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Original Research Article

Optimizing feeding regimen of replacement gilts to improve their reproductive performance and retention rate of their first 2 parities

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ABSTRACT

The effects of age, body weight (BW), and backfat thickness (BF) of replacement gilts at first estrus and first mating on their subsequent reproductive performance and retention of their first 2 parities as sows was evaluated. A total of 3,025 Danish replacement gilts were categorized by farm (allocated to 4 farms), cross combination, age, BW and BF at first estrus and first mating, estrous cycle number at first mating, and flush feeding before first mating. The result shows that all the factors mentioned above were significantly associated with reproductive performance and retention rates of the first 2 parities. Farm 3 had more piglets born alive per litter (BA) ($P < 0.05$). Farms 3 and 4 had more healthy piglets per litter (HP) ($P < 0.05$). Farm 4 had the most piglets weaned per litter (PW) ($P < 0.05$). Landrace × Landrace × Yorkshire (L × L × Y) replacement gilts had the most total piglets born per litter (TB), BA, HP, PW and a higher retention rate of the 2 parities than Landrace × Yorkshire (L × Y) replacement gilts ($P < 0.05$). In addition, flush feeding before first mating had the most TB, BA, HP, PW, and a higher retention rate of the 2 parities than no flush feeding ($P < 0.05$). Because the effects of replacement gilts rearing parameters on reproductive performance traits differed, we used 100 replacement gilts as a unit and the total number of weaned piglets from the first 2 parities as a new index. Replacement gilts undergoing their first estrus between 180 and 210 d of age at 115 to 124.9 kg BW and 14 to 15 mm BF had significantly higher reproductive indexes for their first 2 parities per 100 replacement gilts. Replacement gilts that mated between 210 and 230 d of age at 140 to 149.9 kg BW and 15 to 16 mm BF had optimal reproductive indexes. These results provide a new insight into the complex relationships among these reproductive performance traits and may help guide successful management of replacement gilts as a pivotal starting point for future fertility and longevity of rearing herds.

1. Introduction

Sow lifetime productivity is a complicated and dynamic trait influenced by sow productivity and longevity (Koketsu et al., 2017; Patterson and Foxcroft, 2019). Sow productivity can be measured as lifetime piglets born alive (LPBA), or lifetime piglets weaned (Patterson and Foxcroft, 2019). Sow longevity is commonly measured with the number of piglets born at culling (Koketsu and Iida, 2020) and is affected by sow culling reasons. Replacement gilts are the foundation for maintaining fertility in large-scale pig farms, and adequate replacement gilts development is essential for

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maximizing performance and sow lifetime productivity (Fabà et al., 2018; Patterson et al., 2020). Among sows, 66.3% are culled from the herd as replacement gilts or primiparous sows (Roongsitthichai et al., 2013). Our previous research showed that the average culling parity and LPBA of all culls were 2.27 and 18.65, respectively, and unplanned culls had a lower culling parity and LPBA compared with planned culls (Wang et al., 2019). This considerably affects production costs and herd efficiency and reflects the significance of the rearing phase of replacement gilts for the herd's production units.

Rearing parameters of replacement gilts at first estrus and first mating, including age, body weight (BW), and backfat thickness (BF), are the major criteria to be considered. Age at puberty is characterized by a moderate heritability, reportedly ranging from 0.25 to 0.42 (Li et al., 2018). Early age at puberty is reported to have little effect on the total pigs born or born alive per litter on a per parity basis (Patterson et al., 2010; Li et al., 2018; Thiengpimol et al., 2022). However, age at puberty is generally associated with improved retention rates and sow longevity, and as puberty age decreases, the chance that a replacement gilt is farrowing a first, second or third litter increases (Knauer et al., 2010; Serenius and Stalder, 2007; Magnabosco et al., 2014). Furthermore, replacement gilts BW and growth rate were correlated with the number of ovulations, and each 10 kg increase in BW yielded an increase of 1.1 mm in the corpora lutea (Tummaruk and Kesdangsakonwut, 2015). However, replacement gilts bred at >170 kg were at risk of low retention and locomotion problems over 3 parities (Filha et al., 2010). Filha et al. (2010) recommended aiming for BF >17 mm at first mating to optimize reproduction of one parity. DanBred recommends inseminating replacement gilts at 230 to 250 d of age at 130 to 155 kg BW and 12 to 15 mm BF (DanBred manual, 2018). Hence, different rearing parameters likely affect different rearing targets.

The appropriate indicators must be determined when rearing replacement gilts. The present study was conducted to investigate the influence of age, BW and BF at the first estrus and first mating of replacement gilts, and feeding programs before mating of replacement gilts on their subsequent reproductive performance and retention rate of multiple parities in a large sow herd.

2. Materials and methods

2.1. Animal ethics statement

The animal study was reviewed and approved by the Animal Care and Use Committee of Huazhong Agricultural University.

2.2. Animals and management

The study was conducted from October 2020 to August 2021 on a commercial swine herd in southern China. The study comprised 3,025 completed records of Danish Landrace × Yorkshire (L × Y) and Landrace × Landrace × Yorkshire (L × L × Y) crossbred replacement gilts. The replacement gilts entered the gilt pool on the farms at approximately 165 d of age. After arrival, replacement gilts were kept in pens as groups of 15 to 20 replacement gilts per pen with 1.5 to 2.0 m^2/gilt. To stimulate puberty and induce estrus, a sexually mature boar was introduced to replacement gilts in each pen for 15 min twice daily, beginning when the replacement gilts were an average of 170 d old. Estrus was checked daily using a back pressure test together with observation of vulvar reddening and swelling. Replacement gilts expressing a standing response in front of the boar with clear vulvar symptoms were identified as being in estrus. Estrus was detected by experienced technicians, and the date of standing estrus was recorded daily. The first artificial insemination was performed approximately 12 h after estrus onset, then every morning and afternoon until the replacement gilts were no longer standing.

During the rearing phase, each replacement gilts was provided with water ad libitum and feed approximately at 2.5 to 3.0 kg/d containing 16% crude protein (CP), 3,000 kcal/kg digestible energy (DE), and 0.8% the standardized ileal digestible (SID) lysine before flush. At approximately 14 d prior to mating, “no flush feeding” replacement gilts were fed 2.5 kg/d, whereas “flush feeding” replacement gilts were provided 3.50 kg/d. During pregnancy, replacement gilts and sows were fed 1.8, 2.2, 2.4, and 2.8 kg/d of a corn-soybean diet (3,000 kcal DE/kg, 14% CP, and 0.70% SID lysine) twice daily, from 0 to 3, 4 to 30, 31 to 90, and 90 to 110 gestational days, respectively. After entering the farrowing house, gilts were fed 2.8 to 3.0 kg of a lactation feed twice daily (3,200 kcal DE/kg, 18.0% CP and 1.0% SID lysine), with a gradual reduction from 3 to 1 kg until 1 d before the expected farrowing. During lactation, sows were fed 5.0 to 7.0 kg/d of lactation feed ad libitum.

2.3. Data collection

The replacement gilts were classified by age, BW and BF at first estrus and first mating, nutrition and feeding programs before mating, and the estrous cycle number at first mating (Table 1). Body weight was measured with an electronic scale at first estrus symptoms and first mating. BF was measured at the same time as the BW. An ultrasound device (Lean-meter, Renco Corp., Minneapolis, MN, USA) was used to measure the BF as described previously (Zhou et al., 2018).

Reproductive data were recorded as follows. The numbers of total piglets born per litter (TB), piglets born alive per litter (BA), healthy piglets per litter (HP), stillborn piglets per litter, and mummified piglets per litter were recorded within 24 h postpartum, and the number of pigs was recorded and calculated after cross-fostering and at 21 d of lactation in the first and second parities. Additional data, including culling date, culling proportion, and retention rate of the first and second parities were calculated from the original dataset.

2.4. Statistical analysis

Calculation and statistical analyses were conducted using SAS software (SAS 9.4, SAS Institute Inc., Cary, NC, USA) with the PROC MIXED procedure. Farms, cross combinations, age, BW and BF of the replacement gilts at first estrus; age, BW and BF of the replacement gilts at first mating, feeding program before mating, and the estrous cycle number at first mating were specified as fixed effects. The individual sow and sow housing were used as random effects. In the mixed model, the response variables included TB, BA, HP, and pigs weaned from the 2 parities. Retention rates were binomial traits (0, 1); removal was ‘0’ when replacement gilts were culled and the remaining replacement gilts were ‘1’. Logistic regression was used to analyze the effects of farms, cross combinations, age, BW and BF of the replacement gilts at first estrus; age, BW and BF of the gilts at first mating; and the estrous cycle number at first mating on the retention rates using the GENMOD procedure in SAS. For significant differences, Duncan's test was used for multiple comparisons. Variance component analysis was performed with factors showing significant effects in the analysis of variance (ANOVA), including age, BW and BF. Duncan's test was used for one-way ANOVA. Repeated measures ANOVA using the MIXED procedure in SAS was used to examine the responses of piglet performance, sow BW and BF. Data are presented as means and standard error of the means. $P < 0.05$ indicated a significant difference.

Table 1
The classification of rearing factors of replacement gilts.

No.	Factors	Groups
1	Age of replacement gilts at first estrus, d	<190, 190 to 199, 200 to 209, 210 to 219, 220 to 229, 230 to 239, 240 to 249, 250 to 259, ≥260 (9 groups)
2	BW of replacement gilts at first estrus, kg	<115, 115 to 124.9, 125 to 134.9, 135 to 144.9, 145 to 154.9, 155 to 164.9, ≥165 (7 groups)
3	BF of replacement gilts at first estrus, mm	<14, 14 to 15, ≥16 (3 groups)
4	Age of replacement gilts at first mating, d	<210, 210 to 219, 220 to 229, 230 to 239, 240 to 249, 250 to 259, 260 to 269, 270 to 279, ≥280 (9 groups)
5	BW of replacement gilts at first mating, kg	<130, 130 to 139.9, 140 to 149.9, 150 to 159.9, 160 to 169.9, 170 to 179.9, ≥180 (7 groups)
6	BF of replacement gilts at first mating, mm	<15, 15 to 16, ≥17 (3 groups)
7	Feeding program before the first mating	flush feeding, no flush feeding (2 groups)
8	The number of estruses at first mating	1, 2, 3, 4, ≥5 (5 groups)

BF = backfat thickness.

3. Results

3.1. Effects of replacement gilts rearing factors on litter size and weaning performance for the first 2 parities

A mixed effects model was used to analyze the effects of replacement gilts rearing factors, including farm, cross combination, age, BW and BF at first estrus; age, BW and BF at first mating; estrous cycle number at first mating; feed program before first mating on TB, BA, HP, and piglets weaned per litter (PW) for the first 2 parities. The fixed factors of farm, replacement gilts age at first estrus and first mating, replacement gilt BF at first estrus, and estrous cycle number at first mating were significantly associated with TB for the first 2 parities (Table 2). The factors of farm, age and BW of the replacement gilt at first estrus and first mating, and feed program before first mating were significantly associated with BA for the first 2 parities. The factors of farm, cross combination, BW of replacement gilt at first estrus, and feed program before first mating were significantly associated with HP for the first 2 parities. Farm, cross combination, replacement gilt age at first estrus, estrous cycle number at first mating, and feed program before first mating influenced pigs weaned for the first 2 parities.

3.2. Effect of replacement gilts rearing factors on retention rates for the first 2 parities

Table 3 shows the multivariate logistic analysis results when adjusted for all other independent variables included in the model. Age and BW of the replacement gilt at first mating, and feed program before first mating influenced the retention rates for the first 2 parities. replacement gilt ≥260 d old at first estrus had lower retention rates for the first 2 parities than did replacement gilt <190 d old (odds ratio [OR]: 0.410; 95% confidence interval [CI]: 0.15 to 1.11). The retention rates of the first 2 parities for replacement gilt at BW of 155 to 164.9 kg and ≥165 kg at first estrus were lower than those of replacement gilt at a BW of <115 kg at first estrus (OR: 0.545 and 0.473, respectively; 95% CI: 0.21 to 1.44 and 0.17 to 1.29, respectively). Replacement gilt aged 270 to 279 d and ≥280 d at first mating had lower retention rates for the first 2 parities than did those <210 d old at first mating (OR: 0.333 and 0.204, respectively; 95% CI: 0.16 to 1.76 and 0.06 to 0.75, respectively). Replacement gilt with BW of 170 to 179.9 kg and ≥180 kg at first mating had lower retention rates for the first 2 parities than did those with BW of <130 kg at first mating (OR: 0.639 and 0.592, respectively; 95% CI: 0.23 to 1.24 and 0.33 to 1.28, respectively). Flush feeding before first mating had higher retention rates for the first 2 parities than did no flush feeding (OR: 1.73; 95% CI: 0.97 to 2.23, respectively).

3.3. Effect of farm and cross combination of sows on reproductive performance and retention rates for the first 2 parities

Fig. 1 shows the results for the reproductive performance and retention rates of the first 2 parities according to farm and cross combination. Farm 3 had more BA piglets than did the other 3 farms ($P < 0.05$). Farm 3 and farm 4 had more HP ($P < 0.05$) than did farm1 and farm 2. Farm 1 had significantly fewer weaned piglets than did the other 3 farms, whereas farm 1 had significantly more (both $P < 0.05$). The retention rates for the first 2 parities were significantly higher on Farm4 than on the other farms ($P < 0.05$). The L × L × Y replacement gilts had more TB, BA, HP, and higher retention rates for the first 2 parities than did L × Y ($P < 0.05$).

3.4. Effect of age of replacement gilts at first estrus and first mating on reproductive performance and retention rates for the first 2 parities

Table 3 compares the reproductive performance and retention rates of the first 2 parities between the groups for age at first estrus and first mating. Replacement gilts whose first estrus occurred at

Table 2
Effect of rearing factors of replacement gilts of mixed-effects model on litter size performance and weaning performance of the first 2 parities.

Item	Total born of 2 parities		Born alive of 2 parities		Healthy piglets of 2 parities		Pigs weaned of 2 parities	
	F value	*P* (>*F*)	*F* value	*P* (>*F*)	*F* value	*P* (>*F*)	*F* value	*P* (>*F*)
Farm	3.21	0.01	2.98	<0.01	3.35	0.02	3.53	0.01
Cross combination	2.08	0.09	1.66	0.10	3.21	0.03	3.21	0.01
Age of replacement gilts at first estrus	2.42	0.02	2.08	0.04	0.72	0.67	2.34	0.02
BW of replacement gilts at first estrus	0.79	0.16	1.89	0.05	2.28	0.03	1.67	0.07
BF of replacement gilts at first estrus	1.88	0.05	0.83	0.56	1.02	0.41	0.96	0.46
Age of replacement gilts at first mating	2.23	0.02	2.10	0.03	1.80	0.07	2.53	0.01
BW of replacement gilts at first mating	1.19	0.28	2.17	0.01	0.35	0.91	1.44	0.19
BF of replacement gilts at first mating	1.48	0.09	0.36	0.92	2.21	0.13	1.75	0.09
Feeding program before the first mating	3.05	0.03	3.27	0.02	2.98	0.04	3.15	0.02
The number of estruses at first mating	2.47	0.04	1.83	0.12	1.28	0.28	2.42	0.01

F = equality of variances; *P* = probability; BF = backfat thickness.

Table 3
Variables included in multivariable logistic regression model on retention rate of the first 2 parities.

Factors	Estimate	SE	OR	95% CI	*P*-value
Intercept	3.066	0.755	21.445	–	0.00
Farms					
Farm 1	–	–	–	–	–
Farm 2	−0.330	0.277	0.719	0.42–1.24	0.23
Farm 3	−0.277	0.379	0.758	0.36–1.59	0.47
Farm 4	−0.371	0.278	0.690	0.40–1.19	0.18
Cross combination					
L × Y	–	–	–	–	–
L × L × Y	0.018	0.342	1.03	0.78–1.37	0.84
Age of replacement gilt at first estrus, d					
<190	–	–	–	–	–
190 to 199	−0.055	0.308	0.946	0.52–1.73	0.86
200 to 209	0.013	0.316	1.014	0.55–1.88	0.97
210 to 219	−0.349	0.331	0.705	0.37–1.35	0.29
220 to 229	−0.038	0.378	0.963	0.46–2.02	0.92
230 to 239	0.090	0.476	1.095	0.43–2.78	0.85
240 to 249	−0.208	0.585	0.812	0.26–2.56	0.72
250 to 259	−0.770	0.579	0.732	0.3–2.9	0.12
≥260	−0.892	0.507	0.410	0.15–1.11	0.04
BW of replacement gilt at first estrus, kg					
<115	–	–	–	–	–
115 to 124.9	0.480	0.425	1.616	0.7–3.72	0.26
125 to 134.9	−0.295	0.397	0.745	0.34–1.62	0.46
135 to 144.9	−0.102	0.430	0.903	0.39–2.1	0.81
145 to 154.9	−0.410	0.456	0.664	0.27–1.62	0.37
155 to 164.9	−0.807	0.494	0.545	0.21–1.44	0.04
≥165	−0.949	0.511	0.473	0.17–1.29	0.02
BF of replacement gilt at first estrus, mm					
<14	–	–	–	–	–
14 to 15	0.114	0.326	1.215	0.38–2.53	0.83
≥16	−0.368	0.367	0.731	0.35–2.26	0.27
Age of gilts at first mating, d					
<210	–	–	–	–	–
210 to 219	−0.368	0.520	0.692	0.25–1.92	0.48
220 to 229	−0.520	0.511	0.595	0.22–1.62	0.31
230 to 239	−0.605	0.531	0.546	0.19–1.55	0.25
240 to 249	−0.373	0.549	0.689	0.23–2.02	0.50
250 to 259	−0.652	0.555	0.521	0.18–1.54	0.24
260 to 269	−0.625	0.590	0.535	0.17–1.7	0.29
270 to 279	−1.029	0.608	0.333	0.16–1.76	0.03
≥280	−1.592	0.665	0.204	0.06–0.75	0.02
BW of replacement gilt at first mating, kg					
<130	–	–	–	–	–
130 to 139.9	−0.021	0.438	0.842	0.53–1.94	0.61
140 to 149.9	−0.053	0.425	0.815	0.51–1.68	0.72
150 to 159.9	−0.029	0.434	0.829	0.44–1.41	0.95
160 to 169.9	−0.043	0.454	0.910	0.58–1.44	0.45
170 to 179.9	−0.914	0.485	0.639	0.23–1.24	0.04
≥180	−1.049	0.546	0.592	0.33–1.28	0.03
BF of replacement gilt at first mating, mm					
<15	–	–	–	–	–
15 to 16	0.052	0.312	1.172	0.45–2.29	0.63
≥17	−0.064	0.351	0.911	0.37–2.16	0.72
Feeding program before the first mating					
No flush feeding	–	–	–	–	–
Flush feeding	1.021	0.642	1.73	0.97–2.23	0.04
The number of estruses at first mating					
1	–	–	–	–	–
2	0.041	0.432	1.071	0.36–3.19	0.90
3	0.048	0.321	1.101	0.37–3.26	0.86
4	0.058	0.415	1.183	0.40–3.53	0.76
≥5	0.025	0.387	1.021	0.33–3.15	0.98

SE = standard error; OR = odd ratio; CI = confidence interval; L × Y = Landrace × Yorkshire; L × L × Y = Landrace × Landrace × Yorkshire; BW = body weight; BF = backfat thickness.

≥260 d of age had the lowest ($P < 0.01$) average BA, HP, PW, and retention rates for the first 2 parities, whereas BA and HP did not significantly differ for replacement gilts whose first estrus occurred at < 260 d old (Table 4). Replacement gilts whose first estrous cycles occurred from 200 to 209 d and 210 to 219 d old had the highest average PW of 25.50 and 25.47, respectively. Retention rates decreased as the replacement gilts age at first estrus increased. Replacement gilts whose first estrous cycles occurred from 190 to 199 d and 220 to 229 d had the highest average retention rates for the first 2 parities (75.93% and 76.17%, respectively). Replacement gilts who first mated at ≥280 d old had the lowest average BA, HP, PW, and retention rates for the first 2 parities ($P < 0.01$). Replacement gilts who first mated at < 210 d old and 250 to 259 d old had the highest average BA (28.38 and 28.25, respectively) and HP (26.18 and 26.24, respectively). Replacement gilts who first mated at < 210 d and 230 to 239 d had the highest average PW (25.66 and 25.52, respectively). Replacement gilts <210 d old had the highest retention rate for the first 2 parities at 85.33%.

3.5. Effect of BW at first estrus and first mating of replacement gilts on reproductive performance and retention rates for the first 2 parities

The BW of replacement gilt at their first estrus and first mating significantly influenced the reproductive performance and retention rates of their first 2 parities (Table 5). Replacement gilt with BW of 155 to 164.9 kg at first estrus had a higher BA (28.68) than did the other groups for the first 2 parities. Replacement gilt with BW of 135 to 144.9 kg and 155 to 164.9 kg had the highest TP of 25.97 and 26.06, respectively. Replacement gilt with BW <115 kg and ≥165 kg had lower PW of 23.99 and 22.72, respectively. Retention rates for the first 2 parities decreased as the replacement gilt age at first estrus increased. Gilt with BW of 115 to 124.9 kg had the highest retention rate at 83.67%. Replacement gilt with BW > 180 kg at first mating had a higher BA (28.44) for the first 2 parities than did the other groups, but their retention rate was the lowest at 59.62%. Replacement gilt with BW of 140 to 149.9 kg had greater HP at 25.39.

3.6. Effect of BF at first estrus and first mating of replacement gilts on reproductive performance and retention rates for the first 2 parities

Table 6 lists the reproductive performance and retention rates for the first 2 parities by BF at first estrus and first mating. Replacement gilt with BF >15 mm at first estrus had higher BA ($P < 0.01$), but a lower retention rate ($P < 0.01$) for the first 2 parities. Healthy piglets per litter and PW did not differ among BF groups at first estrus ($P > 0.05$). Replacement gilts with BF ≥7 mm at first mating had more BA and HP than did those with BF ≤14 mm and from 15 to 16 mm ($P < 0.01$). PW and retention rates did not differ for the first 2 parities among BF groups ($P > 0.05$).

3.7. Effect of flush feeding strategy before first mating of replacement gilts on reproductive performance and retention rates of the first 2 parities

Fig. 2 shows the results for the reproductive performance and retention rates of the first 2 parities according to feeding strategy before first mating of replacement gilts. Flush feeding strategy before first mating of replacement gilts had more TB, BA, and HP, and higher retention rates for the first 2 parities than no flushed replacement gilts ($P < 0.05$).

3.8. Effect of estrous cycle number at first mating of replacement gilts on reproductive performance and retention rates of the first 2 parities

Table 7 shows the reproductive performance and retention rates for the first 2 parities by estrous cycle number at first mating of

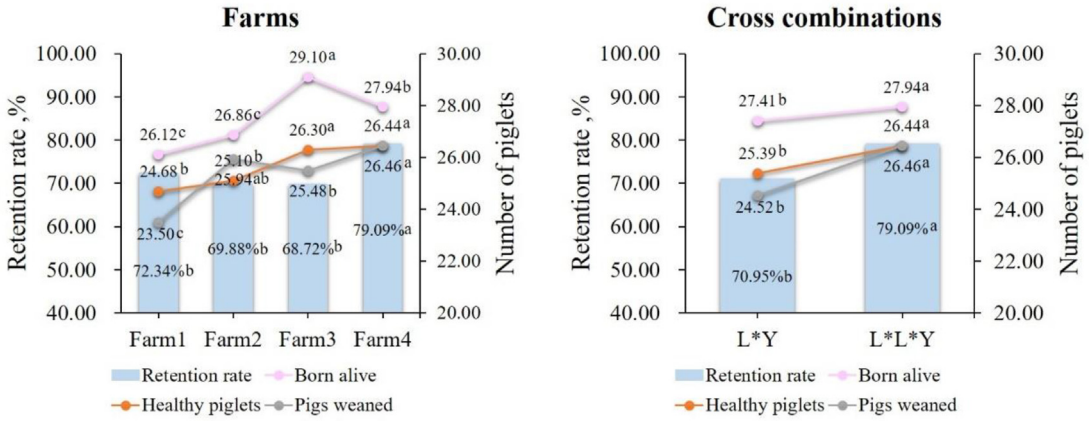

Fig. 1. Effects of farm and cross combination of gilts on reproductive performance and on retention rate of the first 2 parities. [a, b, c] Different letters indicate statistical differences ($P < 0.05$). L × Y = Landrace × Yorkshire; L × L × Y = Landrace × Landrace × Yorkshire.

Table 4
Effect of age at first estrus and at first mating of replacement gilts on reproductive performance (number of piglets) and retention rate of the first 2 parities.

Item	Age of replacement gilt at first estrus, d									SEM	*P*-value
	<190	190 to 199	200 to 209	210 to 219	220 to 229	230 to 239	240 to 249	250 to 259	≥260		
n	183	425	507	400	239	96	51	45	113		
BA of 2 parities	27.36^{a}	28.15^{a}	27.88^{a}	28.09^{a}	26.98^{a}	26.43^{a}	26.29^{a}	27.20^{a}	24.64^{b}	0.11	<0.01
HP of 2 parities	25.37^{a}	25.88^{a}	25.97^{a}	26.24^{a}	25.34^{a}	24.90^{a}	24.41^{a}	25.44^{a}	23.04^{b}	0.10	<0.01
PW of 2 parities	25.20^{ab}	25.00^{ab}	25.50^{a}	25.47^{a}	24.86^{ab}	24.46^{ab}	23.78^{b}	24.11^{ab}	21.43^{c}	0.09	<0.01
Retention rate of 2 parities, %	75.00^{ab}	75.93^{a}	74.43^{ab}	72.21^{ab}	76.17^{a}	74.14^{ab}	69.12^{ab}	64.52^{b}	48.70^{c}	0.27	<0.01
Item	Age of replacement gilt at first mating, d									SEM	*P*-value
	<210	210 to 219	220 to 229	230 to 239	240 to 249	250 to 259	260 to 269	270 to 279	≥280		
n	65	358	473	312	285	219	158	132	57		
BA of 2 parities	28.38^{a}	27.99^{ab}	27.52^{ab}	27.68^{ab}	27.40^{ab}	28.25^{a}	26.78^{b}	26.84^{b}	24.32^{c}	0.11	<0.01
HP of 2 parities	26.18^{a}	25.79^{ab}	25.51^{ab}	25.89^{ab}	25.63^{ab}	26.24^{a}	25.13^{b}	25.53^{ab}	22.42^{c}	0.10	<0.01
PW of 2 parities	25.66^{a}	25.00^{ab}	25.31^{ab}	25.52^{a}	24.62^{ab}	24.98^{ab}	24.46^{b}	24.61^{ab}	21.28^{c}	0.09	<0.01
Retention rate of 2 parities, %	85.33^{a}	77.73^{ab}	75.71^{ab}	72.35^{b}	71.02^{b}	69.77^{b}	69.12^{b}	71.97^{b}	40.74^{c}	0.31	<0.01

BA = born alive per litter; HP = healthy piglets per litter; PW = piglets weaned; SEM = standard error of the mean.
[a,b,c] Within a row, means with different letters indicate statistical differences ($P < 0.05$).

Table 5
Effect of body weight at first estrus and at first mating of replacement gilts on reproductive performance and retention rate of the first 2 parities.

Item	BW of replacement gilt at first estrus, kg							SEM	*P*- value
	<115	115 to 124.9	125 to 134.9	135 to 144.9	145 to 154.9	155 to 164.9	≥165		
n	80	255	367	276	203	782	96		
BA of 2 parities	25.74^{cd}	26.85^{cbd}	27.06^{bc}	27.34^{b}	26.64^{cbd}	28.68^{a}	25.58^{d}	0.11	<0.01
HP of 2 parities	24.43^{bc}	25.31^{ab}	25.61^{ab}	25.97^{a}	25.14^{ab}	26.06^{a}	23.82^{c}	0.10	<0.01
PW of 2 parities	23.99^{b}	25.33^{a}	25.24^{a}	25.18^{a}	24.11^{b}	25.19^{a}	22.72^{c}	0.09	<0.01
Retention rate of 2 parities, %	80.43^{a}	83.67^{a}	75.93^{ab}	73.85^{ab}	73.49^{ab}	68.80^{b}	55.65^{c}	0.29	<0.01
Item	BW of replacement gilt at first mating, kg							SEM	*P*- value
	<130	130 to 139.9	140 to 149.9	150 to 159.9	160 to 169.9	170 to 179.9	≥180		
n	67	283	524	559	375	180	71		
BA of 2 parities	26.30^{c}	26.69^{bc}	27.42^{ab}	27.69^{ab}	27.95^{ab}	27.82^{ab}	28.44^{a}	0.11	0.01
HP of 2 parities	24.70	24.90	25.71	25.72	25.98	25.73	25.65	0.10	0.07
PW of 2 parities	24.27^{b}	24.86^{ab}	25.39^{a}	25.05^{ab}	24.69^{ab}	24.30^{b}	24.85^{ab}	0.09	0.01
Retention rate of 2 parities, %	78.26^{a}	75.71^{ab}	76.43^{ab}	69.88^{abc}	73.40^{abc}	66.53^{cd}	59.62^{d}	0.28	<0.01

BW = body weight; BA = born alive per litter; HP = healthy piglets per litter; PW = piglets weaned; SEM = standard error of the mean.
[a,b,c,d] Different letters indicate statistical differences in the same row ($P < 0.05$).

replacement gilts. The first mating age of the replacement gilts increased significantly as the estrous cycle number increased. Replacement gilts inseminated on their second, third, and fourth estrous cycles had higher BA, HP, and PW ($P < 0.01$). Replacement gilts that first mated at their second estrus had the highest retention rate (76.15%) for the first 2 parities. Overall, replacement gilts whose first mating occurred at their second or third estrus had the best reproductive performance and retention rates.

Table 6
Effect of backfat at first estrus and at first mating of replacement gilts on reproductive performance (number of piglets) and retention rate of the first 2 parities.

Item	BF of replacement gilt at first estrus, mm			SEM	*P*-value
	≤13	14 to 15	≥16		
n	955	635	429		
BA of 2 parities	27.17[b]	27.48[b]	28.42[a]	0.12	<0.01
HP of 2 parities	25.44	25.53	26.15	0.11	0.18
PW of 2 parities	24.59	25.14	25.03	0.09	0.25
Retention rate of 2 parities, %	75.27[a]	73.64[a]	67.89[b]	0.30	<0.01
Item	BF of replacement gilt at first mating, mm			SEM	*P*-value
	≤14	15 to 16	≥17		
n	833	732	494		
BA of 2 parities	27.09[b]	27.32[b]	28.57[a]	0.12	<0.01
HP of 2 parities	25.25[b]	25.56[b]	26.32[a]	0.11	0.04
PW of 2 parities	24.84	24.71	25.48	0.10	0.14
Retention rate of 2 parities, %	71.40	73.57	70.21	0.27	0.42

BF = backfat thickness; BA = born alive per litter; HP = healthy piglets per litter; PW = piglets weaned; SEM = standard error of the mean.
[a,b] Different letters indicate statistical differences in the same row ($P < 0.05$).

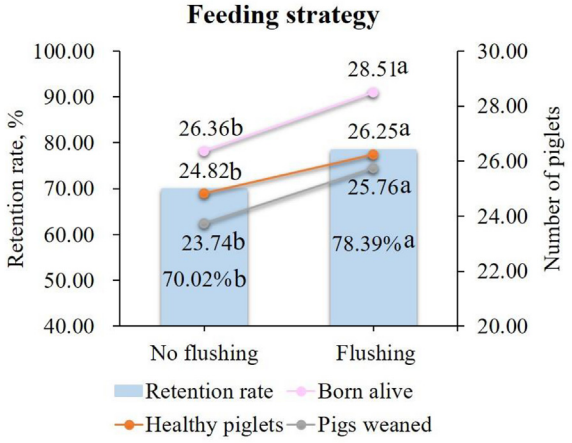

Fig. 2. Effect of flush feeding program before first mating of replacement gilts on reproductive performance and retention rates of the first 2 parities. [a, b] Different letters indicate statistical differences ($P < 0.05$).

3.9. Effect of rearing 100 replacement gilts on litter size and PW for the first 2 parities

Replacement gilts rearing parameters exerted different effects on different reproductive performance traits. Therefore, a comprehensive reproductive index is needed to reflect sow reproductive efficiency. We used 100 replacement gilts as a unit, which yielded the total the number of PW in the first 2 parities as a new index. The unit of 100 replacement gilts yielded litter size and PW number for the first 2 parities by age at first estrus and first mating (Table 8). Replacement gilt aged 190 to 199 d and 200 to 209 d at first observed estrus respectively yielded 20.64% and 24.62% of the population, 2,137.43 and 2,075.11 BA, 1,965.07 and 1,932.95 HP, and 1,898.25 and 1,897.97 PW of the first 2 parities. Although reproductive performance was higher when the initial mating age was less than 210 d, the population proportion was only 3.16%; thus, we recommend 200 to 220 d as the ideal age for first mating. Replacement gilts aged 210 to 219 d and 220 to 229 d at first mating respectively yielded 17.39% and 22.97% of the population, 2,175.66 and 2,083.54 BA, 2,004.66 and 1,931.36 HP, and 1,943.25 and 1,916.22 PW for the first 2 parities. Replacement gilts with BW of 115 to 124.9 kg at first estrus and first mating yielded 12.38% of the population, 2,246.54 BA, 2,117.69 HP and 2,119.36 PW for the first 2 parities (Table 9). Replacement gilts with BW of 140 to 149.9 kg at first mating had 25.45% of the population, 2,095.71 BA, 1,965.02 HP and 1,940.56 PW of the first 2 parities. We recommend BF of 14 to 15 mm at first estrus and 15 to 16 mm at first mating, which respectively yielded 30.84% and 35.55% of the population, 2,023.32 and 2,010.13 BA, 1,880.22 and 1,880.27 HP, and 1,850.97 and 1,817.85 PW of the first 2 parities (Table 10).

4. Discussion

We evaluated the effects of different rearing factors among replacement gilts on reproductive traits, including TB, BA, HP, PW, and retention rate of the first 2 parities. We comprehensively considered the related factors of replacement gilt rearing and obtained a large amount of data. To our knowledge, this is the most extensive report to date on replacement gilt rearing. Farm, age, BW, BF at first estrus and first mating, estrous cycle number at first mating, and feeding programs before mating were significantly associated with reproductive performance and retention rates for the first 2 parities.

Our results showed that the reproductive performance and retention rates of sow were different among farms, which may be related to the management level of different farms. In addition, farm factors, including herd size, herd performance and management practices have been shown to be associated with sow level predictors for sow lifetime performance (Koketsu and Iida, 2020). Replacement gilts reach puberty at their first estrus with an onset of reproductive capability (Roongsitthichaid et al., 2013; See et al., 2018; Knox, 2019). Previous studies had shown that replacement gilts reach puberty depending on minimum thresholds of age, BW and BF content (Hu et al., 2016; Patterson and Foxcroft, 2019; Graves et al., 2019). Some data suggest that the age at first estrus has a positive predictive value for future reproductive performance within a rearing herd (Tummaruk et al., 2007; Roongsitthichai et al., 2013; Masaka et al., 2014). Patterson et al. (2010) reported

Table 7
Effects of the number of estruses at first mating of replacement gilt on reproductive performance (number of piglets) and on retention rate of the first 2 parities.

Item	The number of estruses at first mating					SEM	*P*- value
	1	2	3	4	≥5		
n	594	697	547	195	26		
Age at first mating, d	237.47[cd]	225.77[d]	243.86[c]	262.24[b]	278.09[a]	0.41	<0.01
BA of 2 parities	26.61[b]	27.91[a]	28.00[a]	27.75[a]	26.23[b]	0.13	<0.01
HP of 2 parities	24.85[b]	25.85[a]	26.07[a]	26.03[a]	24.38[b]	0.10	<0.01
PW of 2 parities	23.93[b]	25.55[a]	25.31[a]	25.06[a]	23.65[b]	0.09	<0.01
Retention rate of 2 parities, %	69.70[bc]	76.15[a]	70.98[b]	73.47[ab]	65.71[c]		<0.01

BA = born alive per litter; HP = healthy piglets per litter; PW = piglets weaned; SEM = standard error of the mean.
[a,b] Different letters indicate statistical differences in the same row ($P < 0.05$).

Table 8
Effect of age at first estrus and at first mating of gilts on reproductive efficiency of sows (number of litter size and weaning piglets of the first 2 parities per 100 gilts).

Item	Age of gilts at first estrus, d								
	<190	190 to 199	200 to 209	210 to 219	220 to 229	230 to 239	240 to 249	250 to 259	≥260
Proportion, %	8.89	20.64	24.62	19.43	11.61	4.66	2.48	2.19	5.49
Total BA of 2 parities	2,052.00	2,137.43	2,075.11	2,028.38	2,055.07	1,959.52	1,817.16	1,754.94	1,199.97
Total HP of 2 parities	1,902.75	1,965.07	1,932.95	1,894.79	1,930.15	1,846.09	1,687.22	1,641.39	1,122.05
Total PW of 2 parities	1,890.00	1,898.25	1,897.97	1,839.19	1,893.59	1,813.46	1,643.67	1,555.58	1,043.64
Item	Age of gilts at first mating, d								
	<210	210 to 219	220 to 229	230 to 239	240 to 249	250 to 259	260 to 269	270 to 279	≥280
Proportion, %	3.16	17.39	22.97	15.15	13.84	10.64	7.67	6.41	2.77
Total BA of 2 parities	2,421.67	2,175.66	2,083.54	2,002.65	1,945.95	1,971.00	1,851.03	1,931.67	990.80
Total HP of 2 parities	2,233.94	2,004.66	1,931.36	1,873.14	1,820.24	1,830.76	1,736.99	1,837.39	913.39
Total PW of 2 parities	2,189.57	1,943.25	1,916.22	1,846.37	1,748.51	1,742.85	1,690.68	1,771.18	866.95

BA = born alive per litter; HP = healthy piglets per litter; PW = piglets weaned.

Table 9
Effect of body weight at first estrus and at first mating of gilts on reproductive efficiency of sows (number of litter size and weaning performance of the first 2 parities per 100 gilts).

Item	BW of gilts at first estrus, kg						
	<115	115 to 124.9	125 to 134.9	135 to 144.9	145 to 154.9	155 to 164.9	≥165
Proportion, %	3.89	12.38	17.82	13.40	9.86	37.98	4.66
Total BA of 2 parities	2,070.27	2,246.54	2,054.67	2,019.06	1,957.77	1,973.18	1,423.53
Total HP of 2 parities	1,964.90	2,117.69	1,944.57	1,917.88	1,847.54	1,792.93	1,325.58
Total PW of 2 parities	1,929.52	2,119.36	1,916.47	1,859.54	1,771.84	1,733.07	1,264.37
Item	BW of gilts at first mating, kg						
	<130	130 to 139.9	140 to 149.9	150 to 159.9	160 to 169.9	170 to 179.9	≥180
Proportion, %	3.25	13.74	25.45	27.15	18.21	8.74	3.45
Total BA of 2 parities	2,058.24	2,020.70	2,095.71	1,934.98	2,051.53	1,850.86	1,695.59
Total HP of 2 parities	1,933.02	1,885.18	1,965.02	1,797.31	1,906.93	1,711.82	1,529.25
Total PW of 2 parities	1,899.37	1,882.15	1,940.56	1,750.49	1,812.25	1,616.68	1,481.56

BW = body weight; BA = born alive per litter; HP = healthy piglets per litter; PW = piglets weaned.

Table 10
Effect of backfat at first estrus and at first mating of gilts on reproductive efficiency of sows (number of litter size and weaning performance of the first 2 parities per 100 gilts).

Item	BF of gilts at first estrus, mm		
	≤13	14 to 15	≥16
Proportion, %	48.32	30.84	20.84
Total BA of 2 parities	2,044.87	2,023.32	1,929.59
Total HP of 2 parities	1,914.92	1,880.22	1,775.45
Total PW of 2 parities	1,841.05	1,850.97	1,699.17
Item	BF of gilts at first estrus, mm		
	≤14	15 to 16	≥17
Proportion, %	40.46	35.55	23.99
Total BA of 2 parities	1,933.92	2,010.13	2,005.81
Total HP of 2 parities	1,803.20	1,880.27	1,848.19
Total PW of 2 parities	1,773.63	1,817.85	1,788.92

BF = backfat thickness; BA = born alive per litter; HP = healthy piglets per litter; PW = piglets weaned.

that replacement gilts exhibiting their first estrous behavior at 154 to 180 d old have fewer nonproductive days. Additionally, replacement gilts who reached estrus at > 180 d of age had a lower service rate than did replacement gilts whose first estrus occurred at < 180 d of age (Patterson et al., 2010). The age range for first estrus varies widely. A survey of one herd revealed that first estrus occurred between 147 and 287 d of age and mainly between 196 and 210 d of age (Roongsitthichai et al., 2013). Similarly, 77.6% of replacement gilts exhibited standing estrus within 35 d of starting boar stimulation at around 190 d of age (Filha et al., 2010). We found that replacement gilts exhibiting first estrus at 190 to 230 d old yielded more PW and higher retention rates for the first 2 parities. One study found that crossbred L × Y replacement gilts showed first estrus at 195 d old at BW of 106 kg (range 73 to 112 kg) and BF of 13.0 mm (Tummaruk et al., 2007). Additionally, when replacement gilts had their first observed estrus between 181 and 200 d of age with 110.1 to 120.0 kg BW and 13.1 to 15.0 mm BF, the mean TB and BA were highest in the first 3 parities (Tummaruk et al., 2007). Our results suggest that replacement gilt BW of 155 to 164.9 kg at first estrus had higher BA; BW of 135 to 144.9 kg and 155 to 164.9 kg had the highest TP; BW of 11 to 165 kg had more PW; and BW of 115 to 124.9 kg had the highest retention rate of 83.67%. Although different optimal reproductive performance indexes were achieved, the BW range at first estrus was inconsistent, and BW too high or too low was not a disadvantage for reproductive performance. Backfat thickness >15 mm at first estrus yielded larger BA but a lower retention rate for the first 2 parities. Therefore, it should be comprehensively evaluated.

Replacement gilt age, BW and BF at first mating influence subsequent sow reproductive performance and longevity (Tummaruk and Tantasuparuk, 2015; Kraeling and Webel, 2015). DanBred suggests that replacement gilts reach maximum productivity at 230 to 250 d old, with a weight of 130 to 155 kg and BF of 12 to 15 mm (DanBred, 2018). Roongsitthichai et al. (2013) reported that most replacement gilts were first inseminated between 217 and 238 d (31 and 34 weeks) of age, and 46.7% of these replacement gilts weighed 140 kg, while only 6.9% of them weighed 150 kg when entering the rearing unit. Filha et al. (2010) observed that replacement gilts with heavier BW and BF > 17 mm at first

insemination had a decreased farrowing rate at parity 2, and those replacement gilts were at risk for low retention and locomotion problems over 3 parities. For commercial farms with TN70 replacement gilts, the recommendations are 220 to 245 d of age and 165 to 180 kg BW to obtain an optimal litter size for the first parity (Fan et al., 2020). Our results demonstrated that replacement gilt first mating after 280 d of age had a lower average BA, HP, PW, and retention rate for the first 2 parities. Replacement gilt first mating at 230 to 239 d had the highest average PW, while those first mating before 210 d old had a higher retention rate for the first 2 parities. Replacement gilt with BW > 180 kg at first mating had a higher BA but the lowest retention rate. However, replacement gilt with BF > 17 mm at first mating had a higher BA, but no other indicators differed. Similar to the first estrus parameters, we found different optimal reproductive performance indexes, and the age, BW and BF range for the first mating differed. Therefore, a new index is needed.

Overall, the effects of rearing parameters on optimal reproductive performance indexes were inconsistent. We used 100 replacement gilts as a unit to obtain the total number of PW in the first 2 parities as a new index. The optimal age at first estrus and first mating for replacement gilts were 190 to 210 d and 210 to 230 d, respectively. The optimal BW at first estrus and first mating were 115 to 125 kg and 140 to 150 kg, respectively, and the optimal BF at first estrus and first mating were 14 to 15 mm and 15 to 16 mm, respectively.

5. Conclusions

We evaluated the effects of different rearing factors among replacement gilts on reproductive traits. Age, BW and BF at first estrus and first mating, the estrous cycle number at first mating and flush feeding before mating were significantly associated with reproductive performance and retention rates of the first 2 parities. Because the effects of replacement gilt rearing parameters on reproductive performance traits were inconsistent, we used 100 replacement gilts as a unit to obtain the total number of PW from the first 2 parities as a new index. The results provide new insight into the complex relationships among these variables. The litter size and weaning performance of the first 2 parities per 100 replacement gilts were best for replacement gilts undergoing their first estrus at 180 to 210 d, with 115 to 124.9 kg BW and 14 to 15 mm BF and first mating at 210 to 230 d, with 140 to 149.9 kg BW and 15 to 16 mm BF. These findings may support successful replacement gilt management as a pivotal starting point for the future fertility and longevity of rearing herds.

Author contributions

Jiajian Tan: investigation, data curation, writing-original draft. **Miaomiao Wang:** formal analysis, methodology. **Haiqing Sun:** methodology, resources. **Chao Wang:** formal analysis, software. **Hongkui Wei:** conceptualization, formal analysis. **Siwen Jiang:** project administration, supervision. **Yuanfei Zhou:** conceptualization, methodology, formal analysis, writing - review & editing. **Jian Peng:** conceptualization, funding acquisition, supervision, writing - review & editing.

Declaration of competing interest

We declare that we have no financial and personal relationships with other people or organizations that can inappropriately influence our work, and there is no professional or other personal interest of any nature or kind in any product, service and/or company that could be construed as influencing the content of this paper.

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