

Blood glucose concentration in highly prolific sows before farrowing: Its relationship with parity and litter size

Preechaphon Taechamaeteekul¹ Silvia Comencini² Fabio De Rensis²

Roberta Saleri^{2*} Padet Tummaruk^{1,3*}

Abstract

Farrowing is an energy-demanding period for prolific sows, with blood glucose levels serving as key indicators affecting farrowing outcomes and piglet survival. This study aimed to evaluate blood glucose levels in prolific sows prior to farrowing, assess the prevalence of hypoglycemia in late gestation, and investigate the relationship between blood glucose levels, parity, and litter size under tropical conditions. A total of 67 Danish Landrace × Yorkshire sows were grouped based on litter size (6–14, 15–17, or ≥18 piglets) and parity (2–4 and 5–6). To determine glucose levels, blood samples were collected at 115.8 ± 1.6 days of gestation, at 30 and 480 min after the last feeding before farrowing, and analyzed using a glucometer. On average, blood glucose concentrations decreased from 84.4 ± 2.9 mg/dl at 30 min after feeding to 72.6 ± 2.1 mg/dl at 480 min after feeding ($P < 0.001$). Sows of parities 5–6 tended to have lower blood glucose levels than those of parities 2–4 ($P = 0.081$). In the 30-min group, sows with ≥18 piglets per litter had significantly lower blood glucose levels than those with 6–14 piglets ($P = 0.020$). In conclusion, this study offers a practical method to assess blood glucose in late-gestation sows. Glucose declined post-feeding, with older sows and those carrying ≥18 piglets showing lower levels and higher hypoglycemia risk. Pre-farrowing monitoring may help identify at-risk sows and guide management to prevent complications.

Keywords: farrowing, glucose, litter size, prolific sow, reproduction

¹Department of Obstetrics, Gynecology and Reproduction, Faculty of Veterinary Science, Chulalongkorn University, Bangkok 10330, Thailand

²Department of Veterinary – Medical Science, University of Parma, Via del Taglio 10, 43126 Parma, Italy

³Centre of Excellence in Swine Reproduction, Chulalongkorn University, Bangkok 10330, Thailand

*Correspondence: roberta.saleri@unipr.it (R. Saleri), Padet.t@chula.ac.th (P. Tummaruk)

Received July 25, 2025

Accepted August 27, 2025

<https://doi.org/10.56808/2985-1130.3905>

Introduction

Farrowing is a critical period for sows, requiring substantial physiological adjustments to ensure the well-being of both the mother and her piglets (Muns and Tummaruk, 2016; Adi *et al.*, 2024b). Highly prolific sows in tropical climates, which produce an average of 17.2 piglets per litter, experience a farrowing duration of approximately 338.4 ± 35.2 min without any hormonal regulation of the birthing process (Vongsariyanich *et al.*, 2021). This duration is notably longer compared to the 178.0 ± 73.5 min observed in sows with traditional genetics commonly used in the swine industry over two decades ago (Tummaruk and Sang-Gassanee, 2013). Consequently, the energy status of sows before farrowing has become increasingly crucial. Blood glucose levels serve as a key indicator of a sow's energy status prior to farrowing. As the primary energy source, glucose levels are influenced by factors such as diet, metabolic activity, and hormonal changes during pregnancy. Monitoring blood glucose levels before farrowing is essential to assess the energy needs of sows. In a previous study, the average blood glucose level in sows before farrowing was 77.1 ± 19.3 mg/dl, with a range of 27 to 115 mg/dl (Akkhaphan *et al.*, 2024). Importantly, a positive correlation was observed between blood glucose concentration and colostrum production in sows raised under tropical conditions (Akkhaphan *et al.*, 2024).

The energy demands of sows increase significantly during late pregnancy due to foetal growth and preparation for lactation (Theil *et al.*, 2023). This is particularly critical in modern swine production systems where highly prolific sows are utilized (Tummaruk *et al.*, 2023). Adequate glucose levels are vital to meet these energy requirements (Nielsen *et al.*, 2021). Energy deficiencies are often associated with hormonal changes at the end of gestation, which can affect glucose metabolism (Foisnet *et al.*, 2010). For example, insulin, the hormone responsible for regulating blood glucose, may exhibit altered activity, impacting glucose homeostasis. Insufficient glucose levels before farrowing can result in poor outcomes, including low birth weights and higher piglet mortality rates (Foisnet *et al.*, 2010; Adi *et al.*, 2025). Conversely, excessively high glucose levels may indicate stress or metabolic disorders in the sow, potentially compromising the health of her offspring. A clinical study further demonstrated that sow energy status during farrowing significantly influences farrowing kinetics, the frequency of stillbirths, and the need for farrowing assistance in highly prolific sows (Feyera *et al.*, 2018). The study found that when farrowing commenced within 3.13 h after the last meal, the average farrowing duration was 3.8 h (Feyera *et al.*, 2018). However, when farrowing began 8 h after the last meal, the duration increased to 9.3 h (Feyera *et al.*, 2018). Additionally, the incidence of stillbirths was low when farrowing occurred within 3 h of the last meal, moderate when it began 3–6 h after the last meal, and high when the interval exceeded 6 h (Feyera *et al.*, 2018). These findings underscore the critical role of the interval between the last meal and the onset of

farrowing in determining farrowing performance in modern, highly prolific sows.

Several factors influence blood glucose levels in productive sows, including diet and nutrition, time since the last meal, stress, and environmental conditions (Dumniem *et al.*, 2024; Feyera *et al.*, 2018; Jones, 2023). The type, timing, and composition of feed play a crucial role in regulating glucose levels (Dumniem *et al.*, 2024). For example, a previous study found that sows supplemented with a carbohydrate-rich diet had higher postprandial glucose and insulin levels compared to those on other diets (Dumniem *et al.*, 2024). Additionally, providing carbohydrate-rich compounds in the diet for 11.8 days before insemination improved piglet birth weight and reduced the proportion of piglets weighing less than 1 kg at birth (Dumniem *et al.*, 2024). Proper diet formulation is essential to prevent excessive fluctuations in blood glucose levels (Adi *et al.*, 2022). This is particularly important in modern swine production, where highly prolific sows are widely used, with litter sizes reaching up to 24.8 piglets per litter (Nielsen *et al.*, 2021; Tummaruk *et al.*, 2023). However, no study to date has explicitly examined the potential impact of large litter sizes on the risk of inadequate blood glucose levels in sows before farrowing. The use of a portable glucometer to determine blood glucose levels in peripheral blood has been validated in pigs (Nuntapaitoon *et al.*, 2019) and applied in previous field studies (Carnevale *et al.*, 2023; Akkhaphan *et al.*, 2024). However, to our knowledge, an exact cutoff value for peripheral blood glucose indicating hypoglycemia in pigs has not been established. Nonetheless, glucose levels below 70 mg/dl are commonly regarded as indicative of suboptimal metabolic status and may be associated with prolonged farrowing or reduced colostrum production (Carnevale *et al.*, 2023; Akkhaphan *et al.*, 2024; Dumniem *et al.*, 2025b).

Regular monitoring of blood glucose levels in pregnant sows is critical for the early detection of abnormalities and timely intervention. Tailoring the diet to meet the nutritional demands of the sow, while avoiding significant fluctuations in blood glucose, is especially important for modern, highly prolific sows (Theil *et al.*, 2023; Adi *et al.*, 2024b). Achieving this requires a multifaceted approach that includes balanced nutrition, effective stress management, and environmental optimization. Both research and practical experience continue to highlight the importance of blood glucose monitoring as a key component of comprehensive prenatal care in swine production (Feyera *et al.*, 2018; Nielsen *et al.*, 2021; Akkhaphan *et al.*, 2024). This study aimed to evaluate blood glucose levels in prolific sows prior to farrowing, assess the prevalence of hypoglycemia during late gestation, and investigate the relationship between blood glucose levels, parity, and litter size under tropical conditions.

Materials and Methods

Animals: This study was carried out on a commercial pig farm in Thailand, following standard industry practices for sow management. The farm complied

with local legal regulations, with regular health and welfare monitoring by a veterinarian in accordance with the farm's protocols. The experimental design and animal management followed the ethical guidelines for animal use in research established by the National Research Council of Thailand. Institutional animal care and use committee approval was obtained (approval number 2331034). Data collection was conducted in March 2024 on a farm located in eastern Thailand, involving 67 Danish Landrace × Yorkshire sows with parity numbers ranging from 2 to 6. Blood samples were collected from clinically healthy multiparous sows at 115.8 ± 1.6 days of gestation, prior to the expected farrowing date. All sows were housed individually in farrowing crates and maintained under uniform environmental conditions and feeding schedules. To assess the effect of feeding interval on blood glucose concentration, sows were randomly assigned to one of two groups based on the time elapsed since their last meal: 30 min post-feeding ($n = 23$) or 480 min (8 h, $n = 44$) post-feeding. Blood was collected from the ear vein, and glucose concentrations were measured immediately using a validated portable glucometer (Fig. 1). Following farrowing, sows were classified into subgroups based on the total number of piglets born per litter: 6–14 ($n = 15$), 15–17 ($n = 16$), and ≥ 18 ($n = 36$) piglets. Additionally, sows were grouped by parity into younger (parity 2–4, $n = 28$) and older (parity 5–6, $n = 39$) categories to evaluate the association between blood glucose concentration, litter size, and sow parity.

General management and feeding: The sows were housed in a barn equipped with a standard evaporative cooling system. Throughout the experimental period, the barn's internal temperature fluctuated between 28.2°C and 31.2°C , while relative humidity ranged from 64.0% to 83.0%. Conventional artificial insemination was employed for all sows. During their gestation period, the sows were housed in individual stalls measuring 1.20 m^2 . About one week before their anticipated farrowing date, the gestating sows were transferred to the farrowing house, where they were placed in individual farrowing crates measuring $1.95 \times 0.75 \text{ m}$, located in the centre of the farrowing pens, which measured $2.50 \times 3.00 \text{ m}$. The pens featured a fully slatted design with a concrete base in the centre for the sows and steel slats on either side of the farrowing crate for the piglets. A warm creep area ($1.00 \times 0.60 \text{ m}$) was set up for the piglets on one side of the pen, equipped with a heating lamp. This lamp was activated at night or when temperatures dropped below 30°C during the piglets' first week post-farrowing. Both sows and piglets were given

unlimited access to water through separate nipple drinkers designated for each.

Gestating sows were provided food twice daily at 7:00 AM and 3:00 PM according to a consistent feeding schedule. Initially, the daily feed amounts per sow across gestation weeks were as follows: 2.2 kg in weeks 1–5, 2.0 kg in weeks 6–11, 3.0 kg in week 12, 3.5 kg in week 13, 4.0 kg in week 14, and 4.5 kg in week 15, ensuring their dietary needs were met or surpassed based on National Research Council (NRC) guidelines (NRC 2012). The gestation feed composition included 15.9% crude protein, 2975 kcal/kg of metabolizable energy, and specific percentages of fat, fibre, minerals, and amino acids. Upon moving to the farrowing house at 109 ± 2 days of gestation, sows were transitioned to a lactation diet starting with 2.0 kg for 2–3 days pre-farrowing, featuring slightly different nutritional content, including 15.7% crude protein and higher fat and energy levels (Table 1). Post-farrowing, feeding began at 3.0 kg per day, increasing by 0.5 kg daily until reaching unlimited access (up to 6.0 kg) by the first week of lactation, with feeding frequency increased to four times a day. In the second and third weeks of lactation, sows had unlimited access to feed, with average intakes of 7.0 kg and 8.0 kg per day, respectively.

Blood glucose measurement: A small blood sample (less than 0.3 ml) was collected from the ear veins of sows at 30 and 480 min after the morning meal at 7:00 AM (the last feeding before farrowing) on day 115.8 ± 1.6 of gestation. Only sows that farrowed within 6 h of blood sampling were included in the study. The final number of sows included was 67. Blood glucose levels were measured using a portable glucometer designed to detect concentrations ranging from 10.8 to 599.4 mg/dl (Accu-Chek® Guide, Roche Diagnostics GmbH, Mannheim, Germany) (Fig. 1), which has been validated for use with swine blood samples (Nuntapaitoon *et al.*, 2019; Akkhaphan *et al.*, 2024). The method involves applying a drop of blood to a test strip, requiring approximately 0.6 μL of blood, with results available within 5 to 10 seconds. Based on findings from previous field studies (Carnevale *et al.*, 2023; Akkhaphan *et al.*, 2024), glucose levels below 70 mg/dl are commonly considered indicative of suboptimal metabolic status and may be associated with prolonged farrowing or reduced colostrum production. In the present study, sows were further classified into two groups according to their peripheral blood glucose levels: $< 70 \text{ mg/dl}$ and $\geq 70 \text{ mg/dl}$. Reproductive performance was then compared between these groups.



Figure 1 The portable glucometer used to measure blood glucose concentration in sows (Accu-Chek® Guide, Roche Diagnostics GmbH, Mannheim, Germany).

Table 1 Chemical composition of the gestation and lactation diets (as-fed basis)

Item	Type of diet	
	Gestation feed	Lactation feed
Feed allowance (kg/day)	3.0	6.0
Metabolizable energy (kcal/kg)	2975	3120
Crude protein (%)	15.9	15.7
Fat (%)	1.1	5.4
Fibre (%)	7.2	4.5
Calcium (%)	1.1	1.1
Phosphorus (%)	0.7	0.6
Salt (%)	0.4	0.4
Isoleucine (%)	0.7	0.7
Methionine (%)	0.5	0.6
Threonine	0.7	0.7
Tryptophan	0.2	0.2
Valine	0.8	0.8
Lysine (%)	0.9	1.0

Statistical analyses: The analysis of the data was conducted using SAS software (version 9.4, SAS Institute, Cary, NC, USA). Descriptive statistics were performed to calculate means and standard deviations (SD) for continuous variables and frequencies for categorical variables. Continuous variables were reported as mean $\pm$ SD, while categorical variables were expressed as percentages. Variables such as blood glucose concentration and litter traits were analysed through multiple analyses of variance (ANOVA) using the general linear model (GLM) procedure in SAS. The statistical models accounted for the time interval between the last meal and blood sample collection (30 and 480 min), total number of piglets born per litter (7–14, 15–17, and ≥ 18), parity classes (2–4 and 5–6), as well as the interactions between total born and time interval, between parity class and time interval and between total born and parity class. All interaction effects were evaluated stepwise, retaining only those with a significance level of $P < 0.20$ in the final models. Consequently, the final statistical model for blood glucose concentration included only the interactions between total born and time interval, and between parity class and time interval, while the interaction between total born and parity class was excluded. Least-square means were obtained for each factor's class, and comparisons were conducted among different factor subgroups. The Tukey-Kramer test was employed as a post-hoc analysis to adjust for multiple comparisons among groups. In addition, reproductive parameters of sows with hypoglycemia (glucose < 70 mg/dl) were compared to those with normal blood

glucose levels (glucose ≥ 70 mg/dl) prior to farrowing using the GLM procedure in SAS. The statistical model included the effects of parity classes (2–4 vs. 5–6) and blood glucose levels (< 70 vs. ≥ 70 mg/dl). The interaction between these two factors was tested but excluded from the final model due to a lack of significance ($P > 0.20$). Least-square means for each class were calculated and compared using the Tukey-Kramer test.

For categorical data, such as the proportion of sows with blood glucose concentrations below 70 mg/dl, the analysis was performed using logistic regression under the Generalized Linear Mixed Model (GLIMMIX) procedure in SAS. The statistical model structure was identical to that used for continuous variables, except that a binomial distribution was specified. A P value of less than 0.05 indicated statistical significance in all tests conducted.

Result

On average, blood glucose concentration in sows at 115.8 ± 1.6 days of gestation was 76.6 ± 14.8 mg/dl, with individual values ranging from 26.0 to 127.0 mg/dl. A total of 28.4% (19/67) of sows had blood glucose levels below 70 mg/dl. Mean glucose concentrations were 84.4 ± 19.5 mg/dl at 30 min post-feeding and 72.6 ± 9.6 mg/dl at 480 min post-feeding ($P < 0.001$). Fig. 2 shows the frequency distribution of blood glucose concentrations. At 30 min after feeding, 13.0% of sows had glucose levels below 70 mg/dl, increasing significantly to 36.4% at 480 min ($P = 0.044$).

Descriptive statistics for reproductive performance are summarized in Table 2. The average total number of piglets born per litter was 17.8 ± 4.8 , with 16.1 ± 3.9 liveborn piglets. Notably, 71.6% (48/67) of litters had ≥ 16 piglets. The overall stillbirth rate was 6.2%, ranging from 0 to 35.7% per litter. Stillbirths were frequently observed, ranging from 0 to 6 piglets per litter. Overall, 55.2% of sows had at least one stillborn piglet, and 16.4% had three or more stillbirths. Mummified fetuses were present in 31.3% of litters, ranging from 1 to 3 per litter. Gestation length of sows averaged 117.5 ± 1.4 days, ranging from 114 to 120 days among individuals (Table 2).

According to the multiple analysis of variance, sow blood glucose concentration was significantly affected by the time interval between the last meal and blood collection ($P < 0.001$) and by the litter size category based on the total number of piglets born ($P = 0.017$). However, the interactions between the time interval and litter size category, between parity class and time interval, and between parity class and litter size category did not have a significant effect on blood glucose concentration. Table 3 presents the blood glucose concentrations and reproductive data of sows categorized by the time elapsed since feeding. On average, blood glucose concentrations decreased from 84.4 ± 2.9 mg/dl at 30 min after feeding to 72.6 ± 2.1 mg/dl at 480 min post-feeding ($P < 0.001$). Similarly, the proportion of sows with blood glucose levels below 70 mg/dl increased from 13.1% at 30 min to 36.4% at 480 min post-feeding ($P = 0.044$). However, no significant differences were observed in the other reproductive parameters (Table 3).

Table 4 shows blood glucose concentrations at 30 and 480 min after feeding, along with reproductive data of sows grouped by total litter size into three categories: 6–14, 15–17, and 18 or more piglets per litter. In the 30-min group, sows with ≥ 18 piglets per

litter had significantly lower blood glucose levels compared to those with 6–14 piglets ($P = 0.020$). Sows with 15–17 piglets per litter showed a tendency toward lower blood glucose levels than those with 6–14 piglets ($P = 0.062$). However, no significant difference was found between the 15–17 and ≥ 18 piglet groups ($P = 0.998$). At 480 min after feeding, blood glucose levels did not differ significantly among the litter size groups (Table 4). Interestingly, 36.4% of sows sampled 480 min after feeding exhibited relatively low blood glucose concentrations, regardless of litter size (Table 3). Notably, when sows were classified by litter size, even at 30 min post-feeding, 22.2% of those with litters of 18 or more piglets already showed low glucose levels, which increased to 40.7% when the sampling interval was extended to 480 min (Table 4).

On average, sows of parities 5–6 tended to have lower blood glucose levels than those of parities 2–4, with mean values of 77.0 ± 2.2 mg/dl and 83.1 ± 2.6 mg/dl, respectively ($P = 0.081$). The interaction between parity group and time after feeding was not significant ($P = 0.707$). However, blood glucose concentrations significantly declined from 30 to 480 min post-feeding in both parity groups (Fig. 3).

Table 5 presents the reproductive parameters of sows with hypoglycemia (glucose < 70 mg/dl) compared to those with normal blood glucose levels (glucose ≥ 70 mg/dl) prior to farrowing. No significant differences in reproductive performance were observed between the two groups. However, sows with hypoglycemia tended to have a higher number of piglets born alive per litter than those with normal glucose levels ($P = 0.105$). The interval from the last meal to blood collection was significantly longer in sows with hypoglycemia ($P = 0.032$). Mean blood glucose concentrations were 62.0 ± 2.7 mg/dl in the hypoglycemic group and 82.6 ± 1.7 mg/dl in the normoglycemic group ($P < 0.001$).

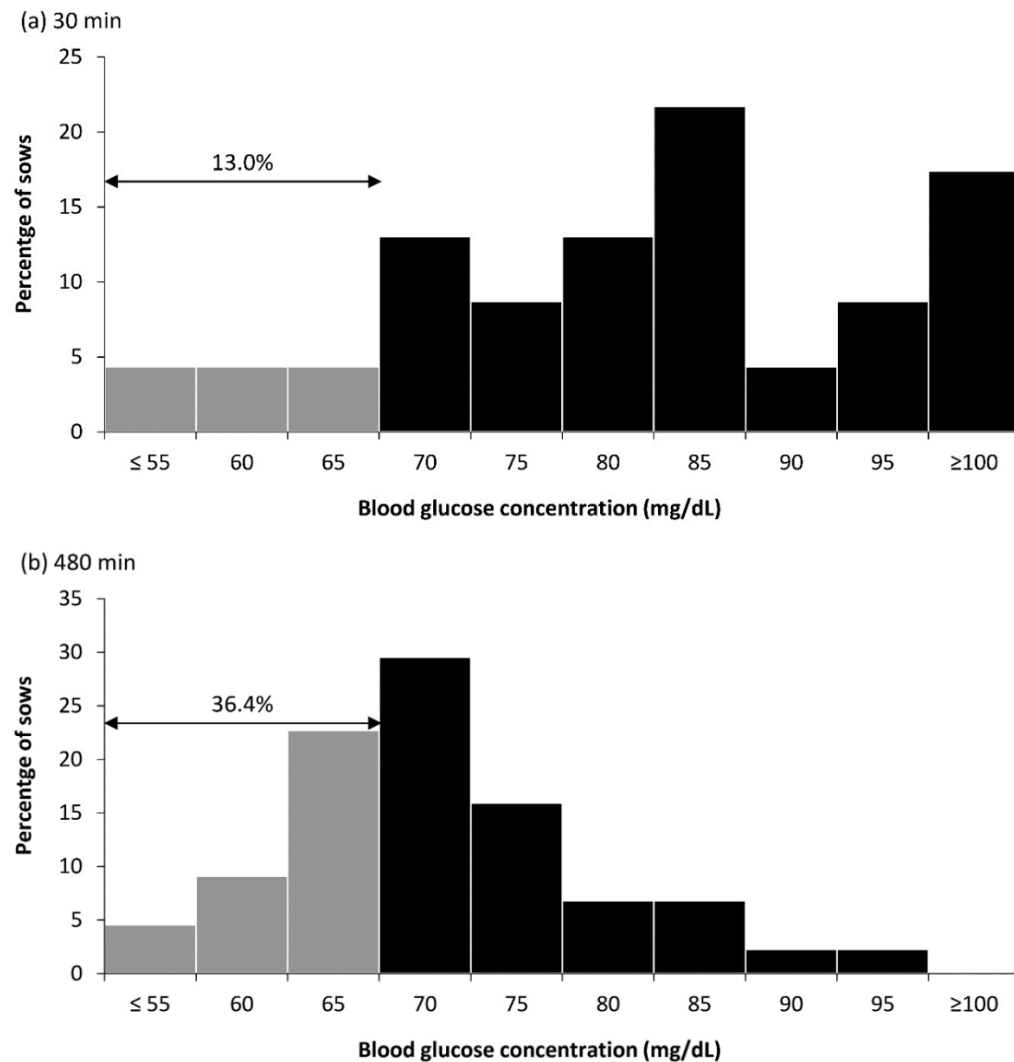


Figure 2 Frequency distribution of blood glucose concentration in sows at 115.8 ± 1.6 days of gestation in multiparous sows under a tropical environment.

Table 2 Descriptive statistics on reproductive performance of 67 Danish Landrace $\times$ Yorkshire crossbred sows. Blood glucose concentrations were measured at 115.8 ± 1.6 days of gestation, either 30 or 480 min after feeding.

Variables	Means $\pm$ SD	Range
Parity number	4.4 ± 1.1	2 – 6
Gestation length (days)	117.5 ± 1.4	114 – 120
Total number of piglets born per litter	17.8 ± 4.8	6 – 28
Number of piglets born alive per litter	16.1 ± 3.9	4 – 22
Mummified foetuses (%)	2.5 ± 5.3	0 – 33.3
Stillborn piglets (%)	6.2 ± 7.7	0 – 35.7
Blood glucose concentration (mg/dl)		
- At 30 min after feeding	84.4 ± 19.5	26 – 127
- At 480 min after feeding	72.6 ± 9.6	39 – 96

Table 3 Reproductive performance and blood glucose concentrations (least square means $\pm$ SEM) in sows at 115.8 ± 1.6 days of gestation, measured at 30 and 480 min after feeding, prior to farrowing.

Variables	Time since feeding (min) ¹		P value
	30	480	
Gestation length (days)	118.1 ± 0.3	117.4 ± 0.3	0.056
Total number of piglets born per litter	16.9 ± 1.0	18.3 ± 0.7	0.258
Number of piglets born alive per litter	15.4 ± 0.8	16.5 ± 0.5	0.307
Mummified foetuses (%)	2.5 ± 1.1	2.6 ± 0.8	0.958
Stillborn piglets (%)	6.2 ± 1.6	6.2 ± 1.2	0.981
Blood glucose concentration (mg/dl)	84.4 ± 2.9^a	72.6 ± 2.1^b	< 0.001
Proportion of sows that had blood glucose level below 70 mg/dl (%)	13.1%	36.4%	0.044

¹ This value represents the time interval between the last feeding and the blood sampling, categorized into two time points: 30 min and 480 min.

Table 4 Blood glucose concentrations (mg/dl) and reproductive performance of sows, categorized by total number of piglets born per litter into three groups: 6–14, 15–17, and ≥ 18 piglets (least square means $\pm$ SEM).

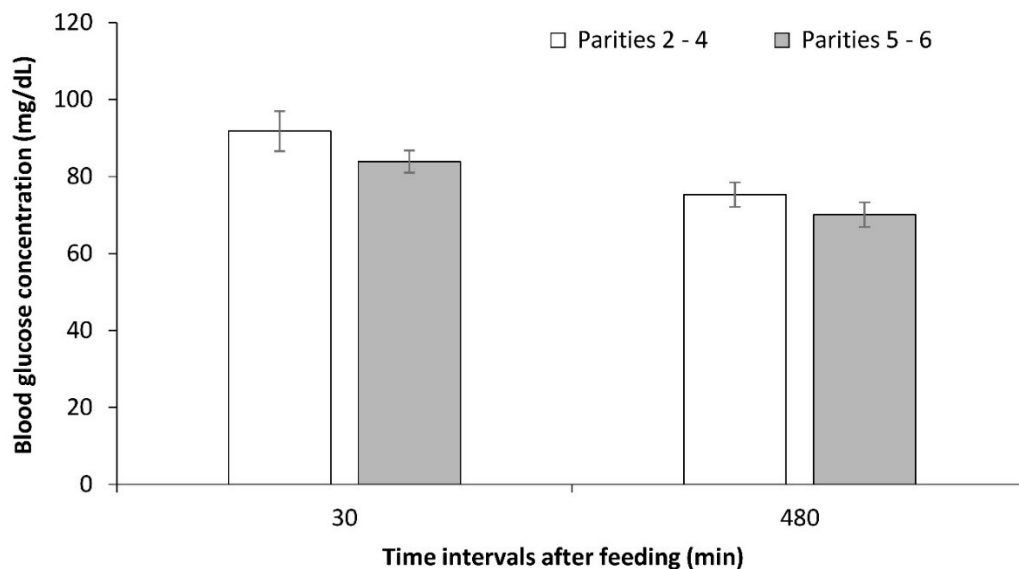
Variables	Total number of piglets born per litter		
	6–14	15–17	≥ 18
Number of sows	15	16	36
Gestation length (days)	118.1 $\pm$ 0.4	117.9 $\pm$ 0.4	117.2 $\pm$ 0.3
At 30 min after feeding			
Total number of piglets born per litter	11.0 $\pm$ 1.0 ^a	15.8 $\pm$ 0.9 ^b	21.3 $\pm$ 0.8 ^c
Number of piglets born alive per litter	10.6 $\pm$ 0.9 ^a	14.7 $\pm$ 0.8 ^b	19.0 $\pm$ 0.7 ^c
Mummified foetuses (%)	5.7 $\pm$ 2.1	1.0 $\pm$ 1.9	2.3 $\pm$ 1.8
Stillborn piglets (%)	1.8 $\pm$ 3.1	5.6 $\pm$ 2.7	8.8 $\pm$ 2.5
Blood glucose concentration (mg/dl)	101.5 $\pm$ 5.2 ^a	81.6 $\pm$ 4.6 ^b	79.1 $\pm$ 4.3 ^b
Proportion of sows that had blood glucose level below 70 mg/dl (%)	0	12.5	22.2
At 480 min after feeding			
Total number of piglets born per litter	11.6 $\pm$ 0.8 ^a	16.0 $\pm$ 0.8 ^b	21.3 $\pm$ 0.5 ^c
Number of piglets born alive per litter	10.5 $\pm$ 0.7 ^a	15.8 $\pm$ 0.7 ^b	18.7 $\pm$ 0.4 ^c
Mummified foetuses (%)	1.5 $\pm$ 1.8	0.1 $\pm$ 1.8	3.6 $\pm$ 1.0
Stillborn piglets (%)	5.4 $\pm$ 2.6	1.4 $\pm$ 2.6	7.9 $\pm$ 1.5
Blood glucose concentration (mg/dl)	73.4 $\pm$ 4.4	72.1 $\pm$ 4.5	72.4 $\pm$ 2.5
Proportion of sows that had blood glucose level below 70 mg/dl (%)	11.1	50.0	40.7

^{a,b,c} Different superscript letters within the same row indicate significant differences ($P < 0.05$).

Table 5 Reproductive parameters of sows with hypoglycemia (glucose < 70 mg/dl) compared to those with normal blood glucose levels (glucose ≥ 70 mg/dl) prior to farrowing.

Variables	Blood glucose levels (mg/dl)		P value
	< 70	≥ 70	
Number of sows	19	48	
Gestation length (days)	117.6 $\pm$ 0.2	117.5 $\pm$ 0.3	0.800
Blood glucose concentration (mg/dl)	62.0 $\pm$ 2.7 ^a	82.6 $\pm$ 1.7 ^b	< 0.001
Total number of piglets born per litter	18.7 $\pm$ 1.1	17.2 $\pm$ 0.7	0.239
Number of piglets born alive per litter	17.2 $\pm$ 0.9	15.5 $\pm$ 0.5	0.105
Mummified foetuses (%)	2.3 $\pm$ 1.2	2.7 $\pm$ 0.8	0.780
Stillborn piglets (%)	4.9 $\pm$ 1.8	6.5 $\pm$ 1.1	0.434
Time since feeding (hours)	6.9 $\pm$ 0.8 ^a	4.8 $\pm$ 0.5 ^b	0.032

^{a,b} Superscripts within a row with different letters indicate a significant difference ($P < 0.05$).

**Figure 3** Blood glucose concentrations in young sows (parities 2–4) and old sows (parities 5–6) at 30 and 480 min after feeding.

^{a,b} Different letters within the same parity group indicate significant differences ($P < 0.05$).

Discussion

With the introduction of genetically enhanced sows with larger litter sizes, the productivity target for pig breeding operations has escalated, aiming for 30–40 pigs weaned per sow annually (Tummaruk *et al.*, 2023). The sows included in the present study were clearly of

highly prolific genetics, as evidenced by an average total of 17.8 piglets born per litter, with the largest litter reaching 28 piglets. Additionally, 71.6% of the sows farrowed 16 or more piglets per litter. This is in line with the genetic potential of the modern sows currently used in the Thai swine industry (Thongkhuy

et al., 2020; Vongsariyavanich *et al.*, 2021; Adi *et al.*, 2024b). However, this increase in litter size has led to a rise in the occurrence of stillbirths, the length of the farrowing process, and the need for farrowing assistance among these modern genetic sows (Tummaruk, 2013; Udomchanya *et al.*, 2019; Adi *et al.*, 2024; Wongwaipisitkul *et al.*, 2024), which can negatively impact the sow's health after giving birth and become a serious animal welfare issue (Tummaruk, 2013; Tummaruk and Sang-Gassanee, 2013; Adi *et al.*, 2025). Currently, highly prolific sows, identified by giving birth to 16 or more piglets per litter, often experience farrowing lengths exceeding 300 min (Oliviero *et al.*, 2010; Björkman *et al.*, 2017; Vongsariyavanich *et al.*, 2021; Akkhaphan *et al.*, 2025). Such extended farrowing durations are linked to an increased rate of stillbirths (Udomchanya *et al.*, 2019; Adi *et al.*, 2024a), with both higher stillbirth rates and longer farrowing periods being more commonly observed in older sows (Adi *et al.*, 2022; Akkhaphan *et al.*, 2025). Hypoglycemia in sows prior to farrowing has been recognized as a major factor contributing to prolonged farrowing and increased stillbirth rates (Feyera *et al.*, 2018; Carnevale *et al.*, 2023). In this study, 28.4% of sows exhibited low blood glucose levels under field conditions, with individual values ranging from 26.0 to 127.0 mg/dl. These findings highlight the relatively high prevalence of hypoglycemia in late-gestation sows and suggest that monitoring blood glucose levels may be beneficial for optimizing peripartum management.

The blood glucose levels observed in this study were comparable to those reported one hour post-farrowing (Dumniem *et al.*, 2024), but slightly lower than those measured after a glucose tolerance test (Jones, 2023; Theil *et al.*, 2023). These differences may be attributed to factors such as time since feeding, analytical method sensitivity, sow parity, and genetic line. As shown in Table 3, blood glucose levels declined significantly over time after feeding, with a higher proportion of sows exhibiting levels below 70 mg/dl at 480 min (36.4%) compared to 30 min post-feeding (13.1%). This suggests that a notable proportion of sows may experience hypoglycemia several hours after feeding, which could reduce energy availability during the periparturient period. Glucose levels below 70 mg/dl are often considered indicative of suboptimal metabolic status and may be linked to prolonged farrowing or reduced colostrum production (Carnevale *et al.*, 2023; Akkhaphan *et al.*, 2024). The decline likely reflects ongoing glucose utilization in the absence of feed intake, a concern during the energy-intensive peri-farrowing phase. Although no significant differences in reproductive parameters were observed, this trend highlights the need for closer monitoring in highly prolific sows with elevated metabolic demands, as more severe or prolonged hypoglycemia may negatively impact farrowing outcomes and colostrum quality (Carnevale *et al.*, 2023; Akkhaphan *et al.*, 2024).

In the present study, 36.4% of sows sampled 480 min after feeding exhibited low blood glucose concentrations. At 30 min post-feeding, 22.2% of sows with litters of 18 or more piglets had glucose levels below 70 mg/dl, which increased to 40.7% at 480 min.

In comparison, none of the sows with 6–14 piglets and only 12.5% of those with 15–17 piglets showed low glucose levels at 30 min post-feeding. However, by 480 min post-feeding, the proportion of sows with glucose levels below 70 mg/dl rose to 50.0% in the 15–17 piglet group, while remaining low at 11.1% in the 6–14 piglet group. These findings suggest that sows with extremely large litters may have greater energy demands that are not met by routine feeding before farrowing, potentially affecting the farrowing process. Additionally, the combination of large litter size and a prolonged interval from the last meal to the onset of farrowing may increase the risk of hypoglycemia prior to parturition. In Denmark, Feyera *et al.* (2018) found that the time elapsed between the last feeding and the start of farrowing significantly affects the length of the farrowing process. Specifically, farrowing that began within 3.13 h of the last meal lasted an average of 3.8 h. In contrast, farrowing that started 8 h after the last meal extended to an average duration of 9.3 h (Feyera *et al.*, 2018). In addition, the research highlighted a correlation between the timing of farrowing relative to the last meal and the stillbirth rate (Feyera *et al.*, 2018). The lowest stillbirth rate was observed in sows that began farrowing within 3 h after feeding, while the highest rate occurred in those that started farrowing more than 6 h after a meal (Feyera *et al.*, 2018). These results underscore the crucial influence of feeding on the farrowing outcomes for highly prolific sows in temperate climates. Similarly, recent research conducted in Brazil has revealed a correlation between the fasting period of sows and their peripheral blood glucose concentration upon entering farrowing (Carnevale *et al.*, 2023). There was also a positive association between blood glucose levels in sows at the beginning and end of the farrowing process. This underscores the significance of maintaining adequate peripheral glycemia at the onset of farrowing to ensure sufficient energy reserves throughout the farrowing process, serving as a protective measure against prolonged farrowing (Carnevale *et al.*, 2023). The present study demonstrated the feasibility of using a portable glucometer to monitor glycemia levels in sows on the days leading up to farrowing, particularly in swine operations facing challenges with prolonged farrowing durations (Akkhaphan *et al.*, 2025). This approach could serve as a diagnostic tool to identify sows with low blood glucose concentrations during farrowing, enabling the implementation of appropriate treatment. Such treatment may include providing additional glucose or energy supplementation at the onset of farrowing and/or administering glucose intravenously (Nielsen *et al.*, 2021) at the end of farrowing in sows showing signs of dystocia. However, the clinical use of blood glucose measurement in sows remains uncommon, and the risk factors associated with low glucose levels require further investigation.

In humans, feelings of hunger can be influenced by various factors, including blood glucose levels (Jones, 2023). Typically, low blood glucose levels (hypoglycemia) can trigger feelings of hunger. When blood glucose drops, the human body signals that it needs more fuel, leading to the sensation of hunger. Normal fasting blood glucose levels generally range

between 70 and 99 mg/dl. People usually start feeling symptoms of low blood sugar when levels drop below 70 mg/dl. Similarly, in our study on sows, at 480 min after a meal, the average blood glucose level was 72.6 ± 2.1 mg/dl, which is close to that in humans. Additionally, the blood glucose levels observed in the sows from this study align with those reported earlier by Terlouw *et al.* (1993), remaining within the normal range both before and after feeding. The blood glucose level in sows was lowest at 60 min before the meal and highest at 120 min after the meal (Terlouw *et al.*, 1993). However, the exact threshold at which a person feels hungry can vary widely depending on individual factors such as metabolic health, how accustomed the body is to certain blood sugar levels, and even how recently and what the person ate (Wever *et al.*, 2021). In pigs, the ability to detect hypoglycaemia based on clinical signs or behaviour, especially in sows confined to farrowing crates before parturition, remains poorly understood. In the present study, sows with blood glucose levels below 70 mg/dl were considered at risk of hypoglycemia. However, the exact cutoff value for defining hypoglycemia in sows remains to be established and cannot be directly compared to human thresholds. While determining a definitive value is still challenging, we considered previously proposed reference ranges associated with farrowing performance and colostrum production in sows (Carnevale *et al.*, 2023; Akkhaphan *et al.*, 2024). For example, a study in Brazil categorized sows' blood glucose levels at the onset of farrowing into three groups: high (≥ 85.0 mg/dl), intermediate (72.0–84.9 mg/dl), and low (< 72.0 mg/dl), and found that those in the low group experienced prolonged parturition (Carnevale *et al.*, 2023). Similarly, in our previous research, sows with high colostrum yield had an average blood glucose concentration of 85.7 mg/dl, whereas those with lower colostrum yield averaged 65.7 mg/dl (Akkhaphan *et al.*, 2024). In the context of the swine industry, which globally employs modern, highly prolific sow genetics, these sows typically undergo a farrowing process lasting about 5.0 h (Muns and Tummaruk, 2016; Adi *et al.*, 2024a; Adi *et al.*, 2024b; Chaiyapatmaetee *et al.*, 2025). Research by Nielsen *et al.* (2021) has shown that maintaining adequate glucose levels is crucial for sows to reduce the duration of farrowing. Consequently, conducting routine blood glucose level checks in sows before they begin farrowing might present a groundbreaking clinical obstetric strategy for managing the farrowing process in highly prolific sows and mitigating the risks associated with prolonged farrowing processes.

On average, sows in the higher parity group (parities 5–6) tended to have lower blood glucose concentrations than younger sows (parities 2–4). This pattern may indicate an age-related decline in metabolic efficiency or glucose regulation, likely influenced by the cumulative physiological burden of repeated gestations and lactations. Supporting this observation, previous research has reported that older sows experience significantly longer farrowing durations compared to younger counterparts (Adi *et al.*, 2022; Adi *et al.*, 2024b; Akkhaphan *et al.*, 2025), and that the incidence of dystocia is higher in sows of parity ≥ 7 than in those of parity 1 or 2–4 (Wongwaipisitkul *et*

al., 2024). These findings suggest that hypoglycemia in older sows could be a contributing factor to prolonged parturition and/or dystocia, particularly in hyperprolific lines. In the present study, the lack of a significant interaction between parity group and time after feeding indicates that the decline in glucose levels over time followed a similar pattern in both parity groups. Nevertheless, blood glucose concentrations decreased significantly from 30 to 480 min after feeding in both groups, reflecting a typical postprandial decline. These results highlight the need for close monitoring of energy status in older sows, especially during the peripartum period when metabolic demands are heightened.

The comparison of reproductive parameters between hypoglycemic and normoglycemic sows prior to farrowing revealed no statistically significant differences. However, there was a tendency for sows with hypoglycemia to have a higher number of piglets born alive, suggesting a potential association between lower glucose levels and increased litter viability, although this did not reach statistical significance. Interestingly, the interval from the last meal to blood collection was significantly longer in hypoglycemic sows, indicating that fasting duration may have influenced blood glucose levels (Feyera *et al.*, 2018). The substantial difference in mean glucose concentrations between the groups confirms the classification and suggests that pre-farrowing glucose dynamics may be influenced by both metabolic and management factors (Akkhaphan *et al.*, 2024). These findings warrant further investigation into the impact of maternal glucose status on farrowing outcomes and neonatal viability.

A limitation of the present study is that blood sampling was designed to be conducted on the expected parturition date, at an average gestation length of 115.8 ± 1.6 days. Unfortunately, not all sows farrowed precisely on the due date, and the exact timing of farrowing onset was not recorded, as most sows farrowed during nighttime hours. However, the date of farrowing was recorded for all animals, and gestation length has been addressed. A previous study conducted in two herds reported that the proportion of sows farrowing ≥ 6 h after their last meal varied between herds, ranging from 22.1% to 47.1%, depending on feeding frequency and the timing of parturition onset (Akkhaphan *et al.*, 2024). Moreover, farrowing onset more frequently occurred during non-working hours (Adi *et al.*, 2022; Akkhaphan *et al.*, 2025), whereas feeding in most herds typically took place during daytime working hours. In the herd where the present study was conducted, sows were fed at 7:00 AM and 3:00 PM. Therefore, the likelihood of sows initiating farrowing more than 6 h after their last meal is relatively common under field conditions. The findings of this study highlight the potential risk of hypoglycemia in sows prior to parturition and suggest that feeding schedules during the prepartum period should be optimized to support better metabolic status.

Although no universally accepted cutoff for hypoglycemia in sows exists, we used 70 mg/dl as an indicator of suboptimal metabolic status, based on previous research and physiological rationale (Carnevale *et al.*, 2023; Akkhaphan *et al.*, 2024). This

value aligns with average postprandial glucose concentrations in healthy sows (73.4–89.3 mg/dl; Dumniem *et al.*, 2024) and with thresholds applied in other mammalian species (Idewu and Heading, 2018; Rodríguez-Trujillo *et al.*, 2025). Concentrations below this level likely indicate insufficient energy to meet the metabolic demands of maintenance, fetal development, and milk production. However, variation among studies, genetic lines, and physiological states suggests this threshold may not precisely define clinical hypoglycemia in all populations, and prevalence estimates should be interpreted as the proportion of sows below a metabolic stress reference point rather than an absolute diagnostic measure.

From a management perspective, proactive nutritional strategies are recommended for periparturient and lactating sows to minimize the risk of hypoglycemia (Decaluwé *et al.*, 2014; Adi *et al.*, 2024c). Consistent energy supply through multiple daily feedings or *ad libitum* access to high-energy diets is particularly important for high-parity or thin sows (Dumniem *et al.*, 2025a). Routine glucose monitoring within 24 h before and after farrowing can facilitate early detection and intervention, such as energy-dense feed supplementation, oral glucose solutions, or dietary adjustments (Adi *et al.*, 2024c; Carnevale *et al.*, 2024).

It is also important to recognize that the results of this study may not fully translate to temperate climates, as ambient temperature and humidity can markedly affect feed intake, metabolic rate, and energy partitioning in sows (Khamtavee *et al.*, 2021; Tummaruk *et al.*, 2023). In tropical environments, chronic heat stress often suppresses voluntary feed intake and redirects energy toward thermoregulation, increasing the risk of negative energy balance and reduced plasma glucose concentrations. Sows under such conditions may develop physiological adaptations, including altered endocrine profiles (e.g., elevated cortisol, reduced insulin sensitivity) and changes in peripheral blood flow, which can influence nutrient absorption and glucose metabolism. By contrast, sows in temperate climates generally experience less sustained heat stress, supporting higher feed intake and more stable energy status during late gestation and lactation. Consequently, the prevalence of hypoglycemia may be lower in temperate regions, although the extent of this difference would likely vary with seasonal conditions and housing systems.

In conclusion, this study demonstrates a practical approach for measuring blood glucose concentrations in late-gestation sows, revealing a wide individual range (26–127 mg/dl). Blood glucose levels were significantly influenced by the time since last feeding, with the prevalence of hypoglycemia (<70 mg/dl) increasing from 13.0% at 30 min to 36.4% at 480 min post-feeding. Pre-farrowing glucose levels may also be associated with litter size and parity, as sows with ≥18 piglets and older sows exhibited lower glucose levels, indicating a higher risk of hypoglycemia. These findings suggest that current feeding practices may not meet the energy needs of these groups, potentially affecting farrowing and colostrum production.

Monitoring glucose levels before farrowing may help identify sows at risk of hypoglycemia and allow for the implementation of management strategies to improve glucose status and reduce the risk of farrowing complications.

CRedit authorship contribution statement

Preechaphon Taechamaeteekul: Writing – review & editing, Validation, Investigation. **Silvia Comencini:** Writing – review & editing, Validation, Investigation. **Fabio De Rensis:** Writing – review & editing, Validation, Investigation. **Roberta Saleri:** Writing – review & editing, Validation, Investigation. **Padet Tummaruk:** Conceptualization, Writing – review & editing, Writing – original draft, Validation, Supervision, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation.

Acknowledgments

This research project is supported by the National Research Council of Thailand (NRCT) (N42A660892). Preechaphon Taechamaeteekul is a grantee of the C2F PhD Scholarship, Chulalongkorn University. We extend our sincere thanks to Dr. Sermsak Jiebna for granting us permission to conduct the experiments on his farm and for generously providing the facilities and animals used in this study.

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

During the preparation of this work, the author(s) used ChatGPT 4.0 (<https://chat.openai.com>) to perform grammatical checks. After using this tool/service, the author(s) reviewed and edited the content as needed and take(s) full responsibility for the publication's content.

References

- Adi YK, Boonprakob R, Kirkwood RN and Tummaruk P 2024a. Factors affecting birth weight and stillbirth in sows housed in a tropical environment. *Reprod Domest Anim.* 59: e14500.
- Adi YK, Boonprakob R, Kirkwood RN and Tummaruk P 2022. Factors associated with farrowing duration in hyperprolific sows in a free farrowing system under tropical conditions. *Animals* 12: 2943.
- Adi YK, Kirkwood RN and Tummaruk P 2024b. Farrowing performance and piglet characteristics of highly prolific sows in a tropical environment. *Thai J Vet Med.* 54(4): 8.
- Adi YK, Kirkwood RN and Tummaruk P 2025. Newborn traits influencing piglet mortality within the first day and between days 1 and 7 after birth in highly prolific sows in tropical environments. *Theriogenology* 246: 117551.
- Adi YK, Taechamaeteekul P, Ruampatana J, Malison M, Suwimonteerabutr J, Kirkwood RN and Tummaruk P 2024c. Influence of prepartum feed levels on colostrum production and farrowing performance in highly prolific sows in a tropical environment. *Animal* 18: 101066.

- Akkhaphan T, Boonprakob R, Grahofers A and Tummaruk P 2025. Seasonal effect on farrowing duration in sows within a temporarily confined farrowing system under tropical climates. *Theriogenology* 238: 117364.
- Akkhaphan T, Ngansucharit K, Srisurach S, Taechamaeteekul P, Adi YK and Tummaruk P 2024. The impact of the interval between the last meal and the onset of farrowing on the duration of farrowing, stillbirth rates, and colostrum production in highly productive sows in a tropical climate. *J Vet Med Sci.* 86(2): 184-192.
- Björkman S, Oliviero C, Kauffold J, Soede NM and Peltoniemi OAT 2017. Prolonged parturition and impaired placenta expulsion increase the risk of postpartum metritis and delay uterine involution in sows. *Theriogenology* 106: 87-92.
- Carnevale RF, Muro BBD, Leal DF, Alves LKS, Monteiro MS, Gomes NAC, Pereira FA, Ferreira FNA, Neta CSS, Watanabe TTN, Almond GW and Garbossa CAP 2024. The effects of feeding sows at onset of farrowing supplemental energy (blend of carbohydrates and glycerol) on farrowing kinetics and piglet vitality. *Animal* 18: 101104.
- Carnevale RF, Muro BBD, Pierozan CR, Monteiro MS, Leal DF, Poor AP, Alves LKS, Gomes NAC, Silva CA, Maes D, Janssens GPJ, Almond GW and Garbossa CAP. 2023. Peripheral glycemia and farrowing traits in pigs: An observational study. *Livest Sci.* 270: 105203.
- Chaiyapatmaetee T, Saenghinghoy N, Charuchinda P, Wichathippayananon T, Ruampatana J, Adi YK, Taechamaeteekul P and Tummaruk P 2025. Intrauterine growth restriction in newborn piglets associated with piglet characteristics, colostrum intake, litter size and parity number in prolific sows. *Theriogenology* 240: 117416.
- Decaluwé R, Maes D, Cools A, Wuylts B, De Smet S, Marescau B, De Deyn PP and Janssens GPJ 2014. Effect of periparturient feeding strategy on colostrum yield and composition in sows. *J Anim Sci.* 92: 3557-3567.
- Dummiem N, Parsons TD and Tummaruk P 2025a. Feeding levels during early gestation in a group-housing system for primiparous sows: Impact on piglet birthweight and litter uniformity. *Anim Biosci.* 38(2): 360-370.
- Dummiem N, Suwimonterabutr J and Tummaruk P 2025b. Colostrum and milk production in sows housed in free-farrowing versus crated systems under tropical conditions: Associations with sow metabolic state, oxidative stress, and piglet survival. *Theriogenology* 247: 117572.
- Dummiem N, Taechamaeteekul P, Suwimonterabutr J and Tummaruk P 2024. Supplementing a carbohydrate-rich diet from late lactation to insemination increased glucose and insulin levels in weaned sows, leading to improved subsequent piglet birth weight. *J Vet Med Sci.* 86(6): 636-644.
- Feyera T, Pedersen TF, Krogh U, Foldager L and Theil PK 2018. Impact of sow energy status during farrowing on farrowing kinetics, frequency of stillborn piglets, and farrowing assistance. *J Anim Sci.* 96: 2320-2331.
- Foisnet A, Farmer C, David C and Quesnel H 2010. Relationship between colostrum production by primiparous sows and sow physiology around parturition. *J Anim Sci.* 88: 1672-1683.
- Gopinath R and Etherton TD 1989. Effects of porcine growth hormone on glucose metabolism of pigs: II. Glucose tolerance, peripheral tissue insulin sensitivity and glucose kinetics. *J Anim Sci.* 67: 689-697.
- Idowu O and Heading K 2018. Hypoglycemia in dogs: Causes, management, and diagnosis. *Can Vet J.* 59: 642-649.
- Jones JM 2023. Glucose: Metabolism and homeostasis. In: *Encyclopedia of Human Nutrition* 4th edition, Volume 3 Elsevier 2023.
- Khamtawee I, Singdamrong K, Tatanan P, Chongpaisan P, Chunniem N, Pearodwong P, Suwimonterabutr J, Nuntapaitoon M and Tummaruk P 2021. Cinnamon oil supplementation of the lactation diet improves feed intake of multiparous sows and reduces pre-weaning piglet mortality in a tropical environment. *Livest Sci.* 251: 104657.
- Muns Vila R and Tummaruk P 2016. Management strategies in farrowing house to improve piglet pre-weaning survival and growth. *Thai J Vet Med.* 46: 347-354.
- National Research Council (NRC). Nutrient Requirements of Swine, 11th ed. The National Academy Press 2012, Washington, D.C., USA.
- Nielsen SE, Feyera T, Skovmose SJW, Krogh U, Eskildsen M and Theil PK 2021. Intravenous infusion of glucose improved farrowing performance of hyperprolific crossbred sows. *J Anim Sci.* 5: 1-11.
- Nuntapaitoon M, Sirisawadi S, Asawakarn S and Tummaruk P 2019. Accuracy of portable human glucose meter (Accu-Chek® Performa) for blood glucose measurement in newborn piglets. *Thai J Vet Med.* 49: 37-42.
- Oliviero C, Heinonen M, Valros A and Peltoniemi O 2010. Environmental and sow related factors affecting the duration of farrowing. *Anim Reprod Sci.* 119: 85-91.
- Rodríguez-López JM, Lachica M, González-Valero L and Fernández-Figares I 2021. Determining insulin sensitivity from glucose tolerance tests in Iberian and landrace pigs. *PeerJ.* 9: e11014.
- Rodríguez-Trujillo R, Batista-Arteaga M and Iusupova K 2025. Glucose levels as a key indicator of neonatal viability in small animals: Insights from dystocia cases. *Animals* 15: 956.
- Terlouw EMC, Lawrence AB, Koolhaas JM and Cockram M 1993. Relationship between feeding, stereotypies, and blood glucose concentrations in food-restricted and restrained sows. *Physiol Behav.* 54:189-193.
- Theil PK, Krogh U, Bruun TS and Feyera T 2023. Feeding the modern sow to sustain high productivity. *Mol Reprod Dev.* 90: 517-532.
- Thongkhuy S, Chuaychu SHB, Buranrak P, Ruangjoy P, Juthamanee P, Nuntapaitoon M and Tummaruk P 2020. Effect of backfat thickness during late gestation on farrowing duration, piglet birth weight, colostrum yield, milk yield and

- reproductive performance of sows. *Livest Sci.* 234:103983.
- Tummaruk P 2013. Post-parturient disorders and backfat loss in tropical sows in relation to backfat thickness before farrowing and postpartum intravenous supportive treatment. *Asian-Australas J Anim Sci.* 26: 171–177.
- Tummaruk P, De Rensis F and Kirkwood RN 2023. Managing prolific sows in tropical environments. *Mol Reprod Dev.* 90: 533–545.
- Tummaruk P and Sang-Gassanee K 2013. Effect of farrowing duration, parity number and the type of anti-inflammatory drug on postparturient disorders in sows: A clinical study. *Trop Anim Health Prod.* 45: 1071–1077.
- Udomchanya J, Suwannutsiri A, Sripantabut K, Pruchayakul P, Juthamanee P, Nuntapaitoon M and Tummaruk P 2019. Association between the incidence of stillbirths and expulsion interval, piglet birth weight, litter size and carbetocin administration in hyper-prolific sows. *Livest Sci.* 227: 128–134.
- Vongsariyavanich S, Sundaraketu P, Sakulsirajit R, Suriyapornchaikul C, Therarachataamongkol S, Boonraungrod N, Pearodwong P and Tummaruk P 2021. Effect of carbetocin administration during the mid-period of parturition on farrowing duration, newborn piglet characteristics, colostrum yield and milk yield in hyperprolific sows. *Theriogenology* 172: 150–159.
- Wever MCM, van Meer F, Charbonnier L, Crabtree DR, Buosi W, Giannopoulou A, Androutsos, O, Johnstone AM, Manios Y, Meek CL, Holst JJ and Smeets PAM 2021. Associations between ghrelin and leptin and neural food cue reactivity in a fasted and sated state. *NeuroImage.* 240:118374.
- Wongwaipisitkul N, Chanpanitkit Y, Vaewburt N, Phattarathianchai P and Tummaruk P 2024. Factors associated with farrowing assistance in hyperprolific sows. *Anim Biosci.* 37:39–49.