter ages for weaning, were removed from the study.

181 *Piglet mortality study*

182 Sow identity, sow parity, farrowing location, farrowing date and the number of live-
183 born and stillborn piglets were recorded post-partum. Four days later, the frequency
184 and cause of piglet mortality since farrowing, as identified by the stockperson
185 (categorised as crushed, low viability or other), and current litter size were recorded.
186 Recording sheets were attached above each pen specifying the day and time (AM or
187 PM) of crate opening, and for the researcher to record piglet mortality during the five
188 day period around crate opening (two days before crate opening, day of opening and
189 two days following crate opening). After this period, additional piglet mortality,
190 weaning date and litter size at weaning were recorded via stockperson records.

191 *Sow behaviour study*

192 Sow behaviours were investigated for a subset of five sows from each treatment
193 across three batches housed in one of the converted rooms. CCTV cameras (Gamut
194 Professional Sony Effio E Bullet CCTV Camera 700 TV Line, 15m Infrared Night
195 Vision (Gamut, Open24 seven Ltd, Bristol, UK)) were installed above six pens, with
196 the same six crates observed for each batch. Cameras recorded continuously from

197 two days before until two days after temporary crate opening. From the video
198 recordings, time of crate opening was identified and continuous sampling of sow
199 behaviour (Table 1) was performed for the subsequent six hours. The same six hour
200 period was then analysed during the day before and day after crate opening.

201 The frequencies, total durations and average durations were calculated for each
202 posture (average duration results described in Supplementary Material S1, Figure S3
203 and Table S1). The incidence and cause of piglet crushing, whereby a piglet became
204 trapped by the sow by any means, was recorded as either fatal or non-fatal.

205 *Statistical analysis of results*

206 The time periods of primary interest were the two days before ('pre-opening'; days 5-
207 7 post-partum) and the two days after ('post-opening'; days 7-9) temporary crate
208 opening, in order to determine and compare the risk of piglet mortality for these time
209 periods. Analyses were also performed for piglet mortality after the post-opening
210 period until weaning ('late'; days 10-27), the early post-partum period ('early'; days 0-
211 4), from parturition until crate opening ('before'; days 0-7), from crate opening until
212 weaning ('after'; days 7-27) and the entire lactation ('total'; days 0-27).

213 Piglet mortality data were analysed using the GLIMMIX procedure in SAS 9.4. The
214 base model included the variable total born litter size and the fixed effects of
215 treatment, housing type (cabin or room), batch (1-4), sow parity (1,2,3,4,5,6+), the
216 number of days between housing and farrowing (0-1, 2-5, 6-7, 8+), litter age at
217 opening (in days; <7,=7,>7), and whether or not a litter had been cross-fostered to
218 consist of all the smallest piglets in that batch ("smalls" based on routine visual
219 inspection and cross-fostering performed by farm staff) were included for all periods
220 of investigation. The variable litter size on day five was included in all models except

221 for the 'early' and 'before' time periods, whilst the continuous variable of litter age at
222 weaning was only included for 'late', 'after' and 'total' piglet mortality models. Due to
223 a chance uneven distribution of total born litter size across the treatments, the
224 interaction of total born and treatment was included for all time periods to correct for
225 this effect. All models used a Poisson distribution, with explanatory variables
226 eliminated in a step-wise manner to create the final models including all variables
227 with a P value < 0.10 .

228 Sow behaviour data were analysed in SAS 9.4 using the PROC MIXED procedure.
229 Sow was included as a repeated factor whilst pen number and whether a day was on
230 the weekend or not (yes/no; to control for reduced stockperson contact during
231 weekends) were used as random factors. Current litter size was included as a
232 continuous variable, with day, treatment, sow parity (1, 2-5, 6+), treatment*day and
233 parity*day as fixed effects. Explanatory variables were eliminated in a step-wise
234 manner to create the final models including variables with a P value < 0.10 , whilst
235 day, treatment and the interaction of treatment and day were forced into all final
236 models.

237 **Results**

238 *Piglet mortality study*

239 Data were included from 416 sows (ALL= 145; AM= 134; PM= 137), with a mean sow
240 parity of 3.48 ± 0.11 (range 1-11; ALL= 3.29 ± 0.19 ; AM= 3.71 ± 0.18 ; PM= $3.47 \pm$
241 0.18). Mean total born litter size was 14.25 ± 0.14 piglets, consisting of 13.72 ± 0.14
242 live-born and 0.53 ± 0.05 stillborn piglets. Mean litter age at crate opening was $7.36 \pm$
243 0.06 days, whilst some crates were opened later than scheduled due to a reliance on
244 stockperson assistance to open crates (ALL = 7.52 ± 0.16 days, range 4-13 days; AM
245 = 7.41 ± 0.06 days, range 7-9 days; PM = 7.15 ± 0.04 days, range 7-9 days).

246 *Piglet mortality risk throughout lactation.* A total live-born piglet mortality of 574
247 piglets was recorded from 5,708 live-born piglets, with a mean live-born piglet
248 mortality of 1.38 ± 0.08 piglets per litter. Total born piglet mortality to weaning was
249 13.38%, consisting of 10.06% of live-born and 3.69% of stillborn deaths.

250 Of the live-born piglet mortality, 60.45% occurred during early lactation (days 0-4),
251 4.88% during pre-opening (days 5-7), 11.15% during post-opening (days 7-9) and
252 23.52% during later lactation (day 10 until weaning). In terms of piglet mortality per
253 litter (mortality/litter): early = 0.834 ± 0.062 , pre-opening = 0.067 ± 0.014 , post-
254 opening = 0.154 ± 0.022 and late = 0.325 ± 0.030 . Adjusting these estimates for the
255 number of days per time period, piglet mortality per litter per day (mortality/litter/day)
256 were calculated as 0.167 for early lactation, 0.034 during pre-opening, 0.077 during
257 post-opening and 0.018 during later lactation. Combining all opening treatments,
258 mortality/litter was significantly higher during the post-opening than pre-opening
259 period ($P < 0.0005$; Wilcoxon signed rank test).

260 *Effect of crate opening treatment and housing type.* Treatment had a significant effect
261 on piglet mortality during post-opening ($P < 0.05$), and therefore the after opening
262 period ($P = 0.052$), being highest for treatment ALL, followed by AM then PM (Figure
263 2a). Piglet mortality was also affected by the housing type, being significantly higher
264 in the rooms than the cabins during pre-opening ($P < 0.01$), late ($P < 0.05$) and
265 therefore the total lactation ($P < 0.05$; Figure 2b).

266 *Effect of days until farrowing and litter age at opening.* The number of days between
267 housing and farrowing affected piglet mortality during late lactation ($P < 0.05$), and
268 therefore after opening ($P < 0.05$). During late lactation, piglet mortality was
269 significantly higher for sows housed 0-1 days pre-partum (0.45 ± 0.07) than sows

270 housed 2-5 days (0.28 ± 0.06 ; $P < 0.05$) or 8+ days (0.22 ± 0.05 ; $P < 0.01$), but not 6-
271 7 days pre-partum (0.38 ± 0.06); whilst late piglet mortality was also significantly
272 lower for sows housed 8+ days than 6-7 days pre-partum ($P < 0.05$). Litter age at
273 crate opening had no significant effect on piglet mortality during any stage of
274 lactation.

275 *Effect of litter characteristics and sow parity.* Piglet mortality increased with
276 increasing live born litter size during the early ($P < 0.0001$), before ($P < 0.01$), late (P
277 < 0.01), after opening ($P < 0.001$) and total lactation periods ($P < 0.0001$); however
278 piglet mortality decreased with increasing total born litter size during the post-opening
279 period ($P < 0.01$). A larger litter size on day five post-partum was associated with
280 lower total piglet mortality ($P < 0.001$), but tended to result in higher pre-opening ($P =$
281 0.058) and post-opening piglet mortality ($P = 0.061$). Piglet mortality was significantly
282 higher within the cross-fostered litters of 'small' piglets during the early ($P < 0.0001$),
283 before ($P < 0.0001$), pre-opening ($P < 0.05$) and total lactation ($P < 0.0001$). Sow
284 parity affected post-opening piglet mortality ($P < 0.05$), being significantly higher for
285 parity six plus sows (0.26 ± 0.06) than parity one (0.11 ± 0.04 ; $P < 0.05$), two ($0.09 \pm$
286 0.03 ; $P < 0.05$), or four (0.07 ± 0.03 ; $P < 0.01$), and tending to be higher than parity
287 three (0.13 ± 0.04 ; $P = 0.067$) and five (0.11 ± 0.05 ; $P = 0.052$).

288 *Sow behaviour study*

289 *Incidence of piglet crushing.* There were no incidents of fatal crushing within video-
290 recorded litters, and only seven non-fatal crush incidents (one stand-to-lie, one
291 lateral-to-ventral, two ventral-to-lateral and three standing on piglet), therefore further
292 analyses on piglet crushing could not be performed.

293 *Sow carefulness during stand-to-lie.* Although treatment or day had no effect,
294 frequency of sniffing or rooting piglets before lying tended to be higher for parity 2-5
295 sows (2.02 ± 0.30) than both parity 6+ sows (0.95 ± 0.41 , $P = 0.054$) and gilts ($1.10 \pm$
296 0.40 , $P = 0.088$). There were no significant effects of day, treatment or parity on the
297 percentage of sniffing or rooting piglets.

298 Frequency of using support structures during stand-to-lie was significantly affected by
299 treatment ($P < 0.05$), being lower in PM (1.77 ± 1.08) than both AM (3.94 ± 1.06 ; $P <$
300 0.01) and ALL (3.29 ± 1.02 ; $P < 0.05$). However, the percentage of stand-to-lie
301 posture changes where support was used was unaffected by treatment or day.
302 Moreover, the percentage of lying events using support was lower amongst gilts
303 ($33.6\% \pm 12.8$) than parity 2-5 sows ($51.0\% \pm 12.0$, $P < 0.05$) and parity 6+ sows
304 ($56.5\% \pm 14.4$, $P = 0.061$).

305 *Frequency of dangerous posture changes.* The frequency of dangerous posture
306 changes are shown in figure 3a. Treatment tended to affect the frequency of stand-
307 to-lie ($P = 0.084$), and within the treatment x day interaction, frequency of stand-to-lie
308 was significantly higher on the day before crate opening for ALL than AM and PM
309 (both $P < 0.05$). Treatment tended to affect the frequency of sit-to-lie posture
310 changes ($P = 0.069$), and within the treatment x day interaction, frequency of sit-to-lie
311 was significantly higher for PM on the day of crate opening than both AM ($P < 0.05$)
312 and ALL ($P < 0.01$), and remained higher than AM on the following day ($P < 0.05$).
313 Sow parity tended to affect the frequency of stand-to-lie posture changes ($P = 0.070$),
314 being higher amongst parity 2-5 sows (7.39 ± 0.72) than parity 1 sows (5.44 ± 0.84 ; P
315 < 0.05) and parity 6+ sows (5.30 ± 1.00 ; $P = 0.077$).

316 Frequency of turning around was significantly higher on the day of crate opening
317 (13.68 ± 1.42) than the day after (7.88 ± 1.42 ; $P < 0.01$). Frequency of turning tended
318 to differ across treatments ($P = 0.078$), being significantly higher for AM ($10.02 \pm$
319 1.56) than PM (4.85 ± 1.56 ; $P < 0.05$), but not ALL (6.65 ± 1.42). Frequency of
320 turning also tended to be affected by sow parity ($P = 0.074$), with parity 6+ sows
321 (4.09 ± 1.69) turning significantly less frequently than parity 1 sows (10.01 ± 1.69 ; $P <$
322 0.05), but not parity 2-5 sows (7.42 ± 1.24).

323 *Total duration of postures.* Total durations of postures are displayed in Figure 3b.
324 Standing duration was significantly affected by day ($P < 0.0001$), being higher on the
325 day of opening than the day before ($P < 0.0001$) or after ($P = 0.01$). Total standing
326 duration differed between treatments ($P < 0.01$), being significantly higher in AM than
327 PM ($P < 0.001$), whilst total standing duration in ALL tended to be both lower than AM
328 ($P = 0.055$) and higher than PM ($P = 0.068$). Total sitting duration tended to differ
329 across treatments ($P = 0.082$), being lower in ALL than both AM ($P < 0.05$) and PM
330 ($P = 0.088$).

331 Total duration of lateral lying tended to be affected by treatment ($P = 0.054$), being
332 significantly lower in AM than PM ($P < 0.05$); whilst total duration of ventral lying was
333 not affected by day or treatment. Total duration of lying (ventral + lateral) was
334 affected by day ($P < 0.001$), being lower on the day of opening than both the day
335 before ($P = 0.0001$) and day after ($P < 0.05$), whilst the day before and day after
336 crate opening also tended to differ ($P = 0.055$). Total duration of lying was also
337 affected by treatment ($P < 0.01$), being lower for AM than both PM ($P < 0.01$) and
338 ALL ($P < 0.05$).

339 Sow parity had a significant effect on the total duration of both ventral and lateral
340 lying (both $P < 0.05$). Parity 2-5 sows had both a lower total duration of lateral lying
341 (211mins \pm 25) and higher total duration of ventral lying (91.4mins \pm 8.5) than parity 1
342 sows (lateral= 258mins \pm 27; ventral= 53.5mins \pm 10.5; both $P < 0.01$), but not parity
343 6+ sows (lateral= 241mins \pm 27; ventral = 70.9mins \pm 11.4).

344 *Riskiness of rolling behaviour.* Across treatments, the frequency of same side and
345 opposite side rolling were affected by day (both: $P < 0.05$), whilst the treatment x day
346 interaction showed a significant increase of same and opposite side rolling on the
347 day of crate opening than the day before within PM only (Figure 4). The frequency of
348 standing between rolling was significantly higher in ALL than PM on the day before
349 crate opening ($P < 0.05$; Figure 4).

350 **Discussion**

351 To our knowledge, this is the first study to specifically measure the immediate effect
352 of temporary crate opening on piglet mortality. The results show that piglet mortality
353 was significantly increased after crate opening, confirming our initial hypothesis that
354 the post-opening period is a particularly dangerous time for piglet losses.

355 Consequently, farms may wish to implement additional measures to reduce piglet
356 mortality during the post-opening period, such as increased supervision (Kirkden *et*
357 *al.*, 2013). Whilst no post-mortem examinations were performed in the current study,
358 it is reasonable to assume that any significant differences in piglet mortality between
359 the pre- and post-opening periods resulted from crushing, as crate opening was the
360 only change to occur within this time period.

361 There are numerous potential causes for this increase in piglet crushing. Firstly,
362 based on the principle of why confining sows reduces crushing, crate opening

363 eliminated the physical restriction of sow body movements. Subsequently, posture
364 changes may be less controlled and therefore faster (Weary *et al.*, 1996), increasing
365 the risk of crushing as piglets have less time to escape. Secondly, sows adapt their
366 behaviour to their environment, therefore a sudden change may be stressful and
367 require acclimation (Chidgey *et al.*, 2015). Sow behavioural adaptation to farrowing
368 crates and pens has been shown between successive parities (e.g. Jarvis *et al.*,
369 2001; Thodberg *et al.*, 2002), therefore the sow's ability to adapt and cope may be a
370 gradual process unsuitable for sudden environmental changes occurring mid-
371 lactation. Finally, not only does crate opening increase the proportion of the pen
372 accessible to the sow, but it also decreases the proportion of the pen providing a safe
373 resting area for the piglets. Therefore, piglets may also be required to adapt their
374 behaviour in response to crate opening. Furthermore, as many temporary
375 confinement systems, including the one used in the current study, are designed to
376 use the same floor space as a traditional farrowing crate, there may be minimal safe
377 space available to the piglets after crate opening, especially towards weaning age
378 when piglets are larger.

379 Despite piglet mortality increasing in response to crate opening, total live-born piglet
380 mortality in the current study was lower than the national average for UK indoor
381 breeding herds (10.1% vs. 11.9% respectively; Agriculture and Horticulture
382 Development Board Pork, 2017), the majority of which use conventional farrowing
383 crates. Some farm surveys have shown that, whilst piglet mortality from crushing may
384 be higher in free farrowing systems, piglet mortality from other causes is higher in
385 crated systems, resulting in no overall difference (Weber *et al.*, 2007; KilBride *et al.*,
386 2012). In contrast, previous studies comparing free farrowing and temporary
387 confinement within the same farm indicate significantly reduced total piglet mortality

388 in the latter (Hales *et al.*, 2015; Chidgey *et al.*, 2015). However, unconfined farrowing
389 systems were relatively new to both the farm staff and sows in these studies, which is
390 likely to increase piglet mortality as stockpersons develop appropriate management
391 routines. Furthermore, changing the farrowing environment of the sows in successive
392 parities can also increase piglet mortality (King *et al.*, *submitted*). In the current study,
393 the temporary confinement system had been in use on the farm for more than one
394 year before the study commenced. However, the farm utilised multiple farrowing
395 systems, therefore the previous farrowing system of individual sows would have
396 differed.

397 Across all crate opening treatments, sow behaviour changed in response to crate
398 opening. However, behaviour on the following day was more analogous to the day
399 before crate opening, suggesting that the novelty of being released from confinement
400 may have been the predominant cause for post-opening behavioural changes. These
401 acute behavioural changes may also explain why piglet mortality was higher in the
402 post-opening period than later lactation. We also measured the riskiness of sow
403 rolling behaviour, as ventral-to-lateral rolling is an important posture change for piglet
404 crushing in free farrowing systems (Weary *et al.*, 1996) and previous studies have
405 found piglet crushing in free farrowing systems to be explicitly caused by rolling from
406 one side to the other (Bradshaw and Broom, 1999; Marchant *et al.*, 2001). During
407 observation periods, no opposite side rolling occurred on the day before, whilst eight
408 of the fifteen sows performed opposite side rolling on the day of crate opening.

409 The different crate opening procedures also resulted in differences in piglet mortality
410 and sow behaviour. Whilst the PM treatment resulted in the lowest piglet mortality, it
411 was also the only treatment with a significant increase in post-opening dangerous
412 posture changes. However, PM posture changes on the pre-opening day were lower

413 than the other treatments, meaning a significant increase was more likely. As
414 behavioural observations were only performed for six hours after crate opening, the
415 different behaviour of PM sows may be due to a temporal difference in observation
416 periods, including the lower level of human disturbance, rather than a temporal
417 difference in crate opening. Increased sitting behaviour is associated with
418 motivational conflict (Jarvis *et al.*, 1997), which in the current study, may indicate PM
419 sows were conflicted between continuing to rest or to actively explore the open pen.
420 This would also explain why the standing duration of PM sows did not significantly
421 increase during the post-opening period, unlike both AM and ALL. The increased
422 sitting behaviour of PM sows may also mean an increased alertness, as sows will
423 often sit when disturbed by external events whilst resting, and increased sow
424 alertness could reduce the risk of piglet crushing. Furthermore, the majority of piglet
425 mortality from crushing is not from the immediate trauma, but rather suffocation, as
426 the risk of a crushing incident being fatal increases with increasing duration of time
427 trapped underneath the sow (Weary *et al.*, 1996). Therefore, whilst increased posture
428 changes may increase the frequency of crushing, fewer crushing events would have
429 a fatal conclusion.

430 Piglet mortality was also lower in the AM than ALL treatment, whilst significant
431 differences were also observed between AM and ALL sow behaviour, but only on the
432 day before crate opening. Whilst opening the crates individually may have avoided a
433 simultaneous peak of post-opening sow activity, sows with younger litters could have
434 been disturbed during the pre-opening period. This could have resulted from either
435 the action of stockpersons opening neighbouring crates of older litters, or the
436 subsequent post-opening increased activity of these sows. However, this pre-
437 opening disturbance of AM sows resulted in a less profound change between pre-

438 and post-opening behaviour in comparison to ALL sows. This could explain the
439 reduced post-opening mortality, as piglets may have become more cautious of the
440 restless sow whilst she was still in confinement. The increased pre-opening activity in
441 AM sows could be a sign of stress or frustration (Jarvis *et al.*, 2001), and may have a
442 welfare implication for future investigation. Furthermore, if additional measures to
443 minimise piglet mortality, such as increased supervision, were implemented during
444 the post-opening period; these would be more efficient if all crates were opened on
445 the same day instead of across several days.

446 Finally, the different housing types used on the farm resulted in different piglet
447 mortality outcomes, being higher in the converted rooms than the cabins during the
448 pre-opening and later lactation periods. Unlike the cabins, pen arrangement in the
449 rooms meant sows had extensive visual contact with other sows in adjacent pens, as
450 well as the opportunity for physical interactions once the crates were opened. This
451 increased sow-sow contact in the rooms may have caused prolonged disturbance,
452 causing increased piglet mortality in later lactation, whilst having no significant effect
453 during the post-opening period as all sows would have been aroused regardless of
454 pen arrangement. Furthermore, as mentioned previously, a change of farrowing
455 system can also increase mortality. The farm in the current study used multiple
456 farrowing systems, however it would have been more likely that sows in the cabins
457 would have farrowed in the cabins previously, due to the larger number of farrowing
458 places in this arrangement (120 in cabins vs. 48 in rooms).

459 A repeat of the current study in a more controlled environment and with a larger
460 sample size, especially for behavioural observations, would be beneficial for
461 validating the results. In particular, a clearer differentiation between the effects of
462 batch vs single opening, and time of day would be beneficial. It would be

463 recommended for behavioural observations to be performed across the 24-hour
464 period to determine the full extent of behaviours affecting piglet mortality. Future
465 research should determine precisely how many hours or days that piglet mortality is
466 increased, and sow behaviour is altered, after temporary confinement crates are
467 opened. Furthermore, crate opening treatment, including time of day, and pen
468 arrangement should be further explored for their effects on piglet and sow welfare.

469 In conclusion, the period following crate opening in temporary confinement systems
470 was a high risk time for piglet mortality, presumably due to accidental crushing by the
471 sow. However, opening crates individually, when piglets reached seven days of age,
472 resulted in lower post-opening piglet mortality relative to opening all crates once
473 piglets reached an average age of seven days, particularly individual opening in the
474 afternoon. Increased pre-opening disturbance in the farrowing house from opening
475 crates individually may have increased the activity of the sows before crate opening,
476 habituating sows and piglets to post-opening sow behaviour changes.

477 **Acknowledgements**

478 The authors would like to thank the stockpersons and owner of the commercial farm
479 involved for facilitating the research and for their commitment to using higher welfare
480 farrowing systems. We would also like to thank J Sainsbury plc for financial support
481 under the FREESOW project.

482 **Declaration of interest**

483 No conflict of interest to declare.

484 **Ethics statement**

485 The project received ethical approval from Newcastle University.

486 **Software and data repository resources**

487 Data not available in an official repository.

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561 **Table 1.** Ethogram of sow behaviours recorded for four hours after crate opening,
 562 and during the same time period on the previous and subsequent days.

Sow behaviour	Description
Standing	Included standing, walking and kneeling.
Sitting	Dog-sitting, with rear and front hooves on the floor.
Ventral lying	Lying with neither shoulder on the ground.
Lateral lying	Lying with one shoulder on the ground.
Dangerous posture changes	Included all downward posture changes (stand-lie, sit-lie) and rolling (ventral-lateral, lateral-ventral).
Turning	Sow is standing and changes body direction by a minimum of 180°, usually from facing front-to-back or back-to-front of the pen.
Sniffing piglets	Sow moves snout towards one or more piglets.
Use of support	Sow leans on pen fixtures during stand-lie transition.
Riskiness of rolling	
Post-standing	A standing event has occurred since the previous rolling event.
Same side	No standing event has occurred, sow rolls onto the same side of the body as the previous roll.
Opposite side	No standing event has occurred, sow rolls onto the opposite side of the body as the previous roll.

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567 **Figure captions**

568 **Figure 1.** Diagram of (a) temporary confinement pen, with (b) arrangement for 16
569 pens per converted room and (c) 20 pens per new cabin. Arrow indicates sow
570 orientation when crate is closed.

571 **Figure 2.** Least square means (\pm s.e.) for piglet mortality. (a) Treatment effects
572 during the post-opening ($P < 0.05$), late lactation ($P > 0.10$) and therefore after
573 opening ($P = 0.052$) periods. (b) Housing type effects indicated between bars for
574 each lactation period (n.s. ($P > 0.05$), * ($P < 0.05$), ** ($P < 0.01$)) and total lactation (\diamond (P
575 < 0.05)).

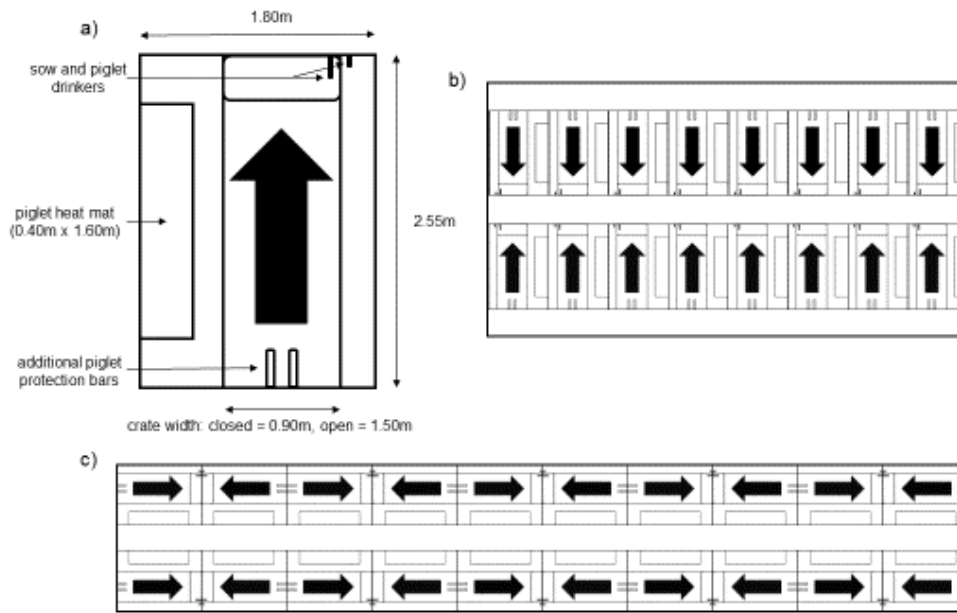
576 **Figure 3.** Least square means (\pm s.e.) for (a) frequency of sow dangerous posture
577 changes and (b) total duration of sow postures. Day effects within each treatment
578 between Before-During and Before-After are indicated on the latter day, whilst
579 differences between During-After are indicated between days for each posture (* ($P <$
580 0.05), ** ($P < 0.01$), *** ($P < 0.001$)) and total postures (\diamond ($P < 0.05$)). Treatment effects
581 within each day are indicated with different letters ($P < 0.05$).

582 **Figure 4.** Least square means (\pm s.e.) for frequency of sow rolling by riskiness
583 category. Day effects within each treatment between Before-During and Before-After
584 are indicated on the latter treatment, whilst differences between During-After are
585 indicated between treatments for each rolling category (* ($P < 0.05$)) and total rolling
586 frequency (\diamond ($P < 0.05$)). Treatment effects within each day are indicated with different
587 letters ($P < 0.05$).

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589 Fig 1

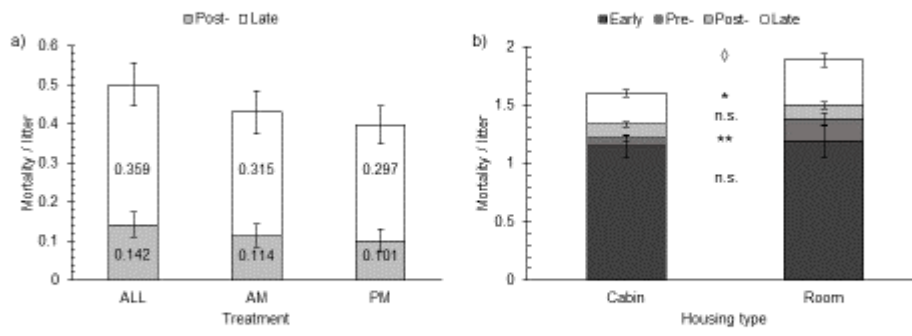
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592 Fig 2

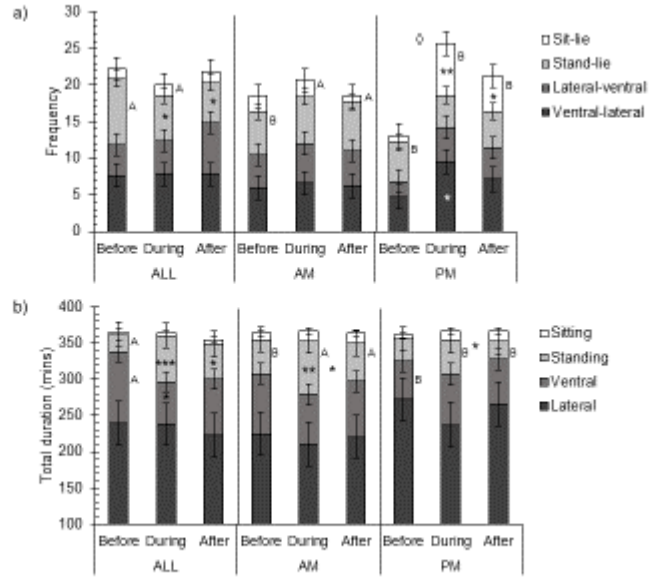
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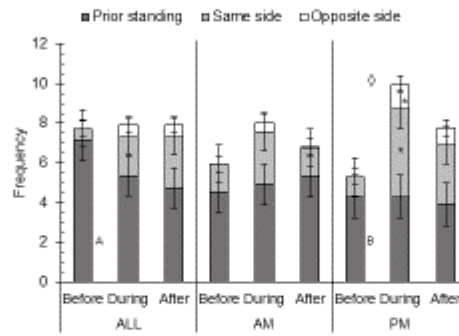
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598 Fig 4

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601 *Animal journal*

602 *Supplementary file*

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604 **Temporary crate opening procedure affects immediate post-opening**
605 **piglet mortality and sow behaviour**

606 R.L. King¹, E.M. Baxter², S.M. Matheson¹ and S.A. Edwards¹

607

608 **Supplementary Methods**



609

610 **Figure S1.** Temporary sow confinement pens in the cabin arrangement, illustrating
611 crates in both the open (left) and closed (right) position (image courtesy of EM
612 Baxter).

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618 **Figure S2.** Temporary sow confinement pens in the room arrangement, illustrating
619 crates in the open position, with the closest sows facing the rear of the pen (image
620 courtesy of RL King).

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632 **Supplementary results**

633 **Supplementary Material S1.** Results for average duration of sow posture changes.

634 *Average duration of postures*

635 Average bout duration of all postures by day and treatment are shown in Figure S2.

636 Average duration of standing differed across days ($P < 0.0001$), being higher on the

637 day of crate opening than the day before ($P < 0.0001$) or after ($P < 0.001$). Average

638 duration of sitting was affected by treatment ($P < 0.05$), being higher for AM than both

639 PM ($P < 0.05$) and ALL ($P < 0.01$). Average duration of ventral lying differed across

640 days ($P < 0.05$), being higher on the day before than the day of crate opening ($P =$

641 0.01) and tending to be higher than the day after ($P = 0.067$).

642 Sow parity tended to affect the average duration of ventral lying ($P < 0.069$) and

643 standing via a parity x day interaction ($P = 0.059$; Table S1). Average duration of

644 ventral lying was lower for parity 1 sows ($4.83\text{mins} \pm 0.70$) than parity 2-5 sows

645 ($6.28\text{mins} \pm 0.61$; $P < 0.05$) or parity 6+ sows ($6.40\text{mins} \pm 0.76$; $P = 0.058$). Average

646 duration of standing was increased on the day of crate opening than the day before

647 or day after for parity 1 sows (before $P < 0.0001$; after $P < 0.01$) and parity 2-5 sows

648 (before $P < 0.001$; after $P < 0.01$), but no different across days for parity 6+ sows.

649 This meant that on the day of crate opening, average standing duration was lower for

650 parity 6+ sows than both parity 1 sows ($P < 0.01$) and parity 2-5 sows ($P = 0.057$;

651 Table S1).

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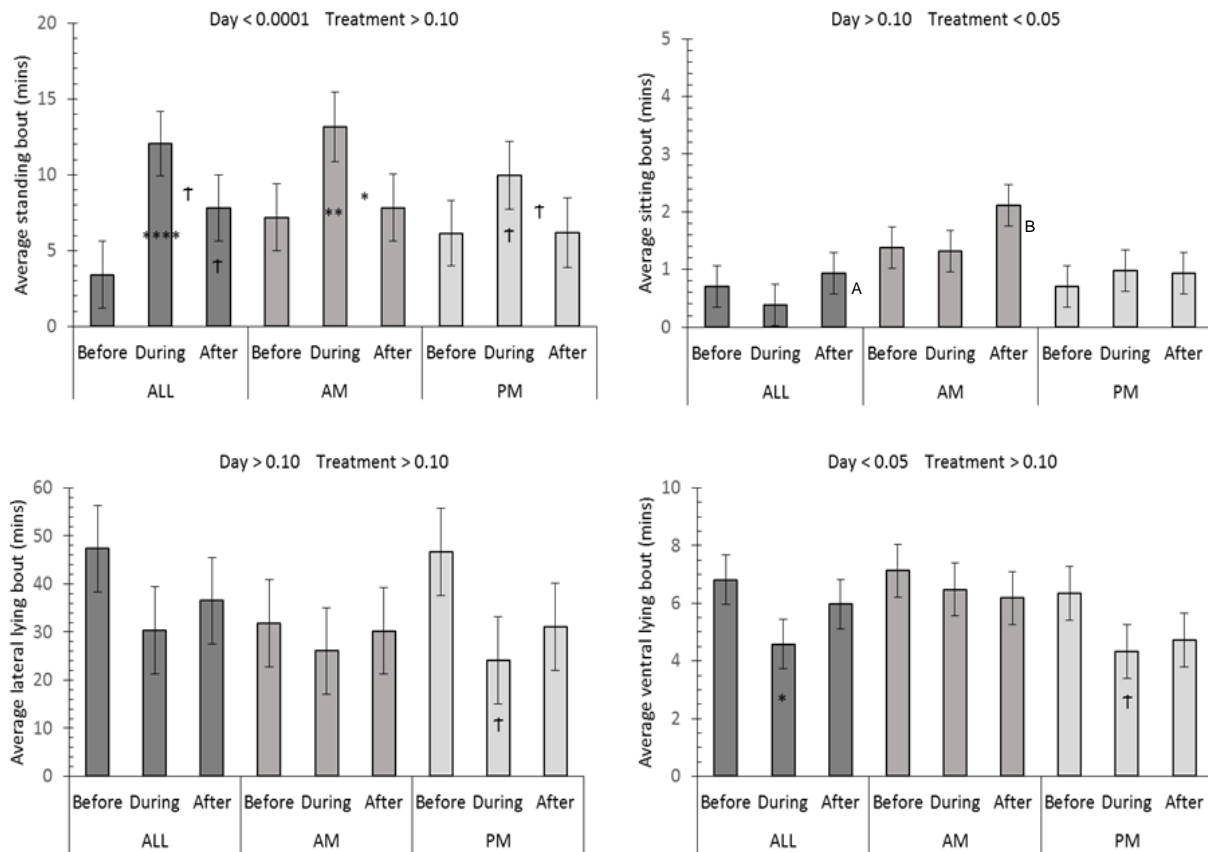
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662 **Figure S3.** Least square means (\pm s.e.) for average duration of sow postures by day
 663 and crate opening treatment. Starting top left, clockwise: standing, sitting, ventral
 664 lying and lateral lying. Day effects within each treatment for Before-During and
 665 Before-After are indicated on the latter bar, with During-After differences indicated
 666 between bars ($\dagger(P < 0.10)$, $*(P < 0.05)$, $** (P < 0.01)$, $****(P < 0.0001)$). Treatment
 667 effects within each day are indicated with different letters ($P < 0.05$).

668

669 **Table S1.** Least square means (\pm s.e.) of average sow standing bout duration (mins)
 670 by sow parity and day relative to crate opening.

Parity / Day	Before	During	After
1	4.35 \pm 2.27 ^a	15.23 \pm 2.37 ^b	8.10 \pm 2.23 ^a
2-5	5.13 \pm 2.01 ^a	11.98 \pm 2.07 ^b	6.54 \pm 1.96 ^a
6+	7.27 \pm 2.23 ^a	7.99 \pm 2.26 ^a	7.16 \pm 2.25 ^a

671 ^{a,b} Values within rows with different superscripts differ significantly ($P < 0.05$).

672