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Postural changes, nursing behavior, and production performance of two breeds of sows in enriched environment

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ABSTRACT - This study was performed to compare changes in posture, nursing behavior, and production performance of two breeds of sows. The posture, postural changes, nursing behavior, and production performance of hybrid Damin (Large White × Min pig, n = 32) and Landrace × Large White (n = 32) sows were observed by video recording for 72 h after farrowing and from 07:00 to 09:00 h and 13:00 to 15:00 h within any successive two-day period of each week from the two to five weeks postpartum. The production performances were compared between the two breeds. Except standing at days 1 to 3 postpartum and sitting at day 2 postpartum, there were significant differences in postures between the two breeds of sows. The frequency of ventral-to-lateral recumbency at day 1 and weeks 4 and 5 postpartum and sitting-to-lying at days 1 and 3 and weeks 4 and 5 postpartum was significantly lower for the Damin than for Landrace × Large White sows. The frequency of standing-to-lying in the first 72 h postpartum was significantly higher for the Damin than for Landrace × Large White sows. At days 2 and 3 postpartum, piglet loss was significantly lower for the Damin than for Landrace × Large White sows. The duration of parturition and farrowing interval were significantly longer for the Landrace × Large White than for Damin sows. The number of live piglets was higher for the Damin than for Landrace × Large White sows. The birth weight of litters and weaning weight of piglets were lower for Damin than for Landrace × Large White piglets. These data suggest that the Damin sows showed stronger maternal instincts through their behaviors and postural changes compared with the Landrace × Large White sows.

Keywords: behaviours, Damin, Landrace × Large White

1. Introduction

Loss of pre-weaning piglets is an important economic and animal welfare problem in swine production. Previous studies have shown that the pre-weaning piglet mortality rate is 11% (Lay Jr., 2002; Roehe et al., 2009; Mazzoni et al., 2018); and other studies have shown that the total number of piglets killed by the sow was 52.1% of pre-weaning piglet mortality, and the crushing of piglets by sows was the major cause of piglet mortality (Damm et al., 2005; Danholt et al., 2011). Piglets are considered to be in greater danger when the sow lies down laterally instead of vertically, especially when the sow lies down by falling on her side (Blackshaw and Hagelsø, 1990; Wechsler and Hegglin, 1997). In a study, the amount of time sows spent sitting was positively correlated with the number of piglets that were crushed, and sows that spent more time sitting seemed more likely to crush piglets (McGlone and Morrow-Tesch, 1990). Rolling behavior is also considered one of the most dangerous movements to piglets (Weary et al., 1996; Wechsler and Hegglin, 1997). Sows spend most of their time in lateral recumbency during parturition and during the first day postpartum (Petersen et al., 1990; Jarvis et al., 1999; Pedersen et al., 2003; Vieuille et al., 2003); therefore, sows must occasionally roll from one side to the other for comfort. The danger of such movements is associated not only with the speed and manner in which the movements are performed but also the frequency of the movements. In addition, breast-feeding influences piglet survival, and increasingly more research is being carried our in this field (Lammers and De Lange, 1986; Edwards and Furniss, 1988). Unfortunately, many conclusions of such studies were found to be inconsistent from previously published works. Many studies have examined maternal behavior in enriched environments (Herskin et al., 1998; Jarvis et al., 2004); however, few have focused on the posture and nursing behavior of different varieties of sows within the same indoor enriched environment. Thus, by using two different breeds of sows, this study was performed to examine the postures and posture-transforming and location behaviors of sows in an effort to improve the survival rate of piglets in a relaxed environment.

The selective breeding in modern swine production mainly focuses on the growth traits of the pigs rather than the maternal ability of the sows (Gourdine et al., 2010). Actually, lactation behavior is significant in swine production, especially in terms of improving farming management practices. The Min pig is a local breed found in northeastern China. It has been characterized as prolific (14.35 piglets per birth) and a good source of meat, and has strong resistance to poor feed quality and cold climates. Thus, the Min pig or its offspring is the preferred breed for local production practices in China.

A good maternal instinct is another outstanding characteristic of the Min pig breed. At the weaning age of 60 days, the sow of this breed has approximately 11 to 12 live piglets per litter (Cui et al., 2011). Thus, by utilizing the maternal advantages of the Min pig, we bred Damin sows (Large White × Min pig) in this study.

This research was performed to compare the behavior and changes in posture of Damin sows with those of Landrace × Large White sows aiming at providing valuable behavioral observations of these local breeds to future pig production.

2. Material and Methods

All procedures used for the study were approved by the institutional animal care and use committee (case no. IACECNEAU20121013). This study was performed in Harbin, Heilongjiang Province, China (45°31'12" E longitude, 126°57'11" N latitude, and 126 m altitude).

Sixty-four first-parity sows of the same age (32 Damin, 32 Landrace × Large White sows) were mated with Duroc (Canadian) males. The litter sizes of Damin and Large White were 14.0±1.4 and 12.3±1.5, respectively. The backfat and body weight of the Landrace × Large White sows and Damin sows showed no significant difference at the time of mating (20.14±1.25 vs. 21.03±0.34 mm and 188.40±5.20 vs. 189.88±4.99 kg, respectively). Sows fed on an automatic feeder in a group-housing pen (5.7 m width × 4.5 m length, containing 10 pregnant sows). The ground was made of concrete and covered with straw. Three water sources were used for natural ventilation for the pregnant sows during pregnancy. The sows were transferred to the farrowing pens seven days before the expected due date. They were randomly assigned to movable individual farrowing pens.

The size of the parturition pen was 4800 × 1600 mm, and each parturition pen was made and separated using galvanized tubes (Figure 1). A straw board was set in the parturition pen, which was divided into lying and active regions. The floor material was concrete, and the slope was 18°. Straw with a maximum thickness of 0.05 m was used as litter material in all parturition pens and supplemented after cleaning every morning.

The sows were fed twice daily (at 07:30 and 16:00 h) in the farrowing pens. The sows were fed 3 kg per day pre-parturition, and the quantity of feed was reduced by 0.5 kg per day in the week pre-parturition. On the first day after farrowing, the sows were fed 0.5 kg. On each of the following days, this amount

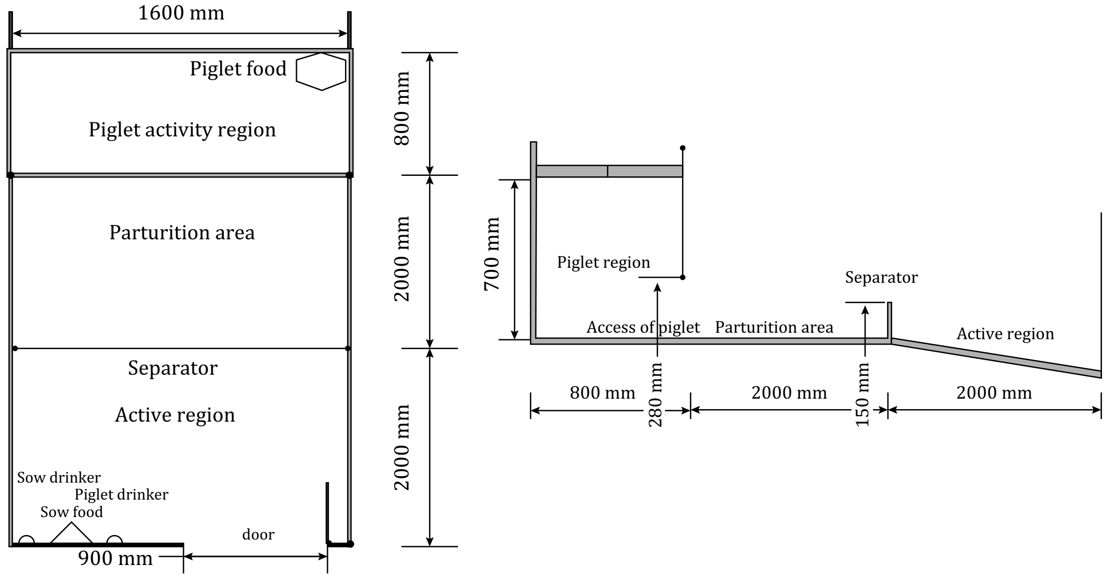

Figure 1 - Structure of the parturition pen.

was increased by 0.5 kg per day until the sows could feed *ad libitum*. After weaning and until mating, the amount of feed for the primiparous sows was decreased to 3 kg per day. All sows were restrictively fed with complete feed. The feed contained the following constituents per kilogram: 12.9 MJ metabolizable energy, 185.0 g crude protein, 50.0 g crude fat, 80.0 g crude ash, and 12.0 g lysine.

During the study period, the temperature and relative humidity of the interior and exterior of the parturition pens was measured daily with a hygrothermograph (Kestrel 4000 Pocket Weather Tracker; Kestrel, Santa Cruz, CA, USA). The daily temperature and humidity inside the farrowing pens ranged from 17 to 22 °C and from 56.8 to 76.4%, respectively, in September. There was a light program at night in the farrowing pen and the illumination was about 30–40 lx. There was a light program and insulation facilities to piglets at 14 days postpartum.

The behaviors of the sows were video-recorded with continuous focal-sampling recording by a video surveillance system (DS-IT5; Hangzhou Hikvision Digital Technology Co., Ltd., Hangzhou, China) for data acquisition to prevent artificially delimited observation times from impacting the test results. At farrowing, all sows were videotaped for 72 h, starting from the first birth of piglets. The 24-h period following the birth of the first piglet was considered day 1 (d1) postpartum. The subsequent 24-h period was day 2 (d2), and the following day was day 3 (d3). During weeks 2 and 5 postpartum, the sows were videotaped twice each week for two consecutive days from 09:30 to 11:30 h and from 13:00 to 15:00 h. Behavioral data from the video records were analyzed. The various behavioral traits are defined in Table 1.

Duration of parturition, farrowing intervals, and numbers of piglets produced were accurately recorded for all sows from the window in the back of the parturition pen. Other recorded parameters included the number of stillborn piglets, number of piglets lost within the first three days postpartum, number of piglets lost at weaning, birth weight of piglets, and weight of piglets at weaning. The mortality rate of the pre-weaning piglets was simply analyzed in terms of sows' postural changes in the first three days postpartum (e.g., lateral recumbency to other postures, ventral recumbency to other postures, standing to lying, and sitting to lying).

All dependent variables were examined for normal distribution using PROC UNIVARIATE of SAS software (Statistical Analysis System, version 9.0) with consideration of skewness, kurtosis, the Shapiro–Wilk test for normality, and a normal probability plot. Variables that were not normally distributed were log-transformed. Variables that were not normally distributed, even when

Table 1 - Behavioral parameters and their definitions[1]

Behavior	Definition
Standing	Assuming or maintaining an upright position on extended legs but remaining stationary[1]
Ventral recumbency	Sow's chest and abdomen touching the floor and front legs stretched or folded under the body[1]
Lateral recumbency	Side contacting the ground[1]
Sitting	Most of sow's body weight and posterior region of her body trunk in contact with and supported by the ground[1]
Lateral recumbency to other postures	Posture change from lateral recumbency to other positions including ventral recumbency, sitting, and standing[1]
Ventral-to-lateral recumbency	Posture change from ventral recumbency to lateral recumbency[1]
Sitting-to-lying	Posture change from sitting to lying, including ventral and lateral recumbency
Standing-to-lying	Posture change from standing to lying, including ventral and lateral recumbency
Duration of nursing bouts	From the time point at which 80% of piglets are engaged in initial massage to the time point at which <80% of the litter is attached to the teats
Nursing frequency	Number of times that sows release milk within a predetermined time period (Gustafsson et al., 1999)

[1] Some behavioral parameters and their definitions are quoted from Hurnik et al. (1995).

log-transformed, were divided into classes. The state behavior was presented as a percentage of the total observations, and the event behavior (such as lateral recumbency to other postures, ventral-to-lateral recumbency, and sitting-to-lying and standing-to-lying movements) was presented as the frequency of the occurrence per hour. Statistical analysis method of Duncan in a general linear model procedure (GLM) in SAS was used to test the behavioral differences between the two breeds and assess time-dependent observations. In addition, Pearson's correlation coefficient in SAS was used to test the Correlations between sows' postural changes in the first three days postpartum and piglet mortality. Because of the different objectives of the observations, time was divided into two separate modules for three days postpartum and weeks 2 to 5 postpartum, as shown below.

The model for the behavioral analysis during the first three days after parturition included the following effects:

$$Y_{ijk} = \mu + Breed_i + Day_j + Breed_i \times Day_j + e_{ijk},$$

in which μ is a general mean, $Breed_i$ is the fixed effect of the breed, Day_j is the fixed effect of the observation day after parturition (d1, d2, or d3), $Breed_i \times Day_j$ is the interaction between the breed and observation day, and e_{ijk} is the random errors associated with observation.

The model for the behavioral analysis during weeks 2 and 5 after parturition included the following effects:

$$Y_{ijkl} = \mu + Breed_i + Week_j + Period_k + Breed_i \times Week_j + Breed_i \times Period_k + e_{ijkl},$$

in which μ is a general mean, $Breed_i$ is the fixed effect of the breed of sow, $Week_j$ is the fixed effect of the observation week after parturition (week 2 or 5), $Period_k$ is the fixed effect of the period during the observation day (07:00-09:00 h or 3:00-15:00 h), $Breed_i \times Week_j$ is the interaction between the breed and the observation week, $Breed_i \times Period_k$ is the interaction between the breed and the period during the observation day, and e_{ijkl} is the random errors associated with observation.

Similarly, analyses were performed using the general linear model procedure for production differences between the two breeds. The following model was set up:

$$Y_{ij} = \mu + Breed_i + e_{ij},$$

in which μ indicates the overall average, $Breed_i$ indicates the effect of the breed on productive features, Y_{ij} indicates the productive features, and e_{ij} is the random errors associated with observation.

Similarly, analyses were performed using the general linear model procedure for production differences between the two breeds. The following model was set up:

$$Y_{ijk} = \mu + Breed_i + Behavior_j + e_{ijk},$$

in which μ indicates the overall average, $Breed_i$ indicates the effect of the breed on data of productive features, $Behavior_j$ indicates the effect of the behavior (lateral recumbency to other postures, ventral to lateral recumbency, standing-to-lying, and sitting-to-lying) on piglet losses during the first three days postpartum, and e_{ijk} is the random errors associated with observation. All data are presented as mean ± standard error.

3. Results

After farrowing, the time spent in lateral recumbency during the first three days was significantly greater for the Damin than for Landrace × Large White sows (d1, P = 0.034; d2, P = 0.041; d3, P = 0.045), and with increased lactation, the lateral recumbency time of the sows decreased (Table 2). There was no significant difference between the two breeds in the lateral recumbency at weeks 2 and 3 postpartum; at weeks 4 and 5, however, we noted significant differences between the two breeds (P = 0.004; P = 0.006, respectively). In addition, on the first three days postpartum, we noted significant differences between the two breeds in the lateral recumbency (P<0.05). During days 1 to 3 postpartum, the time spent in ventral recumbency was significantly lower for the Damin than for Landrace × Large White sows (d1, P<0.01; d2, P = 0.008; d3, P = 0.009). With increased lactation, both breeds of sows showed gradual daily increases in the time spent in ventral recumbency; moreover, after farrowing, the time spent in ventral recumbency at weeks 4 and 5 were significantly lower for Damin than for Landrace × Large White sows (P<0.05).

Table 2 - Time spent in ventral and lateral recumbency, standing, and sitting for Damin and Landrace × Large White sows during the first three days postpartum and weeks 2 to 5 postpartum (%)

Behavior	Breed	Day 1	Day 2	Day 3	Time effect	Week 2	Week 3	Week 4	Week 5	Time effect
Lateral recumbency	Damin	92.0x±3.27	91.3x±4.12	89.2x±3.72	P>0.05	83.1a±17.05	70.8b±26.82	58.5cx±10.56	52.4dx±11.85	P<0.01
	Landrace × Large White sows	88.3ay±3.36	87.9aby±4.23	85.3by±3.71		81.9a±12.38	68.7b±20.82	48.7cy±8.91	42.5dy±7.67	
	Breed effect		P<0.05				P = 0.078			
Ventral recumbency	Damin	2.8x±1.02	3.5x±1.00	4.5x±0.98	P>0.05	5.8a±2.67	14.1b±2.71	12.9bx±3.98	15.2cx±4.56	P<0.01
	Landrace × Large White sows	5.5ay±1.20	7.0aby±0.88	8.7by±0.90		6.5a±2.30	14.2b±3.06	14.7by±5.44	17.6cy±5.30	
	Breed effect		P<0.01				P = 0.145			
Standing	Damin	4.8±0.16	4.6±0.15	5.7±0.36	P>0.05	6.7a±0.45	7.5b±0.36	14.5cx±0.36	16.8cx±0.48	P<0.01
	Landrace × Large White sows	4.8±0.15	4.4±0.23	5.2±2.19		7.2a±0.29	8.0b±049	17.4cy±0.40	21.3cy±0.51	
	Breed effect		P>0.05				P = 0.091			
Sitting	Damin	0.3x±0.22	0.5±0.28	0.4x±0.18	P>0.05	3.7a±0.02	7.5b±0.08	14.0cx±0.08	15.5cx±0.92	P<0.01
	Landrace × Large White sows	1.3ay±0.48	0.6b±0.63	0.7by±0.82		4.3a±0.48	9.0b±0.63	19.1cy±0.82	20.5cy±0.28	
	Breed effect		P = 0.048				P =1.212			

a,b - Different letters in the same row indicate significant differences between observation days (P<0.05).
x,y - Different letters in the same column indicate significant differences between breeds (P<0.05).
Data are presented as mean ± standard error.

At three days postpartum and two to three weeks postpartum, there were no significant differences between the two breeds of sows (Table 2). By weeks 4 and 5 postpartum, the time spent standing was significantly lower for the Damin than for Landrace × Large White sows (P<0.05). In addition, on postpartum subsection days 1 and 3 and weeks 4 to 5 postpartum, the Landrace × Large White sows spent a significantly longer time in the sitting position than did the Damin sows (P<0.05). Furthermore, the sitting behavior was not significantly different between the two breeds at day 2 and weeks 2 to 3 postpartum (P>0.05).

At three days postpartum, all postural changes between the two breeds showed marked changes (P<0.05), except the ventral-to-lateral recumbency at two to three days postpartum and sitting-to-lying at day 2 postpartum (Table 3). In addition, at three days postpartum, the incidence of the lateral recumbency to other postures was significantly higher for Damin than for Landrace × Large White sows (d1, P = 0.024; d2, P = 0.037; d3, P = 0.039). This frequent change in posture for Damin sows was significantly lower than that for Landrace × Large White sows at weeks 4 and 5 postpartum (week 4, P = 0.044; week 5, P = 0.047).

Furthermore, the incidence of the ventral-to-lateral recumbency on day 1 postpartum was significantly lower for Damin than for Landrace × Large White sows (P = 0.014). At weeks 4 and 5 postpartum, the ventral-to-lateral recumbency behavior was significantly higher for the Landrace × Large White sows than Damin sows (P = 0.015; P = 0.018, respectively). At three days postpartum, the frequencies of standing to lying was significantly higher for the Damin sows than Landrace × Large White sows (d1, P = 0.002; d2, P = 0.003; d3, P = 0.007). And at weeks 4 and 5 postpartum, the standing to lying behavior was higher for the Damin than for Landrace × Large White sows (week 4, P = 0.024; week 5, P = 0.037). At days 1 and 3 postpartum, the Damin sows showed a significantly lower incidence of sitting-to-lying down than did the Landrace × Large White sows (d1,

Table 3 - Frequencies of postural changes of Damin and Landrace × Large White sows living indoors at the first three days and weeks 2 to 5 postpartum (/h)

Postural changes/h	Breed	Day 1	Day 2	Day 3	Time effect	Week 2	Week 3	Week 4	Week 5	Time effect
Lateral recumbency to other postures	Damin	1.31ax±0.16	1.48abx±0.15	1.14bx±0.36	P<0.05	1.29a±0.45	1.35b±0.36	1.67cx±0.36	1.90dx±0.48	P<0.001
	Landrace × Large White sows	0.90ay±0.15	0.81aby±0.23	0.55by±2.19		1.30a±0.29	1.39b±049	2.20cy±0.40	2.5dy±0.51	
	Breed effect		P = 0.023				P<0.01			
Ventral-to-lateral recumbency	Damin	1.04ax±0.16	1.29ab±0.15	1.44b±0.36	P<0.05	1.31a±0.45	1.39b±0.36	1.46bx±0.36	1.98cx±0.48	P<0.001
	Landrace × Large White sows	1.15ay±0.15	1.22ab±0.23	1.40b±2.19		1.48a±0.29	1.35a±049	2.00by±0.40	2.45cy±0.51	
	Breed effect		P = 0.047				P<0.01			
Standing-to-lying	Damin	0.54ax±0.16	0.65abx±0.15	0.96bx±0.36	P<0.05	0.65a±0.45	0.66a±0.36	1.01bx±0.36	1.45bx±0.48	P<0.001
	Landrace × Large White sows	0.42ay±0.15	0.35aby±0.23	0.39by±2.19		0.62a±0.29	0.70a±0.42	0.78by±0.40	0.98by±0.51	
	Breed effect		P = 0.028				P<0.01			
Sitting-to-lying	Damin	0.33x±0.16	0.53±0.15	0.53x±0.36	P<0.05	0.65a±0.45	0.66a±0.36	0.78bx±0.36	0.98bx±0.48	P<0.001
	Landrace × Large White sows	1.15ay±0.15	1.22b±0.23	1.40by±2.19		0.78a±0.29	0.75a±049	1.01by±0.40	1.45by±0.51	
	Breed effect		P = 0.230				P = 0.018			

Data are presented as mean ± standard error.
a,b - Different letters in the same row indicate significant differences between observation days (P<0.05).
x,y - Different letters in the same column indicate significant differences between breeds (P<0.05).

P = 0.028; d3, P = 0.032). At weeks 4 and 5 postpartum, the Landrace × Large White sows showed a significantly higher frequency of sitting-to-lying than did the Damin sows (week 4, P = 0.033; week 5, P = 0.044).

The duration of nursing bouts was similar between the two breeds of sows (Table 4). Furthermore, the nursing frequency in weeks 2, 3, 4, and 5 after farrowing was significantly higher for the Damin than for Landrace × Large White sows (P<0.05).

The duration of parturition and the farrowing interval were significantly greater for the Landrace × Large White than for Damin sows (P<0.05). The number of live piglets was significantly higher for the Damin than for Landrace × Large White sows (P<0.05). At three days postpartum, the ratio of piglet loss was significantly lower for the Damin than for Landrace × Large White sows (8.2% vs. 12.7%, respectively; P<0.05). There were no significant differences in piglet loss during the first 24 h postpartum, piglet loss from the fourth day postpartum to weaning, or the number of stillbirths between the two breeds (P>0.05). The litter birth weight and average weaning weight of the piglets were lower for the Damin than Landrace × Large White piglets (P<0.05) (Table 5).

At three days postpartum, piglet mortality was not correlated with all postural changes in both breeds of sows, except at day 1 postpartum, when piglet mortality was correlated with standing-to-lying in both breeds of sows (Table 6).

Table 4 - Nursing behaviors of Damin and Landrace × Large White sows at weeks 2 to 5 postpartum

	Breed	Week 2	Week 3	Week 4	Week 5	Time effect
Duration of nursing bouts(s)	Damin	14.67±0.36	13.86±0.34	13.50±0.69	12.08±0.42	P>0.05
	Landrace × Large White sows	14.84±0.34	13.78±0.32	13.04±0.64	12.55±0.45	
	Breed effect	P>0.05				
Nursing frequency (/h)	Damin	1.38x±0.04	1.37x±0.04	1.37x±0.04	1.35x±0.04	P>0.05
	Landrace × Large White sows	1.24y±0.03	1.22y±0.03	1.10y±0.03	1.04y±0.03	
	Breed effect	P<0.05				

x,y - Values in the same row with a different letter are significantly different from each other.
Data are presented as mean ± standard deviation.

Table 5 - Effect of breed on production index of sows

Production quota	Group		P-value
	Damin (n = 32)	Landrace × Large White sows (n = 32)	
Duration of parturition (min)	156.0a±24.3	254.0b±35.6	0.043
Farrowing interval (min)	10.3a±4.35	18.6b±3.75	0.032
Number of live piglets/nest	14.0a±1.4	12.3b±1.5	0.018
Number of stillbirths	0.6±0.1	0.3±0. 1	0.080
Piglet losses during 24 h postpartum/total piglet losses (%)	63.2±2.5	59.6±2.3	0.500
Piglet losses at days 2 and 3 postpartum/nest (%)	8.2a±2.5	12.7b±2.3	0.024
Piglet losses from the 4th day postpartum to weaning (%)	27.5±2.4	29.5±2.5	0.080
Birth weights of litters (kg)	16.2a±2.62	19.6b±2.02	0.011
Weaning weights of piglets (kg)	5.7a±1.62	9.5b±2.34	0.022

a,b - Different letters in the same row indicate significant differences between observation days (P<0.05).

Table 6 - Correlations between sows' postural changes in the first three days postpartum and piglet mortality

Breed	Behavior parameter	Mortality		
		Day 1	Day 2	Day 3
Damin	Lateral recumbency to other postures	−0.0645	0.1465	0.1926
	Ventral recumbency to other postures	−0.1678	0.0564	0.1475
	Standing-to-lying	0.2451*	−0.2251	0.1456
	Sitting-to-lying	0.0457	0.1214	0.0458
Landrace × Large White sows	Lateral recumbency to other postures	−0.0564	0.2152	0.2032
	Ventral recumbency to other postures	−0.1576	0.0654	0.1456
	Standing-to-lying	0.2985*	−0.2523	0.1546
	Sitting-to-lying	0.2013	0.2065	0.0321

* Correlation is significant at the 0.05 level.

4. Discussion

An important aspect of motherhood is that sows usually remain in the lateral recumbency after farrowing. Piglets change from passive absorption of nutrients in the womb to active feeding after birth, the latter of which is achieved completely through suckling of the breast to obtain the necessary nutrition. Additionally, piglets experience an environmental temperature difference of 5 to 6 °C after birth compared with the womb environment. Thus, when the sow lies in lateral recumbency, the piglets are able to access the breast for nutrition, and the sow provides a warmer environment (Jarvis et al., 1999; Pedersen et al., 2003) while also reducing the risk of crushing the piglets. Within three days after farrowing in the present study, the time spent in lateral recumbency was significantly longer for the Damin than for Landrace × Large White sows. This result was consistent with observations made at three days postpartum, in which the time spent in ventral recumbency was significantly lower for the Damin sows than Landrace × Large White sows. At weeks 2 to 5 postpartum, the sows showed an increased tendency to stand, which might signal a refusal of the sow to permit feeding by the piglet. These observations are similar to the conclusions made by other researchers in the field (Valros et al., 2003).

Ventral recumbency is a sign of the sow's refusal to nurse the piglet; it also represents a major mechanism whereby the sow may achieve weaning. At week 5 postpartum, the time spent in ventral recumbency was lower for the Damin than for Landrace × Large White sows. This behavior may also indicate that Landrace × Large White sows are more smoothly than Damin sows during the weaning process. Sows refused to suckle their piglets in lactation, and they changed the lateral recumbency into ventral recumbency (Liu et al., 2013). However, in terms of the change in the trend of sows' behaviors from weeks 2 to 5 postpartum, each breed exhibited gradual weaning. This observation is also similar to the conclusions made in previously published reports (Valros et al., 2003).

A previous study indicated that the time sows spent sitting was positively associated with the number of times piglets were crushed (McGlone and Morrow-Tesch, 1990). At days 1 to 3 postpartum in the present study, the time spent sitting was significantly lower for the Damin than for Landrace × Large White sows. When the sow lies down, the piglets are not guided to avoid it, and dangerous events are more likely to occur (Marchant et al., 2001). The results might be speculated that when sows were in sitting-to-lying behavior, the risk of crushing piglets was higher for the Landrace × Large White than for Damin sows; the Damin sows might have maternity features that help to reduce piglet mortality. In addition, the ventral or lateral recumbency postpartum indicated a possible use to characterize the maternal abilities of sows in minimizing piglet crushing (Wischner et al., 2009).

The frequency of the lateral recumbency to other postures is also a recognized signal of the sow's refusal to feed the piglets (Valros et al., 2003). With increased lactation, the two breeds of sows in lateral recumbency to other postures increased gradually. In addition, the lateral recumbency to other postures at weeks 2 to 5 was lower for Damin than for Landrace × Large White sows, while at days 1 to 3, it was higher for Damin than for Landrace × Large White sows.

The litter sizes of Damin and Large White sows are different (14.0±1.4 vs 12.3±1.5). At days 1 to 3, lactation pressure was not very high, so Damin sows exhibited higher lateral recumbency to nursing more piglets, but by weeks 2 to 5, Damin sows had more probability to reject lactation because of the high lactation pressure due to growing up of piglets, thus exhibiting lower lateral recumbency. The results of this part showed that the incidence of feeding rejection increased gradually when sows were in the lateral recumbency. With less restriction, the maternal qualities of the sows will have a greater influence on the survival and growth of her litter (Marchant et al., 2001).

Piglets were crushed to death at the highest incidence within the first three days, especially within the first 24 h, after farrowing (Lay Jr., 2002). During this period, the frequency of ventral-to-lateral recumbency of sows might also be closely associated with the number of piglets crushed to death. At day 1, week 4, and week 5 postpartum, we noticed that the frequency of ventral-to-lateral recumbency was significantly lower for the Damin than for Landrace × Large White sows. Thus, we might infer that the Damin sows may actually inherit good maternal characteristics from Min pig in such an indoor-enriched environment (Liu et al., 2013).

Unexpectedly, the frequency of movement from standing to lying was significantly higher for the Damin than for Landrace × Large White sows at days 1 to 3 postpartum, but the mortality of Damin piglets was very low during the first 72 h postpartum (unpublished data). Although some studies have concluded that the standing-to-lying of sows after farrowing may be the most important reason which causes piglet mortality (Baxter et al., 2011), other researchers have disagreed (Weary et al., 1996; Marchant et al., 2001). These inconsistent results might be due to differences in temperature extremes, the environment, sample size, and a variety of other factors. However, because postural changes by Damin sows might not have been fully appreciated, particularly at the level of whole-body behavior, we suppose that better attention to behavioral changes might have protected the piglets from being crushed to death. Our results also suggest that Damin sows in the loose-housing indoor farrowing pens may have inherited important genetic traits from the Min pig and displayed good maternal and mothering characteristics.

No significant differences in duration of nursing bouts at weeks 2-5 postpartum were observed between the two breeds of sows; however, the nursing frequency was significantly higher in the Damin than in Landrace × Large White sows. This finding indicates that Damin sows have higher milk quantity than Landrace × Large White sows because milk quantity is a reliable indicator of maternal ability. Thus, we can infer that the maternal capacity of Damin sows is somewhat superior to that of Landrace × Large White sows in an enriched environment. However, with extended postpartum times, and particularly by the fifth week, we observed a decreasing trend in the breast-feeding frequency and milk production of sows when lying in the horizontal position. This observation is similar to those described previously (Gustafsson et al., 1999; Valros et al., 2002), in which weaning was described as a gradual biological process.

Pre-weaning piglet loss is harmful with respect to sow productivity and economics; however, most piglet loss is a result of crushing by sows (Marchant et al., 2000). In a loose-housing indoor farrowing system, the risk of crushing might increase as sow movement increases (Johnson et al., 1992). In addition, total piglet losses before weaning were relatively small in the present study, similar to the findings obtained by Wülbers-Mindermann et al. (2002). One possible reason is that sows might perform maternal behaviors well in a loose-housing indoor farrowing system, and good lactation performance might improve the adaptability and resistance of suckling piglets. This is similar to the conclusion drawn by Jensen et al. (1988).

In the present study, the birth weight of the Landrace × Large White piglets was significantly higher than that of the Damin piglets, suggesting that the birth weight of piglets might be breed-related. We did not test the milk performance of the two breeds of sows and cannot infer which factors might have caused a difference in the weaning weight between the two breeds of piglets.

The farrowing duration of sows may also affect piglet survival. The longer the farrowing time, the more dangerous it is for piglets that are born later (Herpin et al., 2001). Some previous studies have calculated the duration of farrowing and the interval of farrowing in pigs. The data showed that the average farrowing period ranged from 156 to 262 min and that the average interval of farrowing ranged from 15.25 to 22.4 min (Randall, 1972; van Dijk et al., 2005). In the present study, the duration of farrowing was within the range reported in previous studies, suggesting that the loose-housing farrowing environment may play an important role in affecting the farrowing time. However, the interval of farrowing and duration of parturition were significantly shorter for the Damin than for Landrace × Large White sows. This may be related to differences in endocrine function and birth weight of litters between the two breeds. Furthermore, the comparison of the prolactin concentration between the two breeds of sows after farrowing showed that the difference in prolactin secretion between the two breeds was the main reason for the differences in the farrowing duration and farrowing interval (Farmer, 2016), similar to the findings obtained by Oliviero et al. (2008). In the present study, the piglet loss data indicated that there were no negative effects of the parturition time or interval on the offspring survival rate. The piglet birth data showed that Damin sows may inherit optimal reproduction performance from the Min pig. Therefore, we believe that our study provides valuable information for choosing a breed in indoor production systems.

The loose-housing indoor farrowing system might also improve the welfare level of sows. Compared with other findings, we found that the behavior of Damin sows before and after farrowing had advantages for piglet survival. Our findings also indicate that Damin sows might partly inherit maternal behavior from the Min pig. The relatively low postpartum mortality rate may also be helpful for choosing the best indoor breeds in the future. However, in an indoor farrowing environment, we should not only improve performance but also consider the welfare of the sows and piglets. Reliance on the data of only a few studies is insufficient. Therefore, for a more comprehensive understanding of the sow's maternal ability and performance, further research on environment- and genotype-related factors in the indoor system is required.

5. Conclusions

Damin sows have a superior maternal ability compared with Landrace × Large White sows when measured by the behavioral characteristics observed during early lactation. In addition, the maternal ability of sows plays an important role in the survival of piglets. Therefore, we suggest that the sow maternal traits, including related behaviors, should be considered in breeding selection and that the Damin sow might represent a good choice for the loose-housing indoor farrowing system.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Conceptualization: Q. Han, R. Yi and J. Bao. Data curation: Q. Han and R. Yi. Formal analysis: Q. Han, R. Yi, S. Li and C. Wang. Funding acquisition: Q. Han, S. Cui and J. Bao. Investigation: Q. Han, R. Yi, S. Li, C. Wang and P. Zhao. Methodology: Q. Han, R. Yi and H. Liu. Project administration: Q. Han, R. Yi and J. Bao. Resources: Q. Han, R. Yi and H. Liu. Software: Q. Han, R. Yi and S. Li. Supervision: Q. Han, R. Yi and J. Bao. Validation: Q. Han and R. Yi. Visualization: Q. Han and R. Yi. Writing-original draft: Q. Han, R. Yi, S. Li and C. Wang. Writing-review & editing: Q. Han, R. Yi, S. Li, S. Cui, P. Zhao and J. Bao.

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