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Abstract

The natural weaning process of piglets is a gradual event, whereas in current commercial pig production weaning is a sudden, stressful phase in the pigs' life. Management strategies such as co-mingling of non-littermates before weaning aim to mimic (semi)natural conditions and to stimulate social skills in piglets in order to minimize the adverse effects of stress around weaning. The present study investigated in which way timing of co-mingling non-littermate piglets during lactation in conventional farrowing units had implications for the sow and affected the performance and behaviour of piglets before and after weaning. In the experimental treatments, 3 litters were co-mingled either at day 16 before weaning (n = 27 sows and their litters), day 11 before weaning (n = 27) or day 6 before weaning (n = 27). In the control treatment, piglets were not grouped before weaning (n = 27). In total, 1294 piglets were weaned at 21 days of age. At weaning, piglets from 3 litters within each treatment were mixed. Piglets from the co-mingling system were housed with those they were co-mingled with during lactation, whereas control piglets were mixed with unfamiliar piglets. Co-mingling of non-littermate piglets did not affect sow body condition and lesion scores of udder and teats during lactation. Piglets co-mingled 6 days before weaning tended to gain less weight during d-6 – d-1 before weaning ($P = 0.082$), but piglet growth was not affected during d-16 – d-1. After weaning, the feed to gain ratio in piglets which were co-mingled 6 days before weaning tended to be lowest during the first week after weaning ($P = 0.086$), but no other treatment effects were observed in the post-weaning phase. Skin lesion score of the shoulders and flanks tended to be higher at day 11 before weaning in piglets co-mingled 16 days before weaning ($P = 0.051$) and was highest at day 6 before weaning in piglets co-mingled 11 days before weaning ($P < 0.001$). However, 1 day before weaning no differences in skin lesions were observed. After weaning, the socialized piglets had less skin lesions at the shoulders and flanks compared to control piglets ($P < 0.001$). In conclusion, pre-weaning co-

mingling of non-littermates resulted in less aggression (i.e. lesions) at weaning, suggesting better social skills and a reduction of stress, consistent with a tendency for improved feed to gain ratio in the first week after weaning. Time of co-mingling seemed not crucial.

Keywords

Co-mingling

Piglet

Performance

Weaning

Stress

1. Introduction

In (semi)natural conditions, piglets follow the sow in close proximity outside the nest occasionally from day 4 postpartum onwards (Newberry and Woodgush, 1986; Stangel and Jensen, 1991). As piglets age, their activity increases and they join their mother further away from the nest (Newberry and Woodgush, 1986; Stangel and Jensen, 1991). First social contacts with other members of the herd take place (Petersen et al., 1989). Between week 2 and 7 postpartum social interactions between piglets and other members of the group are frequent and piglets often interact with non-littermates of the same age. By week 7 postpartum, piglets seem to be fully integrated in the herd (Petersen et al., 1989). Most conventional modern pig breeding systems prevent this natural process of socialization. Alternative housing systems and management strategies such as co-mingling of non-littermates before weaning mimic these (semi)natural conditions and aim to develop the social skills in piglets in order to minimize the adverse effects of (social) stress around weaning (Kanaan et al., 2012; Kutzer et al., 2009). It has been repeatedly shown that co-mingling non-littermates before weaning positively affects social behaviour resulting in less aggression and injuries after weaning (e.g. Hessel et al., 2006; Kutzer et al., 2009; Schrey et al., 2019; van Nieuwamerongen et al., 2015; Weary et al., 1999). This may ultimately translate to better performances in the nursery phase (Hessel et al., 2006; Kutzer et al., 2009; Schrey et al., 2019; van Nieuwamerongen et al., 2015). However, literature demonstrates that systems of pre-weaning co-mingling of non-littermates vary not only in design, but also in starting time of co-mingling. For example, piglets interacted with non-littermates as early as from birth (Arey and Sancha, 1996), whereas in other studies co-mingling started at 10-14 days postpartum (D'Eath, 2005; Hessel et al., 2006; Kutzer et al., 2009; Parratt et al., 2006; Pluske and Williams, 1996; Schrey et al., 2019; Wattanakul et al., 1997b; Weary et al., 1999). The latter may accord more with the (semi)natural behaviour in pigs since the sow leaves the nest

77 together with her piglets between approximately 6.5 and 15 days postpartum (Jensen, 1986;
78 Jensen and Redbo, 1987; Jensen et al., 1991; Petersen, 1994; Petersen et al., 1989).
79 Socializing unfamiliar litters considerably late in lactation, such as in the second or third week
80 after farrowing, seems to be more preferable from a practical point of view (Camerlink and
81 Turner, 2017). Indeed, in practice, the timing of grouping non-littermates during lactation
82 might depend on management related proceedings such as individual vaccination of the
83 piglets. Nevertheless, the reasons for choice of timing of grouping as found in literature are
84 limited, yet the question remains to what extent the time of start of co-mingling non-
85 littermates during lactation affects behaviour and performance of sows and piglets both before
86 and after weaning, and whether it offers benefits at all. Few papers already investigated the
87 timing of co-mingling of non-littermates during lactation in conventional farrowing housing
88 (Salazar et al., 2018) or in multi-suckling systems (Thomsson et al., 2015, 2016, 2018;
89 Verdon et al., 2019a, 2019b, 2020).
90 In the present study piglets from 3 litters were co-mingled in conventional farrowing housing
91 by removing the solid partitions between adjacent farrowing pens during lactation, allowing
92 suckling piglets to socialize with non-littermates while the sows remained in their farrowing
93 crate. The time when the partitions were removed differed between the treatments: 16 d, 11d
94 or 6 days before weaning. Weaning age was 21 d. It was hypothesized that early socialization
95 will lead to better social and exploring skills of the piglets, in order to minimize aggression
96 (skin lesions) and improve the transition at weaning, resulting in better performances (body
97 weight, daily gain, (creep) feed intake, feed to gain ratio, mortality) and potentially lower
98 need for medical treatments (faecal score, medical treatments), without negatively affecting
99 the sow during lactation (body condition, feed intake, functional teats, skin lesions, medical
100 treatments).
101

2. Materials and methods

The study was conducted in accordance with the EU Directive 2010/63/EU on the protection of animals used for scientific purposes and by the Belgian royal decree (KB29.05.13) on the use of animals for experimental studies.

2.1. Animals and housing

The study was conducted at a commercial pig farm in Oosteeklo, Belgium. A total of 108 primiparous and multiparous TN70 (Topigs Norsvin) sows and their litters (1404 piglets after standardization; Piétrain × TN70) were studied in 3 batches during 2017-2018. Sows were selected and allocated to the treatments based on their parity (mean ± s.d., 2.85 ± 0.98) and thickness of backfat (mean ± s.d., 14.5 ± 1.9 mm) 2 weeks before expected parturition.

One week before expected farrowing, sows were moved into the conventional farrowing accommodation. The farrowing unit consisted of 96 individual farrowing pens (1.85 m x 2.50 m) with farrowing crates. The farrowing pens were equipped with fully slatted floors and a heated piglet resting area with solid flooring and heater. Piglets were cross-fostered within the two first days of life in order to standardize litters to 13 piglets. Three days after farrowing of the last sow, piglets were identified with numbered ear tags. At day 5 after farrowing of the last sow, piglets were tail docked and vaccinated for *Mycoplasma hyopneumoniae* (MSD Animal Health, The Netherlands). They were also injected with iron (iron (as dextran), 200 mg/ml IM, Dechra, Belgium) and antibiotics (amoxicillin trihydrate, 150 mg/ml IM, Zoetis, Belgium). Males were castrated and administered NSAID (meloxicam, 5mg/ml IM, Dopharma, The Netherlands).

From entry into the farrowing unit, sows received a standard dry commercial transition feed (8685 kJ/kg NE; 14.5 % crude protein). During the lactation period, sows were fed a standard dry commercial lactation diet (9417 kJ/kg NE; 15.8 % crude protein). Piglets were offered creep feed from day 12 before weaning by a feeder located next to the sow, at the anterior side

of the farrowing pen (d-12 – d-6 before weaning: commercial creep feed, 18.0 % crude protein; d-6 – d-3 before weaning: 50/50, commercial creep feed, 18.0 % crude protein / commercial creep feed, 17.5 % crude protein; d-3 – d0 before weaning: commercial creep feed, 17.5 % crude protein). Water was available *ad libitum*.

In total, 1294 piglets were weaned at 21 days of age and transferred to the nursery unit in 72 pens (3.6 m x 1.4 m) with fully slatted floors. Each pen contained 17 to 18 piglets and had one feeder and two nipple drinkers, which were shared by two neighbouring pens. Piglets had *ad libitum* access to water and feed. At weaning, piglets received first on average 0.24 kg/pig commercial creep feed (17.5 % crude protein), followed with the weaner diet (10054 kJ/kg NE; 16.5 % crude protein) during d0-14 post-weaning.

2.2. Experimental design

In order to investigate the effect of starting time of pre-weaning co-mingling of non-littermates, 4 treatments were applied. In the control treatment, sows and their litters were kept under conventional conditions until weaning (27 sows). This means that littermates stayed together in the farrowing pen and had no access to other farrowing pens until weaning. In the experimental treatments, the 2 solid partitions (2.50 m in length) separating 3 adjacent farrowing pens were removed either on day 3 after farrowing of the last sow (mean ± s.d., 5.2 ± 1.4 days postpartum), equivalent to 16 days before weaning (27 sows); or day 8 after farrowing of the last sow (mean ± s.d., 10.0 ± 1.4 days postpartum), equivalent to 11 days before weaning (27 sows); or day 13 after farrowing of the last sow (mean ± s.d., 15.0 ± 1.4 days postpartum), equivalent to 6 days before weaning (27 sows). Thus, in the experimental treatments piglets from 3 litters were allowed to freely move in the space of 3 farrowing pens and to co-mingle with non-littermates, while the sows remained in their farrowing crate.

At weaning, piglets from 3 litters from 3 adjacent farrowing pens within each treatment were distributed over 2 neighbouring pens sharing feeders and nipple drinkers in the nursery.

Piglets from the control treatment were mixed with unfamiliar litters at weaning, whereas piglets from the co-mingling system were housed with those they were co-mingled with prior to weaning. Allocation of piglets to the 2 nursery pens within each group of 3 litters was done based on sow, body weight and gender. Thus, piglets within each group of 3 litters were assigned to 2 neighbouring pens in order to stratify for sow, mean body weight and gender. Each pen contained of 5 to 6 piglets per litter or 17 to 18 piglets in total.

2.3. Performance and health

The individual body weight, backfat thickness and functional teats of sows were recorded at the time the first experimental treatment was implemented, i.e. 16 days before weaning (d–16), and at weaning (d0). All piglets were individually weighed at d–16, –11, –6, and –1 before weaning and d7, 14 and 49 post-weaning. The individual feed intake of sows was registered between d–16 before weaning and weaning. Creep feed intake of suckling piglets was recorded from d–12 until weaning and feed intake of nursery piglets was registered for d0–14 post-weaning. Next, difference in body weight, difference in backfat thickness, average daily gain, within litter-weight variation (i.e. variation coefficient of body weights), average daily feed intake, average creep feed intake and feed to gain ratio were calculated.

Furthermore, mortality and individual use of medical treatments of the animals were registered. A faecal consistency score of piglets was assessed visually per pen daily from d–16 until weaning (score 0: no faeces visible; score 1: hard or slightly moist faeces; score 2: moist or soft faeces; score 3: watery or liquid faeces, indicative for diarrhoea). The highest faecal consistency score per pen was registered and used for calculations. When faecal consistency score 3 was found, individual pigs showing diarrhoea, i.e. wet, irritated backsides, were counted per pen for calculating diarrhoea incidence.

2.4. Feeding behaviour piglets

176 To distinguish eaters from non-eaters 1.0 % chromic oxide was added as indigestible colour
177 marker to the feeds of piglets during the 3 last days before weaning and d0–1 post-weaning
178 (adapted from Bruininx et al. (2002)). Green-coloured faeces demonstrated that the pig had
179 consumed feed (Barnett et al., 1989). The colour of the faeces of each piglet was visually
180 observed at d–1 and at weaning (d0) to evaluate creep feed intake, and twice (morning and
181 evening) at d1 to monitor early diet consumption after weaning by collecting faecal swabs.
182 Piglets were classified as good eaters before weaning when they showed green-coloured
183 faeces at d–1 and at weaning, and they were classified as good eaters post-weaning when they
184 showed green-coloured faeces on both morning and evening at d1. Piglets were classified as
185 non-eaters before weaning when they never showed green-coloured faeces at d–1 and at
186 weaning, and they were classified as non-eaters post-weaning when they never showed green-
187 coloured faeces at d1. Piglets that showed green-coloured faeces at one of the two observation
188 occasions before and after weaning were defined as intermediate, but not further taken into
189 account. Thus, only percentages of good eaters and non-eaters before and after weaning were
190 calculated.

191 *2.5. Skin lesion scores*

192 Skin lesions were assessed as proximate of sow and piglet behaviour. Injuries at the udder and
193 teats (left side udder) of sows were scored at d–16, –11, –6 and –1 before weaning by scoring
194 systems based on van der Peet-Schwering et al. (2015) (Table 1).

195 Damages on snout, skin lesions at the head and ears, and skin lesions at shoulders and flanks
196 of each piglet were scored at d–16, –11, –6, –1 before weaning and d1 post-weaning, based on
197 protocols adapted from Kutzer et al. (2009), Parratt et al. (2006) and van der Peet-Schwering
198 et al. (2015) (Table 1). Skin lesion scores were recorded on both the left and right side of the
199 body and averaged separately for each body part of the piglet.

200 *2.6. Statistical analysis*

Data were analysed with IBM SPSS Statistics version 26.0 (SPSS Inc., Chicago, IL, USA). For the statistical analysis of pre-weaning data, 3 sows and their litters in adjacent farrowing pens were considered the experimental unit for the co-mingling treatments, i.e. 9 replicates per treatment. Sow and respective litter in a single farrowing pen was the experimental unit for the control treatment, i.e. 27 replicates. During the experiment one sow from the treatment co-mingling of non-littermates from day 16 before weaning died for unknown reasons and was replaced by another sow. Therefore, data related to this sow was excluded and data from the remaining 2 sows were considered the experimental unit. One sow from the control treatment was replaced because of severe paralysis of the hindquarter. Data related to this sow was excluded.

For the statistical analysis of post-weaning data, the experimental unit consisted of 3 litters (i.e. 35 to 36 piglets in 2 adjacent pens sharing a feeder and 2 nipple drinkers), i.e. 9 replicates per treatment (co-mingling and control treatments).

All data were tested for normality by Kolmogorov-Smirnov and Shapiro-Wilk test. Homoscedasticity was tested by Levene's test, and robust tests of equality of means using Welch test were used if data were heteroscedastic. Analysis of variance (ANOVA) was performed using the General Linear Model module with treatment as the fixed factor and batch as the random factor. Non-parametric tests using Independent-Samples Kruskal-Wallis test were applied if appropriate. Differences were considered significant at $P < 0.05$ and tendency was considered at $P \geq 0.05$ to $P < 0.10$. Differences among treatments were determined by the Tukey multiple comparison of means test. Data are presented as means with the standard error of mean (SEM).

3. Results

3.1. Pre-weaning animal performance and health

226 Sow body weight, backfat thickness, average daily feed intake and functional teats did not
227 differ significantly among treatments (Table 2). However, backfat thickness tended to be
228 lower 16 days before weaning in sows whose litters were grouped at 16 and 11 days before
229 weaning as compared to other treatments (P = 0.074), however, this was not treatment related
230 since co-mingling was not started yet. Further, no differences in medical treatments of
231 individual sows were found (P > 0.05; data not shown).
232 Body weights of suckling piglets were not affected by treatment at any point in time (Table
233 3). No treatment effects on average daily gain of the piglets during d-16 – d-1 were found.
234 However, piglets co-mingled 6 days before weaning tended to gain less weight during d-6 –
235 d-1 (P = 0.082). The within litter-weight variation coefficient did not vary in the beginning of
236 the lactation period, i.e. 16 days before weaning, and was also not influenced by treatments at
237 day 1 before weaning (Table 3). Creep feed intake during the 12 days before weaning did not
238 differ (P > 0.05).
239 Individual use of medical treatments in piglets before weaning was not influenced by the
240 treatment (P > 0.05; data not shown). Piglet mortality from 16 days before weaning until
241 weaning was similar across treatments and varied between 1.71 and 3.13 % (P > 0.05).
242 Average faecal consistency score during 16 days before weaning also did not differ (1.8; P >
243 0.05) and no effects of treatment on diarrhoea incidence in the 16 days before weaning were
244 found (P > 0.05; data not shown).
245 *3.2. Post-weaning animal performance and health*
246 After weaning, no effects on body weight, average daily gain, average daily feed intake and
247 feed to gain ratio in piglets were found (Table 4). Feed to gain ratio in piglets which were co-
248 mingled 6 days before weaning tended to be lowest during the first week after weaning (P =
249 0.086). Post-weaning individual medical treatments were similar across treatments (P > 0.05;

250 data not shown). After weaning, piglet mortality did not differ between treatments and varied
251 between 0.93 and 1.54 % ($P > 0.05$).

252 *3.3. Feeding behaviour*

253 Before weaning (d-1 – d0), the percentage good eaters was not affected by treatments (Table
254 4). The percentage non-eaters before weaning was significantly affected by the treatment, but
255 Tukey post-hoc analysis could not discriminate treatments. After weaning (d1), no effects in
256 feeding behaviour of piglets between treatments were found (Table 4).

257 *3.4. Skin lesion scores*

258 At day 16 before weaning, the skin lesion score of the udder and teats of the sows differed
259 significantly (Table 5), but Tukey post-hoc analysis could not clarify the effect of treatment.
260 The lesion score at the teats of sows where litters were co-mingled 16 days before weaning
261 was higher compared to control sows ($P < 0.05$). However, it must be noted that this was not
262 treatment related since both skin lesion scores were recorded just before the start of
263 socialization in the experimental treatments. During the experiment, no further significant
264 differences were seen for lesion scores for sows.

265 The overall occurrence of skin lesions at snout and head and ears of piglets before weaning
266 was not altered by treatment (Table 6). In contrast, the lesion score of the shoulders and flanks
267 in piglets co-mingled 16 days before weaning tended to be higher at day 11 before weaning (P
268 $= 0.051$) and the lesion score of the shoulders and flanks in piglets grouped 11 days before
269 weaning was higher at day 6 before weaning compared to piglets co-mingled 6 days before
270 weaning and control piglets ($P < 0.05$) (Table 6, Figure S1). After weaning, piglets in all co-
271 mingling treatments had lower skin lesion scores at the shoulders and flanks compared to
272 control piglets ($P < 0.001$; Table 7, Figure S1). The increase in lesion score shoulders and
273 flanks for control piglets between d-1 (Table 6) and d1 (Table 7) (0.19 *vs.* 1.01) was sharp. No

274 effects on the skin lesion scores at the snout, head and ears in piglets after weaning between
275 treatments were found ($P > 0.05$).
276
277 **4. Discussion**
278 The objective of the present study was to investigate if sow body condition, pig behaviour and
279 performance differed in view of the time of starting to co-mingle piglets from 3 litters during
280 lactation in conventional farrowing housing.
281
282 From the current study, it was clear that co-mingling of non-littermates during lactation did
283 not affect sow body condition, i.e. body weight and backfat thickness. Weary et al. (1999)
284 observed the same. They co-mingled 3 litters at day 11 postpartum while the sows remained
285 confined in their farrowing crates. Further, the present study found no differences in sow body
286 condition between the 3 different co-mingling treatments, which suggests that the time of start
287 of co-mingling piglets during lactation does not affect sow body condition. In contrast,
288 Verdon et al. (2020) observed lower losses in body condition in sows that were grouped with
289 their litters at 7 days of age compared with at 14 days of age. Additionally, Thomsson et al.
290 (2018) observed lower body weight and backfat losses in sows that were grouped with their
291 litters initiated 2 weeks postpartum compared with starting multi-suckling 1 and 3 weeks
292 postpartum. However, it should be emphasized that those studies investigated the timing of
293 grouping in multi-suckling systems (i.e. systems in which sows are not confined in crates and
294 interact with other sows), whereas in our study socialization was applied in conventional
295 farrowing housing where the sows remained in their crates. In our study the number of
296 functional teats and the occurrence of injuries at the udder and teats of the sows was not
297 affected by socialization. A similar outcome was reported by Klein et al. (2016) who grouped
298 piglets from 4 litters in a conventional farrowing system at day 10 postpartum of the youngest

299 litter. Only Camerlink et al. (2018) observed more teat damage at weaning by applying
300 socialization of 2 litters at 14 days of age in a conventional housing system.
301
302 In the current study, the transient increase in skin lesions following mixing of litters during
303 suckling observed in all co-mingling groups suggested that socialization of piglets induced
304 aggressive behaviour immediately after grouping, and in consequence more skin lesions at
305 shoulders and flanks. Probably, this was due to fighting behaviour between piglets for
306 establishing a dominance hierarchy since grouping unfamiliar piglets results in fighting
307 behaviour (Petherick and Blackshaw, 1987), and reciprocal fighting includes lesions at those
308 regions of the body (Turner et al., 2006). Actually, in our study no differences were observed
309 in skin lesion scores at the snout, which is commonly associated with increased competition at
310 the udder, and possibly the occurrence of cross-suckling (van Nieuwamerongen et al., 2015).
311 Interestingly, Pitts et al. (2000) reported that the time spent fighting was shorter in younger, 5
312 days old piglets, resulting in fewer skin lesions (Pitts et al., 2000), which would imply that co-
313 mingling non-littermates considerably early in lactation might be better concerning social
314 behaviour in piglets. Indeed, in the present study the skin lesion score in piglets co-mingled
315 16 days before weaning or at 5 days postpartum seemed to remain reasonably constant during
316 the lactation period. Nonetheless, 1 day before weaning the skin lesion score between
317 treatments did not differ, which suggests that the effects of timing of co-mingling non-
318 littermates might be limited, which agrees with previous studies (Salazar et al., 2018; Verdon
319 et al., 2020), where skin lesions in piglets at day 1 before weaning were alike when grouping
320 unfamiliar piglets at 7, 10 or 14 days postpartum. After weaning, it is clear that co-mingling
321 of non-littermates started at day 16, 11 or 6 before weaning, resulted in lower levels of
322 aggression compared to piglets raised in a conventional farrowing housing system. Since skin
323 lesion scores are an indicator of aggressive behaviour, we assume that co-mingling of non-

littermates during lactation limits aggression in piglets at weaning, which corresponds with several other studies (Bohnenkamp et al., 2013; Hessel et al., 2006; Klein et al., 2016; Kutzer et al., 2009; Lange et al., 2020; Parratt et al., 2006; Schrey et al., 2019; van Nieuwamerongen et al., 2015; Wattanakul et al., 1997a, 1997b; Weary et al., 1999, 2002). Stress at weaning might be reduced since the socialized piglets were not mixed with unfamiliar piglets at weaning, and aggression caused by grouping unfamiliar piglets is related to an increase of cortisol levels (Colson et al., 2012; Deguchi and Akuzawa, 1998; Merlot et al., 2004), implying an activation of central stress pathways (Moeser et al., 2007). Furthermore, it must be noted that the skin lesion scores after weaning were similar for all co-mingling treatments and thus not affected by the timing of grouping, which was in accordance with Salazar et al. (2018), who did not find differences in skin lesions in the immediate post-weaning period between grouping 2 litters at 7 versus at 14 days of age in conventional housing. In the study of Verdon et al. (2019a) the frequency of fights was lower and the duration of fighting shorter in the immediate post-weaning period (i.e. 3.5 h after weaning) in piglets that were co-mingled at day 7 and 14 postpartum in a multi-suckling system compared to conventionally reared piglets. Similar to our study, these authors also did not find differences between the group housing treatments even though in their study piglets at weaning were mixed within the same treatment not only with piglets from familiar litters but also from unfamiliar litters.

In the present study, piglets grouped 6 days before weaning tended to gain less weight during the last 5 days before weaning than piglets grouped 11 days before weaning. This might suggest that a later start of grouping piglets during lactation would negatively affect weight gain before weaning. Despite this result, piglets that were grouped 6 days before weaning had a comparable weight gain to the control piglets. A similar outcome was reported by Parratt et al. (2006) where no differences in pre-weaning performance were found between piglets

group housed 5 days before weaning (at approximately 21 days of age) and conventionally reared piglets. In addition, results of the present study demonstrated no differences between treatments in weight gain during 16 days before weaning, piglet weight at day 16 before weaning and at weaning. This suggests that overall pre-weaning performances of piglets is not affected by co-mingling non-littermates in conventional farrowing housing, which does align with previous similar studies (Camerlink et al., 2018; D'Eath, 2005; Hessel et al., 2006; Kanaan et al., 2012; Kutzer et al., 2009; Morgan et al., 2014; Wattanakul et al., 1997b; Weary et al., 1999). Moreover, the timing of grouping non-littermates before weaning had no effect either. Indeed, Salazar et al. (2018) did not observe differences in pre-weaning performances of piglets socialized at 7 and 14 days of age in conventional housing, but in contrast with our study and abovementioned studies, the co-mingled piglets were lighter during lactation compared to the control piglets. The authors hypothesized that this was due to the enhanced activity of the co-mingled piglets. Thomsson et al. (2016) also observed no differences in pre-weaning performance of piglets socialized in a multi-suckling system at week 1, 2 and 3 postpartum, but it must be noted that no control treatment was included. Furthermore, our results showed no significant post-weaning performance effects of grouping non-littermates at different ages before weaning, which was also found by Salazar et al. (2018). However, in the current study the feed to gain ratio in piglets that were co-mingled 6 days before weaning tended to be improved during the first week post-weaning, suggesting that grouping unfamiliar piglets before weaning could mainly have a positive influence in the immediate post-weaning period. Others came to the same conclusion (Schrey et al., 2019; Turpin et al., 2017a). A possible explanation could be that the piglets might cope better with social stress at weaning, resulting in a reduction of stressors which in turn positively affects gut health by a better utilisation of feed and consequently performance of the piglets in the early post-weaning period. Recent research of van Nieuwamerongen et al. (2018) highlighted the impact

of pre-weaning housing conditions such as co-mingling non-littermates in a multi-suckling system on intestinal function in piglets immediately after weaning, evidenced by a better feed conversion between day 2 and 5 post-weaning and differences in gastrointestinal carbohydrate absorption. Moreover, lower prevalence of aggressive behaviour is associated with a better feed conversion ratio in piglets (Pierozan et al., 2021). However, in studies of Turpin et al. (2017b) and Pluske and Williams (1996) feed conversion was not improved in the immediate post-weaning period by pre-weaning co-mingling non-littermates. Variations in implementation of co-mingling non-littermates during lactation and housing conditions at weaning such as group size and composition might be a reason for discrepancies between studies.

5. Conclusion

In summary, co-mingling 3 litters in conventional housing at 16, 11 or 6 days before weaning at 21 days of age had no implications for the sow's body condition and health. Piglets co-mingled 6 days before weaning tended to gain less weight during d-6 – d-1 before weaning, but overall pre-weaning piglet growth was not affected. A transient increase of skin lesions following co-mingling was observed, but the influence of timing of grouping on the social behaviour of piglets before weaning was rather limited since no differences in skin lesions were found between co-mingling treatments prior to weaning. Though, it was clear that pre-weaning grouping of unfamiliar piglets resulted in less aggression immediately after weaning, which suggested better social skills and reduced stress in the piglets at weaning, as also demonstrated by a tendency for an improved feed to gain ratio the first week after weaning. No other treatment effects in post-weaning piglet performance were found. As the time of co-mingling 3 litters in conventional farrowing housing was not crucial, pig farmers may choose the time of starting in accordance to their management practices.

Acknowledgements

We gratefully acknowledge the commercial farm where the study was conducted and the staff for their generous support. We thank Sarah Goethals, Stijn Apers, Elout Van Liefferinge, Noémie Van Noten, Maryam Majdeddin, Julie Baré and Georgeos Petrellis for their assistance during the experiment. The authors acknowledge the Flanders Innovation & Entrepreneurship Agency (VLAIO) (project HBC.2016.0786), Flanders, Belgium, for their support.

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537 post-weaning behaviour and performance. Appl. Anim. Behav. Sci. 65, 123-135.
538

Table 1. Skin lesion scoring system (based on (protocols adapted from) Kutzer et al., 2009; Parratt et al., 2006; van der Peet-Schwering et al., 2015).

Skin lesion score	Description
Udder	
0	No lesions
1	Superficial damage of the skin of the udder (< 1 cm)
2	One or more large (> 1 cm) superficial lesions / small (< 1cm) deep lesions of the skin of the udder
3	One or more large (> 1 cm) deep lesions of the skin of the udder
Teats	
0	No lesions
1	Small lesions (< 1 cm), no damage of the milk canal
2	Large lesions (> 1 cm), no damage of the milk canal
3	Damage of the milk canal
Snout	
0	No scratches
1	Only a few small scratches (≤ 5 mm)
2	Many small scratches or a number of larger scratches
Head and ears; Shoulders and flanks	
0	No skin lesions
1	Less than 5 superficial lesions (skin unbroken)
2	5 to 10 superficial lesions or less than 5 deep lesions (skin broken and evidence of haemorrhage)
3	More than 10 superficial lesions or more than 5 deep lesions

542 **Table 2. Body weight, back fat thickness, average daily feed intake and functional teats**
543 **of sows housed in treatments conventional housing system (control) or conventional**
544 **housing system with start of co-mingling of non-littermates 16, 11 or 6 days before**
545 **weaning, here referred as d0.**

	Co-mingling of non-littermates			Conventional	SEM	P-value
	d-16	d-11	d-6	housing		
Body weight, kg						
d-16*	243.6	245.9	247.4	242.4	3.0	0.916
d0*	226.8	222.6	226.0	220.9	3.0	0.854
difference d-16 – d0	16.8	23.3	21.3	21.4	1.5	0.544
Back fat thickness, mm						
d-16*	12.9	12.9	13.9	13.8	0.3	0.074
d0	11.1	10.9	11.2	11.2	0.3	0.982
difference d-16 – d0	1.7	2.0	2.7	2.5	0.3	0.646
Average daily feed intake, kg/d						
d-16 – d0	6.5	6.4	6.4	6.3	0.1	0.748
Functional teats						
d-16	14.8	14.8	14.5	15.0	0.1	0.468
d0	13.2	13.4	13.3	13.5	0.1	0.822

*Robust tests of equality of means (Welch test)

546

Table 3. Pre-weaning performance of piglets in treatments conventional housing system (control) or conventional housing system with start of co-mingling of non-littermates 16, 11 or 6 days before weaning, here referred as d0.

	Co-mingling of non-littermates			Conventional housing	SEM	P-value
	d-16	d-11	d-6			
Body weight, kg						
d-16	2.30	2.35	2.25	2.19	0.06	0.653
d-11	3.33	3.45	3.35	3.26	0.06	0.688
d-6	4.58	4.75	4.65	4.48	0.07	0.480
d-1	5.93	6.20	5.89	5.78	0.09	0.285
Average daily gain, g/d						
d-16 – d-11	205	217	218	213	4	0.700
d-11 – d-6	246	259	262	243	4	0.266
d-6 – d-1	271	288	245	259	5	0.082
d-16 – d-1	242	256	242	239	4	0.327
Within litter-weight variation, %						
d-16	18.1	18.9	19.1	16.4	0.6	0.218
d-1	18.6	16.4	17.6	18.2	0.6	0.682
Creep feed intake, g						
d-12 – d0*	65	73	69	61	3	0.322

*N = 53

552 **Table 4. Post-weaning performance and feeding behaviour of piglets in treatments**
553 **conventional housing system (control) or conventional housing system with start of co-**
554 **mingling of non-littermates 16, 11 or 6 days before weaning, here referred as d0.**

	Co-mingling of non-littermates			Conventional	SEM	P-value
	d-16	d-11	d-6	housing		
Body weight, kg						
d-1	6.05	6.29	5.99	5.90	0.06	0.176
d7	6.75	6.91	6.72	6.55	0.07	0.324
d14	8.43	8.55	8.47	8.23	0.08	0.516
d49	23.1	23.3	23.4	22.8	0.2	0.729
Average daily gain, g/d						
d-1 – 7	87	77	92	79	3	0.313
d7 – 14*	240	234	249	240	6	0.883
d14 – 49	420	421	426	415	5	0.852
d-1 – 14	158	150	165	154	2	0.204
d-1 – 49	342	340	348	337	4	0.713
Average daily feed intake, g/d						
d0 – 7	153	147	160	159	4	0.549
d7 – 14	306	294	308	308	3	0.290
d0 – 14	229	220	234	233	3	0.311
Feed to gain ratio						
d0 – 7	1.80	2.01	1.75	2.08	0.05	0.086
d7 – 14*	1.29	1.28	1.25	1.30	0.02	0.883
d0 – 14*	1.46	1.49	1.43	1.53	0.02	0.426
Percentage good eaters, %						
d-1 – 0*	13.6	8.4	10.2	13.0	1.6	0.574
d1	21.3	17.9	16.0	22.5	1.6	0.445
Percentage non-eaters, %						
d-1 – 0	61.7	73.0	72.5	61.4	1.8	0.038
d1	56.8	59.7	56.5	46.6	2.2	0.175

*Robust tests of equality of means (Welch test)

555

556

Table 5. Skin lesion scores of the udder and teats of sows in treatments conventional housing system (control) or conventional housing system with start of co-mingling of non-littermates 16, 11 or 6 days before weaning, here referred as d0.

	Co-mingling of non-littermates			Conventional	SEM	P-value
	d-16	d-11	d-6	housing		
Lesion score udder						
d-16	1.24	1.67	1.63	1.13	0.09	0.041
d-11	1.20	1.26	1.15	1.16	0.10	0.979
d-6	1.07	1.11	0.96	1.05	0.09	0.952
d-1	1.17	1.30	1.22	1.19	0.08	0.958
Lesion score teats						
d-16	1.30[b]	1.19[ab]	1.11[ab]	0.77[a]	0.08	0.026
d-11	1.41	1.11	1.11	1.31	0.11	0.737
d-6[*]	1.30	1.30	1.26	1.23	0.12	0.996
d-1	1.52	1.15	1.30	1.53	0.11	0.543

[a, b]Values with different superscripts within a row are significantly different at $P < 0.05$.
[*]Robust tests of equality of means (Welch test)

562 **Table 6. Skin lesion scores of snout, head and ears and shoulders and flanks of piglets in**
563 **treatments conventional housing system (control) or conventional housing system with**
564 **start of co-mingling of non-littermates 16, 11 or 6 days before weaning, here referred as**
565 **d0.**

	Co-mingling of non-littermates			Conventional	SEM	P-value
	d-16	d-11	d-6	housing		
Lesion score snout						
d-16*	1.03	1.03	1.03	0.97	0.02	0.317
d-11	0.91	0.93	0.91	0.91	0.02	0.979
d-6	0.73	0.76	0.73	0.68	0.03	0.695
d-1	0.47	0.51	0.57	0.45	0.03	0.583
Lesion score head and ears						
d-16	0.92	0.89	0.97	0.90	0.04	0.892
d-11	0.90	0.84	0.87	0.87	0.04	0.971
d-6	0.99	0.91	0.87	0.91	0.04	0.812
d-1	0.86	0.71	0.91	0.80	0.04	0.323
Lesion score shoulders and flanks						
d-16	0.37	0.43	0.31	0.30	0.03	0.309
d-11§	0.30	0.11	0.13	0.11	0.02	0.051
d-6	0.32[ab]	0.49[b]	0.17[a]	0.15[a]	0.03	<0.001
d-1*	0.26	0.36	0.53	0.19	0.04	0.117

[a, b]Values with different superscripts within a row are significantly different at $P < 0.05$.
§Nonparametric test (Kruskal-Wallis test)
*Robust tests of equality of means (Welch test)

566

Table 7. Skin lesion scores of snout, head and ears and shoulders and flanks of piglets at day 1 post-weaning in treatments conventional housing system (control) or conventional housing system with start of co-mingling of non-littermates 16, 11 or 6 days before weaning, here referred as d0.

	Co-mingling of non-littermates			Conventional housing	SEM	P-value
	d-16	d-11	d-6			
Lesion score snout	0.16	0.27	0.30	0.23	0.02	0.216
Lesion score head and ears	0.57	0.48	0.62	0.69	0.03	0.136
Lesion score shoulders and flanks	0.35[a]	0.34[a]	0.61[a]	1.01[b]	0.04	<0.001

[a, b]Values with different superscripts within a row are significantly different at $P < 0.05$.

Supplementary material

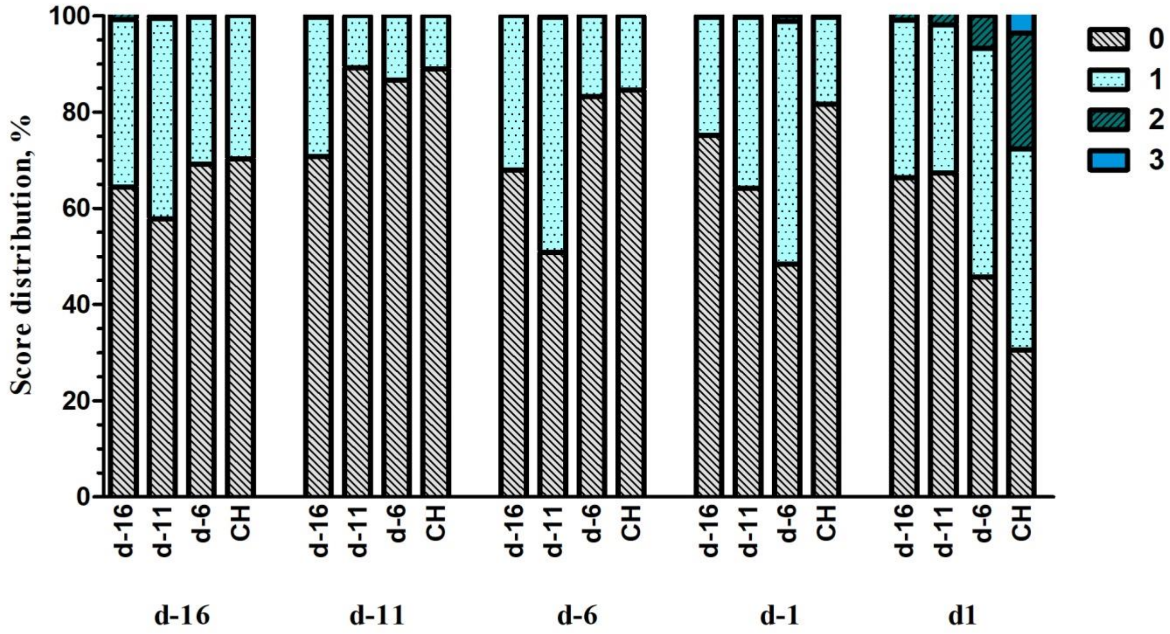

Figure S1. Score distribution of skin lesions at the shoulders and flanks of piglets at d-16, d-11, d-6, d-1 pre-weaning and d1 post-weaning in treatments conventional housing system (CH) or conventional housing system with start of co-mingling of non-littermates 16, 11 or 6 days before weaning. Scoring system from 0–3: 0 = no skin lesions; 1 = less than 5 superficial lesions (skin unbroken); 2 = 5 to 10 superficial lesions or less than 5 deep lesions (skin broken and evidence of haemorrhage); 3 = more than 10 superficial lesions or more than 5 deep lesions.