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Article

# Backfat Thickness at Pre-Farrowing: Indicators of Sow Reproductive Performance, Milk Yield, and Piglet Birth Weight in Smart Farm-Based Systems

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**Abstract:** The importance of backfat thickness in sows lies in its correlation with nutritional status, reproductive performance, and overall health. Identifying the optimum backfat thickness is crucial for determining the ideal energy reserves needed to support successful reproduction and lactation. This research aimed to determine optimal backfat thickness (BFT) of sows in relation to reproductive and lactation performance. In this study, 32 lactating sows were housed in a controlled environment and assigned to four groups based on their BFT before farrowing: <17.00 mm, 17.00–17.99 mm, 18.00–18.99 mm, and ≥19.00 mm. The data were analyzed with One-way analysis of variance, and the association between backfat thickness and sow reproductive performance was examined through Spearman's correlation analysis using SAS software. The results revealed no significant difference between the groups in total born, total born alive, and litter size weaned, but the piglets' survival rate during the lactation period is lower from sows with BFT < 17.00. Moreover, piglet birth weight and body weight at Day 3 were significantly lower in sows with BFT < 17.00 mm. The BFT of sows at weaning showed significant differences among the groups associated with the backfat thickness before farrowing. No significant difference was found in the duration of farrowing. The return-to-estrus interval was longer in sows with <17.00 mm BFT than in those with 17.00–17.99 mm, 18.00–18.99 mm, and ≥19.00 mm backfat thickness, with estrus intervals of 7.17, 6.25, 5.31, and 5 days after weaning, respectively. Numerically, calculated milk yield (MY) is lowest in sows with BFT < 17.00, and the highest MY was obtained from sows with BFT 18.00–18.99 mm. In conclusion, sows with at least 17.00 mm BFT before farrowing are ideal for increasing the lifetime productivity of sows. This study provides valuable insights into the importance of sow management during gestation for subsequent reproductive success.

**Keywords:** farrowing duration; farrowing behavior; weaning-to-estrus interval; body condition score; litter size; stillbirth; smart farming

## 1. Introduction

Swine production is pivotal in meeting the ever-growing global demand for high-quality protein sources. As the demand for pork products increases, it is essential to optimize the reproductive efficiency and growth performance of sows and their offspring. Ensuring the reproductive success of sows and the subsequent growth and development of piglets are paramount for the economic viability and sustainability of the industry [1–4]. Backfat, consisting of lipid, collagen, and water, is crucial when selecting female pigs for breeding herds [5]. Apart from age, body weight, and estrus expressions, backfat thickness significantly influences various reproductive performances, including puberty attainment, total piglets born, and farrowing rate [5]. Recognized as an indicator of body condition, sow backfat thickness has garnered attention for its potential impact on reproductive performance, as well as the growth and vitality of piglets [6]. An increase in sow backfat thickness at 109 days of gestation correlates with a consistent reduction in daily feed intake and a gradual rise in maternal backfat thickness and body weight losses during lactation [7]. In late gestation, the reserved backfat of sows may impact fetal development and milk synthesis [8]. However, excessive backfat thickness before parturition can potentially lead to dystocia in sows [9,10].

Prolonged farrowing can lead to potential umbilical cord rupture, subsequently reducing neonatal piglet viability and vitality [8,11]. It may also increase the stillbirth rate and negatively affect piglet colostrum intake, growth, and survivability throughout lactation [12–14]. Piglet birth weight and weaning are critical determinants of swine production efficiency. Additionally, birth weight stands as a vital factor influencing piglet survival rates [8,10,11]. Nonetheless, piglets born with low birth weight face an elevated risk of mortality in the nursery stage, especially when their colostrum intake is restricted [15,16]. Furthermore, these piglets also experience reduced weaning weight, leading to reduced market weight and compromised reproductive performance [17–20]. Critical for piglet survival and the overall well-being of swine, parameters such as backfat thickness in sows directly affect the economic viability of pork production. The suggested influence of sow backfat thickness on essential growth metrics underscores its potential impact on both the quantity and quality of milk production during lactation. Sow milk yield is crucial in determining the growth rate of nursing piglets [21]. Maes et al. [22] reported that the depth of sow backfat and overall body condition are well-recognized as pivotal factors in optimizing the number of piglets born alive and subsequent reproductive success in highly productive sows.

Reproduction in swine production systems is a complex process influenced by various factors, with sows' nutritional status, parity, environment, and body condition playing a crucial role in reproductive success [6]. Sow backfat thickness indicates the sow's energy reserves, which can affect the sow's ability to support fetal growth, farrowing, and lactation [23]. The energy balance of a sow during the pre-farrowing period has been suggested to affect the number of piglets born, piglet birth weights, and the overall viability of the piglet population. Previous investigations into pre-farrowing sow body condition highlight a positive correlation between backfat thickness and milk yield (3 to 10 days of lactation). A 1.0 mm increase corresponds to a daily yield increase of 271 g, while a 1.0 mm loss is linked to a substantial increase of 403 g per day [8]. The specific mechanisms underlying these correlations remain to be fully elucidated. Thus, this study evaluated the relationship between pre-farrowing sow backfat thickness and its impact on sow reproductive performance, calculated milk yield, farrowing behavior, piglet birth weight, and weaning weight.

## 2. Materials and Methods

### *2.1. Experimental Animals, Housing, and Diets*

The research was conducted at Sunchon National University's experimental swine facility between March 2023 and July 2023. The standard farm management practices were adhered to for the sows and piglets. Estrus synchronization and artificial insemination (AI) were performed following the methods in previous studies [24]. The study involved 32 sows

(Landrace x Yorkshire) housed individually in a gestation crate measuring 2.02 × 0.70 m with autoloading feeding systems and had *ad libitum* access to water.

The pregnancy diagnosis was conducted at 21 and 35 days after performing artificial insemination using a pig ultrasound diagnostic device (Easy Scan Gold, Dongjin BLS Co., Ltd., Gwangju-si, Republic of Korea) [16]. The gestation diet was primarily composed of a corn–soybean meal, with nutritional specifications including 3200 kcal/kg digestible energy, 0.50% standardized ileal digestible lysine (SID Lys), and 16% crude protein (CP) [16,24]. At 107 days of gestation, individual weighing and body condition assessments were conducted on sows before they were transferred to the farrowing room. Subsequently, the sows were categorized into four groups based on their backfat thickness (mm): Group 1 (<17.00), Group 2 (17.00–17.99), Group 3 (18.00–18.99), and Group 4 (≥19.00). Each group consists of 8 sows with an equitable allocation of first parity and multiparous sows with parity numbers ranging from 1 to 6.

From gestation to farrowing, all sows were fed 2.5 kg of the diet daily and housed in a controlled setting with an average ambient temperature of 23 °C and a relative humidity of 62%. Sows were fed five times daily, and automated feeding systems were set at 8:00 am, 11:00 am, 2:00 pm, 5:00 pm, and 10:00 pm. Throughout the gestation period, standard farm feeding management practices were upheld. However, in the lactation period, the feeding quantity was gradually augmented (Table 1).

**Table 1.** Farm feeding management of lactating sows.

| Item | Gestation Period | 1 Day after Farrowing | 2–6 Days after Farrowing | 7–13 Days after Farrowing | 14–15 Days after Farrowing | 16–28 Days after Farrowing |
|---|---|---|---|---|---|---|
| Feeding Amount (kg) | 2.50 | 2.90 | 3.70 | 6.00 | 8.50 | 9.00 |

*2.2. Sow Reproductive Performance, Calculation of Milk Yield, and Return Estrus Interval*

The piglet birth weight, the total number of piglets born, and the number of piglets born alive were recorded for each litter. Although mummified fetuses and stillbirths were not individually weighed, their quantity was documented and added to the overall count of piglets born [16,25]. No obstetric assistance or oxytocin hormones were administered to the sows during the farrowing process [16]. The piglet birth weights were obtained by individually weighing them immediately after birth or within the first 6 h of life. Piglets from sows farrowed at 12:00 am were individually weighed at 6:00 am to collect birthweight data. Subsequently, three and 28 days later, the piglets were individually weighed to assess their weight gain, which was essential for computing milk yield. The milk yield calculation for Days 1–3 involved determining the total weight gained by the live-born piglets and multiplying it by 4.2. Similarly, calculation of the total milk yield from Days 1–28 was performed by multiplying the piglets' litter size weight gained at weaning by a factor of 4.2 [16,26,27]. Subsequently, piglets were cross-fostered within groups to obtain the experimental litter size of 11–13 piglets per sow.

The number of piglets per sow in all groups was set at 11–13 to ensure every litter had access to viable teats. Water was made available starting on the first day after farrowing via nipple drinker, and after three days, the piglets were given ad libitum access to creep feeds. The pre-weaning mortality percentage was determined by dividing the total number of piglets in each group by the number of piglets that died after cross-fostering [16,28]. After 28 days of the lactation phase, the sows were individually weighed to determine their body weight.

The number of days in the sow return-to-estrus interval was determined, starting 3 days after weaning. A FLIR E76 digital infrared thermal imaging camera with an emissivity of 0.95 was used to detect estrus twice a day, at 09:00 and 15:00 [16,24]. The body temperature readings were taken from the vulva at a distance of 1 m from the sow. Sows were in the estrus when their average body temperature was 35 °C above [24]. A more detailed method for detecting re-estrus was elaborated in our previous study [16].

### 2.3. Determination of Sow Body Condition Score and Backfat Thickness (mm)

A single researcher performed the backfat thickness (BFT) and body condition score (BCS) on standing sows after hair removal. The assessment involved employing a digital backfat measuring device (Minitube Backfat meter (AG0307SP), Dongjin BLS Co., Ltd., Gyeonggi-do, Icheon-si, Republic of Korea) and a sow backfat caliper. The measurements were taken at the location of the last rib on each side of the sow, specifically at the $P_2$ point, which is 65 mm from the midline [16,29,30], following the manufacturer's directions. The mean values obtained from the digital backfat measuring device were employed for subsequent analysis. Additionally, the backfat thickness measurement using a caliper was conducted by gently placing the backfat caliper at the identified measurement point on the sow's back, ensuring contact with the sow's skin without excessive pressure. The caliper arms were positioned on either side of the back, with the measurement point centered between them, and the backfat thickness measurement displayed on the caliper was recorded. The body condition score (BCS) was determined through visual estimation and by assessing the ease of feeling the hipbone and backbone of the sow [16]. This was evaluated on a scale ranging from 1 to 5, where 1 represented a visually thin condition and 5 signified that the hipbone and backbone could not be felt. At the weaning period, the BFT and BCS were measured at the same marked spot on both sides of the sow [31]. The assessment of backfat thickness and BCS loss involved calculating the difference between the backfat thickness measured at 107 days of gestation and the measurements taken at the point of weaning [16].

### 2.4. Determination of Farrowing Duration and Distribution Interval

In intensive animal farming, Artificial Intelligence (AI) technology plays a crucial role in facilitating smart farming practices to enhance animal health and welfare, ultimately leading to favorable economic outcomes [32,33]. In this study, each farrowing crate was equipped with a DeepEyes™ camera (M3SEN, Seoul, Republic of Korea) positioned at 2.23 m above the ground, capturing an aerial perspective of the farrowing area for automatic measurement and calculation. The area was video recorded for 24 h using the DeepEyes™ M3SEN cameras. The DeepEyes™ M3SEN camera is an advanced artificial intelligence (AI) sow management system that employs state-of-the-art technology to instantly detect and alert on sow labor, dystocia, health status, and changes in posture, offering immediate feedback to farmers. The farrowing distribution interval, also known as the inter-birth interval (IPBI), was determined by recording the time elapsed between the birth of one piglet and the subsequent piglet within the same litter. The data collected in the farrowing duration and distribution interval were auto-generated by the DeepEyes™ M3SEN camera.

### 2.5. Determination of Frequency and Duration of Standing

The frequency and duration of standing (minutes) were generated from the DeepEyes™ M3SEN camera. The sows were considered standing when their bodies were elevated and supported by 3 or 4 legs. The data were collected for 24 h from 4 days prior to farrowing up to 2 days before farrowing for the pre-farrowing period and from 2 days after farrowing up to 4 days after farrowing for the post-farrowing period. The data were automatically generated using the DeepEyes™ M3SEN cameras, offering insights into the timing and distribution of piglet births within the litter.

### 2.6. Statistical Analysis

All data presented in the table were analyzed using One-way analysis of variance of the Statistical Analysis System (SAS, 2011, Version 9.3, SAS Institute, Cary, NC, USA) software. Spearman's correlation analysis was conducted to examine the association of backfat thickness with sow reproductive performance using the Statistical Analysis System software. Spearman's correlation analysis was performed to investigate the correlation between backfat thickness and sow reproductive performance. $R^2$ values falling within the range of 0 to 30 indicated weak association; those in the 0.31 to 60 range suggested moderate association, while values from 0.61 to 1.00 signified strong association. All analyses were performed with a 95% confidence level, and statistical significance was determined with $p < 0.05$.

## 3. Results

### *3.1. Sow Body Condition Score and Backfat Thickness (mm)*

The average parity numbers and body weights of sows during the pre-farrowing period were not significantly different (Table 2). Although no significant difference was observed between experimental groups in body weight, the data showed that backfat thickness and BCS significantly differed ($p < 0.05$) during the pre-farrowing and weaning phases. During the weaning period, no significant differences were observed in body weight loss, backfat thickness loss, and body condition score loss.

**Table 2.** Average sow backfat thickness (mm) and body condition score at pre-farrowing and weaning phases.

| Parameters | Backfat Thickness (mm) | | | | SEM | *p*-Value |
|---|---|---|---|---|---|---|
| | **<17.00** *n* = 8 | **17.00–17.99** *n* = 8 | **18.00–18.99** *n* = 8 | **≥19.00** *n* = 8 | | |
| **Pre-Farrowing** | | | | | | |
| Parity number | 2.33 | 2.55 | 2.23 | 2.50 | 0.330 | 0.745 |
| Body Weight (kg) | 201.50 | 208.25 | 202.15 | 205.00 | 2.692 | 0.778 |
| Backfat Thickness (mm), Digital | 15.83 $^{c}$ | 17.13 $^{b}$ | 18.19 $^{b}$ | 20.50 $^{a}$ | 0.254 | <0.001 |
| Backfat Thickness (mm), Caliper | 15.83 $^{bc}$ | 17.25 $^{bc}$ | 18.08 $^{ab}$ | 19.50 $^{a}$ | 0.260 | <0.001 |
| BCS | 2.79 $^{b}$ | 3.13 $^{ab}$ | 3.35 $^{a}$ | 3.38 $^{a}$ | 0.052 | <0.001 |
| **Weaning** | | | | | | |
| Body Weight (kg) | 185.17 | 191.83 | 184.76 | 187.75 | 2.992 | 0.825 |
| Backfat Digital (mm) | 13.58 $^{c}$ | 14.88 $^{bc}$ | 16.04 $^{ab}$ | 16.75 $^{a}$ | 0.270 | 0.001 |
| Backfat Caliper (mm) | 13.59 $^{c}$ | 14.68 $^{bc}$ | 15.66 $^{ab}$ | 17.21 $^{a}$ | 0.268 | 0.001 |
| BCS | 2.54 $^{b}$ | 2.81 $^{ab}$ | 2.92 $^{ab}$ | 3.06 $^{a}$ | 0.053 | 0.031 |
| Body Weight Loss (kg) | 16.33 | 16.42 | 17.39 | 17.25 | 1.708 | 0.205 |
| BFT Loss, Caliper (mm) | 2.25 | 2.38 | 2.04 | 2.75 | 0.151 | 0.552 |
| BFT Loss, Digital (mm) | 2.25 | 2.45 | 2.53 | 3.29 | 0.196 | 0.561 |
| BCS Loss | 0.25 | 0.31 | 0.42 | 0.31 | 0.151 | 0.485 |

$^{abc}$ letters with different superscripts within a row indicate significant difference; SEM = standard error of the mean; BCS = body condition score; BFT = backfat thickness.

### *3.2. Sow Reproductive Performance and Calculated Milk Yield*

Table 3 presents sow reproductive performance and calculated milk yield with different backfat thickness (BFT) values during the pre-farrowing period. Most of the parameters did not show significant differences except for piglet birth weight, body weight after 3 days, feed intake, and sow return-to-estrus interval. Although there were no significant variations in most parameters, it was observed that sows with BFT < 17.00 mm had a higher number of born piglets in total. However, this same group also exhibited more mummified and stillborn piglets. Moreover, this group experienced significantly lower birth weights and a numerically lower survival rate (%) at weaning than the other experimental groups, which had backfat thickness ranging from 17.00 mm to ≥19.00 mm. The body weight gained and the weaning weight of piglets in sows with BFT of <17.00 were numerically lower compared to the other experimental groups, but these parameters were statistically comparable ($p > 0.05$).

**Table 3.** Average reproductive performance and calculated milk yield of sow with different backfat thickness (mm) pre-farrowing.

| Parameters | Backfat Thickness (mm) | | | | SEM | *p*-Value |
|---|---|---|---|---|---|---|
| | **<17.00** $n = 8$ | **17.00–17.99** $n = 8$ | **18.00–18.99** $n = 8$ | **≥19.00** $n = 8$ | | |
| **Reproductive Performance** | | | | | | |
| Total Born (head/sow) | 14.00 | 12.42 | 13.77 | 11.00 | 0.041 | 0.208 |
| Mummified (head/sow) | 0.50 | 0.08 | 0.31 | 0.00 | 0.040 | 0.275 |
| Stillbirth (head/sow) | 0.50 | 0.25 | 0.69 | 0.00 | 0.068 | 0.738 |
| Born Alive Litter size (head) | 13.00 | 12.08 | 12.77 | 11.00 | 0.389 | 0.503 |
| Birth Weight (kg) | 1.29 $^{b}$ | 1.45 $^{ab}$ | 1.54 $^{a}$ | 1.54 $^{a}$ | 0.030 | 0.026 |
| Body Weight at day 3 (kg) | 1.53 $^{b}$ | 1.71 $^{ab}$ | 1.83 $^{a}$ | 1.84 $^{a}$ | 0.033 | 0.007 |
| Weight Gained at day 3 (kg) | 0.23 | 0.26 | 0.29 | 0.29 | 0.014 | 0.550 |
| Weaning weight (kg) | 8.03 | 8.33 | 8.41 | 8.82 | 0.137 | 0.692 |
| Weight Gained at Weaning (kg) | 6.74 | 6.89 | 6.88 | 7.29 | 0.132 | 0.797 |
| Litter size Weaned (head) | 11.33 | 11.08 | 11.54 | 10.50 | 0.350 | 0.848 |
| Litter size Weight Gained (kg) | 75.48 | 76.09 | 79.72 | 75.86 | 2.685 | 0.930 |
| Survival Rate, weaning (%) | 86.96 | 91.55 | 90.80 | 95.44 | 0.967 | 0.135 |
| Feed Intake, piglet (kg) | 0.41 $^{a}$ | 0.39 $^{ab}$ | 0.36 $^{ab}$ | 0.34 $^{b}$ | 0.048 | 0.035 |
| FCR | 0.06 | 0.05 | 0.05 | 0.05 | 0.002 | 0.255 |
| Return-to-estrus Interval (REI), (day) | 7.17 $^{b}$ | 6.25 $^{ab}$ | 5.31 $^{a}$ | 5.00 $^{a}$ | 0.218 | 0.005 |
| **Calculated Milk Yield (kg)** | | | | | | |
| Day 1–3 | 12.98 | 13.51 | 15.77 | 13.87 | 1.00 | 0.742 |
| Day 1–28 | 317.03 | 319.58 | 334.83 | 318.59 | 11.27 | 0.930 |

$^{ab}$ letters with different superscripts within a row indicate significant difference; SEM = standard error of the mean; FCR = feed conversion ratio.

A significant increase in the body weight of piglets at Day 3 could be associated with the average calculated milk yield (kg/day) of the sow ($p < 0.05$). During the entire lactation period, sows with a BFT of <17.00 had lower calculated milk yield, which might be the reason for lower weaning weights and survival rates. The return-to-estrus interval (REI) is significantly lower in sows with a BFT of ≥19.00 but statistically comparable to that of sows with a BFT of 17.00 to ≥19.00 mm. The REI of sows with a BFT of 17.00–17.99 mm is also statistically comparable to that of sows with <17.00 mm BFT.

### *3.3. Average Farrowing Duration and Distribution Interval*

There was no significant difference in farrowing duration and farrowing interval, but sows with a BFT of <17.00 mm and ≥19.00 mm had numerically longer farrowing durations (Table 4). In contrast, sows with BFT ranging from 17.00 to 17.99 and 18.00 to 18.99 mm had numerically shorter farrowing durations. In terms of the farrowing distribution interval, a significantly higher number of piglets were delivered in <10 min in sows with a BFT of ≥19.00. However, this result is statistically comparable to that of sows with a BFT of <17.00 and 18.00–18.99. The lowest number of piglets in the farrowing distribution interval in <10 min was recorded from sows with a BFT of 17.00–17.99 mm. No significant difference was recorded in the farrowing distribution interval within 10–30, 30–60, and >60 min.

### *3.4. Average Frequency and Duration of Standing*

The average frequency of standing in sows at pre-farrowing was significantly higher in the group with a BFT of <17.00 mm but statistically comparable to that of sows with 18.00–18.99 mm BFT (Table 5). On the other hand, the lowest frequency of standing was recorded in sows with 17.00–17.99 mm BFT, followed by that of the sows with ≥19.00 mm BFT. The same trend was observed in the frequency of standing after farrowing, wherein sows with a BFT of <17.00 mm obtained the highest record of standing numerically. Irrespective of backfat thickness (BFT) levels, no notable differences were observed in the duration of standing between pre-farrowing and post-farrowing in sows.

**Table 4.** The average farrowing duration and distribution interval of the sow.

| Parameters | Backfat Thickness (mm) <17.00 $n$ = 8 | 17.00–17.99 $n$ = 8 | 18.00–18.99 $n$ = 8 | ≥19.00 $n$ = 8 | SEM | $p$-Value |
|---|---|---|---|---|---|---|
| **Farrowing Duration and Interval (minutes)** | | | | | | |
| Average Farrowing Duration | 200.83 | 154.75 | 170.31 | 201.75 | 11.11 | 0.443 |
| Average Farrowing Interval | 22.00 | 19.42 | 20.15 | 20.25 | 1.63 | 0.966 |
| Maximum Farrowing Interval | 71.83 | 49.58 | 52.77 | 60.75 | 6.09 | 0.653 |
| Minimum Farrowing Interval | 1.33 | 4.25 | 3.00 | 1.50 | 0.41 | 0.061 |
| **Distribution of Farrowing Interval (head)** | | | | | | |
| <10 min. | 7.83 $^{ab}$ | 4.92 $^{b}$ | 6.31 $^{ab}$ | 8.50 $^{a}$ | 0.43 | 0.028 |
| 10–30 min. | 4.00 | 3.92 | 3.54 | 5.75 | 0.32 | 0.237 |
| 30–60 min. | 1.00 | 1.75 | 1.15 | 1.00 | 0.21 | 0.516 |
| >60 min. | 0.50 | 0.42 | 0.69 | 0.50 | 0.54 | 0.837 |

$^{ab}$ letters with different superscripts within a row indicate significant difference; SEM = standard error of the mean.

**Table 5.** The average frequency and duration of standing in sows with different backfat thickness (mm) pre-farrowing.

| Parameters | Backfat Thickness (mm) <17.00 $n$ = 8 | 17.00–17.99 $n$ = 8 | 18.00–18.99 $n$ = 8 | ≥19.00 $n$ = 8 | SEM | $p$-Value |
|---|---|---|---|---|---|---|
| **Frequency of Standing** | | | | | | |
| Before Farrowing [1] | 18.17 $^{a}$ | 10.42 $^{b}$ | 12.38 $^{ab}$ | 11.00 $^{b}$ | 0.92 | 0.026 |
| After Farrowing [2] | 18.50 | 12.67 | 14.00 | 12.50 | 1.32 | 0.497 |
| **Duration of Standing (minutes)** | | | | | | |
| Before Farrowing [3] | 125.83 | 214.00 | 190.62 | 177.50 | 15.87 | 0.318 |
| After Farrowing [4] | 182.33 | 173.42 | 146.31 | 200.25 | 13.00 | 0.591 |

[1,3] collected for 24 h from 4 days before farrowing up to 2 days before farrowing; [2,4] gathered from 2 days after farrowing up to 4 days after farrowing; $^{ab}$ letters with different superscripts within a row indicate significant difference.

## 4. Discussion

The backfat thickness and body condition score at pre-farrowing showed that sows in Group 1 had the lowest BFT and BCS. However, sows with a BFT of ≥19.00 mm exhibited a numerically higher BFT loss at the weaning period. These findings conform to the report of Thongkhuy et al. [8], explaining that too much backfat during the gestation period in multiparous was associated with high BFT loss during the lactation period. These could be attributed to several factors, such as sow energy reserves, metabolic differences, nutrient utilization, and litter size. The primary reason is related to the increased energy demands of lactation. Sows with higher backfat reserves are often in a better nutritional state and have more energy stored in the form of adipose tissue. In the lactation period, as the sow produces milk, there is a notable depletion of energy. Sows mobilize fat stores to meet these heightened energy requirements. Higher backfat levels initially indicate a greater reservoir of stored energy, and as a result, these sows tend to mobilize and utilize more fat during lactation.

The utilization of these energy reserves during lactation supports milk production and body condition maintenance, resulting in reduced backfat thickness. This aligns with findings by Cerisuelo et al. [23], indicating that higher body reserves at pre-farrowing may act as a protective measure for sow performance, mitigating excessive body weight loss and optimizing conditions for improved milk production and litter performance [34]. Moreover, the reserved backfat of sows during late gestation could influence fetal growth and milk synthesis [8]. Conversely, sows with lower initial backfat levels may have limited energy reserves, and might be more susceptible to experiencing negative energy balance during lactation. In such cases, the sow's body might prioritize maintaining essential bodily functions over storing additional energy in the form of backfat.

The total number of piglets born is numerically higher in sows with a BFT of <17.00. However, piglet survival rate (%) and sow calculated milk yield are lower, contributing to the lower BFT loss and low piglet weight gained at weaning. These findings were supported by Decaluwé et al. [31], who reported that BFT during late gestation is predictive of colostrum yield, and BFT can influence the amount of nutrients available for milk production, affecting sow reproductive performance. A significant difference in piglet birth weight was observed, and sows with a BFT of 18.00 mm and above had the heaviest birth weight compared to the other groups. These findings corroborated the reports of Roongsitthichai and Tummaruk [5] on the relationship between backfat thickness level and piglet birth weight from gilts. The researchers concluded that piglets born from gilts with high BFT (18.01–23.00 mm) tend to have higher birth weights than those born from gilts with low BFT. Amdi et al. [35] reported the same observation that piglets delivered from high-backfat gilts had higher growth rates during lactation, together with higher weaning weight. Moreover, gilts and sows with high backfat had a higher percentage of milk fat [5,36], which may contribute to the promotion of weight accumulation and fat deposition in piglets, leading to higher birth weights.

The present results indicate that piglets born from sows with a pre-farrowing backfat thickness (BFT) ranging from 17.00 mm to ≥19.00 mm exhibited significantly greater birth weight and body weight at Day 3, along with a weaning weight that was numerically higher compared to piglets delivered by sows with <17.00 mm BFT. Low birth weight in neonatal piglets is a crucial risk factor for hypothermia due to the high surface-to-volume ratio [8,11]. Low-birth weight piglets are more vulnerable to cold environments than higher-birth weight piglets from the littermates [37]. Moreover, low-birth weight piglets are prone to compete for nursing access with high-birth weight littermates [38], and this heightened competition can potentially result in insufficient milk intake for lower-birth weight piglets. In the current findings, the weight gain of piglets during the lactation period at 3 and 28 days is positively associated with sow calculated milk yield. Sows with <17.00 mm BFT produced lower calculated milk yield than those in other experimental groups; hence, the body weight of piglets from sows with <17.00 mm was lower than that of the other groups. Colostrum and milk provide vital nutrients and are the most essential factors for piglet survival and growth [39], and it is crucial to consider both the nutrient composition and quantity [8].

The levels of BFT showed no significant difference in the number of mummified piglets and stillbirths. Thongkhuy et al. [8] reported that too little BFT (≤12.5 mm) at 109 days of gestation caused an increased proportion of stillborn piglets per litter. One possible reason for the increase in stillbirth is that the fat deposition in the sow birth canal can obstruct the passage, leading to dystocia [11]. This can also cause prolonged labor and weak uterine contractions, leading to more heads of stillborns and the potential development of agalactia, mastitis, and metritis. Although it was not recorded in the present study, it should be noted that sows with a high number of stillbirths and prolonged farrowing duration may be susceptible to secondary uterine inertia, especially when sows have large litter sizes or large piglets [5,9,40]. This condition results from the exhaustion of uterine muscles rather than an inability to contract (primary uterine inertia) [9]. Various factors can influence uterine inertia in sows, and there isn't a straightforward correlation with backfat thickness alone. Primary uterine inertia in sows refers to the inability of the uterus to initiate contractions effectively during the onset of labor. It is a condition where the uterus fails to start contracting as needed for the progression of labor. In contrast, secondary uterine inertia occurs after the onset of labor, where the uterus, having initially contracted, becomes weak or inefficient, causing a delay in labor progression.

Sows with a BFT of <17.00 mm at pre-farrowing had the longest days of the return-to-estrus interval (REI). This corroborates earlier findings that low body weight, BFT, and excessive BFT loss at weaning are associated with prolonged weaning–estrus intervals, increased anestrus rates, and reduced farrowing rate [16,41–43]. Sows with low backfat thickness during lactation experience significant depletion of energy reserves since backfat serves as a crucial energy store. If the fat depletion is excessive, it leads to a negative energy balance. This, along with disruptions in the balance of reproductive hormones, might delay the sow's return to estrus after weaning. Moreover, excessive backfat loss may adversely impact ovarian function, as adequate backfat levels are associated with optimal ovarian activity. The difficulty in meeting nutritional needs due to excessive backfat loss hampers the return to regular estrous cycles. Hence, maintaining the optimal sow body weight and condition throughout gestation and lactation is essential to improve productivity and ensure efficient feed utilization [44].

Farrowing is a potentially distressing and painful experience for sows, and postural alterations and the length of farrowing can serve as stress and dystocia indicators [13]. No significant difference was observed in the farrowing duration, but numerically shorter durations were noted in sows with backfat thickness (BFT) values of 17.00–17.99 and 18.00–18.99. Backfat serves as an energy reserve for the sow during the demanding process of farrowing. Sows with sufficient backfat levels have better energy reserves to support the physical exertion and energy demands of giving birth. Those maintaining adequate backfat levels possess improved energy reserves, providing support for the physical exertion and energy requirements associated with giving birth. Aside from backfat thickness [10], there are several factors that could influence the duration of farrowing. It is associated with the total number of piglets born. This is positively associated with the total number of piglets born [13,45], sow parity number [46], housing environment [40], and breeds [47,48].

A large litter size often requires more energy from the sow to support the birthing process, milk production, and post-farrowing recovery. This increased energy demand might affect the farrowing distribution interval or the inter-birth interval (IPBI). Sows with larger litters may need more time to recover and regain optimal reproductive conditions, impacting the time between successive births. The energy demand for sows on the day of farrowing is estimated to be 1.6 times greater than in late gestation, primarily due to factors like colostrum production, physical activity associated with nest-building behavior, and the labor involved in farrowing [49]. Farrowing may be impaired by inadequate energy availability for uterine contractions [50,51], which leads to higher IPBI towards the end of farrowing and a greater risk of low viability of the piglets born last [12]. While limited reports exist related to the farrowing distribution interval with respect to BFT levels, some key factors that could influence it include genetic, management, and environmental factors.

The frequency and duration of standing in sows are associated with their nesting behavior and specific hormones especially as they approach farrowing [52,53]. In a review, Peltonieme et al. [9] reported that nesting behavioral patterns of sows initiate approximately 24 h before the birth of the first piglet, reaching its peak activity levels between 3 and 8 h before the first piglet's delivery and gradually subside before the first piglet is born [54,55]. Some have argued that the sow nesting instinct may have diminished due to domestication, selective breeding, and confinement in modern farrowing crates [9]. However, there are reports that the modern sow retains a similar need and capacity for nest building as its ancestor, the European wild boar [40,53,56]. The noticeable increase in standing frequency in sows with backfat thickness of <17.00 mm could be linked to lower backfat reserves, potentially leading to heightened sensitivity to pain and restlessness. However, the exact relationship between standing and backfat thickness is still unclear and needs further investigation for a comprehensive understanding.

Interestingly, calculated milk yield is associated with sow backfat thickness at pre-farrowing (Figure 1), as supported by Revell et al. [36], who reported an association between backfat thickness (BFT) and calculated milk yield. Sows with higher backfat thickness may have the potential for greater calculated milk yield compared to sows with lower backfat thickness [36]. However, various factors can influence milk yield, and BFT is just one of the contributing factors. On the other hand, calculated milk yield is significantly associated with the total number of born piglets and live births, which contradicts previous reports that colostrum yield is less correlated with litter size than birth weight [57,58]. It is important to note that colostrum is freely available during parturition, and consistent suckling by piglets is necessary to maintain its secretion during the first 24 h post partum and beyond [9,59]. Consequently, colostrum production is more closely associated with the vitality of piglets and the sow's capacity to produce colostrum [9,60].

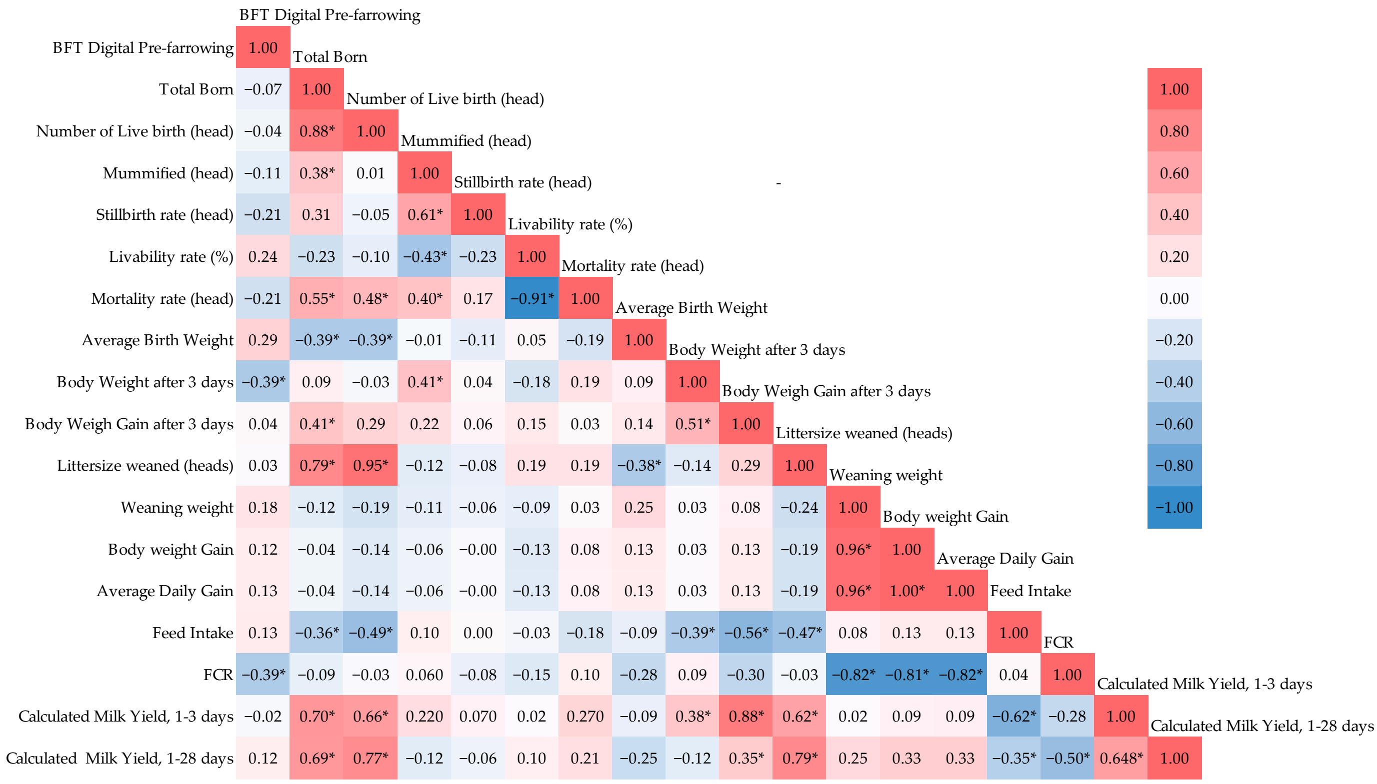


**Figure 1.** Correlations of backfat thickness in sow reproductive performance, calculated milk yield, and piglet growth performance. Legend: Red colors signify a positive correlation between variables, whereas blue colors denote a negative correlation. The intensity of the color reflects the strength of the correlation coefficients, whether positive or negative; * Significantly different ($p < 0.05$).

## 5. Conclusions

Identifying the optimal backfat thickness at pre-farrowing is essential to ensure the presence of adequate energy reserves required to support successful reproduction and lactation. The backfat thickness did not significantly impact the litter size at farrowing, but the survival rate of piglets at weaning is higher in groups of sows with a backfat thickness of 17.00 to ≥19.00 mm, with the lowest survival rate recorded in sows with <17.00 mm BFT. Piglet birth weight is significantly higher in sows with a backfat thickness of 18.00–18.99 mm, and the lowest BFT was recorded in sows with <17.00 mm BFT. Nevertheless, it significantly influenced the sows' nonproductive days (REI). The return-to-estrus interval (REI) was longer in sows with <17.00 mm BFT compared to those with a backfat thickness of 17.00–17.99 mm, 18.00–18.99 mm, and ≥19.00 mm, with estrus intervals of 7.17, 6.25, 5.31, and 5 days after weaning, respectively.

Numerically, the calculated milk yield (MY) was lowest in sows with BFT < 17.00, and the highest MY was obtained from sows with BFT in the range of 18.00–18.99 mm. The calculated milk yield was associated with BFT at pre-farrowing and was influenced by factors such as the total number of piglets born and live births. To optimize the lifetime productivity of sows, maintaining a minimum backfat thickness of at least 17 mm before farrowing is recommended. The association between the number of piglets and calculated milk yield, and the exact relationship between standing and backfat thickness is still unclear and needs further investigation for comprehensive understanding.

The analysis revealed no significant differences in either weaning weight or the number of piglets weaned in all groups. This suggests that variations in backfat thickness within the specified range may not directly impact weaning outcomes. The lack of observed differences in weaning weight and number of piglets weaned indicates that other factors, potentially unrelated to backfat thickness, might be more influential in determining these particular reproductive outcomes. Exploring more and considering additional factors is essential to understanding the complex interactions influencing sow reproductive performance in farming situations. In future research, employing a larger number of sows and including a broader range of backfat thickness levels, considering different parity numbers, is recommended.

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