Sows in mid parity are best foster mothers for the pre- and post-weaning performance of both light and heavy piglets[1]

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ABSTRACT: To improve the performance of lightweight piglets during suckling, producers are advised to create uniform litters using young sows. However, fostering piglets to primiparous sows may confer penalties due to their lower milk yield and milk immunoglobulin concentrations compared with multiparous sows. The objective was to determine the effect of foster sow parity (primiparous (F), second (S), and mid parity (M: parity 3 to 5)) on the performance from birth to day 68 of piglets born light (L: ≤1.25 kg) or heavy (H: 1.50–2.00 kg) and on creep feed consumption. Piglets (n = 507) considered L or H were cross-fostered, creating litters of 13 similar-sized piglets/litter and were randomly fostered to one of the foster parities. All litters were offered creep feed with a green dye to discern between consumers and nonconsumers, and the medication administered was recorded. Medication administrated pre- and postweaning did not differ (P > 0.05) across the different experimental groups. A significantly (P ≤ 0.025) lower number of H piglets were removed as a result of preweaning weight loss from F and S, rather than M litters. The interaction between birth weight and foster parity only affected piglet BW at day 10 (P = 0.020); foster parity did not influence BW of L piglets, but influenced that of H piglets. H piglets in F and M litters (3.82 and 3.80 kg) were significantly lighter (P ≤ 0.013) than H piglets in S litters (4.15 kg). As expected, L piglets performed worse pre- and postweaning than H piglets; they were 4.50 kg lighter at day 68. Foster parity significantly affected BW: F piglets were weaned lighter (P = 0.004) than S and M piglets (7.52 vs. 8.02 kg). Postweaning (day 68) however, F piglets achieved similar BW as S piglets (29.7 vs. 29.9 kg), whereas M piglets performed best (31.2 kg, P ≤ 0.079). Significantly fewer (almost none) of the L than the H piglets consumed creep feed (P < 0.001); significantly (P = 0.007) more F and M piglets were considered consumers than S piglets. The results suggest that irrespectively of birth weight, piglets tend to perform better when in M litters, being weaned heavy and having a high creep feed intake; however, more piglets are removed from such litters preweaning. Although S litters were weaned heavy, they were unable to maintain this BW advantage postweaning, due to their low creep feed intake and F litters remained small throughout. Long-term performance monitoring to slaughter is recommended.

Key words: creep feed, lightweight piglets, pigs, sow parity, teat position, weaning weight

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INTRODUCTION

The practice of cross-fostering lightweight piglets, which has resulted from the increased litter size of modern sows, is currently widespread. Creating litter uniformity has been shown to be

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beneficial for piglets born light with respect to both mortality (Milligan et al., 2001; Deen and Bilkei, 2004) and performance (Douglas et al., 2014; Huting et al., 2017). However, advice on how to implement this practice is conflicting. For example, AHDB Pork, the body that advises pig farmers in the UK, suggests that lightweight piglets should be preferably fostered to young sows, matching the teat size with the small mouths of the piglets (AHDB Pork, 2017), whereas Genus PIC explicitly advises to avoid using primiparous sows for this purpose (PIC, 2015).

Lightweight piglets have an impaired rooting response (Baxter et al., 2008) and reduced locomotion (Vanden Hole et al., 2018). This will most likely increase their latency time between birth and the first suckle (Tuchscherer et al., 2000; Baxter et al., 2008), and impair their ability to massage and drain the teat efficiently (King et al., 1997; Marshall et al., 2006; Declerck et al., 2017). Differences in teat morphology between primiparous and multiparous sows suggest that lightweight piglets should be reared by primiparous sows. Teat accessibility in general decreases with increasing parity (Vasdal and Andersen, 2012) and primiparous sows has smaller teats compared with multiparous sows (≥parity 2) (Balzani et al., 2016a; Ocepek et al., 2016). On the other hand, the milk yield (Beyer et al., 2007; Hansen et al., 2012; Ngo et al., 2012; Strathe et al., 2017) and the Ig concentration in colostrum and milk from primiparous are lower compared with multiparous sows (≥parity 2) (Quesnel, 2011; Cabrera et al., 2012; Carney-Hinkle et al., 2013). This may suggest that rearing lightweight piglets on primiparous sows may compromise their preweaning performance in a similar manner as for piglets born with an average weight (Bierhals et al., 2011; Miller et al., 2012; Carney-Hinkle et al., 2013).

The primary objectives of this study were to investigate the effect of sow parity on the pre- and postweaning performance of piglets born light- and heavyweight, and whether sow foster parity has an effect of mortality, the number of medications administered and creep feed consumption. It was hypothesized that while the performance of lightweight piglets would benefit from fostering to primiparous sows, the same practice would compromise the performance of litters with heavyweight piglets.

Because some of the disadvantages of creating litters consisting of only heavy piglets might be offset by their creep feed consumption (Huting et al., 2017), we also aimed to evaluate the effect of foster parity and birth weight on creep feed consumption and teat consistency. Creating litter uniformity has been shown to impair teat consistency during early lactation (Huting et al., 2017), and although teat consistency is normally established during the first 10 d postpartum (Skok and Škorjanc, 2014), variations in sow milking ability may increase competition for the more productive teats also during later lactation. This might especially be the case for piglets reared by primiparous sows and piglets born heavyweight due to their greater growth potential.

MATERIALS AND METHODS

Experimental Design

The experiment followed a 2 × 3 factorial design with a minimum of six replicates per treatment. The factors considered were piglet birth weight class (light and heavy) and foster parity (primiparous, second, and mid parity sows). In accordance with the methodology of Douglas et al. (2014) piglets considered lightweight (L) were those with a birth weight of ≤1.25 kg (minimum 700 g) and piglets considered heavyweight (H) were those with a birth weight between 1.5 and 2.0 kg. Piglets were cross-fostered within the first 24 h postpartum to create litter uniformity (either light or heavy piglets only) and were randomly allocated to one of the foster parities (see below). This was done to facilitate L piglet performance and to ensure birth weight will not confound the data. Heavy piglets were used to exacerbate the effect foster parity might have on creep feed consumption and subsequent performance. The experiment was conducted at the Cockle Park Farm Newcastle University (Ulgham, Morpeth, UK) during seven consecutive farrowing batches. A total of 507 crossbred piglets (dams were Large White × Landrace and sires were MaxiMus; Rattlerow Farms Limited, Suffolk, UK) were cross-fostered and 39 experimental sows were used. The experiment was approved by the Animal Welfare and Ethics Review Board of Newcastle University (AWERB project ID no. 419), and pigs were maintained in accordance with UK legislation (DEFRA and Red Tractor assurance scheme). Piglets were followed from birth to 10 wk of age.

Animals, Housing, and Management

The unit operated a 3-wk batch system; sows expected to farrow were housed in conventional, partially slatted farrowing crates on Monday. All sows were fed the same home-milled meal (18.5% CP, 9.70 MJ NE/kg diet, and 0.95% total lysine) twice a day (0800 and 1500 hours) at an allowance of 1.0 to 2.0 kg/d depending on appetite before farrowing. Once they had farrowed the allowance increased by 0.5 kg/d, based on appetite, until it reached 10 kg/d (at approximately day 21). Water was available *ad libitum* and the temperature of the farrowing unit was maintained at 21 °C throughout lactation.

The average number of piglets born was 13.2 (range 4–21) with an average birth weight of 1.39 kg (SD = 0.372), including stillborn and mummies, based on all sows that farrowed over the experimental period in the pig unit. During the first 2 d of life, piglets were locked into the covered creep area once a day (during morning feeding at 0800 hours) to minimize crushing. The creep area was heated with an infrared heat lamp and wood shavings were provided as bedding. All newly born piglets had their teeth clipped within the first 12 h of life. Piglets were tail docked, received an intramuscular iron injection (1 mL; Gleptosil, 200 mg iron/mL, CEVA Animal Health Ltd, Amersham, UK) at ~3 d of age, and were vaccinated against *Mycoplasma hyopneumoniae* (M+PAC, Intervet UK, Walton, UK) at ~7 d of age. Piglets had access to a nipple drinker and water trough throughout lactation, and *ad libitum* creep feed (diet 1, see below) was provided from 10 d of age onwards. The creep feed provided was supplemented with 1.0% chromic oxide as indigestible marker (approved by the United Kingdom Food Standards Agency, York, UK).

The day before weaning piglets were vaccinated against *M. hyopneumoniae* (M+PAC, Intervet UK) and porcine circovirus type 2 (Inglevac Mycoflex; Boehringer Ingelheim GmbH, Ingelheim, Germany). After weaning at 28 d of age, littermates were moved to pens (2 × 3 m) equipped with multiple nipple drinkers and a multiple-space feeder in a fully slatted purpose-built research facility, where they stayed until ~10 wk of age. Pigs were fed a commercially available four-stage pelleted diet, of which the first three stages were fed on a kilogram per pig basis. The first diet was fed until 1 kg was consumed (21.6% CP, 12.3 MJ NE/ kg diet, and 1.45% total lysine), the second diet until 2 kg were consumed (21.7% CP, 12.2 MJ NE/kg diet, and 1.39% total lysine), and the third diet until 4 kg were consumed (22.3% CP, 12.2 MJ NE/kg diet, and 1.49% total lysine) per pig. It took the pigs ~21 d to consume these three diets before moving to the grower feed (22.4% CP, 12.0 MJ NE/kg diet, and 1.36% total lysine) which was available *ad libitum* up to 10-wk of age. The initial room temperature was set at 26 °C and was reduced by ~0.2 °C each day until it reached a minimum of 22 °C.

Experimental Procedures

Within 12 h postpartum, piglets were individually weighed to the nearest 1 g. Those that met the birth weight criteria and were free from any physical abnormalities (e.g., splay legs and anemic) were individually ear tagged to enable identification. Neonates that did not meet these criteria were cross-fostered to nonexperimental sows. Piglets were randomly allocated to one of the three parities: primiparous, second parity, or mid-parity sow (parities 3 to 5), whilst balancing for sex and birth parity. Litters of 13 similar sized piglets per sow consisting of only either L or H piglets were created within 24 h after postpartum (day 0). The number of L and H piglets born/birth parity class that farrowed within 24 h from each other varied considerably, therefore piglets originated from a variety of parities. The majority of piglets were cross-fostered; however, 2 to 4 piglets remained with their birth sow.

Pre- and postweaning performance. The experimental protocol had well-defined intervention points according to established farm practices. Piglets that lost weight during the initial 2 d postpartum, or gained <100 g/d during 2 consecutive days from day 3 onwards were removed from the trial and were cross-fostered onto a nonexperimental sow. When litter was reduced to below 10 piglets/sow or a third of the litter lost BW, the whole litter was taken off trial. In addition, the general health of the piglets was examined daily and any interventions were monitored and recorded. Medication administered for scour, swine dysentery, and lameness were Norodine (Norodine 24, Norbrook, Corby, UK), Denagard (Novartis Animal Health, Grimsby, UK), a 50:50 mixture of Pen & Strep (Pen & Strep, Norbrook, Corby, UK), and Tolfine (Tolfine, Vetoquinol, Paulerspury, Towcester, UK), respectively, with the dose depending on the size of the pig. If more than three piglets in a litter were diagnosed with diarrhea the whole litter was treated.

All piglets were weighed at 10 d of age, the point at which creep feed was provided *ad libitum* up to weaning. A feed hopper with two feeding spaces and additional tray covering the slats to ensure any spillage was collected was fixed to the wooden board of the pen close to the creep area. The amount of creep feed offered and refused was measured on a daily basis (0800 hours).

Piglets were individually weighed at weaning and once every week (Wednesday), up to 10 wk of age. At the same time, the amount of feed offered and refused per pen was recorded to estimate weekly feed intake. At ~10 wk of age the pigs were returned to the commercial pig unit.

Teat position and teat consistency. The teat position of each individual piglet was recorded using the teat pair locations 1 to 7, from anterior to posterior, during four successful suckling bouts at days 12 to 13 of lactation. A suckling bout started when more than half of the litter gathered at the sow udder and began massaging, and ended when more than half of the piglets fell asleep at the udder, left the udder, or when the sow changed position. The preferred teat pair of each individual was classified into one of the three groups: anterior (teat pairs 1 and 2), middle (teat pairs 3 to 5), or posterior (teat pair ≥ 6) teat pair. A piglet was given a consistency score (C_i) of 1 when it used the same teat during a suckling bout. The C_i score was used to calculate the consistency score of the entire litter by expressing the number of piglets that scored 1 relatively to the total number of piglets within the litter.

Individual creep feed intake. Individual creep feed intake was accessed in two ways: (i) by the subjective observation of visibly green feces (dye present) and (ii) objectively, measuring color by using a color reader (Huting et al., 2017). We have consistently recorded that creep feed consumption in our farm does not start before day 19 (Huting et al., 2017). Therefore, fecal samples were collected on days 19, 21, and 25, by placing the individual piglet on a weighing scale for a maximum of 4 min, stimulating voluntary defecation; samples with watery feces were excluded from the analysis. Piglets were classed into four different consumer classes (i.e., non, low, moderate, and high) depending on the number of fecal samples that appeared to be visually green (Huting et al., 2017) and fecal samples were accessed using the CIELAB color space (Color reader CR-10, Konica Minolta Sensing Inc., Sunderland, UK) following the methodology of Huting et al. (2017). Fecal color was expressed in three different coordinates including L^* (dark–light), a^* (green–red), and b^* (blue–yellow). Chromaticity coordinate a^*, which when negative indicates greener feces, and hue angle (H^*), which defines how the color is perceived and could be calculated from a^* and b^*, were of interest. It has been shown preciously that feces becomes greener as pigs mature (Huting et al., 2017), therefore fecal samples from two non-experimental litters (6 piglets/litter) of the same batch were taken. These piglets were sampled on the same day as the experimental piglets and were spray marked with different combinations of marks to ensure the same piglets were sampled during all sampling days. The latter was used to correct the obtained estimates for experimental day resulting in adjusted a^* and adjusted H^* (see for detailed methodology Huting et al., 2017). The lower the adjusted a^* and the greater the adjusted H^*, the greener the feces.

Statistical Analysis

Two litters, one primiparous and one mid parity sow, both consisting of L piglets only were removed from trial as their litter sizes became <10 piglets/sow. In addition, during one farrowing batch no second parity sows were available. A chi-square test was carried out to test: (i) whether the reason for removal (e.g., mortality, sickness, and weight loss) and (ii) the quantity of medication administered were affected by birth weight class and foster parity.

The PROC MIXED procedure in SAS version 9.4 (SAS Institute Inc. Cary, NC) was used to analyze the pre- and postweaning performance data. Two different PROC MIXED models were run. Firstly, litter mean was the experimental unit for accessing pre- and postweaning performance. Litter size was adjusted for the removal of piglets (litter size = [(Σ all the piglet hours piglets were suckling)/24 h]/total period in day) and was added to all models as a covariate. Likewise, the average pre- and postweaning feed intake was adjusted to the number of animals that resided with their foster sow or within the pen (Feed intake (g/(day · piglet) = [(total amount consumed in g)/total time (h) piglets spent with their foster sow/within pen] × 24 h). Secondly, the experimental unit for the effect of teat pair class and consumer class on pre- and postweaning performance was piglet nested within litter and litter nested within farrowing batch. Main effects of interest for all mixed models were birth weight class, foster parity, and their interaction. Individual models were run for the different days. Additional main effects of interest for the second model were teat pair class or consumer class and their interactions with birth weight class and foster parity. Because the number of consumers per birth weight class and foster parity were unbalanced, the interactions between consumer class × birth weight class and consumer class × foster parity were excluded from the final model. Sex did not significantly affect pre- and postweaning performance nor did it interact with any of the other variables and was therefore omitted from subsequent analysis. All data were blocked by farrowing batch. Several covariance structures (i.e., first-order auto regression, compound symmetry, and variance components) were tested for the RANDOM effects, and the variance components was selected as it resulted in the lowest Akaike information criteria. The UNIVARIATE procedure was used to test the residual variance. Graphical diagnostics and the Levene's test (HOVTEST) in PROC GLM were used to test whether the population variances were equal. When data were unbalanced, the denominator degrees-of-freedom (**DDF**) Satterthwaite was used for adjusting the DDF to unequal variance and studentized maximum modulus using a Bonferroni correction was used for multiple comparisons; in all other cases, protected difference was used to compare means. Data were expressed as least square means with approximate SED unless stated otherwise. Differences were considered significant at 5% and reported as tendencies at 10%.

Two different logistic regressions (PROC LOGISTIC) were conducted to (i) identify whether piglet likelihood to become a non-consumer or consumer (i.e., low, moderate, and high consumer) was under the influence of birth weight class, foster parity, and their interaction with litter as experimental unit and (ii) whether this was under the influence of teat pair class with piglet as experimental unit. For the first logistic regression a binomial model (Y/n) was used with the sum of piglets belonging to one of the consumer classes (Y) expressed against the total number of piglets in the litter (n). In the second logistic regression, teat pair class was added to determine whether piglet likelihood to become nonconsumer or consumer was influenced by teat pair. The response variable of interest (i.e., consumer class) had more than two levels and was therefore formatted to estimate piglet probability to end up in one of the intermediate consumer classes (low or moderate class), with zero representing everything other than the consumer class of interest. The DESCENDING option was used to ensure the likelihood to end up in the "highest" consumer class was tested.

The Pearson correlation coefficient (r) was used to investigate whether creep feed intake was correlated with adjusted a^* and adjusted H^*, and whether color reader measurements and postweaning performance were correlated.

RESULTS

A total of 132 piglets (26.0%) remained with their birth sow; the remaining 375 piglets were cross-fostered. Mid parity sows had an average parity of 3.57 (SD = 0.756). As expected, litter CV after cross-fostering (day 0) was significantly ($P < 0.001$) greater in L than H litters (14.1, SD = 2.89 vs. 8.24, SD = 3.025), but was neither different between foster parities nor was it affected by the interaction between birth weight class and foster parity ($P > 0.05$).

Although cross-fostering created litters of 13 piglets/sow, litter size decreased over time. Litter size at weaning (day 28.6, SD = 0.46) was significantly ($P = 0.009$) lower for L (11.6, SD = 0.86) than H litters (12.3, SD = 0.86). Primiparous and second parity sows weaned on average 12.3 (SD = 0.86) and 12.1 (SD = 0.86) piglets, respectively, whereas mid parity sows weaned on average 11.5 (SD = 0.87) piglets ($P = 0.063$).

Appendix I shows the total number of pigs allocated and the number of pigs removed or treated. Preweaning mortality (i.e., <2 d of age and day 2–weaning) was significantly ($P \leq 0.034$) different between the different treatments. Irrespective of foster parity, piglets born L had a greater mortality rate (5.6%) when compared with H piglets (0.4%) during the initial first 2 d postpartum. Preweaning removal rate as result of weight loss was significantly ($P = 0.020$) different across the different groups, with parity class affecting the number of L and H piglets removed. For L piglets, this manifested only as a tendency ($P = 0.086$), whereas H piglets reared by primiparous and second parity sows had a significant ($P \leq 0.025$) lower preweaning removal rate compared with similar sized piglets reared by mid parity sows.

The number of preweaning medication administered was not affected ($P > 0.05$) by birth weight class, foster parity, or their interaction. However, the interaction between foster parity and birth weight class ($P \leq 0.013$) affected the number of medications administered for scour and "other" (i.e., meningitis and pneumonia) postweaning. A significantly ($P < 0.001$) lower number of L piglets reared by primiparous and second parity sows were treated for scour, compared with similar sized piglets reared by mid parity sows. No differences were seen for H piglets across the different foster sow parities. Medication administered for "other" on the other hand was significantly ($P < 0.001$) greater for primiparous and second parity sows reared L piglets when compared with mid parity sows reared L piglets. Similar results were seen for H piglets.

Teat Position and Teat Consistency

Teat C_i (i.e., using the same teat during a suckling bout) as expressed relatively to the number of piglets within litter averaged 92.8% (SD = 10.71) and was not significantly ($P > 0.05$) affected by birth weight class, foster parity, or their interaction.

The effect of piglet preferred teat pair on piglet cumulative probability to become nonconsumer or consumer (i.e., low, moderate, and high) is shown in Figure 1. Piglets suckling the anterior and middle teat pair were less likely ($P \leq 0.024$) to be considered high consumer (0.095, SE = 0.0246 and 0.071, SE = 0.0162, respectively) compared with piglets suckling the posterior teat pair (0.208, SE = 0.0460).

Teat position. Table 1 shows the effect of foster parity and preferred teat pair class on piglet performance from birth to 10 wk of age. The interaction between birth weight class and teat pair class did not influence pre- and postweaning performance and the interaction between teat pair class and foster parity tended to influence BW at day 28 ($P = 0.089$). At weaning primiparous sow reared piglets suckling the anterior teat pair only tended to be ($P = 0.074$) heavier compared with primiparous sow reared piglets suckling the posterior teat pair, whereas for second and mid parity sow reared piglets both piglets suckling the middle or posterior teat pair were weaned significantly ($P \leq 0.011$) lighter than piglets suckling the anterior teat pair.

Teat pair class significantly ($P < 0.001$) affected pre- and postweaning performance. On day 28, piglets suckling the anterior teat pair were significantly ($P \leq 0.020$) heavier (8.37 kg, SD = 1.374) than piglets suckling the middle teat pair (7.76 kg, SD = 1.605); piglets suckling the posterior teat pair were the lightest (7.39 kg, SD = 1.249). Only a tendency was sustained postweaning with piglets suckling the anterior teat pair being >500 g ($P \leq 0.082$) heavier at 10 wk of age than piglets suckling the mid and posterior teat pair class. Similar results were seen for ADG between birth and weaning ($P < 0.001$), but not for postweaning ADG ($P > 0.05$).

Creep Feed Consumption

Litter level. Most (>80%) creep feed was consumed during the last week before weaning (days 21 to 28) with half of the total amount consumed (50%) being eaten during the last 3 d before weaning (>d 25). The effect of foster parity and birth weight class on creep feed consumption is shown in Figure 2. Neither foster parity nor the interaction between birth weight class and foster parity significantly affected creep feed intake ($P > 0.05$). However, creep feed consumption was significantly ($P < 0.001$) affected by birth weight class, with L piglets consuming less (65.9 g/piglet, SD = 195) than H piglets (261 g/piglet, SD = 207).

Individual piglet. Figure 3 illustrates the effect of foster parity and birth weight class on the cumulative probability of consumer class (i.e., non, low, moderate, and high consumer). The interaction between birth weight class and foster parity only tended ($P = 0.059$) to influence the probability to become low consumers.

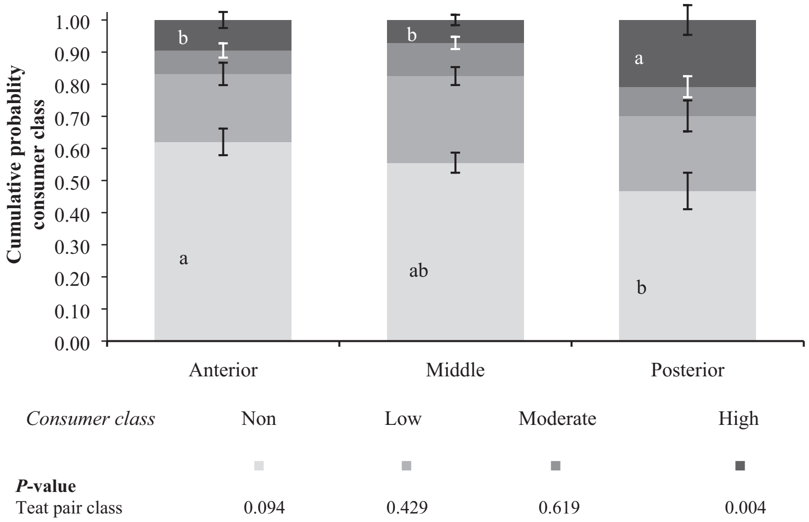


Figure 1. The effect of piglet preferred teat pair on piglets probability to be classified nonconsumer or consumer. Piglets were classified as either nonconsumers or consumers (low, moderate, or high) on the basis of the number of positive fecal samples. Teat pair class was classified according to anatomical location of the teats (i.e., anterior [teat pairs 1 to 2], middle [teat pairs 3 to 5], or posterior [teat pair ≥6]). Data are represented in probability ±SE. Within consumer class bars with different superscripts (a,b) differ significantly ($P < 0.05$) across the different teat pair classes.

Table 1. The effect of foster sow parity (primiparous, second or mid parity sow [parities 3 to 5]) and piglet preferred teat pair class on performance from birth to 10 wk of age[1]

Foster sow parity class	Primiparous			Second			Mid				Significance[2]		
Teat position	Anterior	Middle	Posterior	Anterior	Middle	Posterior	Anterior	Middle	Posterior	SED	Teat pair class	Birth weight × Teat pair class	Foster parity × Teat pair class
Number of piglets													
Day 28	44	88	28	45	77	23	48	87	26				
Day 68	43	87	28	43	77	23	47	87	26				
BW, kg													
Day 0	1.36	1.39	1.34	1.41	1.38	1.37	1.41	1.39	1.37	0.012	0.323	0.111	0.467
Day 28	7.69^{A}	7.51	6.92^{B}	8.50^{a}	7.73^{b}	7.54^{b}	8.90^{a}	8.03^{b}	7.70^{b}	0.113	<0.001	0.783	0.089
Day 34	9.27	8.96	8.40	9.64	9.03	8.85	10.3	9.56	9.29	0.123	<0.001	0.625	0.644
Day 68	30.3	29.8	28.6	30.3	29.5	30.1	32.1	30.9	30.8	0.331	0.032	0.684	0.507
ADG, g/d													
Day 0 to 28	222	215	196	248	224	217	260	231	220	3.70	<0.001	0.813	0.122
Day 28 to 34	263	243	244	191	216	218	234	255	265	12.4	0.566	0.657	0.270
Day 28 to 68	579	572	555	560	559	579	594	586	593	7.38	0.774	0.719	0.538

Within foster parity estimates within row with different superscripts either differ significantly (a,b $P < 0.05$) or tended to differ (A,B $P < 0.10$).

[1] Teat pair class was classified according to anatomical location of the teats (i.e., anterior [teat pairs 1 to 2], middle [teat pairs 3 to 5], or posterior [teat pair ≥6]) and was assessed at day 12. Pigs were cross fostered within 12 to 24 h after birth (day 0), creep feed was provided from 10 d to weaning (day 28.6, SD = 0.46) and piglets remained in the same litter until ~10 wk of age (day 67.6, SD = 0.46). Individual pigs were weighed at birth (within 12 h after birth), day 28, 1 wk postweaning and at 10 wk of age.

[2] In addition to the significant effect shown here, birth weight class affected ($P < 0.05$) all performance parameters. Also foster parity class significantly ($P < 0.05$) affected BW at days 28, 34, and 68.

Birth weight class significantly influenced the probability of being classified as non-consumer or consumer. In general, L piglets had a greater likelihood to be classified as nonconsumers (0.740, [95% confidence interval 0.737, 0.743]) compared with H piglets (0.435, [0.431, 0.438]) and a lower likelihood to be classified as consumers, irrespectively of consumer class. In addition, foster parity influenced the likelihood for becoming non-consumer (P = 0.007), low (P = 0.008) and moderate consumer (P = 0.027). In general, primiparous and mid parity sow reared piglets had a lower likelihood to become nonconsumers and a greater likelihood to become low consumers compared with second parity sow reared piglets. The likelihood to be classified as moderate consumer was significantly ($P \leq 0.044$) greater for primiparous sow reared piglets (0.139 [0.137, 0.141]) compared with second and mid parity sow reared piglets (0.040 [0.039, 0.042] and 0.043 [0.041, 0.044], respectively).

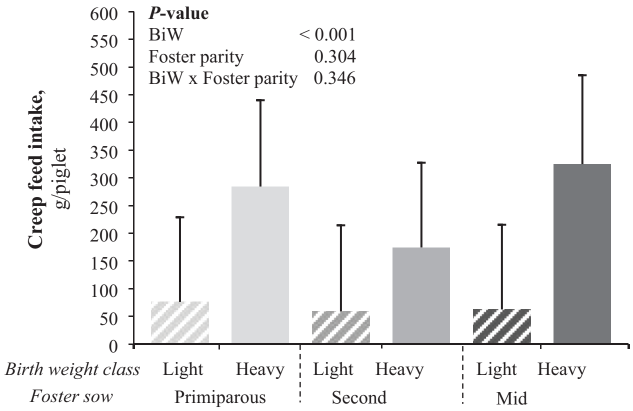
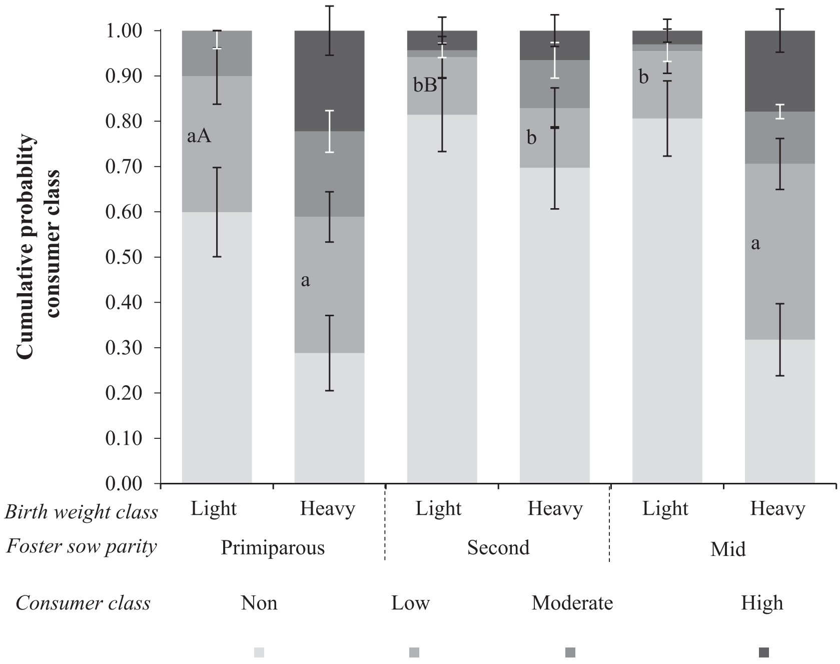


Figure 2. The effect foster sow parity (primiparous, second, or mid parity sow [parities 3 to 5]) and birth weight (BiW) class (light [≤1.25 kg] or heavy [1.50 to 2.00 kg]) on creep feed consumption (g/piglet ± SD).

Table 2 shows the effect of consumer class on piglet performance from birth to 10 wk of age. Consumer class significantly affected BW at day 19 ($P < 0.001$), at the start of fecal sampling, weaning ($P = 0.039$), and at 10 wk of age ($P = 0.020$). Non- and low consumers were significantly ($P \leq 0.040$) heavier at day 19 and weaning compared with high consumers, whereas at 10 wk of age, nonconsumers were significantly ($P \leq 0.044$) lighter than moderate consumers. Furthermore, pre- and postweaning ADG were significantly ($P \leq 0.037$) affected by consumer class. Although high consumers gained significantly less ($P \leq 0.027$) between birth and day 19 and birth and weaning than for instance nonconsumers, they gained significantly ($P = 0.044$) more



P-value	Non	Low	Moderate	High
BiW	<0.001	0.087	0.004	<0.001
Foster	0.007	0.008	0.027	0.130
BiW x Foster	0.248	0.059	0.357	0.497

Figure 3. The effect foster sow parity (primiparous, second, or mid parity sow [parity 3–5]) and birth weight (BiW) class (light [≤ 1.25 kg] or heavy [1.50–2.00 kg]) on the cumulative probability of consumer class. Data are represented in probability ± SE. The comparison for the effect of foster parity on consumer class was made within birth weight class with the different superscripts either differ significantly (^{a,b,c} $P < 0.05$) or tended (^{A,B} $P < 0.10$) to differ.

Table 2. The effect of consumer class on pre- and postweaning performance[1]

Consumer class	Non consumer	Low consumer	Moderate consumer	High consumer	SED	Significance[2]
Number of piglets						
Day 28	261	115	43	47		
Day 68	257	115	43	46		
BW, kg						
Day 0	1.34	1.39	1.44	1.39	0.005	0.508
Day 19	5.90^{a}	5.79^{a}	5.57^{aA}	5.12^{bB}	0.033	<0.001
Day 28	7.90^{a}	7.92^{a}	7.78^{ab}	7.33^{b}	0.046	0.039
Day 34	9.19	9.43	9.59	9.05	0.050	0.126
Day 68	29.8^{b}	30.8^{ab}	31.6^{a}	30.8^{ab}	0.136	0.020
ADG, g/d						
Day 0 to 19	229^{a}	223^{a}	209^{ab}	190^{b}	1.58	<0.001
Day 0 to 28	228^{a}	228^{a}	222^{ab}	209^{b}	1.51	0.031
Day 19 to 28	227	240	249	249	2.30	0.037
Day 28 to 34	217^{b}	253^{a}	294^{a}	276^{a}	4.24	0.001
Day 28 to 68	563^{bB}	583^{aA}	609^{a}	608^{a}	2.78	0.001

[1] Data are expressed at least square means. Averages within row with different superscripts (a,b) differ significantly ($P < 0.05$) or tended (A,B) to differ ($P < 0.10$).

[2] In addition to the consumer class effect shown here, birth weight class affected ($P < 0.05$) all performance parameters except for ADG between days 19 to 28. Also foster parity class significantly ($P < 0.05$) affected BW at days 19, 28, 34, and 68, ADG between days 19 to 28, days 0 and 28, and days 28 to 68.

during the postweaning period (between weaning and 10 wk of age) compared with nonconsumers.

The correlations ($P < 0.05$) between the color readings (i.e., adjusted a^* and adjusted H^*) for the different sampling days (i.e., days 19, 21, and 25) and ADG between weaning and day 34 were generally weak ($r = < \pm 0.40$), as illustrated in Appendices II and III for adjusted a^* and adjusted H^*, respectively. Negative correlations between adjusted a^* and ADG were found, whereas adjusted H^* was positively correlated with ADG. Similar results were found between weaning and 10 wk of age.

Pre- and Postweaning Performance

Table 3 shows the effect of foster parity, birth weight class, and their interaction on piglet performance from birth to 10 wk of age.

Performance at day 10. A significant interaction between birth weight class and foster parity was found for BW at day 10 ($P = 0.020$). Although foster parity did not influence BW of L piglets, it influenced the performance of H piglets. Primiparous and mid parity sow reared H piglets were significantly ($P \leq 0.013$) lighter than second parity sow reared H piglets. In addition, birth weight class ($P < 0.001$), but not foster parity ($P > 0.05$), influenced BW at day 10.

Performance at weaning. BW, total litter weight, and litter CV at weaning were not significantly affected by the interaction between birth weight class and foster parity ($P < 0.05$). However, birth weight class ($P < 0.001$ and $P < 0.001$, respectively) and foster parity ($P = 0.004$ and $P = 0.081$, respectively) influenced weaning weight and total litter weight at weaning. Litter CV at weaning was only influenced by birth weight ($P = 0.029$). Piglets born L were lighter at weaning (7.19 kg, SD = 0.594 vs. 8.55 kg, SD = 0.664), had a greater litter CV (14.7, SD = 3.65 vs. 11.9, SD = 3.69) and a lower total litter weight (85.2 kg, SD = 6.52 vs. 103 kg, SD = 6.69) compared with H piglets. On the other hand, primiparous sow reared piglets were weaned 500 g lighter (7.52 kg, SD = 0.564) when compared with piglets reared by second and mid parity sows (8.02 kg, SD = 0.559 and 8.02 kg, SD = 0.595, respectively).

Performance at 1 wk postweaning. Only birth weight class ($P < 0.001$) and foster parity ($P = 0.011$) influenced piglet BW at 1 wk postweaning; the same was the case for feed intake between weaning and day 34 ($P = 0.006$ and $P = 0.034$, respectively). Lightweight piglets were 1.6 kg lighter at 1 wk postweaning (8.46 kg, SD = 0.631 vs. 10.1 kg, SD = 0.650) and ate less during the immediate postweaning period (183 g/(day · piglet), SD = 46.0 vs. 229 g/(day · piglet), SD = 46.4) compared with H piglets. Postweaning primiparous sow (8.98 kg, SD = 0.595) reared piglets were significantly lighter at day 34 ($P = 0.041$) when compared with piglets reared by mid parity sows (9.67 kg, SD = 0.629). On the other hand, second parity sow reared piglets

Table 3. The effect of foster sow parity (primiparous, second, or mid parity sow [parities 3 to 5]) and birth weight class (light [<1.25 kg] or heavy [1.50 to 2.00 kg]) and their interaction on performance from birth to 10 wk of age[1,2]

Foster sow parity class	Primiparous		Second		Mid			Significance		
Birth weight class	Light	Heavy	Light	Heavy	Light	Heavy	SED	Birth weight class	Foster parity	Birth weight × foster parity
BW, kg										
Day 0	1.06	1.68	1.04	1.71	1.07	1.69	0.013	<0.001	0.828	0.059
Day 10	2.94^{c}	3.82^{b}	2.88^{c}	4.15^{a}	3.08^{c}	3.80^{b}	0.094	<0.001	0.403	0.020
Day 28	6.88	8.16	7.25	8.80	7.43	8.70	0.195	<0.001	0.004	0.664
Day 34	8.29	9.67	8.40	10.0	8.69	10.7	0.216	<0.001	0.011	0.356
Day 68	27.8	31.6	27.8	32.0	28.4	33.9	3.73	<0.001	0.025	0.269
ADG, g/d										
Day 0 to 10	173^{c}	197^{bd}	171^{cd}	227^{a}	186^{c}	196^{b}	8.45	<0.001	0.225	0.025
Day 0 to 28	204	226	217	248	221	245	6.26	<0.001	0.007	0.738
Day 10 to 28	224	246	239	261	240	273	9.19	<0.001	0.022	0.681
Day 28 to 34	227	249	199	203	209	327	24.9	0.057	0.066	0.088
Day 28 to 68	535	602	527	596	538	646	12.7	<0.001	0.039	0.145
Feed intake, g/(day · piglet)										
Day 28 to 34	197	234	174	182	179	271	17.5	0.006	0.034	0.073
Day 28 to 68	649	731	657	725	664	818	21.6	<0.001	0.028	0.073
Feed intake, kg/ piglet										
Day 28 to 34	1.18	1.41	1.04	1.09	1.08	1.63	0.105	0.006	0.034	0.073
Day 28 to 68	25.3	28.5	25.6	28.3	25.9	31.9	0.841	<0.001	0.028	0.073
G:F ratio										
Day 28 to 68	0.824	0.825	0.803	0.826	0.812	0.789	0.077	0.961	0.065	0.065
Total litter CV										
Day 28	14.4	10.6	15.9	11.2	13.8	13.8	1.39	0.029	0.613	0.226
Day 68	11.8	10.2	11.3	9.77	12.5	10.4	1.19	0.079	0.741	0.967
Total litter weight, kg										
Day 28	83.4	98.5	84.6	106	87.6	103	2.30	<0.001	0.081	0.278
Day 68	329	374	328	378	337	400	7.217	<0.001	0.036	0.372

[1] Pigs were cross-fostered within 12 to 24 h after birth (day 0), creep feed was provided from 10 d to weaning (day 28.6, SD = 0.46) and piglets remained in the same litter until ~10 wk of age (day 67.6, SD = 0.46). Individual pigs were weighed at birth (within 12 h after birth), days 10, 19, 28, 1 wk postweaning and at 10 wk of age.

[2] Data are expressed at least square means. Averages within row with different superscripts (a,b,c,d) differ significantly ($P < 0.05$).

ate less (178 g/(day · piglet), SD = 44.9) between weaning and d 34 ($P = 0.044$) when compared with piglets reared by mid parity sows (225 g/(day · piglet), SD = 46.7). No significant ($P = 0.066$) differences were observed for ADG between weaning and 1 wk postweaning between the different sow parities.

Performance at 10 wk postweaning. BW and total litter weight at 10 wk of age were not affected by the interaction between birth weight class and foster parity ($P > 0.05$), whereas G:F ratio between weaning and 10 wk of age only tended to be affected ($P = 0.065$) by this interaction.

BW, total litter weight, ADG, and postweaning feed intake between weaning and 10 wk of age were significantly affected by birth weight class ($P \leq 0.002$) and foster parity ($P \leq 0.036$). Piglets born L were 4.5 kg lighter at 10 wk of age (28.0 kg, SD = 1.80 vs. 32.5 kg, SD = 1.87) and ate less between weaning and 10 wk of age compared with H piglets (657 g/(day · piglet), SD = 65.9 vs. 758 g/(day · piglet), SD = 68.3). Similar results were seen for ADG between weaning and 10 wk of age. Postweaning piglets reared by primiparous sows (29.7 kg, SD = 1.67) were significantly lighter at 10 wk of age ($P = 0.035$) when compared with piglets reared by mid parity sows (31.2 kg, SD = 1.75); piglets reared by second parity sows (29.9 kg, SD = 1.65) only tended ($P = 0.079$) to weigh less than piglets reared by mid parity sows. No significant differences were observed between primiparous (568 g/d, SD = 36.4) and mid parity sow reared piglets (592 g/d, SD = 38.1) with respect to ADG between weaning and 10 wk of age, whereas second parity sow reared piglets gained (561 g/d, SD = 35.8) significantly ($P = 0.046$) less when compared with mid parity sow reared piglets. At 10 wk of age primiparous sow reared piglet tended ($P = 0.054$) to have a lower total litter weight (352 kg, SD = 20.5) compared with mid parity sow reared piglets (369 kg, SD = 21.5). Also postweaning feed intake of primiparous sow reared piglets was significantly ($P = 0.049$) less between weaning and 10 wk of age (690 g/(day · piglet), SD = 61.5) compared with mid parity sow reared piglets (741 g/(day · piglet), SD = 64.4); a tendency was observed between second ($P = 0.065$; 691 g/(day · piglet), SD = 60.6) and mid parity sow reared piglets between weaning and 10 wk of age. G:F ratio did not differ between the different birth weight classes, but tended ($P = 0.065$) to be affected by foster parity with primiparous sow reared piglets tended ($P = 0.072$) to have a greater G:F ratio compared with mid parity sow reared piglets (0.825, SD = 0.035 vs. 0.801, SD = 0.036).

DISCUSSION

Aiming for litter uniformity is an established practice in the industry (PIC, 2015; AHDB Pork, 2017) and has been proven successful in improving the performance of L piglets (Douglas et al., 2014; Huting et al., 2017). In the present study, we investigated what is the best foster sow for light- and heavyweight piglets when reared in uniform litters as the issue currently presents a conundrum. Industry recommendations are often conflicting with respect to foster parity for piglets born lightweight (PIC, 2015; AHDB Pork, 2017).

We hypothesized that teat morphometry of young sows maybe ideal for fostering lightweight piglets. Irrespectively of birth weight, piglets in general have a preference, immediately postpartum, for teats that are smaller in size (i.e., shorter and smaller in diameter) and positioned relatively close to the abdominal midline (Balzani et al., 2016b). Teats that meet the preferred morphometry are the anterior and posterior teat pairs (Balzani et al., 2016b) or teats from primiparous sows (Balzani et al., 2016a; Ocepek et al., 2016). As a result, piglets reared by young sows (parities 1 or 2) need less time between birth and the first suckle compared with piglets reared by older sows (parities 3 to 6) (Vasdal and Andersen, 2012). This is important because the longer it takes for a piglet to reach a teat, the less colostrum it consumes (Declerck et al., 2017) and the more prone it is to die (Devillers et al., 2011; Pandolfi et al, 2017). Given the impaired rooting response (Baxter et al., 2008) and reduced locomotion (Vanden Hole et al., 2018) of piglets born light, teat accessibility and morphology may be of particular importance for them and may not only influence their efficiency to reach and massage the teats during early life (Tuchscherer et al., 2000; Baxter et al., 2008) but also throughout lactation. On the other hand, the lower milk yield seen in primiparous sows (Beyer et al., 2007; Ngo et al., 2012; Quesnel et al., 2015), hinders individual piglet preweaning growth performance. Primiparous sow reared piglets were weaned >10% lighter than multiparous sow reared piglets (Bierhals et al., 2011; Miller et al., 2012; Carney-Hinkle et al., 2013) and this difference was sustained postweaning (Miller et al., 2012). Nonetheless, the aforementioned studies evaluating the effect of foster parity on piglet performance have confounded their data with birth weight (Craig et al., 2017), or focused on the average piglet (1.44 kg) (Bierhals et al., 2011). For instance, due to limited cross-fostering piglets reared by primiparous sows weighed around 10% to 15% less at birth compared with those reared by multiparous sows (Miller et al., 2012; Carney-Hinkle et al., 2013). Furthermore, the effect foster parity may have on pre- and postweaning performance may be more detrimental for H than L piglets. Cross-fostering H piglets to primiparous sows may affect adversely their performance due the lower milk yield (Beyer et al., 2007; Ngo et al., 2012; Quesnel et al., 2015) and the lower weight gain may result in more even sized piglets at weaning compared with H piglets reared by older sows. To that end, in the present study, cross-fostering was applied and focused on L piglets but also H piglets to exacerbate the effect of foster sow parity. Furthermore, a differentiation was made between second and mid parity sows (parities 3 to 5). Second parity sows may be a good alternative for L piglets with respect to teat size and milk yield, compared with mid- and primiparous sows, respectively.

Although, not shown here, the relative back fat and BW loss of the sows were not influenced by birth weight, foster parity or their interaction. The hypothesized interaction between birth weight class and foster parity as presented here only influenced BW at day 10, with H piglets being disadvantaged when reared by primiparous and mid parity sows compared with second parity sows. No differences between foster parities were seen for L piglets. Nevertheless, foster parity did influence the pre- and postweaning performance of piglets irrespectively of birth weight, thus may have influenced L and H piglets in a similar way. Primiparous sow reared piglets were weaned lighter and remained light postweaning. This is in agreement to the results of Ferrari et al. (2014), who retrospectively created birth weight classes and found that primiparous sow reared piglets, irrespectively of birth weight, had a greater probability for low performance up to 6 wk of age than piglets reared by multiparous sows. However, although second and mid parity piglets were weaned with a similar BW, postweaning second parity piglets performed less reaching a similar weight at 10 wk of age compared with primiparous sow reared piglets, whereas mid parity sow reared piglets performed best.

The significant greater preweaning removal rate as a result of weight loss for H piglets reared by mid parity sows compared with H piglets reared by primiparous and second parity sows may be the result of differences in udder and teat quality. Firstly, udder quality deteriorates with increasing parity (Appel et al., 2016). Multiparous sows (parity ≥ 4) are more at risk for mastitis metritis agalactia, mostly seen in the posterior teat pairs (Baer and Bilkei, 2005), resulting in greater sow removal rates due to udder problems compared with primiparous sows (Engblom et al., 2007) and may result in less functional teats per piglet. Secondly, growth variation between the different teat pair locations due to differences in teats milking ability (Kim et al., 2000; Ogawa et al., 2014) becomes more apparent with increasing parity (primiparous vs. multiparous sows: parity ≥ 2) (Dyck et al., 1987; Nielsen et al., 2001). These differences may result in more competition and missed suckling bouts and thus variable growth rates within litter and may explain why H piglets reared by mid parity sows were removed in greater quantities and performed considerably less during early life (day 10) compared with similar sizes piglets reared by primiparous and second parity sows respectively. Our experiment cannot distinguish whether the improved preweaning performance (> d 10) of the piglets reared by mid parity sows is due to reduced litter size, which resulted from piglet removal, increased creep feed consumption or any other factor associated with sow parity.

To our knowledge, this is the first study that has evaluated the effect of foster parity on creep feed consumption of piglets of various birth weights. Milk yield usually plateaus in the third week of lactation (approximately day 18) (Hansen et al., 2012), limiting piglet performance. It has been shown previously that H piglets reared in uniform litters tried to compensate for their insufficient milk intake by consuming creep feed (Huting et al., 2017). This may suggest that fostering H piglets on primiparous sows may stimulate solid feed intake. Although the numerical differences for creep feed intake and consumer class distribution for H piglets as shown here support this hypothesis, the high variation between and within litters may have resulted in the lack of significance for the interaction between birth weight class and foster parity. Yet, foster parity influenced the likelihood for a piglet to become consumer or nonconsumer. Significantly less primiparous and mid parity sows reared piglets were considered nonconsumers (<30%) compared with second parity sows reared piglets (70%). Although second parity sows are thought to have a similar milk yield compared with mid parity sows (Ngo et al., 2012; Quesnel et al., 2015; Strathe et al., 2017), the results here suggest otherwise. The fact that piglets reared by primiparous and mid parity sows ate greater amounts of creep feed implies that they had to compensate for the insufficient milk intake, whereas piglets reared by second parity sows hardly consumed creep feed. The discrepancy among our findings and those of the aforementioned studies warrant further research.

As expected creep feed intake was low for L piglets compared with H piglets (Huting et al., 2017). Nevertheless, L piglets that did start eating creep feed did so considerably late (> d 21) compared with H piglets. This may suggest that L piglets have lower milk requirements to support their reduced growth capacity (Foxcroft et al., 2006) or that differences in gut maturity (Michiels et al., 2013) affect L piglet ability to consume creep feed. However, others suggest that birth weight does not affect the digestive capacity of piglets small intestine (Huygelen et al., 2015).

The positive effect creep feed intake has on subsequent performance has been well documented (Bruininx et al., 2002; Sulabo et al., 2010; Huting et al., 2017). Also here, despite the lower growth rate during the initial 3 wk of lactation, piglets considered high consumers were able to outperform nonconsumers during the last week before weaning. The beneficial effects of creep feed provision on performance, however, is more pronounced during the postweaning period (Bruininx et al., 2002; Sulabo et al., 2010; Huting et al., 2017). Piglets from all consumer classes, irrespectively of being considered low, moderate or high consumer, were ≥1 kg heavier at 10 wk of age compared with nonconsumers. The familiarization with solid feed during lactation is suggested to increase feed intake during the immediate postweaning period positively influencing growth (Bruininx et al., 2002). Because the number of consumers per foster parity was unbalanced, we were unable to formally test the effect of the interaction between consumer class and foster parity on postweaning performance. Therefore, we can only speculate the basis of the cumulative probability of consumer classes differences seen preweaning for the different foster parities and its effect on postweaning performance. Although piglets reared by primiparous sows were weaned 6% lighter than piglets reared by second parity sows, this difference disappeared by week 10 of age. This is most likely a result of difference in preweaning creep feed intake. The combination of the high creep feed intake and similar weaning weights compared with second parity sow reared piglets on the other hand, most likely enabled mid parity sows reared piglets to outperform the rest at 10 wk of age represented by a greater postweaning feed intake and a 1.25 kg heavier BW.

CONCLUSION

As expected piglets born lightweight remained smaller pre- and postweaning, compared with piglets born heavyweight. The absence of a significant interaction between birth weight class and foster parity suggests that foster sow parity influenced pre- and postweaning performance of all piglets in a similar way. Nevertheless, the reduced milking ability of primiparous sows resulted in lower weaning weights compared with piglets reared by second and mid parity sows, and despite their high number of consumers they remained among the lightest postweaning. Although the highest number of consumers were seen for primiparous and mid parity sow litters, a direct link between consumer class and foster parity on postweaning performance could not be made. The BW difference as seen at weaning between primiparous and second parity sows reared piglets disappeared postweaning which may be a result of the low preweaning solid feed intake of piglets reared by second parity sows. The relatively high weaning weight of piglets reared by mid parity sows and their high preweaning creep feed intake, resulted in a significant greater postweaning gain and weight at 10 wk of age. Overall, the results unequivocally suggest that irrespective of piglet size, piglets should ideally be fostered to mid parity sows. The results also justify long-term performance monitoring to reach conclusions on how preweaning manipulations affect performance outcomes to slaughter.

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Conflict of interest statement. None declared.

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