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Influence of blood glucose level on sow traits, farrowing characteristics and piglet parameters in free farrowing sows

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Abstract

Vetsuisse-Fakultät Universität Bern 2025

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Influence of blood glucose level on sow traits, farrowing characteristics and piglet parameters in free farrowing sows

Studies have shown that maintaining adequate blood glucose levels can support the farrowing process in crated sows. This study aimed to evaluate the impact of blood glucose levels on sow traits and farrowing kinetics under free farrowing conditions.

A total of 147 sows were monitored, with blood glucose levels measured at the beginning and end of parturition. The mean farrowing duration was 229 min ± 86 min, with an average of 16.1 ± 3.6 total born piglets. Blood glucose levels of the sow increased significantly at the onset of farrowing 4.44 ± 0.63 to 4.72 ± 0.79 mmol/L at the end. Older sows (≥5 litters) exhibited lower blood glucose at the onset of farrowing (4.3 ± 0.6 vs. 4.6 ± 0.6 mmol/l, p=0.021) and required more farrowing assistance (62% vs. 37%, p=0.001), having nearly twice as many stillborn piglets as younger sows (1.42 ± 1.5 vs. 0.78 ± 1.5). No significant correlation was found between blood glucose level and farrowing duration, suggesting that blood glucose levels at the onset of farrowing are not reliable predictors of prolonged farrowing (> 300 min) or dystocia (>1h piglet-piglet interval) in free farrowing systems. Overall, while glucose is essential for uterine energy during farrowing, the study concludes that other factors, such as sow age, meal timing, and temperature-humidity index, also play critical roles in farrowing success.

Future research should further explore these interactions to enhance sow and piglet performance in free farrowing systems.

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Zusammenfassung

Vetsuisse-Fakultät Universität Bern 2025

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Einfluss des Blutzuckerspiegels von Muttersauen auf den Geburtsprozess, Sauenparität und Ferkelparameter unter Bedingungen der freien Abferkelung

Studien haben gezeigt, dass die Aufrechterhaltung eines angemessenen Blutzuckerspiegels den Abferkelprozess bei Sauen in Kastenständen unterstützen kann. Ziel dieser Studie war es, den Einfluss des Blutzuckerspiegels auf den Geburtsprozess, Sauenparität und Ferkelparameter unter Bedingungen der freien Abferkelung zu untersuchen.

Insgesamt wurden 147 Sauen beobachtet, wobei der Blutzuckerspiegel zu Beginn und am Ende der Geburt gemessen wurde. Die durchschnittliche Abferkeldauer betrug 229 ± 86 Minuten, bei durchschnittlich 16,1 ± 3,6 geborenen Ferkeln. Der Blutzuckerspiegel der Sau stieg während der Geburt von 4,44 ± 0,63 mmol/L auf 4,72 ± 0,79 mmol/L an. Ältere Sauen (≥ 5 Würfe) hatten zu Beginn der Geburt einen niedrigeren Blutzuckerspiegel (4,3 ± 0,6 vs. 4,6 ± 0,6 mmol/l; p = 0,021) und benötigten häufiger Geburtshilfe (62 % vs. 37 %, p = 0,001). Zudem hatten ältere Sauen nahezu doppelt so viele totgeborene Ferkel wie jüngere Sauen (1,42 ± 1,5 vs. 0,78 ± 1,5). Es konnte jedoch keine signifikante Korrelation zwischen Blutzuckerspiegel und Abferkeldauer festgestellt werden, was darauf hindeutet, dass der Blutzuckerspiegel zu Beginn der Geburt kein zuverlässiger Prädiktor für eine verlängerte Geburt (> 300 min) oder Dystokie (> 1h Ferkel-Ferkel-Intervall) in freien Abferkelsystemen ist.

Zukünftige Studien sollten diese Zusammenhänge weiter untersuchen, um die Leistung und das Wohlbefinden von Sauen und Ferkeln in freien Abferkelsystemen zu verbessern.

Geburt, Energieversorgung, Fasten, Geburtsdauer

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Influence of blood glucose level on sow traits, farrowing characteristics and piglet parameters in free farrowing sows

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ABSTRACT

Studies have shown that maintaining adequate blood glucose levels can support the farrowing process in crated sows. This study aimed to evaluate the impact of blood glucose levels on sow traits, farrowing kinetics, and piglet parameters under free farrowing conditions. A total of 147 sows were monitored, with blood glucose levels measured at the beginning and end of parturition. In addition, the blood glucose level of the first, seventh, and last-born piglets was evaluated immediately after birth. The mean farrowing duration was 229 ± 86 min, with an average of 16.1 ± 3.6 total born piglets. Blood glucose levels of the sow increased significantly at the onset of farrowing 4.44 ± 0.63 to 4.72 ± 0.79 mmol/L at the end of farrowing. Blood glucose levels of sows at the onset of farrowing were related to the first–born piglet (r = 0.2; *P* = 0.011) as well as at the end of farrowing with the last–born piglet (r = 0.2; *P* = 0.018). Sows that consumed their last meal in the evening before farrowing exhibited higher blood glucose level (4.50 ± 0.62 mmol/L; *P* = 0.009) and tended to have a longer farrowing (238 ± 86 min; *P* = 0.053) duration compared to those that last ate in the morning (4.34 ± 0.64 mmol/L; 216 ± 85 min). Older sows (≥ 5 litters) exhibited lower blood glucose at the onset of farrowing (4.3 ± 0.6 mmol/L vs 4.6 ± 0.6, *P* = 0.021) and required more farrowing assistance (62 vs 37%, *P* = 0.001), having nearly twice as many stillborn piglets as younger sows (1.42 ± 1.5 vs 0.78 ± 1.5). The temperature-humidity index (**THI**) is a combined index of relative humidity and air temperature, to posit a perceived equivalent temperature. THI correlated negatively with blood glucose at the onset of farrowing (r = –0.16; *P* = 0.047). No significant correlation was found between blood glucose level and farrowing duration, suggesting that blood glucose levels at the onset of farrowing are not reliable predictors of prolonged farrowing (> 300 min) or dystocia (> 1 h piglet-piglet interval) in free farrowing systems. Overall, while glucose is essential for uterine energy during farrowing, the study concludes that other factors, such as sow age, meal timing, and temperature-humidity index, also play critical roles in farrowing success. Future research should further explore these interactions to enhance sow and piglet performance in free farrowing systems.

Implications

Studies have shown that maintaining adequate blood glucose levels can support the farrowing process. In this study, blood glucose levels were evaluated in free farrowing sows at the beginning of farrowing. The findings indicated that monitoring glucose levels alone is insufficient to predict the farrowing duration or the occurrence of dystocia. Instead, factors such as sow age, feeding schedule, and the temperature-humidity index were found to have a greater impact on farrowing outcomes. These results highlight the importance of incorporating these variables into management strategies to optimise farrowing duration, reduce stillbirth rates, and limit the need for obstetrical interventions.

Introduction

The farrowing process is of crucial importance for the health of both the sow and the piglets. A short farrowing duration reduces the number of stillborn piglets (Langendijk and Plush, 2019) and is beneficial for the puerperium of the sow (Björkman et al., 2017). Farrowing is an energetically demanding physiological event, requiring the sow to mobilise substantial energy rapidly to support uterine contractions and successful delivery. Glucose serves as the primary energy source for the uterus (Theil et al., 2022), making the maintenance of adequate blood glucose levels critical for meeting the heightened energy demands associated

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with farrowing (Feyera et al., 2021). The fasting blood glucose levels in sows range from 2.5 to 4.1 mmol/L between the 30th day of gestation and the 20th day of lactation (Zvorc et al., 2006). Blood glucose levels around farrowing vary across different studies, with the widest range observed in Feyera et al. (2018), ranging from 1.6 to 7.2 mmol/L. However, Bautista Rivas (2020) found that blood glucose levels around farrowing do not differ from those of non-farrowing sows. In early pregnant sows, the maximum blood glucose level is reached 30 min after feeding, followed by hypoglycemia with the lowest level occurring around 75 min, and a return to fasting levels approximately 180 min after the meal (Père et al., 2000). Interestingly, after day 85 of gestation in sows, insulin sensitivity decreases, resulting in a prolonged hyperglycemic phase after feeding without subsequent hypoglycemia. However, this study was conducted only up to day 110 of pregnancy and therefore, data on glucose metabolism during the peripartal period are lacking (Père et al., 2000).

This is particularly relevant as feed rations are often reduced around the expected time of farrowing to prevent constipation, which can prolong farrowing duration and increase the prevalence of Postpartum Dysgalactia Syndrome (Tabeling et al., 2003). However, it is questionable whether this will allow the sow to obtain adequate energy for the farrowing process. The energy requirements of sows are significantly higher around farrowing (Theil et al., 2022) and increased energy intake leads to a reduced farrowing duration, due to the higher blood glucose level of the sows (Che et al., 2019). This aligns with the study of Feyera et al. (2018), who found that sows with low arterial glucose levels experienced significantly longer farrowing durations, an associated risk of stillborn piglets, and a greater need for farrowing assistance. Additionally, a strong negative correlation between the time since last meal and the arterial glucose level was observed (Feyera et al., 2018). In an observational study (Carnevale et al., 2023), a negative correlation between the fasting period and blood glucose levels at the start of farrowing with subsequent farrowing duration was confirmed. In contrast, Gourley et al. (2020a) did not find a significant correlation between the interval between the last meal and the start of the farrowing process on the subsequent farrowing duration.

Glucose infusion prior to farrowing has been shown to significantly reduce the stillbirth rate (16.1 vs 7.4%) but had no effect on the farrowing duration (8.17 vs 8.09 h) (Nielsen et al., 2021). Oral supplementation during farrowing with a mixture of carbohydrates, resistant starch and glycerol reduced the piglet expulsion time by 20 min (Carnevale et al., 2024). Thus, all these studies show that sufficiently high blood glucose levels at farrowing are needed for a short parturition process, thereby reducing the number of stillborn piglets associated with the parturition process (Carnevale et al., 2024; Carnevale et al., 2023; Feyera et al., 2021; Tucker et al., 2022). All previous studies have focused on crated sows, and currently, no information is available on the role of glucose around farrowing in free farrowing sows. Sows housed in a free farrowing system have a shorter farrowing duration by allowing the sows to express their nest–building activity and having higher levels of oxytocin (Bill et al., 2021; Egli et al., 2022; Jahn et al., 2022; Oliviero et al., 2010; Trachsel et al., 2021). Apart from the housing system, the housing conditions also have an impact on the farrowing kinetics and piglet survival. Wegner et al. (2016) showed that temperature and relative humidity on the day of farrowing and the day before significantly affected the number of live born and stillborn piglets. An increased risk of stillbirth and a delayed expulsion of placenta was also reported by Zhao et al. (2022) for heat–stressed gilts. Zhao et al. (2022) defined heat stress from temperatures above 25 °C and 40–50% relative humidity in accordance with Muns et al. (2016).

There is still a lack of knowledge about the level of blood glucose and farrowing kinetics in free farrowing systems. The different farrowing characteristics in free farrowing systems compared to crated farrowing systems might impair the transfer of study results (Carnevale et al., 2023; Feyera et al., 2018; Nielsen et al., 2021) gained in farrowing crates. As farrowing crates are due to be phased out in the European Union (Moustsen et al., 2023), the understanding of loose–housed sows will become even more important in the near future.

The study hypothesised that the sow's glucose level at the onset of farrowing affects both the farrowing process and the number of stillborn piglets in a free farrowing system. In addition, the time elapsed between the last meal and the start of farrowing influences glucose levels in a free farrowing system, allowing for early identification of sows more likely to experience obstetrical disorders. It was also hypothesised that there would be a correlation between the blood glucose levels of the sows and their offspring due to the placenta, which would allow a non-invasive method of testing the blood glucose level from the umbilical cord of the piglets. Furthermore, the study hypothesised that the age of the sow influences the blood glucose level due to different body composition, such as higher back fat, which could impact glucose regulation.

Therefore, the aim of this study was to evaluate the impact of blood glucose on farrowing kinetics and traits of the umbilical cord of piglets under free farrowing conditions.

Material and methods

Animals and management

The study was conducted between August 2023 and December 2023. A total of 151 farrowings from Swiss crossbred sows (Swiss Landrace × Swiss Large White) on one farm with a free farrowing system were observed. The mean parity number was 4.2 with a range from parity 1 to parity 9. All sows were artificially inseminated and then housed in groups during gestation. One week before farrowing, the sows were moved to the farrowing unit containing 30 identical free farrowing pens. Room temperature and relative humidity were recorded hourly from the day the sows entered the farrowing unit until weaning using a data logger (testo 174H, testo AG, Lenzkirch, Germany). The pens were 5.6 m^2 (2.15 × 2.6 m) in size, and 50% of the floor was slatted. In addition, every pen had a piglet nest of 0.9 m^2. The farrowing pens were cleaned and disinfected and left empty for at least five days before the arrival of new animals. The farrowing pens were cleaned twice a day and received sawdust and wheat straw (approximately 1 kg /day) as nesting and rooting material. The sows were fed a commercial liquid diet twice a day at 0700 and 1700 h which contents are given in Table 1. At both feeding times, the sows received 50% of their total daily allowance and feed intake was controlled one hour after feeding. The feeding curve differed between pregnant gilts and sows and is shown in Table 2. This study protocol was approved by the Cantonal Veterinary Office of Solothurn (Licence Nr. SO 03/2023).

Prefarrowing and farrowing parameters

General information on sows was collected including animal identity and parity. Sows with severe lameness and reduced general condition were excluded from the study. Backfat thickness was evaluated using ultrasound (MyLab™OneVet, SV3513 Vet) with the P2 method (Dourmad et al., 2001), recording three measurements each 6.5 cm left and right of the dorsal line at the last rib in all sows. At the onset of parturition, a drop of blood was collected from an ear vein of the sow within 30 min of the expulsion of the first piglet and blood glucose was evaluated (**GluOP**). Blood glucose was measured using a glucose meter (ACCU-CHEK®

Table 1
Predicted ingredient composition and nutritive values of lactation diet for sows.

Item	Value
Ingredient composition, % of fed basis	
Wheat	28.8
Corn	20.0
Soybean meal 47.5% CP	17.0
Barley	10.0
Wheat bran	10.0
Oat	3.0
Sunflower meal	2.5
Soybean oil	2.0
Amino acid mixture	1.9
Calcium carbonate	1.2
Sugar	1.0
Salt	0.7
Mixed fats	0.6
Mineral supplement [1]	0.5
Acid mixture	0.4
Benzoic acid	0.3
Monocalcium phosphate 21%	0.1
Nutritive values	
Digestible energy MJ/kg	14.0
Ash, % in fed basis	5.2
CP, % in fed basis	19.0
Crude fat, % in fed basis	5.5
Crude fibre, % in fed basis	4.1
Total lysine, % in fed basis	1.02
Calcium, % in fed basis	0.6
Phosphorus, % in fed basis	0.45

[1]Supplied per kg diet: 12 000 IU Vitamin A; 1 000 IU Vitamin D3; 0.025 mg 25-Hydroxycholecalciferol; 70 mg Vitamin E; 40 mg L-Carnitine; 1438 FTU 6-Phytase; 150 mg Iron; 100 mg zinc; 15 mg copper.

Table 2
Feed intake curve from the end of gestation to farrowing in gilts and sows.

	Gilts	Sows
Days of gestation	Megajoule digestible energy per day	Megajoule digestible energy per day
110	33	40
112	32	40
113	32	37
115	28	32
116	28	30
118	28	30

instant, Roche) validated for porcine blood in previous studies (Manell et al., 2016). Piglet blood glucose was collected from the umbilical cord. The first piglet (**pGluF**), the 7th piglet (**pGluM**) and the last piglet (**pGluL**) were sampled immediately after birth before colostrum intake. The piglet assumed to be the last of the litter was sampled. If another piglet was born afterwards, the previous sample was discarded, and a new sample was taken from the actual last piglet. Within one hour after the last piglet was born, the postpartum sample of the sow (**GluPP**) was collected. The expulsion time of each piglet was recorded, along with its status at birth (alive, stillborn, or mummified). The time of expulsion of placental parts was recorded. Farrowing assistance was performed if more than one hour had passed since the birth of the last piglet. Manual assistance was provided, and once all reachable piglets were extracted; 20 IU of oxytocin was administered intramuscularly. Blood glucose levels were then measured using the same method described above. After the expulsion of the last part of the placenta, liveborn and stillborn piglets, mummies as well as the placenta parts were weighed within 2 h after farrowing. Piglets were classified as born alive if they physically moved or were breathing immediately after birth in accordance with Gourley et al. (2020a). Stillborn piglets were classified as fully developed piglets with the absence of any vital signs.

Statistical analysis

Data management of the raw data was carried out in a spreadsheet (Microsoft Office Excel 365). All statistical analyses were performed using SPSS (IBM SPSS Statistics version 29.0.0). Several parameters were adjusted and categorised for the further statistical analysis. The onset of farrowing after the last meal was categorised into three categories: less than 3, 3–6 and > 6 h based on the results of Feyera et al. (2018). Farrowing duration was defined as the time interval between the expulsion of the first and the last piglet and was categorised into physiological farrowing duration (≤ 300 min) and prolonged farrowings (> 300 min) in accordance with Oliviero et al. (2010). The duration of placenta expulsion was defined as the time interval between the first expelled placenta and the last expelled part of placenta (Trachsel et al., 2021). The Piglet-placenta duration was defined as the time interval between the expulsion of the first piglet and the expulsion of the last placenta or piglet, whichever was later (Bolliger et al., 2025). Two data sets were removed as outliers because of prolonged farrowing duration (17 h 38 min resp. 10 h 10 min). Both outliers significantly degraded the normal distribution and dispersion in the quantile–quantile plot (QQ plot) and were therefore manually removed from the raw data.

The heat index 24 h prior to farrowing was calculated, as this period typically marks the onset of nest-building behaviour, which signals the beginning of the dilation phase of parturition. This period is critical, as it influences the sow's physiological and behavioural preparation for farrowing. In addition, Wegner et al. (2016) showed that temperature and relative humidity within 24 h before farrowing have an impact on the number of live born and stillborn piglets. Therefore, temperature and relative humidity of the last 24 h before farrowing were converted into a heat index (Equation 1) using the following established equation by Rothfusz (1990).

Equation 1: Heat index calculation according to the equation of Rothfusz (1990). T = mean temperature in Celsius in the last 24 h before farrowing, H = mean relative humidity in % in the last 24 h before farrowing

$$\begin{aligned} HI = & -8.784695 + 1.61139411 \times T + 2.338549 \times H \\ & - 0.14611605 \times T \times H - 1.2308094 \times 10^{-2} \times T^2 \\ & - 1.6424828 \times 10^{-2} \times H^2 + 2.211732 \times 10^{-3} \times T^2 \times H \\ & + 7.2546 * 10^{-4} \times T \times H^2 - 3.582 \times 10^{-6} \times T^2 \times H^2 \end{aligned}$$

As parity is known to affect farrowing characteristics (e.g. liveborn piglet, stillborn piglets), and preliminary analyses showed that glucose concentrations at the onset of farrowing were affected by parity, sows were categorised into two subsets based on their parity: data were divided into one subset for younger sows (≤ 4 litters) and another for older sows (≥ 5 litters). To further analyse the effect of the blood glucose levels at the onset of farrowing, three categories were formed with low (< 4.2 mmol/L), intermediate (≥ 4.2 and ≤ 4.7 mmol/L) and high (> 4.7 mmol/L) blood glucose level subsets. Cut-off points were chosen in order to get a similar distribution of the number of animals. On 16 sows, farrowing assistance was performed after the last piglet was expelled. Therefore, this parameter was divided into two variables for the statistical analysis: total performed obstetrical intervention and farrowing assistance with subsequent delivery of piglets. Hence, for farrowing duration, the variable farrowing assistance with subsequent delivery of piglets was used, whereas for Piglet-placenta duration, the variable total performed farrowing assistance was used. The variables were tested for normal distribution with the Shapiro-Wilk test. As farrowing duration was not normally distributed, it was transformed using Log10-function. Descriptive statistics are presented for the variables total born piglets, stillbirth rate, farrowing duration, GluOP, GluPP, time between last meal and onset of farrowing (**TLMOF**), pGluF, pGluM and pGluL. Correlation analysis was performed between glycemic parameters of sows and piglets and reproductive performance parameters. Results are presented as Spearman correlations (r) and significance levels (p). In accordance with Cohen's guidelines (Cohen, 2013), correlation coefficients were considered weak if they were less than |0.3|. In addition to the magnitude of the correlation coefficients, the corresponding *P*-values were taken into account to accurately assess the statistical significance of the observed relationships.

Initially, differences between groups were evaluated using ANOVA. When variables were normally distributed, ANOVA followed by Fisher's Least Significant Difference posthoc test was applied. For variables that did not meet normality assumptions, Tamhane-T2 was used for multiple comparisons. Mean differences were considered statistically significant when *P*-values were less than 0.05, and values between 0.05 and 0.1 were interpreted as a statistical trend. To further explore associations between predictor variables and the outcomes of interest, generalised linear mixed models (**GLMM**) were applied. A backward elimination strategy was employed to refine each model. All potential predictors were initially included, and the predictor with the highest *P*-value was sequentially removed. This process was repeated until all remaining predictors had a *P*-value less than 0.05. For the continuous dependent variables such as farrowing duration, stillbirth rate, and GluOP, the following predictors were initially included:

For GluOP: run, parity, heat index, weight, backfat thickness, TLMOF, and last feeding time.

For farrowing duration: run, parity, HI, weight, backfat, TLMOF, last feeding time, GluOP, GluPP, farrowing assistance, total born piglets, and stillbirth rate.

For binary outcomes (e.g., yes/no, presence of stillborn piglets yes/no, and prolonged farrowing yes/no), GLMMs with a binomial distribution were used. The same backward elimination procedure was applied to these models. This combined statistical approach enabled both the assessment of mean differences between groups (via ANOVA) and the identification of significant predictors for key outcomes (via GLMM), providing a comprehensive understanding of the relationships within the data.

Results

Descriptive statistics

Data from 149 free farrowing sows were included in the analysis. Three records were partially excluded due to missing values. The mean farrowing duration was 229 ± 86 min, with an average of 16.1 ± 3.6 total born piglets. The mean piglet-placenta duration was 422 ± 130 min. During the last 24 h before farrowing the mean room temperature was 22.4 ± 1.2 °C (Min: 18.2 °C, Max: 25.1 °C) and the relative humidity of 60.8 ± 10.5% (Min: 46.9%, Max: 79.6%) resulting in a mean heat index of 24.6 ± 0.9 °C. 117 of the 149 farrowings had a mean heat index of over 24.5 °C in the last 24 h before farrowing. Descriptive statistics are shown in Tables 3 and 4.

An overview and significant differences of the blood glucose levels at the onset of farrowing grouped by parity are shown in Fig. 1.

Table 3
Descriptive statistics of key farrowing parameters for free farrowing sows and for sows categorised according to their last prefarrowing feeding time.

Parameter	Item	Total	Last feeding before farrowing	
			0700 h	1700 h
Number of sows (n)		149	59	90
Parity (n)	Median	4	4	4
	Range	1–9	1–9	1–9
	Mean ± SD	4.2 ± 2.4	4.2 ± 2.5	4.2 ± 2.4
Backfat (mm) [1]	Median	17.7	17.5	17.7
	Range	6.2–31.8	6.2–28.7	7.7–31.8
	Mean ± SD	17.9 ± 5.2	18.1 ± 5.6	17.8 ± 5.0
Time last meal and onset of farrowing (min)	Median	277	277	275
	Range	23–844	23–584	27–844
	Mean ± SD	315 ± 181	305 ± 153	321 ± 198
Total born piglets (n) [1]	Median	16	16	16
	Range	7–24	7–23	8–24
	Mean ± SD	16.1 ± 3.6	15.4 ± 3.9	16.5 ± 3.4
Stillbirth rate (%)	Median	4.8	0.0	5.0
	Range	0.0–56.3	0.0–31.3	0.0–56.3
	Mean ± SD	6.2 ± 8.9	4.7 ± 6.6	7.2 ± 10.0
Farrowing duration (min)	Median	206	192	219
	Range	82–477	82–477	100–465
	Mean ± SD	229 ± 86	216 ± 85	238 ± 86
Farrowing assistance (%)	Mean	49	47	50
Blood glucose levels at onset of farrowing in sows (mmol/L)	Median	4.4	4.3	4.4
	Range	3.1–6.8	3.1–6.8	3.1–6.2
	Mean ± SD	4.4 ± 0.6	4.3 ± 0.6	4.5 ± 0.6
Blood glucose levels postpartum in sows (mmol/L)	Median	4.7	4.7	4.6
	Range	2.3–7.4	3.0–6.9	2.3–7.4
	Mean ± SD	4.7 ± 0.8	4.8 ± 0.7	4.7 ± 0.8
Blood glucose levels of the first–born piglets (mmol/L)	Median	2.2	2.3	2.2
	Range	1.0–4.7	1.2–4.7	1.0–4.0
	Mean ± SD	2.3 ± 0.7	2.3 ± 0.7	2.3 ± 0.7
Blood glucose levels of the piglets born in the middle (mmol/L)	Median	2.3	2.5	2.3
	Range	1.0–5.2	1.0–5.2	1.2–4.3
	Mean ± SD	2.4 ± 0.8	2.5 ± 0.8	2.4 ± 0.7
Blood glucose levels of the last–born piglets (mmol/L)	Median	2.6	2.7	2.6
	Range	0.9–9.5	1.4–5.3	0.9–9.5
	Mean ± SD	2.8 ± 1.2	2.9 ± 0.9	2.8 ± 1.3

[1] parameter with normal distribution.

Table 4
Descriptive statistics of farrowing parameters in free farrowing sows categorised as low parity (≤ 4) or high parity (≥ 5).

Parameter	Item	Parity 1–4	Parity 5 and older	*P*-value
Number of sows (n)		81	68	
Time last meal to onset of farrowing (min)	Median	297.6	271.6	
	Range	23.4–784.5	45.7–844.0	
	Mean ± SD	319.5 ± 175.7	309.1 ± 188.2	0.729
Blood glucose levels at onset of farrowing in sows (mmol/L)	Median	4.5	4.2	
	Minimum	3.1–6.8	3.1–5.8	
	Mean ± SD	4.6^a ± 0.6	4.3^b ± 0.6	0.021
Blood glucose level in sows postpartum (mmol/L)	Median	4.7	4.7	
	Range	2.3–7.4	3.3–6.1	
	Mean ± SD	4.7 ± 0.9	4.7 ± 0.6	0.595
Total born piglets (n) [1]	Median	15.0	17.0	
	Range	7.0–24.0	8.0–24.0	
	Mean ± SD	15.1^a ± 3.4	17.2^b ± 3.5	<0.001
Stillbirth rate (%)[1]	Median	0.0	5.6	
	Minimum	0.0–56.3	0.0–31.6	
	Mean ± SD	4.8^a ± 9.0	7.9^b ± 8.5	0.031
Farrowing duration (min)	Median	198.7	216.0	
	Range	82.4–477.4	126.4–405.8	
	Mean ± SD	231.1 ± 101.1	227.4 ± 63.5	0.796
Farrowing assistance (%)	Mean	37.0%	63.2%	0.013

[a,b]Values within a row with different superscripts differ significantly at $P < 0.05$;
[1] normal distribution.

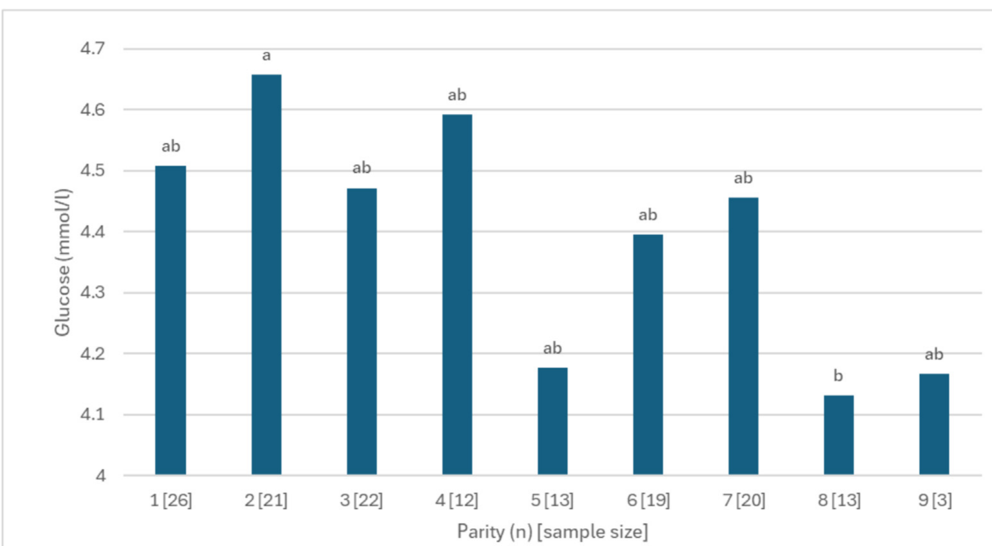

Fig. 1. Blood glucose levels at the onset of farrowing in free farrowing sows grouped by parity. Higher-parity sows (≥5) exhibited lower blood glucose levels than lower-parity sows (≤4). Different letters indicate statistically significant differences between groups.

GluOP in sows showed significant negative correlations with the time since last meal (r = –0.337, $P < 0.001$) and the parity number (r = –0.205, P = 0.013). GluOP was significantly lower ($P < 0.001$) than GluPP (4.44 vs 4.71 mmol/L) and positively correlated with GluPP (r = 0.355, $P < 0.001$). GluOP correlated positively with blood glucose level at first farrowing assistance (r = 0.276, P = <0.001) and pGluF (r = 0.209, P = 0.011). pGluM correlated with pGluF (r = 0.177, P = 0.042) and pGluL (r = 0.279; P = 0.001). TLMOF was significantly correlated with the farrowing duration only among older sows (≥ 5 parity) (r = 0.24; P = 0.048), but not among younger sows or overall. Further details are provided in Table 5. Blood glucose levels showed a negative correlation with TLMOF (r = –0.337; $P < 0.001$), declining by 0.068 mmol/L for each additional hour. The rate of decrease did not differ significantly between younger (≤ 4 parity) and older sows (≥ 5 parity) (Fig. 2).

At the onset of farrowing, 52 sows had blood glucose levels below 4.2 mmol/L (group "low"), 54 sows had levels between 4.2 and 4.7 mmol/L (group "intermediate") and 42 sows had levels above 4.7 mmol/L (group "high"). No significant differences in farrowing duration, litter size, or stillbirth rates were detected across these groups, though sows of the low glucose group were significantly older and had longer intervals between TLMOF compared to the high group. Details are presented in Supplementary Table S1.

Significant differences in GluOP, litter size, and stillbirth rate were observed between groups based on the interval from TLMOF (Table S2). Sows with TLMOF < 3 h had higher GluOP and a higher stillbirth rate compared to those with TLMOF ≥ 3 h.

Farrowing assistance was performed in 49.0% of the sows (n = 73), with 52 requiring a single intervention, 19 requiring two, and 2 requiring three. Additional details regarding farrowing assistance in relation to glucose parameters are provided in Table S3.

Piglet blood glucose increased from firstborn (2.26 ± 0.69 mmol/L) to middle (2.44 ± 0.77 mmol/L, P = 0.032) and last-born piglets (2.80 ± 1.18 mmol/L, $P < 0.001$), indicating progressive elevation during farrowing. Blood glucose levels of sows at the onset of far-

Table 5
Spearman correlation coefficients for key farrowing parameters in free farrowing sows. Showing only significant coefficients.

Item	P	BF	TLMOF	TB	SR	FD	GluOP	GluPP	GluOI	pGluF	pGluM	pGluL	GluFA
P		−0.240**		0.351**	0.337**		−0.205*		−0.239**				0.301**
BF	−0.240**								0.179*				−0.174*
TLMOF							−0.337**						
TB	0.351**				0.343**	0.237**							
SR	0.337**			0.343**		0.267**							0.185*
FD				0.237**	0.267**				−0.251**				0.396**
GluOP	−0.205*		−0.337**					0.355**	0.276**	0.209*			
GluPP							0.355**		0.257*			0.202*	
GluOI	−0.239**	0.179*				−0.251**	0.276**	0.257*					
pGluF							0.209*				0.171*		
pGluM										0.171*		0.279**	
pGluL								0.202*			0.279**		
GluFA	0.301**	−0.174*			0.185*	0.396**							

Abbreviations: P = Parity, BF = Backfat, TLMOF = Time last meal to onset of farrowing, TB = Total born piglets, SR = stillbirth rate, FD = Farrowing duration, GluOP = Sow Glucose at onset of farrowing, GluPP = Sow glucose postpartum, GluFA = Sow glucose after first farrowing assistance, pGluF = Glucose first piglet, pGluM = Glucose middle piglet, pGluL = Glucose last piglet.
** = *P* < 0.01 (2 sided)
* = *P* < 0.05 (2 sided).

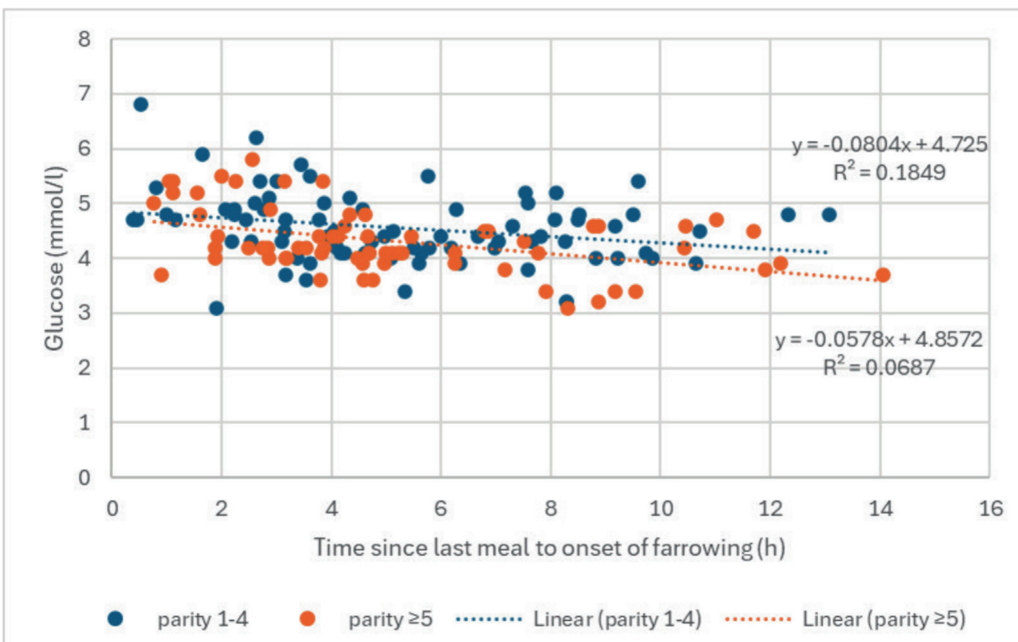

Fig. 2. Blood glucose levels of free farrowing sows, categorised in low- and high-parity sows (parity ≤4 vs ≥5) plotted against time since the last meal, revealing a significant linear decline with increasing fasting duration.

rowing were related to the first–born piglet (r = 0.2; *P* = 0.011) as well as at the end of farrowing with the last–born piglet (r = 0.2; *P* = 0.018).

Generalised linear mixed models

A Generalised Linear Mixed Model (Table 6) was used to identify predictors of GluOP including parity, time of last meal, heat index and TLMOF. The model was statistically significant ($P < 0.001$) with acceptable fit (AIC = 261.6; BIC = 279.6; R^2 = 0.239). Sows with fewer than 5 litters had significantly higher GluOP levels, averaging 0.252 mmol/L more than sows with 5 or more litters (β = 0.252, 95% CI: 0.069–0.435, *P* = 0.007). Feeding time also significantly influenced GluOP. Sows that had TLMOF at 0700 h exhibited GluOP levels that were 0.192 mmol/L lower compared to those fed at 1700 h (β = –0.192, 95% CI: –0.380 to –0.004, *P* = 0.046). Additionally, GluOP decreased slightly with longer intervals between the TLMOF (β = –0.001 mmol/L per minute, 95% CI: –0.002 to –0.001, $P < 0.001$). The heat index was negatively associated with GluOP, with each unit increase in heat index associated with a 0.126 mmol/L reduction in GluOP (β = –0.126, 95% CI: –0.229 to –0.023, *P* = 0.016).

Discussion

The aim of the study was to evaluate the impact of blood glucose on farrowing kinetics and piglet parameters under free farrowing conditions. Measurement of glucose with blood from the ear vein is a minimally invasive and feasible method to assess

Table 6
Final generalised linear model of the factors affecting blood glucose levels at onset of farrowing in free farrowing sows.

Item	Estimated least squares mean response regression coefficients	SE	95% coefficient interval		
			Lower	upper	*P*-value
Parity					
≥5 litters	4.283	0.0696	4.147	4.420	0.007
<5 litters	4.535	0.0644	4.408	4.661	
Last meal					
07:00:00	4.313	0.0745	4.167	4.459	0.046
17:00:00	4.505	0.0603	4.386	4.623	
Time last meal to onset of farrowing	−0.001	0.0003	−0.002	−0.001	<0.001
Heat index	−0.126	0.0524	−0.229	−0.023	0.016

the sows' current level of glucose. A continuous observation of the glucose would have led to an exact gradient during the whole farrowing process, but arterial catheters are prone to clotting and are far more invasive than the used method (Feyera et al., 2018). A limitation of this study is that the data were obtained from only one farm and assessed by five different observers, which may have introduced observer bias.

Consistent with previous findings in crated sows, blood glucose levels were higher in GluPP than in GluOP (Carnevale et al., 2023; Gourley et al., 2020b). Gluconeogenesis is believed to increase during parturition to meet the uterus's energy demands and the rising need for glucose as a precursor for lactose in milk synthesis (Gourley et al., 2020a). After delivery of the final piglet, uterine energy demands decline, leading to a rapid rise in blood glucose levels (Theil et al., 2022). In the present study, only the blood glucose levels of sows with dystocia were measured during farrowing. Interestingly, their glucose concentrations at the time of intervention were positively correlated with GluOP ($r = 0.321$, $P = 0.002$), suggesting a continuous increase in glucose throughout parturition rather than a sudden spike at the end. This contrasts with previous findings that showed a decline in glucose one hour after the onset of farrowing, particularly in sows that began farrowing more than six hours after their last meal (Feyera et al., 2018). Sows with dystocia are often classified as experiencing farrowing fatigue, and blood glucose has been proposed as a marker for energy depletion (Nielsen et al., 2021). This study observed a high prevalence of farrowing assistance, which was defined as an interval exceeding 60 min between consecutive piglets. In contrast, previous studies have used a 45-minute interval to define the need for farrowing assistance (Nam and Sukon, 2022, Ward et al., 2019), a criterion that would have resulted in an even higher incidence of dystocia events in this cohort.

Overall, sows requiring farrowing assistance had significantly lower GluOP compared to eutocic sows (4.358 vs 4.522 mmol/L, $P = 0.041$), although TLMOF did not differ significantly between these groups. However, after including sow parity in the statistical model, no significant difference in GluOP was detected. In this study population, 46% of the sows were in parity 5 or higher, and the GLM analysis demonstrated lower GluOP values in older sows. Given that higher-parity sows are also more susceptible to requiring farrowing assistance (Wongwaipisitkul et al., 2024), the association between reduced GluOP and dystocia is likely confounded by parity. Indeed, when parity was included in the binary logistic regression model, neither GluOP nor TLMOF was significantly associated with the likelihood of farrowing assistance. This contrasts with previous studies, which found that lower GluOP levels and longer TLMOF were associated with prolonged farrowing duration and a higher incidence of dystocia (Carnevale et al., 2024; Carnevale et al., 2023; Feyera et al., 2018; Nielsen et al., 2021). However, in this study, sows with dystocia showed normal blood glucose levels.

Furthermore, contrary to earlier literature, no association was detected between GluOP and farrowing duration. The free farrowing system implemented in this study, allowing increased mobility and expression of maternal behaviours, may have influenced the observed results. Nonetheless, additional studies are necessary to validate this assumption.

Although the correlation between sow and piglet blood glucose was weak, it is noteworthy, as low maternal glucose may place piglets at risk of neonatal hypoglycemia, which has been linked to increased mortality within the first seven days (Panzardi et al., 2013). Piglets are generally born with low glucose levels (< 2.78 mmol/L), and higher concentrations at birth may reflect hypoxia during parturition rather than enhanced postnatal adaptation (Herpin et al., 1996). In this study, piglet glucose levels increased progressively from pGluF (2.3 ± 0.7 mmol/L) to pGluM (2.4 ± 0.8 mmol/L) and finally to pGluL (2.8 ± 1.2 mmol/L), suggesting that last-born piglets exhibited higher glucose concentrations, potentially reflecting prolonged labour or peripartum hypoxia. However, other stress markers in piglets, such as meconium staining or ruptured umbilical cords, did not corroborate this hypothesis in this study.

Prefarrowing nest-building behaviour may compete with uterine activity for glucose, particularly in free-farrowing systems where sows are more active after their last meal (Nielsen et al., 2021). Sows are generally more active during daytime hours (Berensmann et al., 2018; Theil et al., 2022), which likely increases glucose metabolism and contributes to lower GluOP. The observed negative correlation between heat index and GluOP further supports this hypothesis. Elevated ambient temperatures may induce mild heat stress, increasing energy expenditure and reducing blood glucose levels. However, additional indicators of heat stress, such as respiratory rate or skin temperature, were not measured in this study. The upper limit of the thermoneutral zone for sows is approximately 22 °C with 60–70% relative humidity, corresponding to a heat index of 24.5 °C (Lucy & Safranski, 2017; Rothfusz, 1990). In this study, 117 farrowings occurred when the mean heat index exceeded 24.5 °C during the 24 h preceding parturition, suggesting that most sows may have experienced mild heat stress. Further research is needed to clarify the effects of heat stress on blood glucose levels in free-farrowing sows.

In this study, the interval between the last meal and the onset of farrowing (TLMOF) influenced GluOP but did not affect farrowing duration or stillbirth rate. Although 51 of the 149 sows had a TLMOF exceeding 6 h, a threshold associated with increased risk of prolonged farrowing and stillbirths in Feyera et al. (2018), no such association was observed here. Notably, studies reporting a correlation between TLMOF and farrowing duration involved longer farrowing times (348 ± 162 min, Feyera et al., 2018; 251 min, Carnevale et al., 2023) compared to the present cohort (229 ± 86 min), which may explain the discrepancy. Interestingly, our results align with those of a recent study (Akkhaphana et al., 2024). The authors suggested that the lack of correlation between TLMOF and farrowing duration may be explained by the high prevalence of farrowing assistance and the restricted expression of nest-building behaviour due to confinement, a behaviour known to substantially increase glucose consumption prior to farrowing (Theil et al., 2022). Although a high prevalence of farrowing assistance was observed in this study, the GLM analysis found no significant correlation between TLMOF and farrowing duration, even after correcting for farrowing assistance when analysing only sows without farrowing assistance. In this study, the decrease in GluOP per hour of TLMOF was 0.068 mmol/h, which contrasts with the much lower decrease of 0.018 mmol/h reported by Carnevale et al. (2023) and the significantly higher decrease of approximately 0.65 mmol/h reported by Feyera et al. (2018).

Conclusion

Measuring blood glucose levels at the start of farrowing appeared to be an unreliable predictor of prolonged farrowing and the risk of dystocia in free farrowing systems. Sows with more than five parities had lower blood glucose levels compared to younger sows and were more prone to dystocia and delivering stillborn piglets. While glucose is a crucial energy source for the uterus during farrowing, a successful farrowing process also depends on other nutrients and overall farrowing management.

Supplementary material

Supplementary Material for this article (https://doi.org/10.1016/j.animal.2025.101643) can be found at the foot of the online page, in the Appendix section.

Ethics approval

The study protocol was approved by the Cantonal Veterinary Office of Solothurn (Licence Nr. SO 03/2023).

Data and model availability statement

The data/models were not deposited in an official repository but are available from the authors upon request.

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

During the preparation of this work the author(s) did not use any AI and AI-assisted technologies.

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CRediT authorship contribution statement

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Declaration of interest

None.

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Eigenständigkeitserklärung

Ich, erkläre hiermit, dass ich die vorliegende Dissertation selbständig verfasst habe und keine anderen als die angegebenen Quellen benutzt habe. Alle Stellen, die wörtlich oder sinngemäss aus Quellen entnommen wurden, habe ich als solche gekennzeichnet.
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