Animal 18 (2024) 101247

Contents lists available at ScienceDirect

Animal

The international journal of animal biosciences

Sow and litter performance after cross-fostering one surplus piglet and co-mingling the litters at early lactation

G.P. Zanin, L. Santos, D.M.S. Tomm, D.F. Silveira, F.P. Bortolozzo, R.R. Ulguim, A.P.G. Mellagi *

Department of Animal Medicine, Faculty of Veterinary Medicine, Federal University of Rio Grande do Sul (UFRGS), Porto Alegre 91540–000, Brazil

ARTICLE INFO

Article history:
Received 27 October 2023
Revised 3 July 2024
Accepted 5 July 2024
Available online 22 July 2024

Keywords:
Hyperprolificity
Milk yield
Piglet lesion
Socialization
Udder lesion

ABSTRACT

The number of piglets born alive is frequently greater than the functional teats, and some farms are equalizing litters with surplus piglets, limiting piglet udder access. Removing the barrier among farrowing crates may allow piglets to socialize and seek other sows. Thus, we evaluated the effects litter size at cross-fostering and socialization on the sow and piglet performance during lactation. Two factors were included in a 2 × 2 factorial design: socialization and litter size relative to sow functional teat number at cross-fostering. Litters (n = 189) were then assigned to one of four groups: **CONT+0** (litters not co-mingled with no additional piglet), **CONT+1** (not co-mingled with one additional piglet), **Co-M+0** (co-mingled with no additional piglet), **Co-M+1** (co-mingled with one additional piglet). Piglets were cross-fostered from 12–16 h after birth, and 24 h later, Co-M groups were socialized by removing the barrier between two adjacent pens. During lactation, sows lost more caliper units in the + 1 group than in the + 0 group (P = 0.04). The number of functional teats did not differ among groups, but Co-M sows had a higher udder lesion score at weaning than CONT (6.55 vs 4.83; P < 0.01). Furthermore, +1 sows had fewer vacant teats throughout lactation (P < 0.01). Milk yield did not differ among the groups ($P \geq 0.13$). Regarding the number of weaned piglets, no difference was observed for socialization (P = 0.84), but + 1 sows weaned 0.67 more piglets than + 0 (P < 0.01). Although CONT+0 had the heaviest piglets at weaning (P < 0.01), litter weight did not differ among the groups ($P \geq 0.08$). Facial and joint lesions were frequently observed in Co-M (P < 0.01) than CONT. Piglet loss rate did not differ among treatments (overall rate = 12.6%; $P \geq 0.26$). The removal rate, however, was more frequent in + 1 litters than in + 0 (P < 0.01). Death due to starvation was higher in CONT+1 than CONT+0 (P < 0.01) but did not differ between the Co-M groups (P = 0.99). Litters formed with one additional piglet relative to functional teat number weaned more piglets, albeit with lower individual weight. Litter socialization may alleviate the impact of high litter size but shows greater percentages of udder injuries and facial and joint lesions in weaned piglets.

Implications

With hyperprolificity, the number of piglets born alive commonly exceeds the functional teats. This study demonstrates that it is possible to wean piglets exceeding the number of functional teats. Cross-fostering with one additional piglet, however, can lead to increased piglet lesions and reduced piglet weaning weight, but with similar litter weight. Co-mingling the litters reduced some negative results, such as lesion occurrence and starvation in litter with surplus piglets.

Introduction

Piglet survival and growth performance during the suckling phase are crucial for the productivity of modern hyperprolific genotypes. Cross-fostering is a practice that equalizes the number of piglets according to weight (Bierhals et al., 2012), sow parity (Bierhals et al., 2011), and the number of functional teats (Vande Pol et al., 2021). It is performed within 24 h after farrowing, ensuring colostrum intake, and before, the teat order is established (McBride, 1963). Despite being a common management, there is no recommended standard protocol for commercial farms. Most studies involve litters ranging from 6 to 13 piglets (Neal and Irvin, 1991; North and Stewart, 2000; Giroux et al., 2011; Heim et al., 2012), far from the litter size achieved with contemporary hyperprolific sows. Furthermore, larger litters bring some chal-

* Corresponding author.
E-mail address: ana.mellagi@ufrgs.br (A.P.G. Mellagi).

https://doi.org/10.1016/j.animal.2024.101247
1751-7311/

lenges, such as intense lactational catabolism, greater competition among piglets for udder access, and reduced availability of milk for each piglet, factors that can increase preweaning mortality and compromise animal welfare (Bortolozzo et al., 2023). In contrast to the large litter size, modern sows have, on average, 13.9 functional teats (Earnhardt and Knauer, 2019), resulting in litters formed by more piglets than functional teats. Using nurse sows or performing artificial supplementation are, thus, strategies to mitigate the poor piglet access to nutrients in hyperprolific herds (Kirkden et al., 2013; Baxter et al., 2020). Some limitations of these practices include high costs, high labor intensity, and increased disease transmission among suckling piglets (Schmitt et al., 2019; Garrido-Mantilla et al., 2021).

Recently, Vande Pol et al. (2021) evaluated litters cross-fostered with two piglets in addition to the number of functional teats, and despite the higher mortality of this treatment, 0.7 more piglets were weaned than the cross-fostering group with the same number of piglets and teats. Increasing litter size may also impact udder integrity and sow body condition score at weaning. Nursing failures due to teat fights or low milk production can compromise adequate piglet growth. Preweaning piglet socialization by co-mingling the litters is performed by removing the barrier between two (D'Eath, 2005; Salazar et al., 2018) or more pens before weaning (Wattanakul et al., 1997; Hessel et al., 2006), providing the piglets with free access to this space (Salazar et al., 2018; Guzmán-Pino et al., 2021), and would be a strategy to compensate for nursing failures in large litters. Some studies have reported that early socialized piglets are less aggressive, can rapidly form stable dominance hierarchies, and have a higher growth rate after weaning (D'Eath, 2005; Kutzer et al., 2009; Salazar et al., 2018). Socialization may allow piglets to access other sows, providing more access to functional teats and increasing suckling performance.

Therefore, given the challenges of the production system for the survival of large litters, the objective of the current study was to investigate the effects of early socialization and cross-fostering according to the number of functional teats regarding sow traits and the performance of their litters. We hypothesized that (i) cross-fostering can be performed with an additional piglet regarding the number of functional teats, with satisfactory sow and litter performances, (ii) co-mingling the litters can be used in combination to increased litter size to expand the possibility of access to functional teats, improving piglet performance and survival during the suckling period.

Material and methods

The study was conducted on a breeding-to-weaning farm with a population of 6 000 sows, in the north of Santa Catarina State, Southern Brazil.

Housing, animals, and management

On day 113 of gestation, sows were moved to farrowing rooms and individually housed in crates 2.3 m long × 1.8 m wide in the acclimatized farrowing room with an adiabatic evaporative cooling system. Sows were fed a standard lactation diet based on corn and soy (3 370 Mcal ME per kg, 17.8% CP, and 1.1% digestible lysine) according to the farm protocol: 2 kg/d from housing until farrowing, and sows were fed *ad libitum* during lactation. Water was provided *ad libitum* throughout the entire period.

Farrowing was assisted, and immediately after birth, piglets were dried, and their umbilical cord was clamped. On average, the number of total born was 16.0 ± 0.2 (SD) piglets (7–28 piglets) and the number of born alive was 15.2 ± 0.2 piglets (7–23 piglets). After these procedures, they were moved close to the sow teats to ensure colostrum intake. Tail-docking and iron dextran glucoheptonate IM injection (MS FerroSafe, MS Schippers) were performed at 3 days of age. Piglets did not receive creep feeding during the lactation period and were not subjected to tooth resection.

Experimental design

This study used 189 sows/litters (Landrace × Large White – PIC Camborough, Hendersonville, TN, USA) and was carried out from the day of cross-fostering (12–16 h after farrowing) to 20 days of piglet age. Sows were selected on the day of farrowing according to the following characteristics: Body condition score (**BCS**) (2–3; Young et al., 2004), caliper units (5–15, within a 1–25 scale; Knauer and Baitinger, 2015), parity (2–7), teat functionality score (1 or 2; Vande Pol et al., 2021), and the number of functional teats (14 or 15 teats). Caliper measures quantified the angularity from the spinous process to the transverse process of a sow's back (Knauer and Baitinger, 2015). The sows were equally distributed to the treatments according to parity, caliper units, and BCS.

Four groups were evaluated: **CONT+0** (n = 43), with the same number of piglets and functional teats available; **CONT+1** (n = 46), with one piglet more than the number of functional teats available; **Co-M+0** (n = 48), with the same number of piglets and functional teats available in two socialized litters (co-mingling); **C0-M+1** (n = 52), with one piglet more than the number of functional teats available in two socialized litters. Therefore, a 2 × 2 factorial was obtained, evaluating two classes of litter size (**LS**): with the same number of piglets and functional teats - +0 – or one additional piglet than the number of functional teats - +1 and two classes of socialization (**SOC**): litters that were co-mingled - **Co-M** – or not co-mingled - **CONT**. All piglets were adopted, and there were no more than four littermates, with similar proportions among sex, piglet weight (1.2–1.5 kg), and the within-litter CV at a maximum of 10%. Socialization was performed 24 h after cross-fostering by removing the physical barrier between two adjacent litters. Only piglets had free access between pens. Sows from adjacent pens had the same number of functional teats and similar parities.

Experimental procedures

Regarding sow body condition, the BCS, caliper units, and backfat thickness (**BT**) were evaluated on D0 (at cross-fostering) and D20 (at weaning) of lactation. Backfat thickness was determined by a single technician on the P2 position using ultrasound equipment with a linear transducer frequency of 3.5–5 Mhz (Sonoscape®, A6V, Co. Ltda, Shenzhen, China).

The numbers of functional teats and udder lesions were evaluated at D0, D5, and D20. Udder lesions were scored as follows: 0 – no wounding; 1 – one or two superficial scratches not penetrating the full derma thickness; 2 – more than three superficial scratches; 3 – superficial scratches and less than three deeper wounds; 4: superficial scratches and more than three deeper wounds; 5 – deep and large wounds (laceration); 6 – deep and infected wounds (Gallois et al., 2005), for each udder section, anterior (first two pairs of teats), middle (three or four central teat pairs), and posterior (last two pairs of teats). The overall lesion score was the sum of scores of all regions. The difference between the number of piglet and functional teat on D0 was calculated, and when negative, it was defined as vacant teat. The milk yield was calculated from litter weight and growth rate following the equations from Noblet and Etienne (1989):

$$\text{Estimation for D0 to D5 (kilograms/day/piglet)} = (2.64 \times \text{ADG}) + 67$$

$$\text{Estimation for D5 to D20 (kilograms/day/piglet)} = (1.83 \times \text{ADG}) + (72.9 \times \text{piglet BW}_{\text{D5}}) + 176.$$

The results of these equations were multiplied by the number of piglets for each day.

Piglets were individually weighed (with a 10-g-precision digital scale) and visually evaluated for face, body, and joint injuries on D0, D5, and D20. Face and body injuries were scored according to severity (Camerlink et al., 2018), in which 0 – no injuries, 1 – minor scratches, and 3 – large patches of merged lesions. Moreover, the score of all joint injuries was classified according to Kilbride et al. (2009) from 0 to 3, as follows: 0 – no lesion; 1 – < 25% of the joint/dermis injured; 2 – 25%–50% of the joint/dermis injured; 3 – > 50% of the joint/dermis injured.

Piglets that had died within 24 h after cross-fostering were replaced with piglets of the same sex, age, and weight. This management ensured that litter size remained the same at the time of barrier removal. All animals were checked daily. During lactation, piglets with low viability, severe injuries, or fallback piglets were removed from the study and placed in another sow. Mortality was recorded daily, and a necropsy was performed to identify the cause of death.

Statistical analysis

The statistical analyses were performed using the Statistical Analysis System software, version 9.4 (SAS® Inst. Inc., Cary, NC). Data are expressed as least squares means (LSmeans) ± SEM in the text, whereas RMSE is used in Tables. The models included socialization (CONT and SOC), litter size (+ 0 and + 1), and their interaction as fixed effects. Week of selection was included as random effect. The Tukey–Kramer test was used for multiple comparisons, and differences were considered significant at $P \leq 0.05$. Effect size for the significant effect of the fixed factors is reported using Cohen's *d* or odds ratio indices, depending on the variable (Sullivan and Feinn, 2012). The sow (and her litter) was considered an experimental unit. When significant, the number of functional teats at cross-fostering was included as a covariate in the models.

Generalized linear mixed models (GLIMMIX procedure) were employed to accommodate normal or non-normal response variable distributions. For maternal body condition at weaning, values on D0 were used as covariates. Analyses of sow BCS, BCS change during lactation, udder lesion scores, and piglet lesion scores were performed considering a multinomial ordinal distribution using a logistic regression model (GLIMMIX procedure). The percentages of loss of piglet (mortality and removal), piglets with injuries (facial, body, and locomotor), and causes of death were analyzed using the GLIMMIX procedure fitted assuming a binomial distribution. The within-litter CV was fitted as beta distribution. The other variables were analyzed assuming a normal distribution after checking the residual assumptions, using standard diagnostics on residual plot patterns. Repeated measure models were used for milk production, individual piglet weight, litter weight, and within-litter CV considering socialization, litter size, time (D5 and D20), and their interactions as fixed effects.

Results

There were no differences in sow characteristics among the groups ($P \geq 0.14$) for parity (3.8 ± 0.1), body condition score (2.9 ± 0.03), caliper unit (10.3 ± 0.2), backfat thickness (11.5 ± 0.2), and the number of functional teats (14.60 ± 0.04), validating the randomization process. Litter size after cross-fostering was 14.6 ± 0.01 for + 0 groups and 15.6 ± 0.01 for + 1 groups (Cohen's $d = 1.65$; $P < 0.01$), whereas no difference ($P = 0.94$) was observed between CONT and Co-M groups (15.09 ± 0.01 piglets).

Sow body condition, udder traits, milk production and number of piglets

There was no effect of socialization, litter size, or their interaction for sow BCS and backfat thickness at weaning ($P > 0.15$; Table 1). However, sows from the + 1 group slightly lost more caliper units during lactation ($d = 0.25$; $P = 0.04$) and, thus, showed lower caliper unit values than + 0 sows ($d = 0.20$; $P = 0.04$).

On D5, the number of functional teats was not affected by socialization, litter size, or their interaction ($P \geq 0.10$; Table 2). Whilst an interaction ($P = 0.05$) between socialization and litter size was found for the number of functional teats at weaning (D20), multiple comparisons using the Tukey–Kramer test showed no differences among treatments ($P \geq 0.13$). There was no effect of socialization ($P \geq 0.19$) and the 2-way interaction ($P \geq 0.11$) for the difference between the number of piglets per teat. Conversely, litters with one additional piglet showed less vacant teats at all time points than + 0 litters ($P < 0.01$; Fig. 1).

Regarding the udder lesions on D5 (Table 2), there was no difference among the treatments ($P \geq 0.18$); at weaning, however, Co-M sows showed a higher score of udder lesions than CONT sows ($d = 0.41$; $P = 0.01$). No significant effects of litter size or the interaction between socialization and litter size were observed for udder lesion score. No significant effects of socialization, litter size, or their interaction were found in the distribution of animals with different scores of lesions (Supplementary Figure S1) in anterior, middle, or posterior regions ($P \geq 0.12$) on D5. On D20, however, socialization influenced the distribution of udder lesion scores, where Co-M sows showed a higher *P* of having more serious injuries in the anterior (OR = 3.23; $P < 0.01$) and middle (OR = 2.31; $P < 0.01$) regions than CONT sows. No fixed effect influenced the lesions in the posterior udder region on D20 ($P > 0.07$).

On D5, the number of suckling piglets was greater (+0.30 piglet) in the Co-M compared to the CONT group ($d = 0.43$; $P < 0.01$) and in the + 1 compared to the + 0 litters (+0.87 piglet; $d = 0.85$; $P < 0.01$), as shown in Table 2. No significant interaction between socialization and litter size was found in the number of piglets on D5 ($P = 0.82$) and D20 ($P = 0.40$). On D20, +1 sows weaned 0.67 more piglets than + 0 ($d = 0.43$; $P < 0.01$), with no effect of socialization ($P = 0.84$).

Milk production (Table 3) was affected by socialization × litter size interaction ($P = 0.02$). After the Tukey-Kramer test, however, no significant differences were observed within each factor ($P \geq 0.13$). The litter size × time interaction was also observed ($P = 0.04$) for milk production. Nevertheless, both + 0 and + 1 groups were similar within each time point ($P \geq 0.43$), while D5 and D20 were different in both litter size groups ($P < 0.01$).

Piglet growth performance

Piglet weight was significantly affected by the interaction between socialization and litter size ($P = 0.01$; Table 3). Within Co-M group, litter size did not influence piglet weight (3.77 vs 3.74 kg, for + 0 and + 1, respectively; $P = 0.98$); while in CONT, piglets from + 0 were heavier than + 1 (4.04 vs 3.75 kg, respectively; $d = 0.16$; $P < 0.01$). In + 0 group, CONT piglets were heavier than in Co-M (4.04 vs 3.77; $d = 0.15$; $P < 0.01$), but no effect of socialization was observed in + 1 piglets ($P < 0.99$). Although piglet weight was also influenced by socialization × time interaction ($P = 0.03$), the multiple comparison (Tukey-Kramer test) showed that both Co-M and CONT groups were similar within each time point ($P = 0.15$ and $P = 0.06$; for D5 and D20, respectively), while D5 and D20 were different in both socialization groups ($P < 0.01$).

Table 1
Effect of early socialization (SOC) and litter size (LS) on body characteristics of sows on D20 (at weaning) and change of body condition during lactation.

Variables	SOC		LS		RMSE	*P*-value		
	Co-M (n = 100)	CONT (n = 89)	+0 (n = 91)	+1 (n = 98)		SOC	LS	SOC×LS
BCS	2.78	2.73	2.80	2.72	0.34	0.16	0.50	0.32
Caliper	9.96	9.70	10.09	9.57	2.07	0.32	0.04	0.39
BT, mm	10.97	10.90	11.11	10.76	2.27	0.76	0.16	0.32
BCS change	−0.07	−0.16	−0.10	−0.12	0.36	0.16	0.45	0.32
Caliper unit change	−0.32	−0.58	−0.19	−0.71	1.76	0.32	0.04	0.39
BT change, mm	−0.48	−0.55	−0.34	−0.69	1.73	0.76	0.16	0.32

Values: least square means and RMSE.
Abbreviations: Co-M: co-mingled litter at D2; CONT: non-co-mingling litter; +0: litters with no additional piglet to the number of functional teats on D0; +1: litters with one additional piglet to the number of functional teats on D0; BCS: body conditional score; BT: backfat thickness.

Table 2
Effect of early socialization (SOC) and litter size (LS) on the number of functional teats, score of sow udder lesions, and numbers of suckling piglets during lactation on D0 (at cross-fostering), D5 (day 5), and D20 (at weaning).

Variables	SOC		LS		RMSE	*P*-value		
	Co-M (n = 100)	CONT (n = 89)	+0 (n = 91)	+1 (n = 98)		SOC	LS	SOC×LS
Functional teats								
D5	13.86	14.04	13.92	13.98	1.01	0.19	0.66	0.10
D20	12.63	12.94	12.72	12.85	1.39	0.25	0.62	0.05[1]
Udder lesion score								
D5	3.30	2.64	2.83	3.11	3.33	0.18	0.54	0.23
D20	6.55	4.83	5.44	5.94	4.57	0.01	0.44	0.42
Number of piglets								
D0	15.12	15.12	14.60	15.61	0.10	0.94	<0.01	0.79
D5	14.79	14.49	14.21	15.08	0.79	<0.01	<0.01	0.82
D20	13.72	13.68	13.36	14.03	1.29	0.84	<0.01	0.40

Values: least square means and RMSE.
Abbreviations: Co-M: co-mingled litter at D2; CONT: non-co-mingling litter; +0: litters with no additional piglet to the number of functional teats on D0; +1: litters with one additional piglet to the number of functional teats on D0.
[1] Despite the significant interaction, comparisons of means (Tukey-Kramer) within each factor revealed no differences ($P \geq 0.13$).

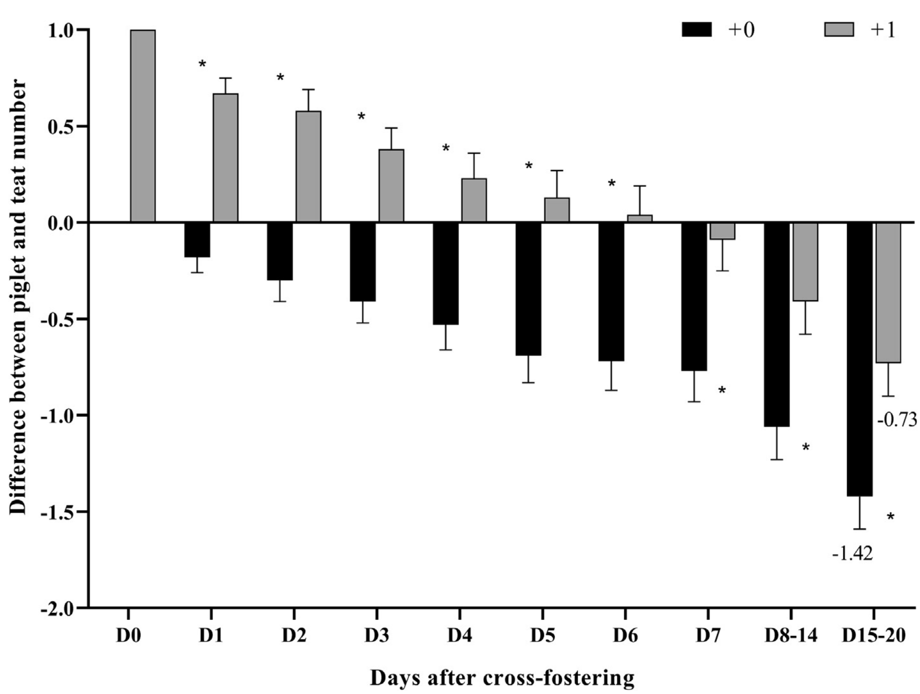

Fig. 1. Differences between piglet and teat number during lactation, according to litter size. Values were calculated based on the teat number at D0. Values are presented as means ± SEM. Cohen's d = 1.48, 1.31, 1.02, 0.91, 0.88, 0.77, 0.64, 0.54, and 0.50 for D1, D2, D3, D4, D5, D6, D7, D8-14 and D15-20, respectively. +0 = litters with no additional piglet to the number of functional teats on D0; +1 = litters with one additional piglet to the number of functional teats on D0. * indicates a significant difference between + 0 and + 1 groups ($P < 0.01$). Socialization and interaction between socialization and litter size were not significant at any time point ($P \geq 0.19$ and $P \geq 0.11$, respectively).

Table 3
Effect of socialization (SOC), litter size (LS) and time (T) on milk production, and piglet and litter weight, analyzed as repeated measures.

Variables	Co-M		CONT		RMSE	*P*-value						
	+0 (n = 48)	+1 (n = 52)	+0 (n = 43)	+1 (n = 46)		SOC	LS	T	SOC×LS	SOC×T	LS×T	SOC×LS×T
Milk production, kg/day						0.37	0.63	<0.01	0.02[1]	0.52	0.04[2]	0.35
D0 to D5	6.20	6.38	6.77	5.99	1.37							
D5 to D20	9.06	9.48	9.57	9.43	1.36							
Piglet weight, kg						<0.01	<0.01	<0.01	0.01	0.03	0.06	0.12
D5	2.06	2.04	2.19	2.03	0.16							
D20	5.48	5.44	5.90	5.47	0.60							
Litter weight, kg						0.19	0.97	<0.01	0.03[3]	0.08	0.81	0.09
D5	29.88	30.91	30.78	30.00	2.83							
D20	73.54	76.57	79.22	75.78	10.85							

Values: least square means and RMSE.
Abbreviations: Co-M: co-mingled litter; CONT: non-co-mingling litter; +0: litters with no additional piglet to the number of functional teats on D0; +1: litters with one additional piglet to the number of functional teats on D0. D0 (at cross-fostering), D5 (day 5), and D20 (at weaning).
[1] Despite the significant interaction, comparisons of means (Tukey-Kramer) within each factor revealed no differences for piglet weight ($P \geq 0.13$);
[2] Despite the significant interaction, both LS groups were similar within each time point, while D5 and D20 were different in both LS groups ($P < 0.05$).
[3] Despite the significant interaction, comparisons of means (Tukey-Kramer) within each factor revealed no differences for litter weight ($P \geq 0.08$);

Litter weight was also affected by the interaction between socialization and litter size ($P = 0.03$; Table 3). The multiple comparisons with Tukey-Kramer test, however, revealed no significant differences within each factor for litter weight ($P \geq 0.08$).

The within-litter variation (CV) during lactation was not affected by socialization ($P = 0.28$) but by litter size ($P < 0.01$) and time ($P < 0.01$). Within-litter CV was higher in + 1 than + 0 litters (16.3 ± 0.4% vs 14.3 ± 0.4%; $d = 0.38$) and on D20, compared to D5 (18.3 ± 0.4 vs 12.3 ± 0.2%; $d = 1.30$).

Piglet mortality

Regarding the piglet loss rate (dead and removed piglets), there were no effects of socialization ($P = 0.82$) or litter size ($P = 0.26$) or their interaction ($P = 0.92$). The removal rate was higher for the + 1 compared to the + 0 group (3.4 ± 0.5 vs 1.6 ± 0.4%, respectively; OR = 2.13; $P < 0.01$), with no significant effect of litter socialization ($P = 0.37$) or the 2-way interaction ($P = 0.28$). The general mortality rate was 8.4%, with no effect evidenced for any fixed factor ($P \geq 0.64$). Crushing corresponded to 49.5% of the mortality, followed by starvation (37.8%) and other reasons (12.8%). Treatment effect for each reason is shown in Supplementary Figure S2. An interaction between socialization and litter size showed that within the CONT group, the litter + 1 group had an increased mortality due to starvation, compared to + 0 (OR = 3.92; $P < 0.01$). Contrarily, adding the extra piglet to the Co-M group did not compromise mortality for this cause ($P = 0.99$).

Piglet lesions

On D5, a significant 2-way interaction was observed for the occurrence of facial lesions (Table 4), where within + 1 groups, CONT and Co-M piglets did not differ (49.0 ± 1.9 vs 50.5 ± 1.8%; P=0.94). In + 0 groups, higher occurrence of face lesions (OR = 1.78; $P < 0.01$) was observed in Co-M (47.7 ± 1.9%) compared to CONT (33.8 ± 1.9%). In Co-M groups, litter size was not significant ($P = 0.94$), while within CONT, + 1 litters showed more facial lesions than + 0 piglets (OR=1.88; $P < 0.01$).

A greater proportion of piglets displaying body scratches (Table 4) was observed in CONT compared to the Co-M group (OR = 1.60; $P < 0.01$) and in + 1 litters compared to + 0 litters (OR = 1.42; $P = 0.05$). A higher occurrence of joint injuries (Table 4) was observed in Co-M litters than in CONT litters (OR = 1.40; $P < 0.01$) and in litters with one additional piglet compared to no surplus piglet (OR = 1.22; $P = 0.03$). The socialization × litter size interaction did not influence body ($P = 0.43$) and joint lesions ($P = 0.98$).

At weaning, the Co-M litters had more piglets with facial (OR = 1.65; $P < 0.01$); and joint lesions (OR=1.64; $P < 0.01$), compared to the CONT group (Table 4). Body lesion occurrence was not affected by the fixed effects ($P \geq 0.06$). Litter size did not affect the occurrence of lesions at weaning ($P \geq 0.14$). The score of all lesions is depicted in Supplementary Table S1.

Discussion

The number of functional teats did not show the same genetic improvement as that observed in the number of piglets born alive. In highly prolific herds, producers face the challenge of more piglets born alive than functional teat availability. When there is limitation to use females as nurse sows, producers must be aware of the benefits but also limitations of the number of piglets exceeding the functional teats. Our findings illustrate the benefits and disadvantages of using cross-fostering and co-mingling at an early age.

Implication for sows

Cross-fostering is generally performed based on the number of functional teats, i.e., by placing the same number of piglets in relation to the number of available teats. Nonetheless, preweaning mortality is concentrated during the first 3 days of life (Panzardi et al., 2013), and some teats are eventually not stimulated. In this study, we observed that, although the number of functional teats did not differ among sows, sows with an additional piglet had fewer vacant functional teats, and even at weaning, they showed 0.69 fewer vacant teats than + 0 sows. Interestingly, the proportion of piglets per functional teat was positive until D7 in + 1 sows, demonstrating that teat use was greater throughout lactation. Recently, Arend et al. (2023) observed 1.8 more functional teats at weaning in sows with 15–16 piglets compared to those with 12 piglets (two vacant teats), even though both groups lost 2.2 teats during lactation, but with different teat numbers at lactation onset (15.8 and 14.0 teats, respectively).

Aggressive competition for udder access may produce lesions and discomfort to the sow and, depending on the severity, compromise her longevity. Udder lesions were not affected by the main factors in early lactation, but co-mingling litters, on the other hand, resulted in more severe lesions in the anterior and middle portions of udders at weaning. In a previous report, a greater score of teat lesions was also found in sows with socialized litters (performed

Table 4
Effect of piglet early socialization (SOC) and litter size (LS) on the percentages of occurrence of face, body, and joint lesions in piglets on D5 (day 5) and D20 (at weaning).

Variables	SOC		LS		RMSE	*P*-value		
	Co-M (n = 100)	CONT (n = 89)	+0 (n = 91)	+1 (n = 98)		SOC	LS	SOC×LS
D5								
Face	49.10	41.19	40.58	49.74	24.94	<0.01	<0.01	<0.01
Body	4.13	6.43	4.37	6.09	11.06	<0.01	0.05	0.43
Joint	28.87	22.45	23.70	27.45	18.20	<0.01	0.03	0.98
D20								
Face	34.29	24.03	27.56	30.25	29.25	<0.01	0.14	0.19
Body	35.26	38.87	35.98	38.13	1.40	0.06	0.26	0.13
Joint	19.15	12.61	15.91	15.30	16.07	<0.01	0.68	0.32

Values: least square means and RMSE. Data were analyzed as binomial distribution.
Abbreviations: Co-M: co-mingled litter; CONT: non-co-mingling litter; +0: litters with no additional piglet to the number of functional teats on D0; +1: litters with one additional piglet to the number of functional teats on D0. The SOC×LS interaction for facial lesions on D5 is described in the text.

on day 14 of lactation; Camerlink et al., 2018). However, van Kerschaver et al. (2021) reported that injuries at the udder and teats were not affected by three litters co-mingled at days 16, 11, or 6 before weaning. In co-mingled litter with biological piglets at D2, it was observed that 99% of the piglets suckled in their own mother (Guzmán-Pino et al., 2021). As only adopted piglets were used in the present study, the udder integrity should be more explored in further studies to investigate if the origin of the piglets plays an important role in udder lesions. Olsen et al. (1998) describe that in multisuckling systems, it may be important to use sows with a high milk yield because the piglets compensate for a sow's lower milk yield by suckling another sow. In our study, milk yield from D0–D5 and from D5-20 were not affected by socialization or litter size. Interestingly, one additional piglet in the litter did not trigger more mammary lesions in the sow.

Litter size and socialization did not influence sow BCS and BT, but we observed a slightly higher caliper unit loss (0.53 caliper units) in sows with one additional piglet. In another study, socialization did not affect BT and weight in individuals of conventional crates (van Kerschaver et al., 2021). However, studies that evaluated the body condition of females grouped in multisuckling systems observed a more significant loss of BW in sows that were socialized 2 weeks after farrowing compared to those that were socialized 1 and 3 weeks after farrowing, with no difference in BT loss (Thomsson et al., 2018). Studies on body reserve mobilization in sows with surplus piglets are scarce. Nevertheless, the effect of nurse litter size on body reserve mobilization is well established. In another study, primiparous sows fully stimulated (15–16 piglets with a minimum of 15 teats) lost more body reserves during lactation than females with 12 piglets and 14 functional teats (Arend et al., 2023). In the present study, primiparous sows were not included; thus, further studies are needed to verify if a higher BW loss can be found in young sows fostering surplus piglets. Besides, the maternal condition score at weaning was evaluated at D20. In scenarios with extended lactation, sows might experience higher mobilization with increased litter size. Interestingly, Kobek-Kjeldager et al. (2020) did not observe difference in sow weight loss and feed intake in a 28d-lactation in females nursing 14 or 17 piglets.

The number of weaned piglets per sow is an important productive indicator of herd management. As observed in the present study, Wattanakul et al. (1997) also found no difference between the number of weaned piglets in co-mingling (14 days of life) and control groups. Similarly, Hultén et al. (1995) also found no effect of co-mingling the litter (2–3 weeks after farrowing) on the number of weaned piglets. However, the number of weaned piglets was greater in the + 1 group, weaning 0.69 more piglets than in the + 0 treatment. Similar findings were found in litters with two more piglets than the number of functional teats, although the 0.7 more piglet group did not differ significantly from the control (Vande Pol et al., 2021). Kobek-Kjeldager et al. (2020) compared litters with the same numbers of functional teats and piglets (14 piglets) and litters with more piglets than functional teats (17 piglets), and the treatment with additional piglets weaned approximately one more piglet.

Implications for piglets

Piglet lesions are common since they compete for suckling and form the litter hierarchy (Fraser, 1975; De Passille and Rushen, 1989). Face injuries and joint abrasion are believed to occur during suckling episodes. Whilst face lesions may result from teat dispute (Fraser, 1975), joint abrasion comes from repeated rubbing on the floor (Mouttotou et al., 1999). These findings illustrate more competition in large litter for an available teat. In the present study, more low-severity lesions were observed in the piglet face, along with scratches on the body and joint abrasion. Litter size had a significant effect on lesion occurrence in D5 but had low importance at weaning, possibly due to the ratio between piglet and teat, i.e., the proportion of piglets per teat was lower from D7 onwards, reducing competition. In this trial, piglets were not subjected to tooth resection, which may favor facial lesion incidence (Gallois et al., 2005).

Interestingly, however, even with the mixture taking place at the beginning of lactation, the effect of socialization on lesion occurrence persisted until weaning. This aggressive behavior seems to be important for piglet socialization after weaning. Camerlink et al. (2018) reported a greater increase in skin lesions in socialized (day 14) than in control piglets, with no difference in face and joint lesions. Interestingly, after weaning (26 days of age), pigs were kept in their original groups and regrouped at 8 weeks of age, when socialized pigs had 19% fewer skin lesions than the control group. Indeed, positive behavioral responses at weaning have been shown in socialized piglets at 10 or 12 days of age (Hessel et al., 2006; Morgan et al., 2014). Irrespective of the time of socialization (7 days or 14 days of life), Salazar et al. (2018) suggested that mixed piglets showed more aggressive and play behaviors than control piglets; however, the number of skin lesions indicated that co-mingled piglets were involved in less fights. In the present study, the number of body scratches was marginally lower in Co-M litters than in CONT litters. To the best of our knowledge, this is the first study involving litter co-mingling at 48 h of life with adopted piglets, and the piglet had a few hours to be familiar before mixing. Thus, more studies need to be carried out involving biological piglets, different co-mingling times, and an increased number of litters to be mixed to determine the effects on piglet behavior and the incidence of skin injuries.

Vasdal and Andersen (2012) showed a lower piglet mortality when there were fewer piglets per teat in a litter. Similarly, three additional piglets resulted in a greater mortality risk, but access to a milk replacer mitigated the mortality of supernumerary litters (Kobek-Kjeldager et al., 2020). In our study, although the piglet loss rate was similar among the groups, +1 groups showed higher removal rates and starvation, mainly in not co-mingled litters (CONT). These causes are associated since the most common reason for removal was falling behind. Thus, raising more piglets per teat seemed to interfere with milk access, but this effect can be alleviated by co-mingling the litters. It is important to emphasize that the piglet had no access to a creep feeding, as standard protocol of the farm. Creep feeding could be considered in future studies using extra numerary litters to increase the options for nutrient intake.

The major causes of mortality in the present study were crushing and starvation, with no difference between treatments LS or SOC. These causes are the main causes of death reported in the suckling period (Muns et al., 2016). In a recent study, crushing and starvation did not significantly differ in litters with two additional piglets compared to the control (Vande Pol et al., 2021). Mortality also did not differ in co-mingled litters from other studies (Wattanakul et al., 1997; van Kerschaver et al., 2021). According to van Nieuwamerongen et al. (2015), co-mingling litters can reduce mortality when the producer improves the management practice. Li et al. (2009) evaluated data from 5 years of production and observed a reduction in preweaning mortality over the years in a group housing system, attributed to improved management practices, as avoiding heat stress, increasing young sow proportion in the herd, and removing sows showing elevated preweaning mortality.

Litter weight and CV at weaning were not influenced by litter size; however, the higher individual weight observed in CONT+0 may be due to the low competition for teats, with higher milk intake and fewer nursing failures, reflecting the impact on an individual basis. Litter weight, however, can reflect the kg weaned/sow, an interesting economic indicator that assesses productivity on a herd basis. Similarly, litter and piglet weight did not differ among the groups with two piglets less, control, or two piglets more than the teat number in the study by Vande Pol et al. (2021). Interestingly, when a milk replacer was used, supernumerary groups showed improved litter and individual weight (Kobek-Kjeldager et al., 2020). Thus, combining other tools with rearing extra piglets might be beneficial for hyperprolific herds.

Co-mingling the piglets did not affect piglet weight, within-litter CV, and litter weight during lactation. A lack of effect on piglet growth was also observed in socialized litters at 10 days (Morgan et al., 2014) or 14 days of age (Camerlink et al., 2018). Piglets co-mingled at 7 or 14 days of age showed a lower growth rate compared to control piglets during lactation, but with no difference after weaning (Salazar et al., 2018). The authors suggested that the greater overall activity observed in socialized piglets resulted in a lower growth performance. Although we did not follow the piglets after weaning, a previous study showed a better performance of co-mingled piglets in the postweaning phase (Hessel et al., 2006), probably due to high feed intake (van Nieuwamerongen et al., 2015).

To develop a full picture of co-mingling litters and the increased number of piglets per teat, additional studies are needed, including prolonged lactation period, primiparous sows and increasing the number of extra piglets. Further research might explore co-mingling litters at different ages, using biological piglets, primiparous sows, and increasing the number of extra piglets. Although some promising results and limitations were found, several questions remain to be answered. More information regarding these practices is needed to maximize sow and litter pre- and postweaning performance. With more information, economical approaches can be drawn for several scenarios.

In conclusion, this study shows that litters with one additional piglet allowed sows to have less vacant teats without highly compromising sow body condition at weaning. Besides, these sows weaned 0.67 more piglets. However, piglet growth and weaning weight were reduced, and the number of lesions was increased in both piglets and sows. Mortality was not affected by treatments, but litters with one additional piglet showed a greater proportion of starvation and removal rates. Despite that, co-mingling the litters alleviated some of these results, such as lesion occurrence in piglets on day 5 and starvation in + 1 groups.

Supplementary material

Supplementary material to this article can be found online at https://doi.org/10.1016/j.animal.2024.101247.

Ethics approval

All management and procedures for this study were approved by the CEUA – Ethical Committee of Animal Utilization/UFRGS (Federal University of Rio Grande do Sul), Process Number 42824.

Data and model availability statement

None of the data were deposited in an official repository. The data and models that support the study findings are available from the authors upon request.

Declaration of Generative AI and AI-assisted technologies in the writing process

During the preparation of this work the author(s) did not use any AI and AI-assisted technologies.

Author ORCIDs

Gabriela Piovesan Zanin: https://orcid.org/0009-0009-1553-0147.
Laura dos Santos: https://orcid.org/0009-0001-8965-7425.
Dalila Tomm: https://orcid.org/0009-0004-2805-6396.
Danielle Fermo Silveira: https://orcid.org/0009-0008-0046-8937.
Fernando Pandolfo Bortolozzo: https://orcid.org/0000-0001-5302-328X.
Rafael da Rosa Ulguim: https://orcid.org/0000-0002-7210-1607.
Ana Paula Gonçalves Mellagi: https://orcid.org/0000-0002-0296-5637.

CRediT authorship contribution statement

G.P. Zanin: Writing – original draft, Methodology, Investigation, Formal analysis, Conceptualization. **L. Santos:** Investigation, Data curation. **D.M.S. Tomm:** Investigation, Data curation. **D.F. Silveira:** Investigation, Data curation. **F.P. Bortolozzo:** Writing – review & editing, Methodology, Investigation, Conceptualization. **R.R. Ulguim:** Writing – review & editing, Methodology, Conceptualization. **A.P.G. Mellagi:** Writing – review & editing, Supervision, Methodology, Formal analysis, Conceptualization.

Declaration of interest

The authors declare no conflicts of interest.

Acknowledgments

This study was financed in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior - Brasil (CAPES) - Finance Code 001, Brazil. Our sincere thanks to Master Agroindustrial (Papanduva, Santa Catarina, Brazil) for the partnership.

Financial support statement

This research received no specific grant from any funding agency, commercial or not-for-profit section.

References

Arend, L.S., Vinas, R.F., Silva, G.S., Lower, A.J., Connor, J.F., Knox, R.V., 2023. Effects of nursing a large litter and ovarian response to gonadotropins at weaning on subsequent fertility in first parity sows. Journal of Animal Science 101, skac39.
Baxter, E.M., Schmitt, O., Pedersen, L.J., 2020. Managing the litter from hyperprolific sows. In: Farmer, C. (Ed.), The Suckling and Weaned Piglet. Wageningen Academic Publishers, NL, pp. 71–106.
Bierhals, T., Mellagi, A.P.G., Heim, G., Bernardi, M.L., Wentz, I., Bortolozzo, F.P., 2011. Performance of litter after crossfostering of piglets between females of parity order 1 and 5. Acta Scientiae Veterinariae 39, 942.
Bierhals, T., Magnabosco, D., Ribeiro, R.R., Perin, J., da Cruz, R.A., Bernardi, M.L., Wentz, I., Bortolozzo, F.P., 2012. Influence of pig weight classification at cross-fostering on the performance of the primiparous sow and the adopted litter. Livestock Science 146, 115–122.
Bortolozzo, F.P., Zanin, G.P., Ulguim, R.R., Mellagi, A.P.G., 2023. Managing reproduction in hyperprolific sow herds. Animals 13, 1842.
Camerlink, I., Farish, M., D'eath, R.B., Arnott, G., Turner, S.P., 2018. Long term benefits on social behaviour after early life socialization of piglets. Animals 8, 192.
D'Eath, R.B., 2005. Socialising piglets before weaning improves social hierarchy formation when pigs are mixed post-weaning. Applied Animal Behaviour Science 93, 199–211.
de Passille, A.B., Rushen, J., 1989. Suckling and teat disputes by neonatal piglets. Applied Animal Behaviour Science 22, 23–38.
Earnhardt, A.L., Knauer, M., 2019. PSII-3 The genetics of functional teats in swine. Journal of Animal Science 97, 215–216.
Fraser, D., 1975. The 'teat order' of suckling pigs: II. fighting during suckling and the effects of clipping the eye teeth. The Journal of Agricultural Science 84, 393–399.
Gallois, M., Le Cozler, Y., Prunier, A., 2005. Influence of tooth resection in piglets on welfare and performance. Preventive Veterinary Medicine 69, 13–23.
Garrido-Mantilla, J., Sanhueza, J., Alvarez, J., Culhane, M.R., Davies, P., Allerson, M. W., Torremorell, M., 2021. Impact of nurse sows on influenza A virus transmission in pigs under field conditions. Preventive Veterinary Medicine 188, 105257.
Giroux, S., Robert, S., Martineau, G.P., 2011. The effects of cross-fostering on growth rate and post-weaning behavior of segregated early-weaned piglets. Canadian Journal of Animal Science 80, 533–538.
Guzmán-Pino, S.A., Luna, D., Salazar, L.C., Poblete-Grez, P., Figueroa, J., 2021. Effect of switching sows' positions during lactation on suckling behaviour and performance of co-mingling piglets. Applied Animal Behaviour Science 241, 105391.
Heim, G., Mellagi, A.P.G., Bierhals, T., Souza, L.P., Fries, H.C.C., Piuco, P., Seidel, E., Bernardi, M.L., Wentz, I., Bortolozzo, F.P., 2012. Effects of cross-fostering within 24h after birth on pre-weaning behaviour, growth performance and survival rate of biological and adopted piglets. Livestock Science 150, 121–127.
Hessel, E.F., Reiners, K., van Den Weghe, H.F.A., 2006. Socializing piglets before weaning: Effects on behavior of lactating sows, pre- and postweaning behavior, and performance of piglets. Journal of Animal Science 84, 2847–2855.
Hultén, F., Lundeheim, N., Dalin, A.M., Einarsson, S., 1995. A field study on group housing of lactating sows with special reference to sow health at weaning. Acta Veterinaria Scandinavica 36, 201–212.
Kilbride, A.L., Gillman, C.E., Ossent, P., Green, L.E., 2009. A cross sectional study of prevalence, risk factors, population attributable fractions and pathology for foot and limb lesions in preweaning piglets on commercial farms in England. BMC Veterinary Research 5, 31.
Kirkden, R.D., Broom, D.M., Andersen, I.L., 2013. Invited review: piglet mortality: management solutions. Journal of Animal Science 91, 3361–3389.
Knauer, M.T., Baitinger, D.J., 2015. The sow body condition caliper. Applied Engineering in Agriculture 31, 175–178.
Kobek-Kjeldager, C., Moustsen, V.A., Theil, P.K., Pedersen, L.J., 2020. Effect of litter size, milk replacer and housing on production results of hyper-prolific sows. Animal 14, 824–833.
Kutzer, T., Bünger, B., Kjaer, J.B., Schrader, L., 2009. Effects of early contact between non-littermate piglets and of the complexity of farrowing conditions on social behaviour and weight gain. Applied Animal Behaviour Science 121, 16–24.
Li, Y., Johnston, L., Hilbrands, A., 2009. Pre-weaning mortality of piglets in a bedded group-farrowing system. Journal of Swine Health and Production 18, 75–80.
McBride, G., 1963. The "teat order" and communication in young pigs. Animal Behaviour 11, 53–56.
Morgan, T., Pluske, J., Miller, D., Collins, T., Barnes, A.L., Wemelsfelder, F., Fleming, P. A., 2014. Socialising piglets in lactation positively affects their post-weaning behaviour. Applied Animal Behaviour Science 158, 23–33.
Mouttotou, N., Hatchell, F.M., Green, L.E., 1999. The prevalence and risk factors associated with forelimb skin abrasions and sole bruising in preweaning piglets. Preventive Veterinary Medicine 39, 231–245.
Muns, R., Nuntapaitoon, M., Tummaruk, P., 2016. Non-infectious causes of pre-weaning mortality in piglets. Livestock Science 184, 46–57.
Neal, S.M., Irvin, K.M., 1991. The effects of crossfostering pigs on survival and growth. Journal of Animal Science 69, 41–46.
Noblet, J., Etienne, M., 1989. Estimation of sow milk nutrient output. Journal of Animal Science 67, 3352–3359.
North L., Stewart A.H., 2000. The effect of mixing litters pre weaning on the performance of piglets pre and post weaning. Proceedings of the British Society of Animal Science 2000, 135–135.
Olsen, A.N.W., Dybkjær, L., Vestergaard, K.S., 1998. Cross-suckling and associated behaviour in piglets and sows. Applied Animal Behaviour Science 61, 13–24.
Panzardi, A., Bernardi, M.L., Mellagi, A.P., Bierhals, T., Bortolozzo, F.P., Wentz, I., 2013. Newborn piglet traits associated with survival and growth performance until weaning. Preventive Veterinary Medicine 110, 206–213.
Salazar, L.C., Ko, H.L., Yang, C.H., Llonch, L., Manteca, X., Camerlink, I., Llonch, P., 2018. Early socialisation as a strategy to increase piglets' social skills in intensive farming conditions. Applied Animal Behaviour Science 206, 25–31.
Schmitt, O., Baxter, E.M., Boyle, L.A., O'Driscoll, K., 2019. Nurse sow strategies in the domestic pig: I. consequences for selected measures of sow welfare. Animal 13, 580–589.
Sullivan, G.M., Feinn, R., 2012. Using effect size or why the P value is not enough. Journal of Graduate Medical Education 4, 279–282.
Thomsson, O., Magnusson, U., Bergqvist, A.S., Eliasson-Selling, L., Sjunnesson, Y.C.B., 2018. Sow performance in multi-suckling pens with different management routines. Acta Veterinaria Scandinavica 60, 1–5.
van Kerschaver, C., Vandaele, M., Degroote, J., van Tichelen, K., Fremaut, D., van Ginneken, C., Michiels, J., 2021. Effect of starting time of co-mingling non-littermates during lactation on performance and skin lesions of sows and piglets. Livestock Science 250, 104563.
van Nieuwamerongen, S.E., Soede, N.M., van der Peet-Schwering, C.M.C., Kemp, B., Bolhuis, J.E., 2015. Development of piglets raised in a new multi-litter housing system vs. conventional single-litter housing until 9 weeks of age. Journal of Animal Science 93, 5442–5454.
Vande Pol, K.D., Bautista, R.O., Olivo, A., Harper, H., Shull, C.M., Brown, C.B., Ellis, M., 2021. Effect of rearing cross-fostered piglets in litters of differing size relative to sow functional teat number on preweaning growth and mortality. Translational Animal Science 5, txab193.
Vasdal, G., Andersen, I.L., 2012. A note on teat accessibility and sow parity - consequences for newborn piglets. Livestock Science 146, 91–94.
Wattanakul, W., Sinclair, A.G., Stewart, A.H., Edwards, S.A., English, P.R., 1997. Performance and behaviour of lactating sows and piglets in crate and multisuckling systems: a study involving European White and Manor Meishan genotypes. Animal Science 64, 339–349.
Young, M.G., Tokach, M.D., Aherne, F.X., Main, R.G., Dritz, S.S., Goodband, R.D., Nelssen, J.L., 2004. Comparison of three methods of feeding sows in gestation and the subsequent effects on lactation performance. Journal of Animal Science 82, 3058–3070.